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RESD

Renewable Energy and Sustainable Development (RESD) is a biannual international peer-reviewed journal which presents a global forum for dissemination of research articles, case studies and reviews focusing on all aspects of renewable energy and its role in sustainable development. The topics of focal interest to RESD include, but are not limited to, all aspects of wind energy, wave/tidal energy, solar energy, as well as energy from biomass and biofuel. The integration of renewable energy technologies in electrical power networks and smart grids is another topic of interest to RESD. Experimental, computational and theoretical studies are all welcomed to RESD.

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Biofuels – On the way to sustainability? Opinion

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Biofuels contribute to cover the strongly increasing energy demand within our global transportation system. The current status of biofuel production can be summarized on a world wide scale as follows [1, 2]:

- Bioethanol. About 97 Billion l of ethanol (2,218 PJ) were produced in 2015. Roughly 57 % were provided within the US (56.1 Billion l; 1,282 PJ; primarily from corn) and approx. 28 % in Brazil (26.8 Billion l; 614 PJ; mainly from sugar cane). The remaining 15 % were produced in Europe and Asia.

- Biodiesel / HVO. In 2015, ca. 32 Billion l (1,050 PJ) Biodiesel / HVO have been sold. Brazil provided ca. 3.5 Billion l (116 PJ) and Germany roughly 3.2 Billion l (105 PJ). The market in North America is dominated by the US with 16 % of the global production (168 PJ). The remaining rest is widely distributed throughout the world and comes from smaller markets like Argentine, Indonesia and other countries.

- Other biofuels. To a very minor extend, also bio-methane as well as pure vegetable oil are used within the transport sector. But on a global scale the contribution of these options is negligible.

Related to the overall energy demand for transportation purposes this biofuel use of roughly 3.3 EJ (2015) represents a share of less than 3 % [3]. This small share could only be realized over time due to administrative measures implemented by various governments already years ago. There have been manifold communicated reasons to justify these legal measures as well as the resulting financial support from the public purse [4]:

- Contribution to the reduction of greenhouse gas (GHG) emissions;
- Protection of scarce and finite fossil fuel resources;
- Domestic energy provision and thus an increased security of fuel supply;
- Use of agricultural surplus production and thus avoidance of set aside land;
- Creation of employment and income in rural areas as well as development of perspectives for farmers e.g. suffering from low prices due to over-production;
- Convenient inclusion into existing technology and market structures of transportation based on fossil fuels;
- Development and demonstration of technological processes with a high export potential and thus the option of creation of value.

These arguments were always questioned critically by parts of the public and especially by environmental NGOs. Among others, the following arguments have been presented:

- The GHG savings are marginal because the production process for biofuels is quite energy consuming (i.e. no or only negligible net GHG savings);

- Due to direct and indirect land use change effects (LUC and iLUC) possible GHG reductions are inverted to (significantly) higher GHG emissions compared to fossil fuel use (i.e. biofuels contribute to rain forest clearing);

- Biofuels contribute to food scarcity and hunger especially in less developed countries due to increasing food prices that are triggered by an increasing demand for land and agricultural products as well certain political instruments that distort the market (e.g. subsidies);

- Biofuels contribute to monoculture and industrial agriculture as well as to the reduction of biodiversity.

Due to this ongoing social debate, significant efforts to minimize negative consequences and to increase acceptance have been made especially within the European Union (EU) in recent years. For example, the following measures have been implemented by the European Commission (EC):

- Agricultural feedstocks used for biofuel production need to come from sustainable sources; this has to be certified by an independent body. In contrast, no legal sustainability requirements for agricultural feed and food products exist.

- The subsidies for biofuels are tied up with an assessment of the achieved GHG savings, which are calculated based on a pre-defined mandatory methodology [4]. By decision of the European Parliament, indirect land use change effects are not taken into consideration due to unsolved methodological problems related to their assessment [5].

- According to the European Commission (EC), additional land demand that results from ambitious biofuel targets can mostly be fulfilled by conversion of land that has been set aside since decades in order to stabilize market prices resulting from overproduction [6].

- The markets for biofuel feedstock are small compared to the respective markets for food and fodder [7]. Thus, the biofuel markets influence the price creation on the global stock markets only to a minor extend.

Nevertheless, serious concerns of a considerable share of the politically active population especially in Western world countries still exist. In order to increase acceptance and to reduce negative consequences of biofuel provision and use, the measures outlined above can only be seen as a (promising) starting point. The overall long term development goal should be that markets for food and feed, markets for biomass as a raw material as well as energy markets support each other by stabilization of the respective biomass prices. Additionally common sustainability standards need to be implemented for these various markets. This is true because typically a large share of biomass is produced regardless of its later use. Market mechanisms “decide” for which purpose (e.g. food, feed, raw material, or biofuel) the biomass available on the market will ultimately be used.

Fertile land and thus also biomass produced on this land are a priori a limited resource. Additionally, yields vary due to changing environmental conditions (e.g. drought, flooding, and infestation). Due to these uncertainties, producers are forced to realize a certain over-production exceeding the expected demand to survive economically. Thus – from the view point of the producer – it would be helpful to implement market based measures to level or at least to slow down price variations at the global biomass markets. Energy markets can act as such a stabilizing element because biofuels and conventional fossil fuels can be exchanged completely and immediately. They can help to level out price variations of biomass by taking up agricultural products in case of a global production exceeding the demand from the food and feed market. Vice versa, biofuel production could be reduced in case of low yields and a resulting shortage of biomass to alleviate pressure on the food and feed market. One precondition for creating such a harmonized or stabilized market is that sustainability criteria, which are already mandatorily applied to biomass feedstocks used for biofuel production, are applied to all traded agricultural products regardless of their use. Consequently, such a concept could boost a more sustainable agricultural and forestry primary production

Furthermore, the following targets need to be achieved in the years to come in order to increase competitiveness, reduce negative environmental consequences and to promote acceptance of biofuels:

- Widening of the biomass resource basis; this includes better crops, the use of organic wastes as well as "new" biomass feedstocks (e.g. algae);
- Technological advances in biomass production and downstream processing in order to increase efficiencies throughout the overall provision chain;
- Better combination of biomass production and processing for the various markets to exploit synergy effects and minimize losses (e.g. promotion of the bio-refinery concept);
- Improved assessment of sustainability criteria throughout the overall provision chain; this includes also aspects like impacts on biodiversity and soil properties, iLUC, child labor etc.

Such aspects are essential to cope with an increasing demand for biomass driven by a growing world population, changing consumption patterns as well as an increasing demand for renewable energy provision and industrial purposes. All over, tremendous progress has been made in recent years in increasing sustainability and efficiency of biofuel production. Nevertheless, this process has not come to an end yet.

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About Professor Martin Kaltschmitt

Professor Martin Kaltschmitt studied for petroleum engineering and did his PhD in the field of renewable energies. Afterwards he headed a research group in the field of biomass / renewable energy at Stuttgart University where he did his habilitation. After a research stay at King's College in London and at the University of California at Berkeley he has been promoted to the managing director of the Leipzig Institute for Energy. In 2006 he has been appointed to a full professor at Hamburg University of Technology where he is heading the Institute of Environmental Technology and Energy Economics. Between 2008 and 2010 he was in parallel the scientific managing director of the German Biomass Research Centre located in Leipzig/Germany. He published more than 15 books and more than 350 articles in scientific magazines. He gave also more than 400 presentation on scientific conferences and seminars. He has been active in supporting the EC, several German ministries, DFG, DAAD, FFG, GIZ and others.

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The Challenges of Safety Culture: *No more risk!*

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According to A. Maslow's [1] hierarchy of human needs the need for safety and security is a priority for mankind. The concept 'safety culture' appeared only in 1986, when the Chernobyl disaster made the whole world muse upon human relationship with technology [2]. This global catastrophe was a caution, but not for everyone. Potent academic systems and elaborated instruments of a huge economical value have been invoked in maintaining the satisfaction of biogenetic needs, whereas any manual on safety topic has not been issued yet.

Even such progressive communities as the European Union, elaborating long-term strategic decisions, do not find clear and reasonable principles that would encourage to choose safe technologies with respect to present and future generations. Giving way to the ostensible effectiveness of centralized technologies such as equipment, communication, energetic that are well-disposed to big business, the majority of politicians and even scientists are not able to estimate the risk that is programmed in the choice of dangerous and insecure technical decisions. It is not still realized that none of the technologies is worth a human life or safety.

The level of social maturity is a factor stipulating the merge of two concepts 'safety' and „a person". At the time when industrial priorities were dominant the concept 'safety techniques' had been used putting stress on peculiarities of working with technical devices and on the ways manpower could be adjusted to them. Later the term 'Safety of labour' appeared. It drew attention to the labour process and its peculiarities. The assimilation of European culture has determined the introduction of the notion 'personnel safety and health' to labour relations. The postindustrial stage of humanity development brings the new understanding of major values. Individual is now identified as a personality as well as human life is understood as the major value. The natural and social environment becomes a means for fostering the human welfare. It is necessary not to talk about safety in general, having in mind wealth, nature, boarders, etc., but rather to talk about the most important aspect – human safety. No doubt that all the things that are related to 'safety' are interconnected and have an influence on the safety of human beings.

So, what does 'human safety' mean? From the biological point of view, the proper regime, nutrition, hygiene, comfortable place of living, clothing serve for ensuring the better organism work. The proper 'exploitation' of the organism and the one's unity with nature and social environment - these are the means empowering to ensure the higher quality of life and duration of proper life. The unity with nature and social environment influence the quality of personality. And that is of a major importance to life duration. So, the proper life durability could be considered as an indicator of a human beings' safety according to biogenetic theory.

Human safety is closely related and even merges with the characteristics of 'freedom'. On the basis of virtual relation theory, freedom could be understood as a chance for passing the continuous spontaneous development cycle not interrupting it. So we can ground the concept 'safety' in this theory. Safety is freedom from any dependence that could worsen or even break the natural life cycle. Struggling for freedom means struggling for safety as well as for eliminating undesired impacts on life conditions. So, conceding freedom as an implicit objective, safety should be as well conceded as an equal and unarguable life criterion.

Safety can be determined as the ability to foresee future. This ability allows not just to foresee future (no matter successfully or not) but to do it in order to meet one's needs. Seeking for safety people tend to analyze the factors, related to different accidents, and, on their basis, elaborate the ways of prevention of traumatism and diseases. However, the financial support for such kind of researches is not sufficient. That is why it should be confessed, that human need for safety is not realized as a major demand nowadays. Risk remains the usual part of people's life, work and leisure. The facts about traffic accidents, wrecks are perceived as usual. It is not mused upon the possibility not only to foresee these accidents but upon a necessity to preserve each person's life.

All the factors that reduce the duration of human life could be treated as a threat for one's safety. Improper care about the organism, unhealthy habits, overwork, diseases, pollution, stresses; all these factors decrease life quality, duration and safety. These factors could be divided into two groups: internal factors, that depend on a person and external factors that are provoked by the environment.

Depending on the impacts to safety time, these factors could be long-term, momentary and extreme. Long-term factors are: climate, unsuitable place of life, poor nutrition, unsuitable social relations, etc. These factors have a continual impact on life duration, and, when achieve the critical mass, they violate some certain organism or/and personality systems. They provoke ailment, diseases and augur early death. Knowledge allows avoiding long-term factors. If one is aware of the negative impact of some factor, he tends to avoid them, unless the natural and social environment restricts one's actions. So, the formation of knowledge society as well as scientific researches should serve for everyone to be aware of negative natural, social, work and other factors and be able to avoid them.

Momentary factors usually occur in a very short period of time, so that one is not able to estimate and avoid them. In the case of momentary factors safety depends on a person's ability to react and move quickly. Good reaction could help to avoid the majority of momentary factors and their impacts. It is important, that nothing would interrupt the reaction and constrain movements. Such factors as sports and proper leisure help to keep fit and healthy.

The most dangerous factors for human life are extreme factors that could not be avoided by a person. These factors overcome people in reaction, force, stamina, etc. These are different traffic accidents, explosions, fires, earthquakes, tsunami, avalanche. In such a situation one is usually helpless. Neither movements, nor reaction could help a person. What is left – just to pray for the best.

The most reliable way to avoid extreme factors is related to choice of proper buildings, techniques, means, etc. depending on the peculiarities of a geographical locality. The majority of people have an opportunity to choose a safer (in the aspect of natural cataclysms) place of living. The increasing impact of human activity on nature calls out the more frequent and intensive cataclysms. It is noted, that in locations of lower seismic activity there appears a risk of much stronger earthquakes. Floods, hurricanes have become more frequent. That is why it is safer to live in low (1-2-floor) buildings, far from water reservoirs, avoid mountains, etc.

The question of avoiding techno factors' impact is of a major importance. These factors are: weaponry, transport means, energy equipment, mechanisms and devices. These factors by themselves are the definite source of disaster. People are not able to avoid their impacts: different crashes, accidents, fires. The tendency „to use a device till it breaks down or till an accident' augurs disasters. The hope to foresee the possible accident usually lets down. That is too difficult a task even for computer programs.

The solution should be found in developing exploitation culture, that empowers to avoid malfunction or wearing out of technical devices or their parts. Program equipment should be elaborated in order to ensure the supervision of exploitation of technical devices, their service and utilization as well as to protect from injuries. The aspect of utilization should be solved by the organization that projects or produces the equipment or devices. It should not become the responsibility of community members.

The time will soon come, when people totally change their point of view on technical equipment safety. We believe that an accident would not occur. However, it is not worth to take risk. Moreover, it is necessary to realize the principle „no more risk". That means totally avoid the technical equipment, any devices, chemical elements' repositories, etc. those are unsafe for us. It is said 'God helps the one who cares about safety'. Of course, it is difficult to avoid risky factors even trying to escape them. That means that intentional risk increases the general risk.

It is important, that technical progress stimulates people (despite they do not realize this fact) to use safer techniques. For instance, energy is decentralized and this allows avoiding accumulation of a huge amount of thermal or nuclear energy in one place. Such a huge amount of energy (no matter which: thermal, nuclear), high voltage facilities, chemical elements' repositories increase the risk of accidents; moreover it is difficult to ensure their safety. One of the decentralization solutions is to reject any kinds of burning. For instance, wind power plants that are established on the safe distance from consumers do not evoke any risk. The solar energy batteries will be even safer. They will be attached to windows and provide the necessary amount of energy to houses.

The charging of various devices with the help of batteries, accumulators is being improved as well. The clearance and the power of energy used is reduced. There appear such devices that already use the energy of human organism. So, the decentralization of technical equipment provides a possibility to avoid accumulation of huge amounts of energy in one particular place and, as a circumstance, escape a risk to human safety.

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The 'no more risk' principle is important in arranging and taking decisions on selection of energy technologies. In Lithuania, for example, increasing prices on oil and gas as well as complicated accessibility induces to choose the only alternative – to build one more nuclear power-plant. Such progressive countries as Denmark, Sweden and Germany have resigned the dangerous technologies, putting priority on renewable sources of energy. The dominant European strategy of sustainable development requires drawing attention on economical, ecological, social priorities, stressing the accountability to present and future generations.

Another way to encourage solving one of the objectives of human safety is the usage of modern technical equipment that could compensate the limited human reaction or mobility. Those are various positional, location, orientation, navigational systems that assume the function of safety insurance. Humanity development will bring new safety requirements for technical equipment and technology. Every work place, every service or facility must be certified in the aspect of safety. Settlements will be isolated from dangerous energy-plants. Any burning or dissemination of harmful odor must be forbidden.

After declaring human life to be the fundamental value, the activity of governmental and self-governmental institutions will be assessed on the basis of this criterion. The factors that stimulate proper life duration will be considered as positive and progressive. We will be able to assess the activity of political parties or/and politicians according to their input to improving human life quality. Then, politicians themselves will search for negative factors and eliminate them. At this particular stage the systemic scientific researches will be of a major importance. These researches will render assistance in distinguishing these factors and elaborating the ways of their elimination.

The relevance of safety need will radically change the relation between governance and self-governance, between employers and employees and their responsibilities for personnel safety and health. In the governance conception that is employer who is responsible for employees safety and health. It is considered that an employer should ensure complying of safety rules. Though it is proved that nobody is able to ensure safety unless an employee him/herself is interested in it. Self-control is much more effective in case of labour safety motivated by self-preservation and self-governance.

In contrast, the dominant governance conception presupposes employer‘s responsibility for employees' safety.

That is why the implementation of self-governance and self-management methods is the main way of encouraging employees' self-safety thus reducing the number of accidents at work. Firstly it is important to consider everyone's independent personality whose life is a value. Every work place should meet the safety requirements, moreover every specialist should have a certificate, proving one‘s ability to work safely.

Group work should be organized on the basis of self-governance principle. A group should have a right to elect a leader and solve the safety questions all together. In this case employees are responsible for their safety themselves.

The most important principle in work conditions should be 'no more risk'. Any act in disregard of safety laws and rules should not be justified. Only the totally independent personality may oppose the incitement of a leader or an employee not to pay attention on safety requirements.

Apparently, the dimensions of safety culture look forward to the attention and efforts of scientists from various spheres, who could help to realize the meaning of human safety and create the means for its insurance. The demand for the best intellectual potential that would focus on urgent methodological, anthropological, sociologically, technological issues of safety insurance has matured. This is clearly seen through our needs.

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About Julija Melnikova

Dr. Julija Melnikova is a senior researcher at Klaipeda University. She is responsible for project management and implementation of research projects. J. Melnikova coordinates the work of staff in the projects and is responsible for dissemination activities. She has experience in international relations since 2010, in particular in projects under Erasmus+ (K2 Capacity building in the field of Higher education, K2 Strategic partnership in higher education), Horizon 2020, NordPlus, Interreg etc. J. Melnikova is a member of international associations (European Teacher Training Association, Black and Baltic Sea Consortium, Institute for Sustainable Development). She carries out external expert's activities in National Agency for Academic Programme Evaluation, Centre of Education Development (Lithuania). She is an external expert for Klaipeda region in «EPALE» (European Platform for Adult Learning) project. The field of her research is Education management. She has many academic articles and has presented the results of her research at more than 20 international scientific conferences.

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The importance of interpretive social science to promoting renewable energy and sustainable development

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A few years ago I was privileged to hear one of the UK's leading scientists speak on 'tackling climate change' at my university (Krebs 2010). Lord Krebs is a zoologist, and as Chair of the Adaptation Sub-Committee of the UK Government's Committee on Climate Change he has a significant role in advising government on this major challenge of our times. What struck me was that the major challenges he presented demand social science to answer them:

- Wll we switch from talking to doing?
- Are we prepared to elect a Government that is more coercive?
- Are we prepared to stop getting richer and consuming more?
- Wll we invest in technologies for a green prosperous future?

Clearly these are a) crucial b) about politics and society and c) without obvious answers. To be sure, in the field of sustainable development and renewable energy there are many technical issues unresolved: around efficiency and implementation, about what works best in particular settings and so on. This is why the research reported in this journal, amongst others, is so important. But as I understand it the fundamental science in this field is largely known, with a few outstanding exceptions such as light-weight storage of electricity. The Big Questions are social.

One of the papers which has most influenced me was not an academic article, but a project report about failure to achieve an 'obviously' desirable goal: its title was 'Why don't people plant trees?' (Skutsch 1983). This seems to me the fundamental research question. We know sustainable development is important, we know renewables are crucial, but why isn't this knowledge acted on? And who is 'we' in those sentences? And why doesn't the rest of the world listen to 'us'? Scientists and engineers have a tendency to view the answers to this in terms of a combination of ignorance and irrational politics, and so see solutions in terms of transferring knowledge. 'If only they (the public, the government) would listen to our expertise, based in objective scientific knowledge, then everything would be OK.'

There is, however, a great deal of social science – scattered across disciplines such as politics, public administration, sociology, science and technology studies and so on - which explains why this very rational 'deficit model' doesn't work. We know that expert knowledge, particularly in application, is often flawed; that disbelief or distrust of those who claim expertise is often rational, based on prior experience; and that many different, equally valid lines of argument and calculations of what really matters are in play in any policy process. Moreover, any technical 'solution' will create winners and losers when put into practice. Sometimes this is obvious: the US administration under President Bush was quite rationally (not simply ideologically) opposed to climate change science, given its links with the oil industry. Sometimes the losers are less visible but perhaps more worthy of our concern: poor farmers who lose their land to biomass crops, or to solar farms. So competing value judgements are always present.

Investigating how and why policy is developed and is (or isn't) implemented is a crucial step towards addressing Lord Krebs' questions. Taking its theoretical tools from the disciplines listed above, one particular branch of social science has much to offer: interpretive policy analysis. This studies policy making as an interactive process between individuals who are both enabled and constrained by the institutional, cultural, linguistic and material resources available to them. It assumes the (sometimes conflictual) coming together of different motivations and values, and does not assume that one particular form of knowledge will be recognised as necessarily 'better' – in fact a central concern is how different kinds of knowledge are valued and come to be powerful within policy making.

Interpretive policy analysis is well established, though still not the mainstream in policy studies: more prevalent in Europe than in North America, and much less developed elsewhere in the world, although this is changing. This is partly the outcome of academic traditions, and partly also due to the context within which researchers work: for example in the Middle East it is usually harder to access the workings of government than in Europe, with lower expectations that public officials should be open to study by researchers. (Even in Europe this is not necessarily easy: from my own experience local government in the UK is relatively open, but access to observe central government policy making in practice can still be hard to negotiate.)

This has to change. Alongside the continuing investigation of the technical aspects we need scholars worldwide who will investigate policy making for sustainable development and renewable energy alongside the development of technical knowledge. If we are to make the most of the latter we need answers to the questions: what are the institutional barriers to sustainable development? How do ideas about sustainable development get adapted and sometimes watered down? How do other interests and social goals intersect with the sustainable development agenda? And, finally, what might be done differently to enable the necessary changes by governments and communities? My hope is that this journal can play its part in this crucial task.

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About Dr. Steve Connelly

Senior Lecturer at the University of Sheffield's Department of Urban Studies & Planning, he graduated from Oxford University with a BA in Physics & Philosophy and then took up a career in overseas development. Having worked in India, Sri Lanka, Sudan and Eritrea, and gained an MSc in Forestry at the Oxford Forestry Institute, he returned to the UK with a commitment to public participation in governance and sustainable development, and an intellectual interest in why these desirable goals are often not achieved. This was the topic of his PhD at the Sheffield Department of Urban Studies & Planning, where he was appointed as Lecturer in the Department in 2002 and Senior Lecturer in 2011. He is now the Director of the department's doctoral programme – one of the largest and most diverse in its discipline in the UK.

Underlying his research is a concern about what happens to knowledge, and to values of democracy and sustainability, in complex policy making processes. In particular he is intrigued and concerned by how and why apparently widely-valued outcomes do not become dominant: the 'why don't people plant trees?' question. His recent research has examined how academic research is used by central government policy makers, and how different kinds of knowledge are valued within programme evaluation.

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Sustainable Development and Social-Ecological-Technological Systems (SETS): Resilience as a Guiding Principle in the Urban-Industrial Nexus

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***Abstract* -** This conceptual paper focuses on the connection between system resilience and sustainable development. Setting an inclusive frame and beginning with stating the nature of complexity related to the sustainability challenge and the resultant uncertainty of planning and management within socio-economic domains, the article describes the demand for a system approach and emphasizes the importance of a resilience-oriented approach to sustainable development, including the provision of correlated conceptual frameworks, as opposed to an efficiency paradigm.

The first part of the article mirrors on a systematic collection, assessment and reflection of scientific contributions alongside sustainable development/ sustainability strategies, resilience thinking and especially combinations of both with system theory/ nested systems theory, using a qualitative integrative research review method. Sources principally consider progressive explicitly interdisciplinary directions of the scientific community, evolved through the recent decades as sustainability sciences. The scientific state of knowledge is contextualized with sub-chapters of introduction, problem statement, and demand profile for problem solutions as well as system resilience as point of reference.

The central focus of the second part is on urban and industrial spheres of un-sustainability as well as their functional inter-connectedness as a main potential driver for progress in sustainable development. Elements of rooting sustainable development in a stronger consideration of an urban-industrial nexus proposed here are suggested for a consideration of resilience to describe more appropriate system constitutions and intra-connections as well as better system boundaries for assessments and innovative solutions. For the guiding of a more inclusive view of system agents inside the urban-industrial nexus, expansion of Social-Ecological Systems (SES) towards Social-Ecological-Technological Systems (SETS) as guiding resilience based framework is proposed. The urban-industrial nexus and SETS are considered as a basis for new research directions of sustainability sciences.

***Keywords* -** Sustainable Development, Sustainability Challenge, System Thinking, Resilience, Systems Integration, Urban-Industrial Nexus, Social-Ecological Systems (SES), Social-Ecological-Technological Systems (SETS), Sustainability Science.

I. INTRODUCTION

As an epochal contribution to the future of the world, the international community recently adopted their SDGs, the “Sustainable Development Goals” (Sachs 2015, United Nations 2015). To produce practical and measurable progress towards sustainability, 17 goals have been identified as SDGs covering all critical ecological, social and economical issues corresponding to sustainable development and a number of grand global challenges. Although they differ in an improved level of concreteness, the SDGs stand in the tradition of the former Millennium Development Goals (MDGs) and the Rio Process (Sachs 2012). The aim is to meet concrete objectives –which is of ultimate importance- while at the same time base progress on a safe operating space for humanity, respecting the planetary boundaries (Folke and Rockström 2009, Rockström, Steffen et al. 2009, Rockstrom and Klum 2015, Steffen, Richardson et al. 2015).

The concept of sustainability and the practice oriented directions towards sustainable development have been discussed widely in the academic and non-academic world from many perspectives, producing different and also partly contradictory baseline understandings (Brundtland, Khalid et al. 1987, Costanza and Patten 1995, Elkington 1997), up to sophisticated scientific discourses about the inner meaning of constitutional frameworks and theories

(Ayres, van den Berrgh et al. 2001, Ekins, Simon et al. 2003, Neumayer 2003, Dietz and Neumayer 2007) and detailed refinements and advanced conceptualizations (Kay, Regier et al. 1999, Ravetz 2006, Kajikawa 2008, Liu, Mooney et al. 2015, Steffen, Richardson et al. 2015). Apart from numerous understandings and definitions we can identify a consensus in a target orientation stating the "goal of sustainable development is to create and maintain prosperous social, economic and ecological systems" (Folke, Carpenter et al. 2002).

However, the way to achieve this ultimate goal remains untrustworthy and is not based on a deep consensual framework or a resulting sufficient agenda process. This cannot be changed by political conventions alone, but needs deeper conceptualizations on its basis.

The objective of this paper is to serve this need by integrating consolidated scientific fundaments that are able to guide sustainable development concretely and reliably in form of a conceptual framework. A stronger system thinking perspective is favored to explore the beneficial relationship between concepts of sustainability and system resilience. A resilience anchored sustainable development of crucial drivers and functional leverage domains of the socio-economic sub-systems would be of great advantage to improve the coordinates for sustainable development and to find more appropriate and deeper rooted conceptualizations on the course. In this sense an elaboration on more appropriate system boundaries with respect to integration of crucial and powerful driver spheres of (un-)sustainability would be required. On such a foundation, outlines of guiding frameworks for assessment and development can be prepared or existing ones could be refined and extended. This would represent promising perspectives for those who are committed with a stronger progress for sustainability in science, society, economics and the public policy sector.

II. METHODOLOGICAL OVERVIEW

As the basis of the conceptual developments of this article stands a desktop literature review process, based on the methodology of integrative research review (Cooper 1989, Cooper 1998) with the aim of a hermeneutic synopsis of the approaches and findings, the generation of new problem overviews of major problem areas as well as related scientific propositions and solution proposals. According to Cooper (1989) and Hsia (2015), the review process was executed as a qualitative meta-analysis, oriented on primarily the state of research on sustainability theory, resilience theory as well as both in combination (e.g. in the terms of Social-Ecological Systems frameworks, SES, by Ostrom (2009) and other system-related conceptions), and secondly on the trends in research in the field of sustainability theory, resilience and sustainable development and system theory derived approaches in this context. The review used Thomson Reuters (preferably Web of Science) as well as Elsevier (preferably ScienceDirect) databases under use of EndNote software in facultative consolidation with a Google scholar search. The search mode was restricted to key-terms in the context of sustainability and resilience in peer-reviewed journals with an explicitly visible interdisciplinary chorus of established modern sustainability sciences. Centrally important and meta-oriented forums of research publication, such as "Nature", "Science" or "Proceedings of the National Academy of Science (PNAS)", have been considered as far as topic(s) and author(s) are related to the first condition. The accompanying Google scholar search was also considering centrally important and highly cited book and policy paper publications if they stand in a contents connection to the peer-reviewed journal publications of the first instance.

An extensive database of the relevant literature was developed in EndNote software for the further work process. The integrative research review process was consisting of (1) problem and task definition, (2) data collection, (3) summaries and clusters, (4) evaluation of data points, and (5) analysis and interpretation. The integrative research review was then embedded into a conceptual framework and theory building process adopted on the basis provided by Meredith (1993) and Wacker (2008). The conceptualization phase is an iterative process involving extensive reading, additional collection of literature, synthesis, and refinement of the framework via structured discussions with scientific scholar groups over a period of 15 months (under additional use of shared EndNote resource groups).

Within the scope of this paper, literature findings and synthesis of the state of research are contextualized in a first step with the subchapters of introduction, problem statement, demand profile for problem solutions as well as system resilience as point of reference, considering specific propositions and demands according to the suggestions of Wacker

(2008). In a second step trends in research in coherence with state of research are developed as logical deduction into the conceptual chapters of the urban-industrial nexus and the social-ecological-technological systems (SETS), principally oriented to Handfield and Melnyk (1998).

In accordance with Meredith (1993), this paper provides elaborations on conceptual frameworks, presented in text explanations and conceptual figures on the fundament of a number of interrelated scientific propositions which explain phenomena and/ or provide understanding of un-sustainability, sustainability/ sustainable development, system resilience, social-ecological/ economic-ecological interactions as well as sustainable economics/ ecological economics. The methodology to accomplish then conceptual frameworks and model building consists of an integration of a number of different journal contributions, summariz(ing) the common elements, contrast(ing) the differences, and extend(ing) the work in some manner (Meredith 1993).

III. CONCEPTUAL PROBLEMS COPING WITH THE SUSTAINABILITY CHALLENGE

Apart from complicated and counterproductive disagreements and unconsolidated ambitions in the political and economic arena, as characterized amongst others by Sachs (2016), the author can put forward three fundamental interrelated obstacles on the way towards sustainable development course corrections related to the status of research and practice:

- The academic world still shows divergent perceptions and itself has unconsolidated knowledge about sustainability as well as counter-productive self-conceptions still depending on disciplinary ways of thinking and research (Lawrence 2015, Wilkinson, Horwitz et al. 2015, Alder 2016). Sustainability Science as a newer and more inclusive school of academic acting based on post-normal science (PNS) (Ravetz 1987, Funtowicz and Ravetz 1995) is still no mainstream in the academia and needs to become much stronger. The actual ineffectiveness of the traditional science system was already maturely described and is more striking the more complex the societal challenge gets (Funtowicz and Ravetz 2003, Ravetz 2006, Kläy, Zimmermann et al. 2015).
- Practical implementation in economics/ industrial, technological and social sectors suffers from the first obstacle and itself shows no “applied” approach to create really fundamental course corrections and radical alternatives within and across sectors to improve their performances towards sustainability (Shrivastava 1995, Tonelli, Evans et al. 2013, Whiteman, Walker et al. 2013).
- Beside the inappropriate non-consolidated or totally missing common referential background of respective actor groups, a low operationalization potential even of recognized references, irritated by supposedly blurred or misperceived concepts of sustainability, hinder a stronger but urgently needed progress in understanding, action and monitoring for sustainability (Dietz and Neumayer 2007, Neumayer 2012, Davies 2013, Barkemeyer, Holt et al. 2014).

The above obstacles are inherently connected to stakeholder groups, their explicit knowledge stocks, mindsets and abilities do correspond with the overriding complexity of the sustainability challenge itself: The economic, social and ecological dimensions of reality come out as closely coupled in their actual performances. Principally we have moved away from the bounded, controllable scope of traditional products and services to rather boundaryless, erratic realms of industrial, ecological and social system interrelationships (Fiksel 2006). Climate change, urbanization, resource scarcity, and the causal dynamic texture of a globalized industrial economy are intermediate snapshots of a multifaceted regime shift, but do generate further regime shifts in highly complex cascades and on various levels and scales of the social, ecological and economical organization of a transformed planet (Folke and Rockström 2009, Hughes, Carpenter et al. 2013, Hoekstra and Wiedmann 2014, Steffen, Richardson et al. 2015). Each particular course of socio-economic developments (e.g. expansion of cities, course of industrial branches, transition in energy supply), as parts of this complexity, is in conclusion highly volatile. It is noteworthy to understand that the widespread understanding of sustainability in terms of the “people, planet, profit” bottom line (Elkington 1997) or the politically accented Brundtland-Definition of inter- and intra-generational justice (Brundtland, Khalid et al.

1987) use social, economical and ecological spheres as reductionist categories and at last superficial perceptions of a much more complex reality. The politically influenced reductionist approaches on sustainability helped to introduce a new way of thinking and made sustainability quite popular, but are not helpful to cope afterwards and consequently with the underlying complexity of the challenge as well as to operationalize strategies in and across sectors of our socio-economic system.

In an effort to structure root causes of un-sustainability we can identify that human pressures on the planet are strongly associated with the global duality of urbanization and industrial backgrounds in a functional amalgamation (Seto and Satterthwaite 2010, Ahern 2011, Liu, Mooney et al. 2015). Accordingly, both sustainable urban development (SUD) and green economy play central roles in the discussion on global sustainability transitions (Bugliarello 2006, Jänicke 2012). In both directions of discourse, the cross-cutting energy transition away from massive use of fossil resources towards renewable energy resources and closing of supply loops is a central agenda issue (Heinberg 2004, Atkinson 2007, Kaygusuz 2012, Twidell and Weir 2015). Taking up the overstretched capacity of the global climate system and its tipping points for risky regime shifts of the system and its ecological and socio-economic interconnections, a really fast progress towards a renewable based industrial economy is now the decisive step (De Vries, Van Vuuren et al. 2007, Schellnhuber and Martin 2014, Galil 2015). As Negro, Alkemade et al. (2012) indicate, the transition process shows dangerously slow pace. Following Dangerman and Schellnhuber (2013), the slow pace of necessary change as well as some backfiring against sustainable solutions also belong to complex nature of systems and can be explained as a powerful dynamic locked-in effect, described by Senge (1990).

IV. A DEMAND PROFILE FOR SYSTEM ALTERNATIVES AND ALTERNATIVE SYSTEMS

The building of sustainable systems in the sense of integrating highly complex interplays of unsustainable domains is still ineffective and should be taken as a major motivation for progress in sustainability sciences (Clark and Dickson 2003, Fiksel 2006, Kerkhoff 2013). Practically it becomes unfeasible to execute autonomous assessments and planning for sustainability in a particular industry or a social sector without being confronted with broader repercussions in manifold functionally contiguous sectors (Fiksel 2006). It will become necessary to relate countermeasures and alternative solutions to the actual status quo of existing sectors in economical/ industrial or social life to transform current settings into new and better arrangements.

To effectively overcome the above described disadvantages, affected stakeholders have to intentionally mirror the complexity of real world systems in the achieved assessments and alternative countermeasures for sustainable development. Bearing in mind the above statements, the author can recapitulate as a first step for a profile of system alternatives and alternative systems demands enumerated hereunder:

- Academic as well as practical expertise need a more consolidated referential knowledge background of sustainability science, a solid basis on which interfaces can jointly be operated on in the sense of post-normal science (PNS). This background must encompass a system understanding of problem(s) and their dynamics as well as a systemic approach of connecting alternatives, improvements and innovations in its system complexity.

- Stakeholders have to understand that course corrections in their effectiveness do depend on often counterproductive system effects that could hinder better solutions even if better knowledge is available. Counterproductive conservative structures can very successfully hinder progress through power and inherent counterforce against change in systems, even if this leads to false solutions or a down pacing of needed progress.

- Ultimate drivers of a system transition such as corresponding urbanization and industrialization should be explored in their systemic interconnectedness as strong solution drivers in an integrated way instead of using reductionist categories of actually systemically interrelated social, economic and ecological spheres. A stronger focus on urban-industrial drivers treats them as nuclei of change through leverage functions into other systemically related transformation fields.

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To perceive problems correctly in their comprehensiveness and to cope with complexity, system thinking is a possible prerequisite. In a systems thinking approach the investigated entities and their environment are interpreted from a systemic viewpoint, starting with the analysis of fundamental elements and finally considering more complex related systems (Bertalanffy 1950, Bertalanffy 1968). Each entity is seen as a (sub-)system in its relationship to other systems, placed at higher levels of observation. The features of this "system of systems" can be detected in sub-systems and is described as principles of nested systems hierarchies or nested systems organization (Bossel 2007). The principle unit of analysis is a system made up of multiple compartments, structures and processes that can be described as functions or 'services' within the system (Odum and Barrett 1971). Figure 1 introduces central termini of the nested systems theory.

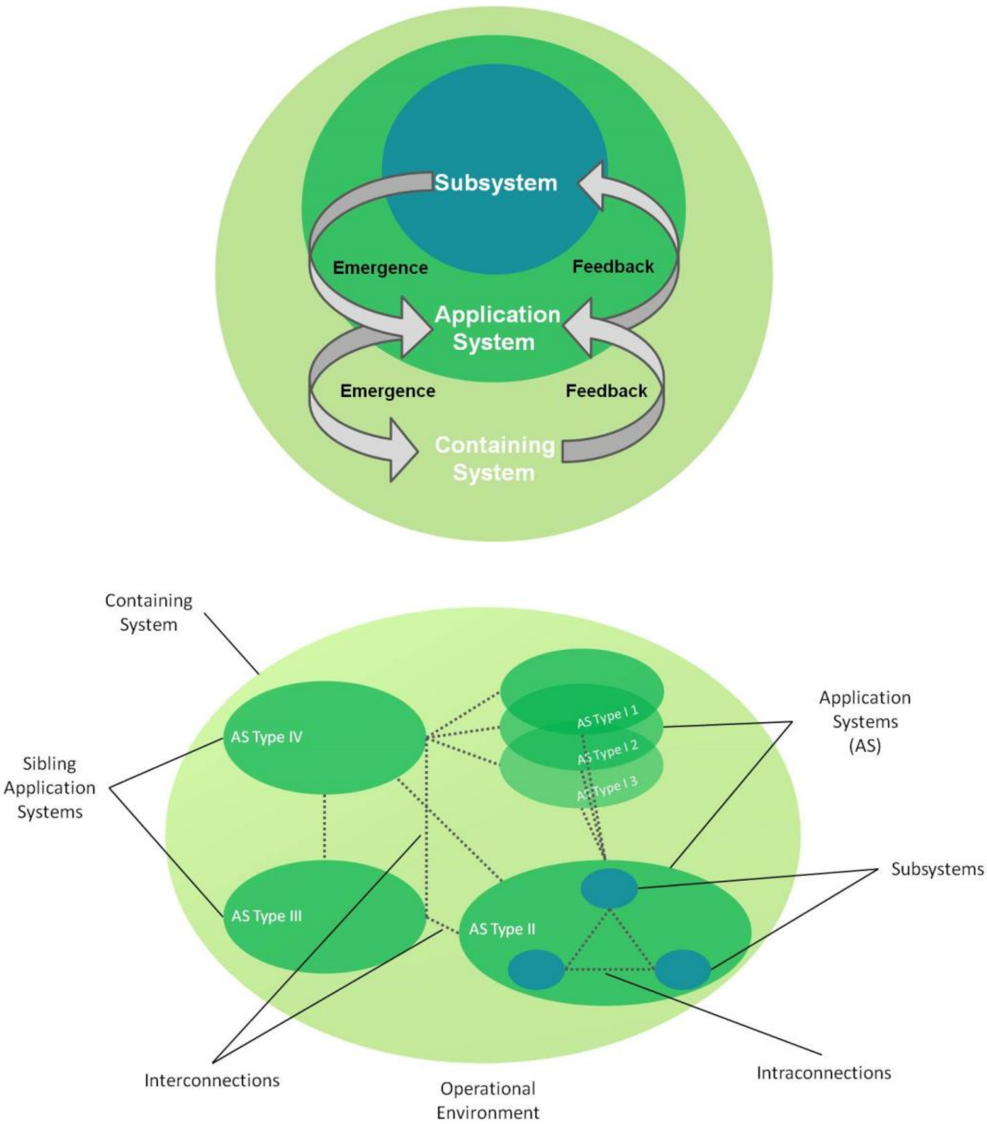

Fig .1. Nested Systems Hierarchies (a)/ Nested Systems Organization (b)

Beyond the analytical perspectives on the system status and system organization, concrete alternative system-oriented management approaches and setting of new integrated systemic frames upon decisions and actions on sustainable development are obligatory (Korhonen and Seager 2008, Wiek, Farioli et al. 2012, Miller, Wiek et al. 2014). To reach this goal, institutions have to effectively balance their demands and need to be enabled to cope with uncertainty as a result of complexity (Fiksel 2006, Fiksel 2015). In line with Joseph Fiksel we can identify central questions in concern of a performance demand profile for future socio-economic systems, as enumerated below:

- How can socio-economic systems achieve long and short-term economic success AND long term social stability AND productivity AND long term ecological integrity under changing conditions of the greater system environment?

- What solutions can science provide to better understand the interlinked behaviours and emerging risks as well as opportunities of complex social, economic and ecological sub-systems contained in bigger system operation orders?

- How can this be applied to design and management of institutional as well as technological, infrastructural and managerial systems to meet societal demands, especially in the cross-sector of (renewable) energy as a conditioning factor for the sustainability performance?

V. SYSTEM RESILIENCE AS POINT OF REFERENCE FOR SOLUTION DESIGNS

To operationalize the demand profile we can learn from the complex system behaviour of natural ecosystems emerged through millions of years of (co-) evolutionary processes of the systems, their compartments and nested levels of mutual organization. A central ability and furthermore an organizational principle of natural systems to adapt its functionality and structures dynamically against interference is described as system resilience, or simple: resilience. Resilience of a system counts on compartments ("agents") and their interrelations to entirely emerge sustainability, literally as durability or survival of the system in a dynamic surrounding of subtle or sudden change.

This view assumes natural systems as an interesting model for the above described demands. The observation of natural ecosystems shows that not only transient shocks lead to a destabilization of systems, but also chronic stress, slow and subtly changing conditions, can play an important role (Rapport 1995). Both are true for factors and processes referred to un-sustainability. The description of system resilience has its scientific origin in the early 1970s (Holling 1973). The concept has undergone some refinements, but a contemporary definition concentrates on conditions for multiple flexible equilibriums. Resilience commonly refers to "... the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control its behaviour" (Gunderson 2000). In addition to these notions of resilience, further interlinked core aspects are given, including the extent to which the system is capable of self-organization (Perrings and Walker 2004) as well as its ability to build and increase capacity for learning and adaptation (Folke, Carpenter et al. 2010). This understanding of resilience is still unwieldy to operationalize for sustainable development. A more applicable detailing of the resilience concept was delivered by Walker, Holling et al. (2004). The state of systems is considered in four dimensions:

- latitude - width of the "basin of attraction" in which the system is able to operate
- resistance - difficulty of changing the system
- precariousness - how close is the trajectory of the system to a threshold
- cross-scale relations (panarchy) - how much are other attributes affected by sub-systems

In simple terms system resilience can be illustrated with a ball in a basin. An interference or disturbance of the system leads to a more or less powerful displacement and motion of the ball. Normally the ball will return into a stable equilibrium in the middle of the basin after a disturbance. Resilience is determined by the width and depth of the basin, so that the system would lose its original properties when the ball is moved over basin rim, indicating the exceeding of thresholds and the following tipping points of system stability (figure 2). So both the intensity of stress or disturbance on a system and the lowering or elevation of its thresholds (system properties, displayed as structures, functions or services) has influence on the system resilience.

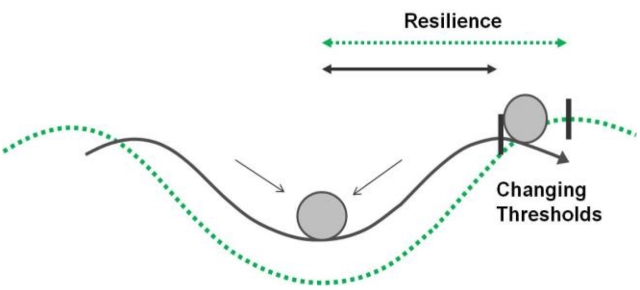

Fig .2. Illustration of System Resilience (Source: Stockholm Resilience Centre, modified)

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It is striking how much this can be transferred to socio-economical, socio-technological and industrial systems and their ultimate dependence on an ecological meta-system. Resilience design is driven by the need for flexible adaptation and insight into limited forecasting capacities and non-linear behaviour of complex dynamic systems. With help of the above four dimensions of system state, referred to as "capacities", first qualitative or even quantitative descriptions of resilience can be specified and practicable design options to enforce abilities to learn and to innovate (self-) repair capacities as forms of adaptation can be derived.

Crucial for adaptive capacity is the broadening and diversification of the resource base of desired sustainable systems. The diversity and presence of multiple and also redundant elementary structures, as reserves or buffers, ensure ancillary services, even if conditions change drastically and/or if key elements fail (Folke, Carpenter et al. 2002, Folke, Carpenter et al. 2010, Brown and Williams 2015). This is the main reason why from a system thinking view, strategies of pure eco-efficiency do not lead to sustainable improvements (Korhonen and Seager 2008, Fiksel 2015, Korhonen and Snäkin 2015). Simply lean and energetically optimized resource systems, for example in industrial or urban contexts, cannot meet needed flexibility and adaptability in terms of an "in vivo" fluctuating environment. In the longer term they may be inefficient due to lower long term persistence in their economic performance and thus bring new risks and additional costs.

The way how agents and interrelationships are organized is decisive for emergence of system resilience against internal and external disruptions. Taking this perspective, resilience can be more interpreted in terms of conserving functions than cementing structures. In our context, an ultimate meaning to achieve this would have functional integration of agents belonging to social, economical and ecological dimensions and include their levels of interconnectedness into our strategy. However, a resilience perspective is significantly connected to understanding of dynamics and to plan and manage within social–ecological systems (SES) (Folke 2006, Walker, Gunderson et al. 2006) as well as for dynamics of ecological-economic systems (Derissen, Quaas et al. 2011, Chopra and Khanna 2014). In this context, a focus is on adaptive management and governance as a linking momentum between the socio-economic and the ecological sub-systems in concern of ecosystem goods and services (ESGS) (Costanza, d'Arge et al. 1997, De Groot, Wilson et al. 2002, de Groot, Alkemade et al. 2010) provided by the ecological system part and the management systems for resource use by institutions/ organizations determined by the socio-economic part (compare figure 3).

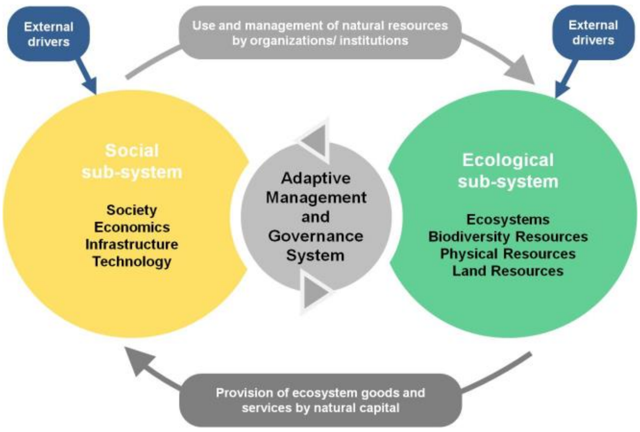

Fig .3. Resilience through Adaptive Management and Governance in SES, after Ostrom (2009), strongly modified

To some extent the notion of resilience at more practice oriented policy interfaces, even in international organizations, often remains disproportionally restricted to efforts enforcing physical infrastructure resilience in light of climate change impacts; see e.g. UNISDR (2012). Although this is an important field, it is essential to note that a truly resilience guided strategy of generally anthropogenic, specifically socio-economic sub-systems, would address more fundamental skills, essentially related to social networks to reconfigure, establish or maintain infrastructures (Hahn, Schultz et al. 2008, Cote and Nightingale 2012, Bahadur, Ibrahim et al. 2013). It is important to be aware that compensation capabilities in response to uncertainties derive from the behaviour of the stakeholders (individual or as organizational entity) as structural and dynamic properties of the system.

A system needs to be open to learning as a main prerequisite for dynamic knowledge stocks, adaptation policies and intervention strategies, to reorganize structural elements, innovating social and ecological components and - in the end - keep up their key functions as ultimate purposes of the system independent from original infrastructural settings. Therefore, institutions need to be open and flexible in order to allow continuity in working and learning and consequently support an increase in their adaptive capacity. Thomas and Twyman (2005) as well as Bahadur, Ibrahim et al. (2013) consider decentralization, equity, justice and social diversity as key issues for effective governance for sustainability. Decentralization can lead to management and decision making structures, which are closer to specific needs of communities. So decisions made can be robust, reliable and long-term. Also in case of an upcoming crisis in a decentralized system the breakdown of one authority will probably not lead to a collapse of the entire system.

On the whole, the author states that with regard of SES, resilience is addressed to a spectrum of sub-systems and organizational layers within systems. Consequently specific organizational concreteness for the social-cultural sub-system (with norms, values, mindsets, etc.), the ecological sub-system (resource base, ecosystem services, carrying capacities and thresholds, etc.), the institutional frames (learning, flexible organizational forms, etc.), important interfaces of the social and the ecological as well as technological assets (maintenance, supply-demand relations, services, etc.), infrastructure (redundancy, reliability, response capacity, etc.) or management and engineering (flexibility, modularity, collaborative solutions, user integration, etc.) can be articulated. This can help to built up better and more structured approaches to implement resilience design strategies in specific work fields of sustainable development (figure 4).

Fig .4. Resilience Design in ecological and socio-economic sub-systems

For the entirety of an observed system and for each sub-system or interface the following four system aspects/ properties play conditioning and cross-oriented roles in resilience design:

- System resources and system agents comprehensiveness and diversity, relating to buffers, alternatives and stocks
- System structures and boundaries to encompass driving functions for a long term viability
- System dynamics defining interactions as balancing, enforcing or attenuating feedbacks
- System capabilities as (re-)configurability of the system dynamics on the basis of stakeholders and institutions and their adaptive capacities

Section 6 will be devoted to a necessary systems integration of (a) resources and (b) structures to ensure basic meta-strategies comprehensive enough for long term viability. This is considered as presuming for active system configurability and the potentials to generate sustainable dynamics and capabilities of and within systems. Section 7 will thereafter outline framework constitutions to portray (c) dynamics and to plan and manage those dynamics to positively influence (d) system capabilities.

VI. SYSTEMS INTEGRATION: EXPLORING THE URBAN-INDUSTRIAL NEXUS

Before taking concrete resilience based development strategies into account, a crucial step in the definition of the application system is answering the questions:

- What is part of the system, and what is not?
- On which nested organizational layers are parts/ agents operating with which consequence for the emerging performance?
- What are driving or critical or determining (sub-) structures and agents?
- And in which boundaries is their interrelationship effectively situated?

The difficulty where an observed system shows practicable system boundaries depends on the one hand if it is "complete enough" to follow a specific purpose under a given level of complexity, and on the other, to find manageable/planable units and interconnections. Both determine success or failure of efforts for sustainable development. The concrete result of such a selection process may differ in specific contexts on micro- or meso-scales, but more important some fundamental strategic propositions for the macro-scale have to be met in a first instance.

Specifying the operational context of sustainable development, beside many particular (sub-)sectors (agriculture, transport systems, fishery, water management, etc.) literature can be detected purposely on resilience guided sustainable development of urban systems as well as of industrial systems as two core drivers causing global un-sustainability. For urban systems, Ahern and colleagues (Ahern 2012, Ahern, Cilliers et al. 2014) promote five strategies to build resilience capacity and a trans-disciplinary collaboration is proposed, concerning biodiversity, urban ecological networks and connectivity, multi-functionality, redundancy and modularization as well as adaptive design in and of urban systems. In the industrial context others are exemplifying the efficiency vs. resilience question on the basis of comprehensive value chains and material flow networks of and in-between firms considering sourcing, production, distribution and consumption sub-structures of supply chains (Zhu and Ruth 2013, Chopra and Khanna 2014) and derive new policy recommendations rooted in industrial ecology (Deutz and Ioppolo 2015).

The synthesis of functionally highly interrelated aspects as urban-industrial nexus is still missing, although further systems integration of in fact inseparable forces for (un-)sustainability is considered highly necessary (Liu, Mooney et al. 2015) and obvious for industrial and urban spheres. The reason for this misperception might still be a foreground attention to the physical appearance of (infra-) structures of typically urban- or industrial phenotypes. Apart from conventional sectoral thinking a demand-supply rationale, respectively source-sink relationships, makes the interdependency of the two areas understandable: The overshoot of the planet's ecological capacity can be specified in terms of a drastic resource overconsumption of resources at sinks, already causing acute or predictable scarcity at sources on regional or global scale, and by overstretching carrying capacities of the global system (eco-capacity: the ability to absorb or to assimilate caused disturbances), e.g. by destabilizing the global climate (Rockström, Steffen et al. 2009, Barnosky, Hadly et al. 2012, Hoekstra and Wiedmann 2014, Rockstrom and Klum 2015, Steffen, Richardson et al. 2015). Urban systems are the main drivers of this impact and are systematically connected within a complex nexus of sources and sinks of materials and energy. The drastic disproportional impact of urban systems on the global eco-capacity has been illustrated through the application of ecological footprinting methodology to complex urban agglomerations (Rees and Wackernagel 1996, Rees 1997, Rees 2001, Wackernagel, Kitzes et al. 2006). While currently urban areas represent some two percent of the earth surface and inhabit slightly more than 50 percent of the global human population, they consume approximately 70 percent of natural resources and are responsible for roughly 80 percent of the global greenhouse gas emissions (Girardet 2000, Marchal, Dellink et al. 2011). Thus, urbanization needs to be considered as a key for understanding and solution of interlinked demand and supply problems in the era of global environmental change. Therefore, it is necessary to make changes in perceptions of cities including their supply systems and critical dependencies and shift the planning and management system boundaries beyond the conventional urban form and structure towards functional sources and sinks pattern in urban-industrial nexus considerations. Sources would then incorporate not only typical industrial capacities but also those capacities which are sources for the sources in form of ecological resources and/ or ecosystem goods and services ("industrial production as consumption of natural capital") for the background of ecological economics (Costanza, Daly et al. 1992, Rees 2003, Wiedmann, Minx et al. 2006). Sources could better be described as eco-industrial sources to make clearer that sourcing at the ecological resource and ecosystem goods and services play an important role for the further processing in industrial production on the way towards mainly urban sinks.

This shift towards intersectoral approaches across the traditional sector borders is a logical consequence of the earlier introduced system thinking approach. It is necessary to integrate production, demand and supply systems from a 'system of systems' perspective. System thinking provides methodological and structured approaches due to its ability to consider sub-system layers as well as the operational environments within the larger system in forms of nested organizations (Bossel 1987) and supports capturing the dynamic, complex and interdependent nature of the connected (sub-)systems (Sterman 2000).

The urban-industrial nexus represents a shift from a structural or spatial towards a more functional reception of boundaries to reveal the conceptual inseparability of the two drivers for sustainability. Helpful aspects of such an integrated functional viewpoint are the definition of concrete functional domains of supply to link up eco-industrial sources with urban consumption sinks within the urban-industrial nexus. Those functional domains could be characterized by concepts of supply chain management (SCM) in terms of (a) operations and service levels (plan, source, make, deliver, use, recycle) to perform the supply function and by the dynamics of (b) material and non-material resource flows (resources, goods, commodities, energy, information and value) along the structures of a supply chain. Additionally, (c) supporting typological factors of functional interrelationships (conditioning, trigger, limiting and integrating factors) describe the quality of the relationship between source and sink to serve sustainability of the respective systems (Krumme 2006). Figure 5 shows principle compartments and relationships consisting of resource level, operations level and factors level between the eco-industrial and urban sub-systems.

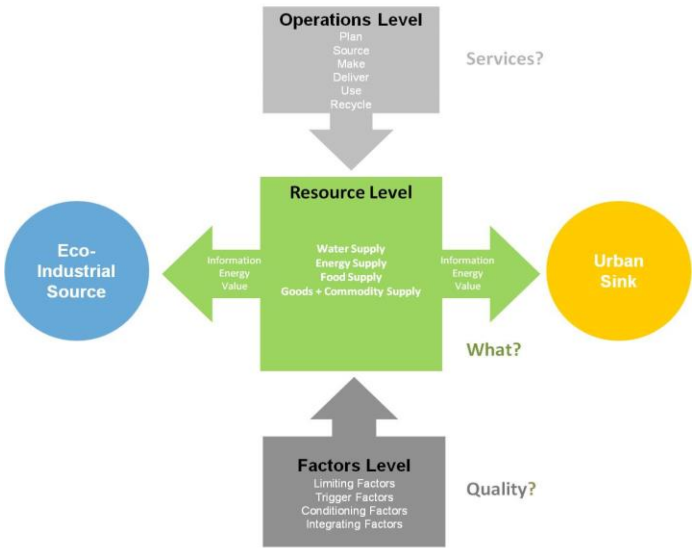

Fig .5. Elements of Urban-Industrial Functional Domains of Supply

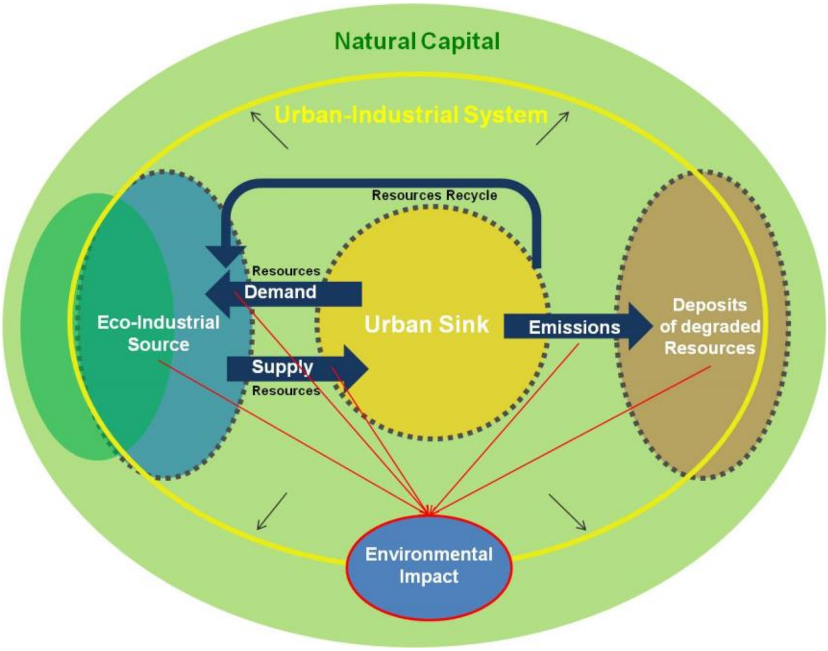

Fig .6. Advanced Ecological Economics Urban-Industrial System Metabolism Model

Once the relationship between eco-industrial source and urban sink is qualified by description of functional domains, the relationship can be embedded into a more comprehensive functional metabolism model in an approach of ecological economics and industrial ecology. Figure 6 shows a non-spatial urban-industrial system metabolism model as a consequence of the functional view of source-sink relations: The urban-industrial system is described as an expanding unit within the finite surrounding system of natural capital. The expansion is driven by both demand and supply between source and sink. The environmental impact is inclusively driven by supply and demand combined with turnover of resources, the effects on the eco-industrial source (in terms of conversion of natural capital into human or industrial capital), all kind of emissions on which the urban sink signs responsible for, and non-recyclable deposits of degraded resources if only a part of resource turnover can be redirected in form of a closed loop towards the eco-industrial source.

Planning and management of an urban-industrial system in a resilient and sustainable manner would consider all system compartments and interrelationships against the background of resilience design. It primarily addresses the multifold factors of the expansion function and of the environmental impact function in an integrated way to reduce both functions under the thresholds of the carrying capacity of the finite natural system. In parallel an increase of the closed loop function between the two sub-systems would be enforced. The establishment of a more integrative system boundary and consideration of interrelated structures as shown in figure 6 and the quality of their relationships demonstrated in figure 5 represent a first ultimate step towards a resilience orientation. Furthermore, it provides several supplementary directions for methodological improvement of the proposed basic functional model.

Such a new perspective directs itself to Jay Forrester's urban and industrial dynamics (Forrester 1961, Forrester 1969, Forrester 1997), basic operations research such as the Viable System Model (VSM) by Stafford Beer (1984) and some recently established links of VSM to sustainability science (Panagiotakopoulos, Espinosa et al. 2016), bio-economics and thermodynamic receptions of ecological-economic resource systems (Georgescu-Roegen 1975, Georgescu-Roegen 1993) or even ecological footprint methods (Rees and Wackernagel 1996, Wackernagel, Kitzes et al. 2006). All these provide a meta-perspective of nested system organizations beyond a classical sectors view and apart from foreground phenotypic structural perceptions. In terms of first outlines of understanding the language of system dynamics methodology could be appropriate to approach more complex and dynamic levels of functionalities in the urban-industrial nexus.

After initial steps for systems integration of resources and structures, as the first two of four main system aspects of resilience design (section 5) could be demonstrated, the next section adds dynamics and capabilities and integrates all four system resilience design aspects together in a final illustrated model contextualized with an advanced resilience framework on the basis of the earlier presented SES (figure 3).

VII. FRAMEWORK FOR RESILIENCE GUIDANCE: SOCIAL-ECOLOGICAL-TECHNOLOGICAL SYSTEMS (SETS)

Resilience orientation makes clear that sustainability as a steady state is impracticable. Sustainability refers to dynamics of interrelated (sub-)systems to emerge a variety of response forms of systems and their agents in multiple and alternative equilibriums within dynamic environments, evident in the behaviour of natural ecosystems. As natural systems a socio-economic system, or in the context of this article an urban-industrial system in a more specific focus, depends in its ability to adapt to changing conditions (adaptability) on different system capabilities (based on fundamental distinct capacities) that can be actively or passively developed, can flourish or being deteriorated. Therefore, against the backdrop of resilience design, system dynamics and system capabilities stand in a significant affiliation to each other.

Building on the system-theoretical background of system ecology with the goal of resilience, the researcher can interpret technological, economic, social and environmental factors of urban-industrial systems as interoperable compartments of a dynamic network equilibrium that considers all system compartments as an "ecosystem" building up system capabilities as characteristic properties. Resilience as a guiding concept allows us encompassing and systematizing the relevant key performance factors for sustainable operations in the networked and nested order of urban-industrial systems.

As mentioned earlier, resilience oriented sustainable development strategies point out on inner control and steering mechanisms of social-ecological systems (SES) (see figure 3). Elinor Ostrom convincingly elaborated SES as guiding frameworks (Ostrom 2007, Ostrom 2009, McGinnis and Ostrom 2012) and initiated a new direction of further works on the synthesis of sustainability, resilience and SES (Xu, Marinova et al. 2014) up into strategic and operational spheres of trans-disciplinarity (Binder, Absenger-Helmli et al. 2015). In order to move forward the general perception of sustainable development frameworks, science is recently about to come up with an integration of the technological sphere into SES as social-ecological-technological systems (SETS), particularly for sustainable urban development (Krumme 2016, McPhearson, Pickett et al. 2016). Technology was seen before as a compartment of the social sub-system of SES. In terms of guiding frameworks for sustainable development of strongly artificially transformed environments, such as infrastructures in urban or industrial systems, the question about the transformative capacity of technology and its contribution to socio-economic system capabilities arises more strongly. It seems obvious but still poorly reflected that technology plays a determining role in the functional contexts of the urban-industrial nexus and its significance for (un)-sustainability. The question is how the role of technology in modern societies and respectively for sustainable systems driven by the society institutions and organizations can more precisely be described.

It is useful to go back to the original meaning of technology, which comes from the Greek word tekhnologia as "systematic treatment" and from tekhnē as "art" or "skill". If we take into account that the human species' use of technology began with the conversion of natural resources into simple tools, it becomes significant how much the human ability to control and adapt to the natural environments is affected and driven by technology. In this context, technology can also describe a more comprehensive frame of methods, processes, materials, machines, tools and techniques and can be considered an 'enabler' on the interface of social organizations and their environment to facilitate the capture, distribution and repeatable application of value creating knowledge (DeSanctis and Poole 1994, Earl 2001) (figure 7).

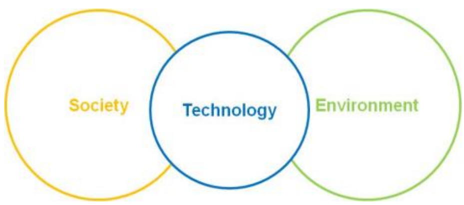

Fig .7. Technology in a sustainability context

As illustrated below, such a comprehensive understanding of technology makes the depiction of dynamics for sustainable development frameworks more complete and accents further design options to strengthen resilience (figure 8). The presented illustrated model puts the dynamics of SETS on a platform of the four cross-oriented resilience design system aspects. A number of attributes correlated to four resilience design elements exemplifies the affecting of environmental, social and (new) organizational-technological capacities and their determining sub-systems in SETS. The inner arena shows the dynamics of SETS, oriented on visualization by Hahn, Schultz et al. (2008) for fundamental SES, complemented with a new technological sub-system against the background of the above made explanations. Including the new technological dimension a SETS comprises of ecosystems as natural capital being managed and used by stakeholders and their institutions. This central interplay between humans and natural environment is enabled by a technological sphere in terms of a broad understanding of instruments, processes and methods as explained above. The management and governance systems provide frameworks with which technology is contextualized. The way of management operations is itself influenced by societal norms and values.

The system resilience against external drivers of change of such a SETS imagination depends essentially on carrying capacities of the ecosystem base as well as capacities of institutions and organizations. The way how this bilateral relationship works is enabled by adapted forms of technology and infrastructure on the interface between the social institutions and their management systems as well as the ecological functions of natural capital. Technology, therefore, plays a role as enabler of operational management modes and specific operations being more or less sustainable. A conditioning factor for the described interplay is fulfilled by progress in knowledge and competence capacities that are able to transform institutional as well as management assets of the system and, more subtle, also values and norms (and vice versa).

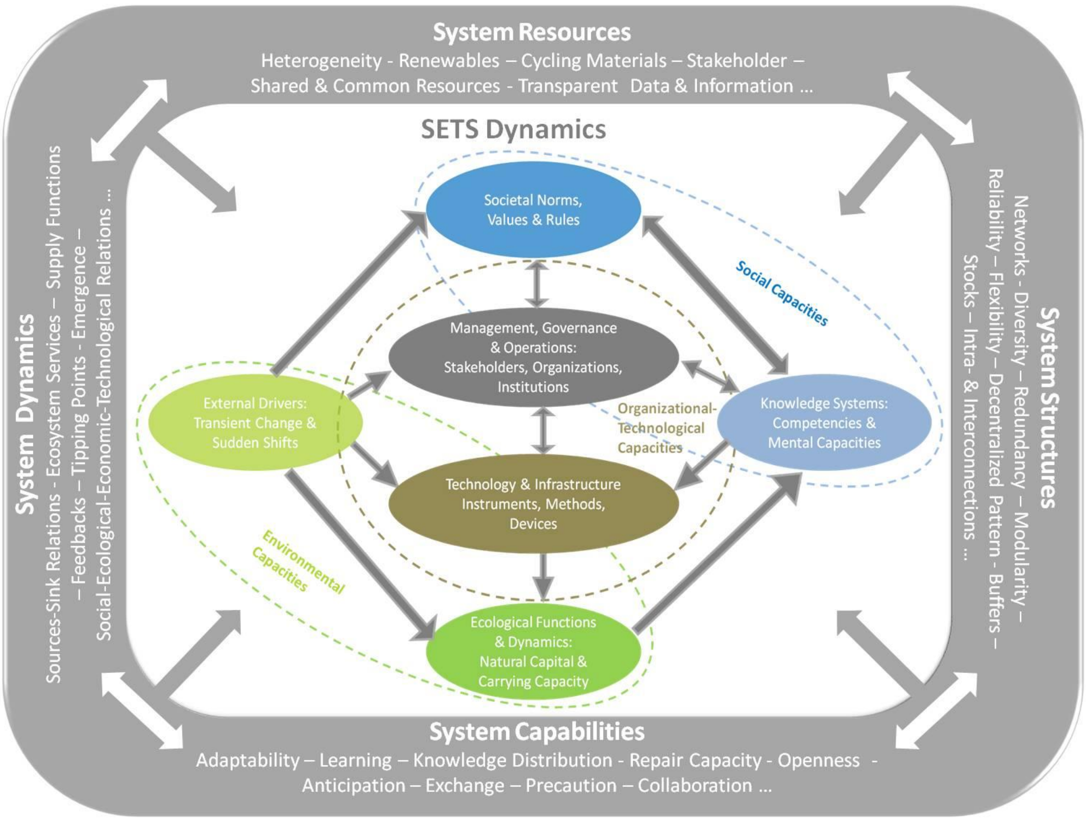

Fig .8. Conceptual Model of Resilience Design Dimensions and SETS Dynamics (own conceptualization with reference to Walker, Holling et al. 2004, Hahn, Schultz et al. 2008)

An exemplification on the earlier mentioned importance of post-fossil energy system conversion may initially reveal resilience driven system design options out of this model:

We can exemplify both external and internal design opportunities from the above explanations. Post-fossil renewable energy networks are driven by a consensus on minimizing negative impacts on the natural capital base and limiting socio-economic actions below thresholds within ecological carrying capacities (to assimilate impacts and/or to avoid negative feedbacks, transient shifts or sudden shocks to the socio-economic system). It also integrates ecological services and natural cycles of ecosystem productivity in energy harvesting, while keeping a functional balance between natural productivity and consumption rates. Besides working on infrastructure and spatial pattern (a heterogeneity of green renewable energy sources, infrastructural facilities and energy transport modes, electricity networks and smart grids, energy storage facilities, interactive consumption sub-systems, intelligent energy efficient devices at the consumption side), resilience design may also affect the relationships within the system and influence embeddedness of elements into higher and lower levels of a nested hierarchy organization. This would touch upon concrete hierarchy levels of planning and of operating the networks (levels of complex systems operations management, participatory network designs in decentralized pattern and local, regional (semi-) autarky of closed energy production and supply systems). It would also mean that a sustainable energy transition represents some paramount questions of the institutional and “bottom up” stakeholder frameworks, taking into account that knowledge of sustainability issues and a directed competence and capacity building, empowerment and awareness raising (incorporating all stakeholder groups) would not only increase the quality of results. It would also improve their ability to survive and flourish and also their ability to flexibly modify intermediate results in an iterative manner and to produce continuous improvement and innovation in terms of adaptive management.

VIII. CONCLUSION AND OUTLOOK

The article took up the complex and dynamic system nature of the sustainability challenge and transferred problems into a system based reception of both un-sustainability and sustainability. It has been made clear that truly effective countermeasures necessitate a system thinking approach. Nested systems organization provides not only a structuring of problems in terms of drivers, effects, feedbacks and complex interrelationships. They also ask for principles how systems are able to cope with existential disturbances and stresses through complex and dynamic interplays of system compartments with differentiated feedbacks in multiple equilibriums of the affected system while upholding the essential functions and structures to fulfil the general purpose of the system, defined as resilience. A resilience guided design of socio-economic sub-systems and their interconnected ecological sub-systems applied in a holistic frame is favoured as a concrete orientation for more deeply understood sustainability strategies. It was furthermore demonstrated that for the purpose of sustainable systems, social networks and their organizations/ institutions play a decisive role for success or failure in our efforts towards sustainability.
Based on four categories of resilience design system properties two central strands of conceptual improvement could be discerned:

- Systems integration based on source-sink and respectively supply-demand rationales with setting advanced inclusive system boundaries towards centrally important urban-industrial systems. The result encompasses and systematizes the relevant key performance factors for a sustainable operations framework of an urban-industrial nexus as an advanced ecological urban-industrial metabolism model and introduces functional domains as new conceptual term into the sustainability discourse.

- Advancement of SES to SETS as guiding framework to concretize a newly contextualized role of technology together with other driving forces within dynamics for sustainable development, especially in heavily transformed artificial environments such as urban-industrial systems. Dynamics of SETS could be brought together on a platform of four resilience design system properties, namely: resources, structures, capabilities and dynamics.

As a future direction for further elaborations the synthesis of the urban-industrial nexus (resources and structures in new integrative boundaries) with SETS as an advanced framework (additionally considering capabilities and dynamics) can formulate new impulses for transition actions in the frame of sustainable development. Such frameworks can help:

- Understanding of sustainable or unsustainable systems by providing a more complete and realistic picture on dynamics
- Guiding and structuring of planning and management for alternative systems or system alternatives
- Making urban-industrial systems, their governance structures and their transition pathways comparable
- Supporting sustainable socio-economic transitions, and
- Determining future needs for research.

Hence, learning and capacity building play an imperative role for resilience, the co-production of science with the public sector, business and civic organizations are needed to successfully implement new developments. For science stakeholders, this bears two resilience specific meanings: to better understand needs and options for sustainable solutions through transition research and to take part as a promoter of sustainable development based on a specifically academic competence and through exploring new trans-disciplinary methodological settings and experimental innovation designs as transformative research. Combining transition research with transformative research will accentuate a new role of post-normal science without which the desired development will not take place (Wiek, Farioli et al. 2012, Miller, Wiek et al. 2014).

A ground for such integrative research and transition settings is contributed by Evans (2011) relating experimental cities with a system approach and resilience design. A combination with a strong system dynamics based ecosystem approach (Kay, Regier et al. 1999, Newman 1999, Newman and Jennings 2012) would broaden the experimental city towards the here proposed urban-industrial system boundaries as innovative coordinates for sustainable development.

This should be taken as a strong motivation to further enhance the exchange between sustainability oriented academic disciplines together with stakeholders from business, policy and the civil society in appropriate work interfaces and platforms under a suggested stronger systems integration and with this to substantially contribute to resilience of social, economic and ecological dimensions of the planetary system as a whole.

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Smart Seaports Logistics Roadmap

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Abstract - In the digital world, a smart concept became an essential feature for port organizations to serve as intelligent hubs in the world transport networks. Smart ports are the trend for the future long-term strategies. Henceforth, ports aims at contributing to sustainable growth by establishing the appropriate conditions for the adoption of new management energy models based on low environmental impact and triggering innovation of both technologies and processes. The scope of this paper is to examine three main issues of smart ports; smart port arctic logistics roadmap, smart port challenges and obstacles in arctic port areas, and the criteria and Key Performance Indicators (KPI) guiding the assessment of ports against this concept. The main purpose is to develop a smart arctic logistics roadmap for the future.

Keywords - Arctic logistics, smart port, logistics roadmap, smart intelligence.

I. INTRODUCTION

The importance of the smart port concept is strategically increasing in the last years as a future trend in the maritime industry. The new trend of smart port will lead to rely on the new management energy models, which are based on low environmental impacts and prompting the innovations of both processes and technologies. Consequently, smart ports will contribute to sustainable growth. Nowadays, most of the countries and unions, such as the European Union, have released new transport infrastructure policies. The purpose is to enhance the transport networks around the world, remove bottlenecks and technical barriers, and reachi remote markets in less times. All these trends rely on investing in the new technologies (Hamalainen, 2015).

The investment in the new technologies will lead to a greener and smarter transport systems, globally. Thus, the future trend for governments is to conduct ‘technology platforms’ that contributes to defining the future transport strategies, including integration of the supply chains and providing the needed innovation.

On the other hand, the Green Corridors have become an important feature for denoting the smart transport corridors, where advanced technology and co-modality are used to achieve energy efficiency and reduce environmental impact. The characteristics of a green corridor include, for example:

- Sustainable logistics solutions
- High safety
- High quality
- Integrated logistics concepts
- Optimal utilization of all transport modes
- Harmonized regulations with openness for all actors
- A concentration of national and international freight traffic
- Efficient and strategically placed trans-shipment points
- Supportive infrastructure
- Innovative logistics solutions, including information systems

Those green corridors will lead to smart corridors where intelligent transport services can be provided. Ports are considered the main members within those smart corridors. In other words, smart corridors including a maritime transport leg require smart ports. The aim is to improve the commuter services, enhance the traffic safety and make the traffic flow smoother, especially at the borders.

II. RESEARCH PROBLEM

This paper aims to address the following problem:

- What is the logistics roadmap for the future smart seaports?

This requires discussing those criteria that affect the transformation of seaports to be smart in the future. In turn, the paper will explain the challenges and obstacles facing smart ports. Also, smart port and the 2050 visions will be illuminated in order to highlight the required roadmap for both the authorities and stakeholders.

III. METHODOLOGY

The objective of the SMART ARCTIC logistics roadmap in seaports is to formulate a future vision and discuss the required roadmap for the ports. Hence, the approach of this paper is including the arctic context; including arctic competence and policy making, environmental informatics and mobile technology, and smart logistics and transport. Explanatory methodology will be applied in this paper and the philosophy is objectivist ontology. It aims to discuss the nature of reality, where the objectivist ontology deals with what is physically real, with no regard to the social objects, and where the results are based on the facts of the findings derived from real investigation (Maylor and Blackmon, 2005).

IV. THE SMART PORT CONCEPT

The smart port concept can be displayed as the port where the environmental impacts, operations, and the energy consumption are addressed. The main concern for the future maritime industry is to transform ports into Smart Sustainable Cities (SSC) in the global supply chains. ITU (2015, p. 8) defined the SSC as " is an innovative city that uses information and communication technologies and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects". This concept can be applied to seaports with certain criteria.

V. SMART PORT KPIS AND CRITERIA

Med (2015) has discussed 23 criteria and 68 key performance indicators (KPIs) against the smart port concept in relative to the environmental impacts, operations, and the energy consumption dimensions. Figure 1 displays most of the key criteria in relation to the smart port concept.

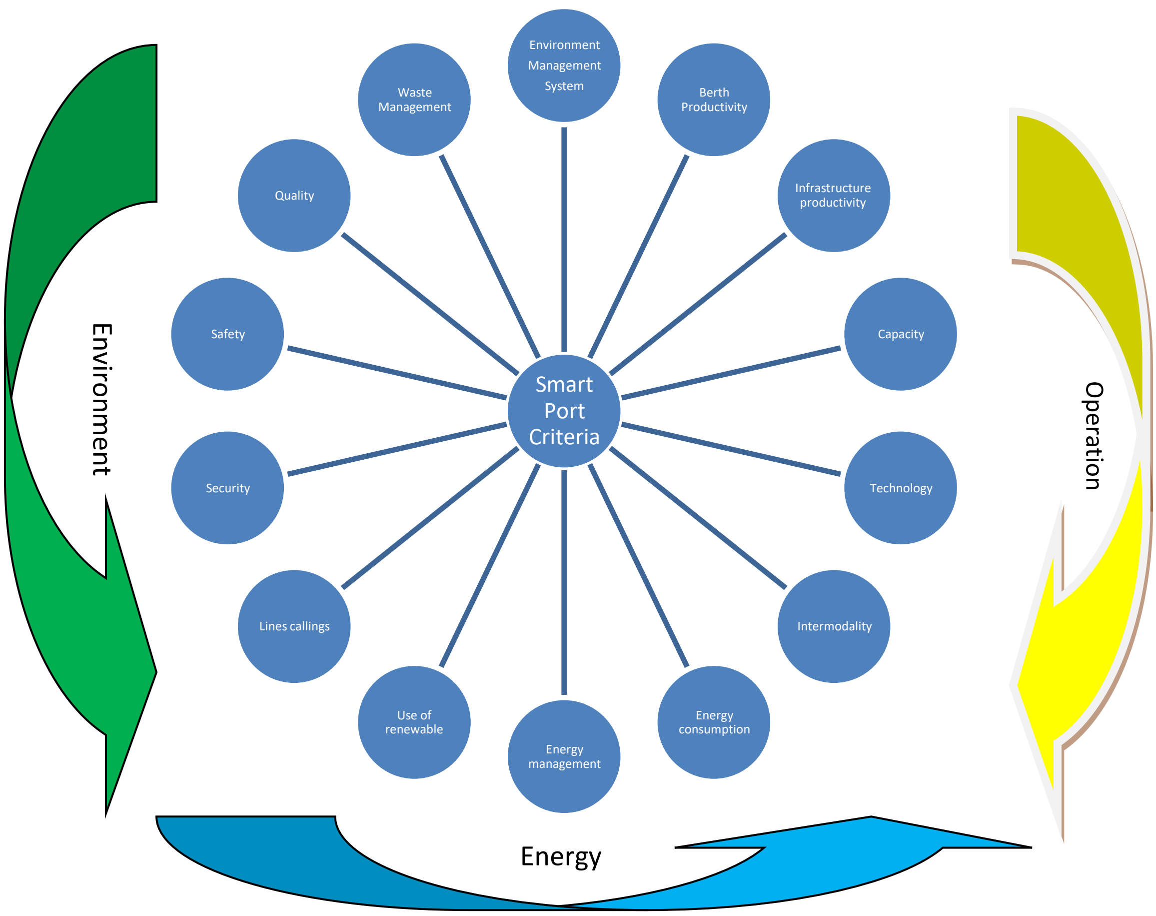

Fig .1. Scheme of some criteria in the different topics defined in the smart-port concept Source: Med (2015)

In ports operations, measuring productivity is the most common performance criteria (Cullinane et al., 2004). It includes sub measures such as berth productivity , berth efficiency and others which can be used to measure the productivity of the smart ports. The infrastructure productivity is another criterion where it ensures the cost-effective yard operations. Also, the combined capacity of infrastructure and equipment is important in order to accommodate an increase of the ships' sizes. Its availability helps enhance the ports' competitiveness. From the operational point of view, the reliable, accurate and secure flow of information is essential in order to provide quick, reliable services and operations at seaports. For the intermodality criteria, it helps to speed up the flow of goods within the logistics chains, reduces cargo handling and prevents damage or loss of the handled cargoes at ports (Matajic, 2010).

In terms of energy, the energy consumption presents an important criterion for improving the smart port performance, enhancing the ports' sustainability and strengthening the competitiveness (CISCO, 2003). Energy efficiency and savings can take place in ports at the various operations, buildings, equipment and warehouses. Hence, renewable energy technologies can be applied to ports such as wind, photovoltaic and marine technologies.

In other environmental contexts, different maritime and port activities can lead to pollutions. Hence, different environmental performance indicators can be particularly useful for both the authority and a wide range of stakeholders in providing evidence of progress and the achievement of environmental objectives. Those indicators include, for example, soil waste, air pollution and water contamination (Puig M., 2012). Waste management is a highly required philosophy by the new trend of smart ports in the future (and more particularly in the case of recycling processes).

Smart ports have to adopt their strategies to provide such services that raise the service quality provided at ports, such as repair, replacement and repositioning the equipment at different terminals. Also, an attraction towards the investment in port is a mandatory requirement in smart ports, where the investment in research innovation and development will incur an updated the security systems (Piniella 2009; Trelleborg 2010).

VI. CHALLENGES FACING SMART PORTS

Applying the smart port concept is facing a number of challenges as the concept has to contribute to the sustainable development of sea and waterways activities, which is known as "blue growth". This can be achieved by improving the performance levels of navigation and harbour calls, within a transport chain between the sea/waterway and the land and spatial planning between all those activities within the port boundaries. These challenges are:

- The first challenge is to enhance the competitiveness of the maritime industry as it involves numerous stakeholders in a wide range of activities such as shipbuilding, equipment, repair, and transformation of ships, offshore technology and the new on-going sector of renewable marine energies. It increases renowned knowledge in complex high-tech ships. This industry must be capable, in an international competitive environment, of remaining competitive in order to meet the demands of various users such as ship owners, importers, exporters, freight forwarders and shipping lines. Being a smart port leads to provide safe, secure, environmentally friendly and economic operations.

- One additional challenge involves the skills acquired by operators of the sea based (or related) industry. In order to maintain the sea industry attractive, it needs to rely on high-performance staff.

- The challenge facing the intermodality and associated cost of transferring goods between different means of transport raises a need for technological improvements on ships and at the port terminals.

- The highest challenge is to eliminate the global CO2 emissions originating from sea transport.

- Ship energy efficiency is another challenge due to a future context of rarefaction of oil and power.

- Smart ports play an indispensable role in providing damage control, security control, and illicit acts control such as theft, piracy, immigration and terrorism.

VII. SMART PORTS PARAMETERS

There are a number of parameters that should be considered in determining the smart ports roadmap. These parameters are:

- The ship use; new generations of ships are released in the maritime industry according to the economic, technological, environmental and regulatory developments.
- Re-structuring the main world economic centers and the new sources of growth will affect the role of the transshipment ports.
- New kind of goods, such as drinking water, hydrogen, captured CO2, carried by sea requires developing new specific urban logistics at seaports.
- A new need for modular ship is highly required in order to reduce the total operating costs. Those modular ships can be used for several purposes such as fishing and scientific usage.
- Structuring of industrial stakeholders within the maritime industry operating in the same or neighboring port areas.
- Fragmented and globalized value chains of logistic / supply chain operators, service providers and users.
- The industrial ecosystem.

VIII. SMART PORTS AND THE 2050 VISIONS

For the ports' future, the 2050 visions have been developed to presume long term economic contexts primarily defined by the type and size of ships. In vision 1, ship owners replace orders to build ships with latest innovation and quality and accommodate high capacity. This requires the shipyards to deploy low-labor cost and / to run fast production cycles. This will lead the shipyards to look for countries where they can get lower labor cost, optimized services, and modular maintenance. In turn, this vision explains the optimization of costs and the global fragmentation of the value chains.

In vision 2, the ship owners will demand their ships to perform new uses. The purpose is to minimize the purchasing costs and to provide competitive operations.Similarly, the switching signals of the lower switches (S_2, S_4, and S_6) can be determined.

Table 1. The Smart Ports and the 2050 Visions

Future Uses	Current Uses	New Uses
Worldwide	**Vision 1** Optimizing costs	**Vision 2** New standardized market niches
A local-level industrial ecosystem	**Vision 3** High-tech specialization	**Vision 4** Complexity and customization

Source: ADEME, 2015

In vision 3, industrialists in the maritime industry aim to utilize renewable energies for the ships' designs. They aim to reduce the materials costs and operating expenditures, especially when ordering mega ships. Extended engine life, energy savings and new energies such as green ships are examples of this vision, which implies new requirements from ports. In vision 4, the maritime transport will move towards global integration. This will lead to improve the quality and performance levels of the ships. Sharing port facilities will result in achieving optimal utilization of the available facilities at ports.

IX. OBSTACLES FACING TRANSFORMATION INTO SMART SEAPORTS

ADEME (2015) discussed a number of obstacles facing the future maritime transport in two main groups as follows:

A. Lack of technological solutions

- to reduce the consumption of fossil energies
- to reduce the environmental impacts of the ships
- to resolve the safety/security challenges faced by ships, their crews, passengers and goods
- lack of permanent monitoring and adaptive maintenance technologies
- lack of efficient production methods to increase competitiveness

B. Socio-economic, organizational and regulatory

- loss of national skills in certain key/strategic fields
- lack of guarantee funds to support the risk taken by the ship owner
- lack of research and testing capacities dedicated to sea transport
- restrictions connected to port infrastructures
- social acceptability of the new ship uses

- adoption of innovations by crews

X. CONCLUSION

This paper aims to contribute to the development of a logistics roadmap to identify future priority opportunities and capability needs for the ports to be smart in the future. It starts with discussing the most important criteria in relation to smart ports as a roadmap template. The most important challenges and obstacles facing the smart ports were then highlighted, based on the previous defined criteria as adapted to new and future contexts.

In conclusion, there is a strong emphasis on a move towards integrated intermodal transport systems, reducing emissions, implementation of track & trace solutions, and focusing on more automation and integration of data.

XI. RECOMMENDATIONS

In reviewing the required KPIs for smart ports as a roadmap and discussing the challenges and obstacles facing the transformation of ports to be smartic logistics nodes, it is recommended for both the stakeholders and the authorities at seaports to:

- Promote quality jobs and working conditions
- Encourage investment in technology
- Secure transport
- Apply a ‘One-stop-shop’ concept
- Spread over the tracking and tracing technologies
- Adopt the legislation themes in the maritime industry
- Enhance the capacity and quality of the infrastructure
- Improve the environmental and waste management systems
- Adopt the corridor management strategies
- Develop and implement Sustainable Energy Action Plans

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Three-to-Five-Phase Matrix Converter Using Carrier-based PWM Technique

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Abstract **-** This paper proposes a simple carrier-based PWM (CBPWM) technique to control the three-to five-phase Direct Matrix Converter (3×5 DMC). The proposed technique uses the indirect modulation approach to control the 3×5 DMC such as a three-phase bidirectional rectifier followed by five-phase voltage source inverter (VSI). Based on this approach, it is possible to synthesize the desired five-phase output voltages with sinusoidal three-phase input currents and unity input power factor. A CBPWM method is suggested for each stage independently including both linear and overmodulation operating modes. By the proposed technique, in both operating modes, the maximum possible overall Voltage Transfer Ratio (VTR) is achieved. Moreover, this technique allows the input power factor to be controlled by controlling the input current displacement angle. The feasibility of the proposed technique has been verified by a series of simulation and experimental results based on Matlab/Simulink and dSPACE-DS1104 platform. The results show that a sinusoidal output and input waveforms can be achieved with a maximum possible VTR in the linear region. However, in the overmodulation region, a maximum possible VTR is achieved at the cost of some distortion of output and input waveforms. Therefore, this technique can be used for the application where a higher VTR is essential.

Keywords **-** Five-phase, matrix converter, carrier-based PWM, overmodulation.

I. INTRODUCTION

N recent years, Matrix Converter (MC) is attracting extensive attention as a direct power converter that can convert the electrical energy from an ac source to an ac load [1]-[3]. The MC uses a matrix of semiconductor devices to connect the m-phase supply to the n-phase load directly [2]. It has been recognized as an alternative approach to overcome the drawbacks of conventional VSIs [4]. It also offers some distinct advantages such as: (i) sinusoidal input current and output voltage waveforms, (ii) natural four-quadrant operation, (iii) potential for compact design, and (iv) the input power factor can be fully controlled [4]-[6]. However, reduced output voltage, increased the semiconductor switches, complexity of the modulation technique and sensitivity to supply voltage disturbances are the main drawbacks [7]. Therefore, the industrial applications of this type of converter are limited [1].

Generally, the matrix converter can be represented as a single-stage (direct) or a double-stage (indirect) configuration [3], [7]. The different modulation techniques that can be applied on this type of converter are classified, according to the converter configuration, into two main categories, namely; direct and indirect modulation techniques [8]. The direct modulation technique is based on representing the matrix converter as a single-stage (direct) configuration. In this approach, the output voltage is obtained directly by the product of the input voltage and the switching-states modulation matrix representing the converter. On the other hand, the indirect modulation technique is based on the indirect (double-stage) configuration of the matrix converter in which the converter is represented as a rectifier-inverter combination without any dc-link. Using either direct or indirect configuration of MC, the CBPWM or SVM techniques can be applied.

The matrix converter was firstly introduced as a direct 3×3 phase configuration in [2] and steadily grew, pushed by the progress of the power electronics technology. Firstly, Venturini proposes a direct modulation CBPWM technique for the 3×3 MC [9]. The maximum obtainable output voltage using this technique does not exceed 0.5 of the input supply voltage. However, it has been increased to 0.866 using a third-harmonic injection [10]. On the other hand, the Space Vector Modulation (SVM) technique is found to be a very powerful solution to control the MCs [5]. According to the converter configurations, the SVM technique for controlling the matrix converters can be classified into direct SVM (DSVM) and indirect SVM (ISVM). The ISVM is proposed for 3×3 MC in [4]-[5]. In addition, the DSVM technique of 3×3 MC is presented in [11]-[12]. Recently, some research works have concentrated on the development of multiphase MC as an alternative to the conventional ac–dc–ac multiphase VSI [8], [13]-[24]. The SVM technique is developed to control the 3×5 MC in the linear modulation operating mode based on DSVM and ISVM [13]-[15]. The maximum obtainable output voltage, based on this modulation technique, equals 0.7887 from the input supply voltage. However, the complexity of the system is increased. In order to reduce the complexity of the multiphase MC system, the CBPWM techniques and Direct/Indirect Duty Cycle techniques have been introduced and developed.

The CBPWM is a simple PWM approach for controlling the MCs, in which the converter switching signals are obtained by comparing the reference modulating signals with a triangular carrier-wave. This technique was firstly reported by [25] for controlling the 3×3 MC, based on the direct converter configuration, in the linear modulation operating mode. A comprehensive solution to extend the operation of this technique in over-modulation operating mode is presented in [26]. This modulation technique has been developed to 3×5, 3×6, 3×7 and 3×9 MCs in [17], [18], [20] and [8] respectively. A new CBPWM technique, based on the indirect converter configuration, is proposed for the 3×3 MC [7]. In addition, a generalized CBPWM method, based on the correlation between SVPWM and CBPWM techniques, is proposed for 3×3 and 3×5 MC [6], [16]. In this method of modulation, one symmetrical triangular-carrier signal is used to generate the gating signals for both rectifier and inverter stages of the IMC. Furthermore, a generalized direct duty ratio based PWM technique has been presented to control the 3×k MC [21]. A specific case of the 3×5 MC is chosen to illustrate the control algorithm proposed in [21]. However, in the previous works [13]-[17] and [21], it is found that the output phase-voltage of the 3×5 MC is limited to 78.87 percent of the input phase-voltage. This value represents the theoretical limit of the output voltage in the linear operating mode. The output voltage can be increased if the converter is operated in the over-modulation mode.

Therefore, this paper aims to present a simple and more efficient CBPWM technique to control three to five-phase matrix converters, which can be used to supply a five-phase induction motor drive system that delivers some advantageous features for industrial applications. The basic concept of the proposed technique is already published in [27]. Thanks to its simplicity, the proposed technique will be based on the indirect modulation of the 3×5 MC which control the converter as a double stage converter. Therefore, the carrier based PWM methods are applied for each stage independently. The proposed modulation will maximize the converter VTR by operating the converter in the overmodulation mode as well as in the linear modulation mode. It also controls the input power factor by controlling the input current displacement angle. The proposed modulation technique is verified using simulation and experimental results based on a laboratory prototype and the dSPACE-DS1104 controller platform and the results are compared by the existing SVM technique.

II. THREE- TO FIVE-PHASE MATRIX CONVERTER TOPOLOGIES

The power circuit topology of three- to five-phase (3×5) MC for the direct and indirect configuration are shown in Fig. 1 and Fig. 2. The direct configuration uses a 3×5 matrix of bidirectional switches as depicted by Fig. 1 to connect any of the input phases (A, B or C) to any of the output phases (a, b, … or e). Therefore, the output voltages (v_a, v_b, … and v_e) can be directly determined from the input three-phase voltages (v_A, v_B and v_C). On the other hand, the indirect configuration uses three-phase bidirectional rectifier and five-phase inverter as shown in Fig. 2.

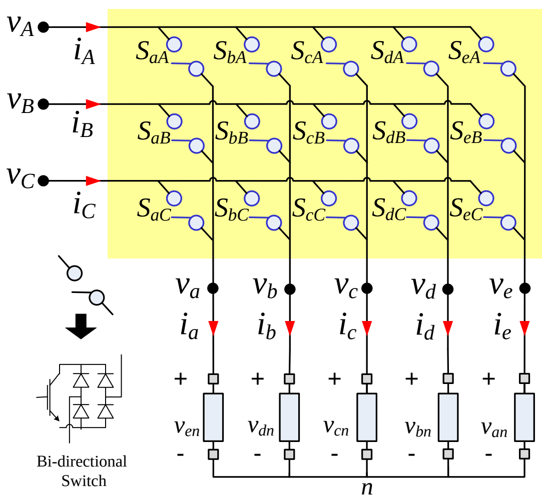


Fig .1. Power circuit topology of the direct configuration of the 3×5 MC.

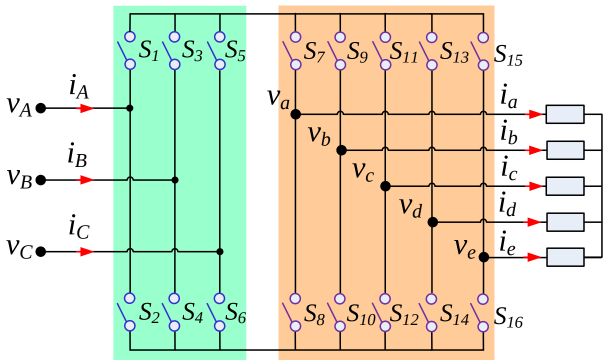


Fig .2. Power circuit topology of the indirect configuration of the 3×5 MC.

III. PROPOSED CBPWM ALGORITHM FOR 3×5 MC

Carrier-based PWM technique has been obtained by comparing the modulation signals with a high frequency carrier-wave. Since the proposed technique is based on the indirect modulation of the MC, it is necessary to determine a set of modulating signals for the rectifier and inverter stages and compare it with the carrier wave to obtain the switching signals. The resultant switching signals from the comparisons are combined to get the overall switching-states modulation matrix of the 3×5 MC. In the proposed technique, due to the nature of the rectifier and inverter operation, the control of the rectifier stage uses a saw-tooth carrier signal, while a symmetrical triangular carrier signal is used for the inverter. In both stages there are three-operating modes; 1) linear mode, 2) overmodulation mode and 3) stepped operating mode. In the following subsections, an illustration of the proposed modulation technique for both stages is introduced.

A. *Modulation of Rectifier stage*

The rectifier stage has to generate a virtual dc-link voltage (V_{dc}) by chopping input three-phase voltages. This operation is performed by the rectifier switches, which are divided into two groups; namely upper $\{S_1,S_3,S_5\}$ and lower $\{S_2,S_4,S_6\}$ groups.

Three switches in a group connect all input phases to one terminal of the dc-link. Therefore, in order to avoid short-circuit on the input phases or open-circuit on the dc-link only one switch in a group must be turned on at a time. This means

$$S_1 + S_3 + S_5 = 1$$
$$S_2 + S_4 + S_6 = 1 \qquad (1)$$

The virtual dc-link voltage can be obtained from the input voltages by the rectifier-switching matrix as follows:

$$\begin{bmatrix} +\frac{1}{2}v_{dc} \\ -\frac{1}{2}v_{dc} \end{bmatrix} = \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} . \begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} \qquad (2)$$

Assuming that, the three-phase input voltages are balanced and given by:

$$\begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \hat{V}_i \begin{bmatrix} \sin\theta_A \\ \sin\theta_B \\ \sin\theta_C \end{bmatrix} \qquad (3)$$

where $\hat{V}_i$ is the input peak voltage and $\theta_A = \omega_i t$, $\theta_B = \omega_i t - 2\pi/3$, $\theta_C = \omega_i t + 2\pi/3$ are the respective phase angle with an input angular frequency of ω_i.

1. Rectifier-Stage Modulating Signals Calculations

The modulating signals for the rectifier switches, δ_R (δ_1-δ_6, where $\delta_1$represents the modulating signal of the switch S_1 and so on) can be derived as:

$$\delta_{1,2} = \pm m_R \sin(\theta_A + \emptyset)$$
$$\delta_{3,4} = \pm m_R \sin(\theta_B + \emptyset) \qquad (4)$$
$$\delta_{5,6} = \pm m_R \sin(\theta_C + \emptyset)$$

where m_R is the rectifier-stage modulation-index and $\emptyset$ is the input-current displacement-angle. In the linear-modulation operating mode, the rectifier-stage modulation-index m_R does not exceed 0.5 [25].

In order to satisfy the constraint in (1), the summation of the modulating signals of the upper-group switches and that of the lower-group switches should equal one in a switching cycle [26]. However, the modulating signals obtained in (4) do not satisfy this condition. Therefore, offset signals must be added to the modulating signals [26]. Firstly, the absolute value of each modulating signal (d_A, d_B, d_C) is added to cancel the negative half-cycle. Hence, the resultant signals have a lower limit that equals zero. However, the summation of the modulating signals does not equal one all a time. In order to solve this problem, another offset signal ε should be added to the modulating signals. The modified modulating signals are given by:

$$\begin{aligned} \delta_{1,2} &= \pm m_R \sin(\theta_A + \emptyset) + d_A + \varepsilon \\ \delta_{3,4} &= \pm m_R \sin(\theta_B + \emptyset) + d_B + \varepsilon \\ \delta_{5,6} &= \pm m_R \sin(\theta_C + \emptyset) + d_C + \varepsilon \end{aligned} \quad (5)$$

where

$$\begin{aligned} d_A &= |m_R \sin(\theta_A + \emptyset)| \\ d_B &= |m_R \sin(\theta_B + \emptyset)| \\ d_C &= |m_R \sin(\theta_C + \emptyset)| \end{aligned} \quad (6)$$

$$\varepsilon = (1 - (d_A + d_B + d_C))/3 \quad (7)$$

Therefore, aiding with (5), the modulating signals of all rectifier switches in each switching period can be easily determined. Fig. 3 illustrates the determination process of the rectifier upper-switches modulating signals. The modulating signals of the rectifier lower-switches can be determined by the same manner. The resulting rectifier-stage modulating signals waveforms corresponding to the maximum value of the rectifier-stage modulation-index $(m_R = 0.5)$ are shown in Fig. 4.

2. Carrier-based Modulator of the Rectifier-Stage

The function of the carrier-based modulator is to compare the modulating signals with a common triangle carrier-wave in order to determine the switching signals. The proposed modulator is simple to implement and needs only the calculation of the rectifier-stage modulating signals, δ_R. Fig. 5 shows the proposed modulator and the generated switching signals of the rectifier upper-switches in which a triangular carrier-signal of an amplitude in the range of [0, 1] and a frequency of "f_{c1}" are compared with the three regular-sampled (i.e. assumed constant in each switching period) modulating signals of the upper switches (δ_1, δ_3, and δ_5). Hence, the switching signal of the upper switches (S_1, S_3, and S_5) are obtained. Similarly, the switching signals of the lower switches (S_2, S_4, and S_6) can be determined.

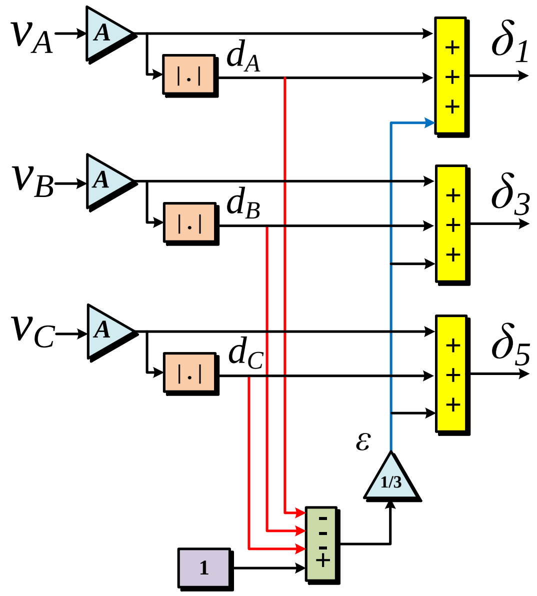


Fig .3. Determination of the rectifier upper-switches modulating-signals, $A = m_R/\hat{V}_i$

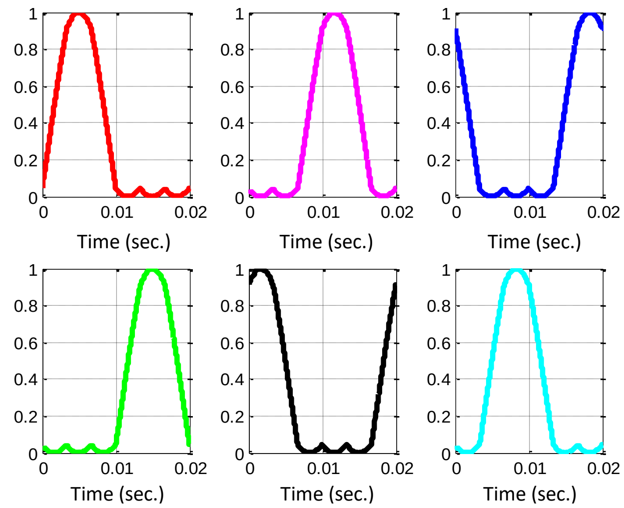
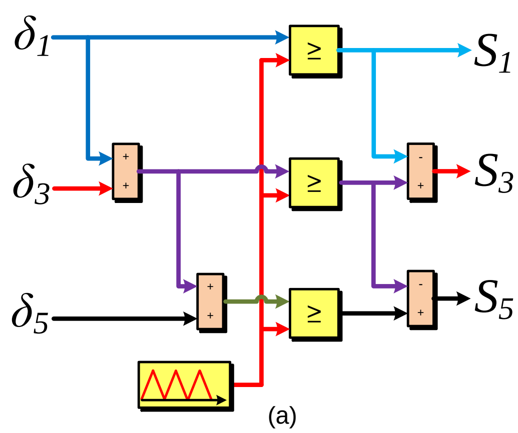


Fig .4. The rectifier stage modulating signals waveforms at $m_R = 0.5$



(a)

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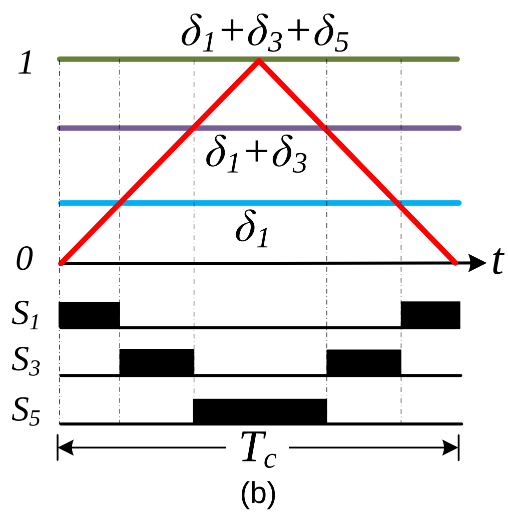


(a) schematic-diagram (b) waveforms

Fig .5. Carrier-based modulator and switching signals for the rectifier upper-switches.

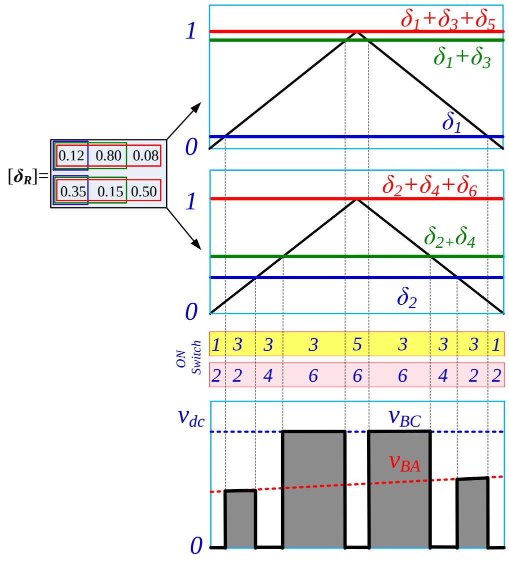


Fig .6. dc-link voltage generation from the rectifier-stage modulator.

3. Generation of the Virtual dc-link Voltage

Once the rectifier switching-signals are determined, the virtual dc-link voltage can be obtained according to (2). Fig. 6 illustrates the process of the instantaneous dc-voltage generation. It is clear to observe that, the dc-voltage level varies between maximum and medium value of the input line-voltage. The average dc-link voltage can be determined by substituting the value of each modulating signal obtained from (4) into the corresponding rectifier switch in (2), this yields;

$$V_{dc} = 3\hat{V}_i m_R \cos \emptyset \qquad (8)$$

Equation (8) shows that the maximum possible dc-link voltage can be obtained at $m_R = 0.5$ and zero input-current displacement angle. Therefore, the maximum possible dc-link voltage in the linear-modulation operating mode is 1.5 times of the peak input phase-voltage. Accordingly, the maximum VTR of the rectifier stage in the linear-modulation operating mode equals 1.5.

4. Rectifier-stage Overmodulation Operating Mode

In order to obtain a maximum allowable dc-link voltage, each switch in the upper group must be turned on when the corresponding input phase voltage is the highest input-voltage at the instant considered [28]. In contrary, each switch in the lower group must be turned on if the corresponding input phase voltage is the lowest input voltage at the instant considered. In other words, in order to obtain the maximum allowable dc-link voltage, the rectifier stage must be operated as a conventional three-phase diode rectifier-circuit. From this concept, the input phase-voltages described in (3) should be divided into six sectors, as shown in Fig. 7, where the polarity of one input phase-voltage is always opposite to the other two phases. This may be defined as a rectifier-stage over-modulation operating mode. An illustration of the proposed over-modulation operating mode, including the switching state of the rectifier switches and the generation of the maximum possible dc-link voltage, is presented in Fig.7. The maximum possible dc-link voltage in this operating mode is 1.654 times of the peak input phase-voltage. Therefore, the maximum obtainable VTR of the rectifier stage in the over-modulation operating mode equals 1.654. Thus, it can be concluded that the proposed rectifier-stage over-modulation mode has the same performance of the corresponding one applied for 3×3 MC [29] and extended for 3×7 MC [20].

In this operating mode of operation, the generation of the rectifier–stage switching signals can be easily implemented according to the flowchart given in Fig.8.

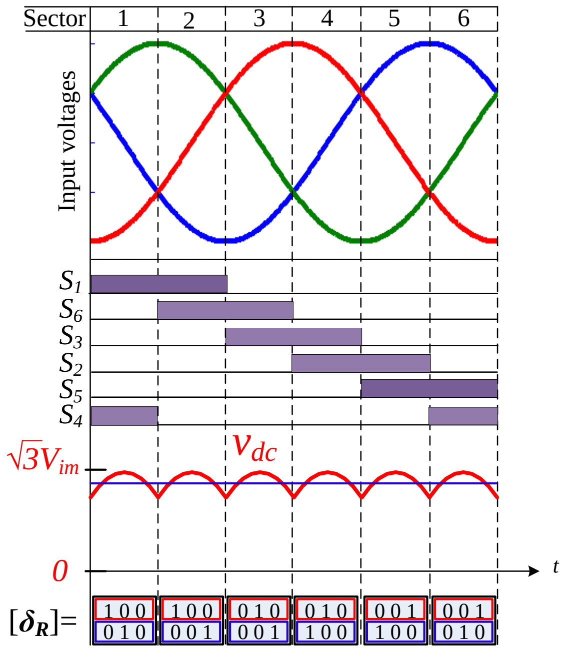


Fig .7. Illusrtation of the rectifer-stage overmodulation operating mode

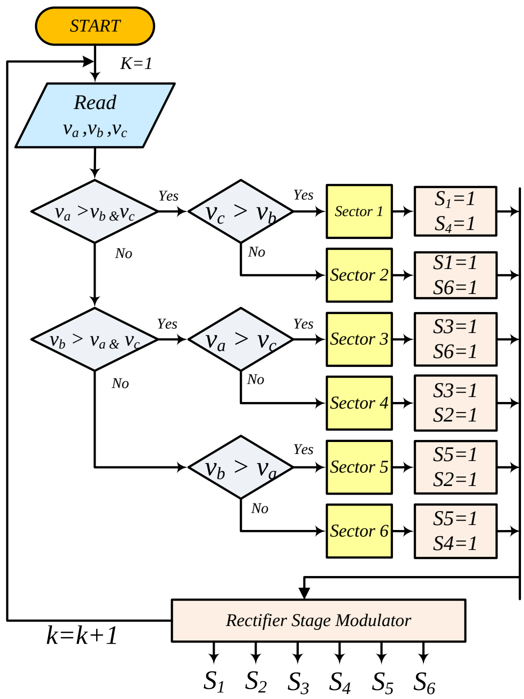


Fig .8. Flowchart showing the generation of the rectifier–stage switching signals in the over-modulation operating mode

B. Inverter-stage Control (ISC)

The inverter-stage has to generate the desired output five-phase voltages from the virtual dc-link voltage. This operation is performed aiding with the switching states of the five-phase inverter-switches, which can divided into five groups (legs); namely, leg-*a* {S_7, S_8}, leg-*b* {S_9, S_{10}}, leg-*c* {S_{11}, S_{12}}, leg-*d* {S_{13}, S_{14}} and leg-*e* {S_{15}, S_{16}}.

In order to avoid short-circuit on the virtual dc-link voltage or open-circuit on the load terminals, the two-switches in each leg must be operated in a complementary operating mode. This means;

$$S_j + S_{j+1} = 1 \qquad (9)$$

where *j*=7, 9, …, 15. The output voltages can be obtained from the dc-link voltage by the inverter switching-matrix as follows:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \\ v_d \\ v_e \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \\ S_{13} & S_{14} \\ S_{15} & S_{16} \end{bmatrix} \cdot \begin{bmatrix} +\frac{1}{2}v_{dc} \\ -\frac{1}{2}v_{dc} \end{bmatrix} \qquad (10)$$

The reference five-phase output voltages are assumed to be balanced and given by:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \\ v_d \\ v_e \end{bmatrix} = \hat{V}_o \begin{bmatrix} \sin(\omega_o t) \\ \sin(\omega_o t - 2\pi/5) \\ \sin(\omega_o t - 4\pi/5) \\ \sin(\omega_o t + 4\pi/5) \\ \sin(\omega_o t + 2\pi/5) \end{bmatrix} \qquad (11)$$

1. Inverter-stage Modulating Signals Calculations

The modulating signals for the upper switches of inverter stage, δ_I $(\delta_7, \delta_9, \ldots \delta_{15})$ can be obtained according to the general formula used for the five-phase VSI as follows [28];

$$\begin{aligned} \delta_7 &= m_I \sin(\omega_o t) \\ \delta_9 &= m_I \sin(\omega_o t - 2\pi/5) \\ \delta_{11} &= m_I \sin(\omega_o t - 4\pi/5) \\ \delta_{13} &= m_I \sin(\omega_o t + 4\pi/5) \\ \delta_{15} &= m_I \sin(\omega_o t + 2\pi/5) \end{aligned} \qquad (12)$$

where δ_7 represents the modulating signal of switch S_7 and so on, m_I is the inverter-stage modulation index and ω_o is the desired output frequency in rad/sec. it is well known that the value of m_I determines the magnitude of the output voltage and it is selected between 0 and 1 for the linear modulation operating mode, while in the overmodulation mode m_I it is greater than one.

Comparing the modulating signals of (12) with the common carrier signal, results in the appropriate switching signals of the inverter upper-switches. In addition, the switching signals of the inverter lower-switches can be easily obtained as complementary for the corresponding signals of the upper-switches. Due to using pure sinusoidal modulating signals, this modulation technique is generally known as sinusoidal PWM (SPWM) in which the VTR of the inverter stage does not exceed 0.5 in the linear modulation operating mode. However, for optimal utilization of the virtual dc-link voltage, an offset signal should be added to the modulating signals, given in (12). This offset signal is named Injected Zero Sequence Signal (ZSS), δ_{zs} [29]. Different types of the injected zero-sequence signals result in different schemes of CBPWM technique. the Fifth-Harmonic Injection PWM (FHIPWM) and the Continuous Space Vector PWM (CSVPWM) are the widely used schemes [29], [30].

In the FHIPWM scheme, the linear modulation mode of the five-phase inverter stage can be extended by injecting an amount of the fifth order harmonic-signals to the sinusoidal modulating signals. This increases the output voltage without reaching the over-modulation mode limit. The value of δ_{zs} in this scheme is selected as follows [31]:

$$\delta_{zs} = -1/5m_I sin(\pi/10)\, sin(5\omega_o t) \qquad (13)$$

It is found that this technique can increase the fundamental component of the output voltage up to 5.15% rather than that of SPWM [13].

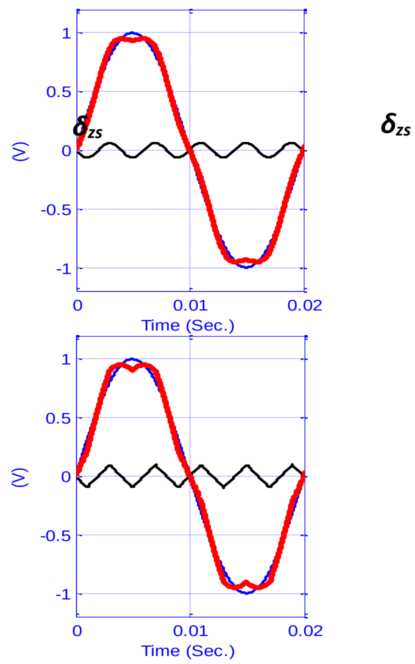
On the other hand, the value of the injected zero-sequence signal, δ_{zs} in the continuous SVPWM (CSVPWM) scheme is given by [31]-[32]:

$$\delta_{zs} = -1/2(\delta_{MAX} + \delta_{MIN}) \qquad (14)$$

Where

$$\delta_{MAX} = max(\delta_7, \delta_9, \delta_{11}, \delta_{13}, \delta_{15})$$
$$\delta_{MIN} = min(\delta_7, \delta_9, \delta_{11}, \delta_{13}, \delta_{15})$$

The modulating and the injected zero-sequence signals of both FHIPWM and CSVPWM schemes for output frequency of 50Hz are illustrated in Fig. 9. On the other hand, it is well known that the maximum available VTR that can be obtained when the inverter stage is in stepped-wave operation is equal to 0.636 [33].



(a) FHIPWM-scheme (b) CSVPWM-scheme

Fig .9. Modulating and injected zero-sequence signals waveforms of both FHIPWM and CSVPWM schemes for output frequency of 50Hz

2. Inverter-stage Carrier-based Modulator

Fig. 10 shows the schematic diagram of the inverter-stage modulator in which the triangular carrier signal of an amplitude in the range of [-1, 1] and a frequency of "f_{c2}" is compared with the five-phase modulating signals of the upper switches. This results in the switching signal of the corresponding switches. By inverting the resulting switching signals, the switching signals of the lower switches can be obtained.

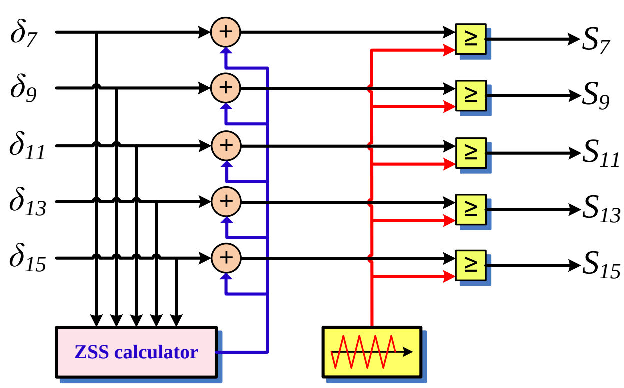


Fig .10. Carrier-based modulator configration of the inverter stage

IV. VOLTAGE TRANSFER RATIO OF 3×5 MC USING THE PROPOSED CBPWM TECHNIQUE

Based on the proposed CBPWM technique of the 3×5 MC, there are two VTRs that should be controlled; the VTR of the inverter-stage, VTR_I and the VTR the rectifier-stage, VTR_R. Hence, the overall VTR can be obtained as:

$$VTR = VTR_R \times VTR_I \qquad (15)$$

Since both stages can be operated in either linear or over-modulation operating modes, the maximum overall VTR in the linear operating mode can be achieved if the VTR of each stage is controlled to be equal to its maximum value in this operating mode. On the other hand, the MC can operate in the over-modulation operating mode if one or both stages are over-modulated. Therefore, the over-modulation operating mode of the MC is classified into three modes; namely, Rectifier-stage over-modulation mode (RSO), Inverter-stage over-modulation mode (ISO) and both stages over-modulation mode (BSO). The overall VTRs of 3×5 MC using the proposed CBPWM technique are given in Table-I.

Table 1. VTRs of 3×5 MC Using the Proposed CBPWM Technique

Rectifier \ Inverter	Linear		ISO (VTR = 0.636)
	SPWM (VTR = 0.5)	CSVPWM (VTR = 0.525)	
Linear (VTR = 1.5)	0.75	0.7887	0.954
RSO (VTR = 1.654)	0.827	0.8697	1.052

It can be observed that the maximum obtainable overall VTR equals 1.052 when both stages are over-modulated. However, when both stages are operated in the linear mode, the maximum overall VTR equals 0.7887. It can be concluded, supported by the proposed modulation technique, that the maximum obtainable overall VTR is exactly the same as that obtained, using the SVM technique, in [14], [15] when both stages are operated in the linear mode. In addition, the VTR can increase when one or both of sides are over-modulated.

V. IMPLEMENTATION PROCEDURE OF THE PROPOSED CBPWM TECHNIQUE TO CONTROL THE 3×5 MC

to control the switches of the 3×5 MC, based on the proposed technique, the switching signals generated by both the rectifier and inverter stages should be firstly combined, based on the presented mathematical model of the converter, using equations (2) and (10). Fig. 11 shows the layout of the implementation procedure of the proposed technique. This procedure is used in both the simulation and experimental processes. Fig. 11 shows that there are two main traces that are used for controlling both the rectifier and inverter stages, including modulating signal and carrier-wave generation, and gating-signals modulators.

It can be clearly observed that the desired rectifier-stage VTR and the input-current displacement angle are defined to calculate the appropriate modulating signals of the rectifier-stage based on (5). From which the rectifier-stage switching signals are obtained via rectifier-stage modulator. On the other hand, the desired inverter-stage VTR and the output frequency are used to determine the modulating signals of the inverter-stage based on (12). Hence, the switching signals of the inverter-stage can be generated via inverter-stage modulator.

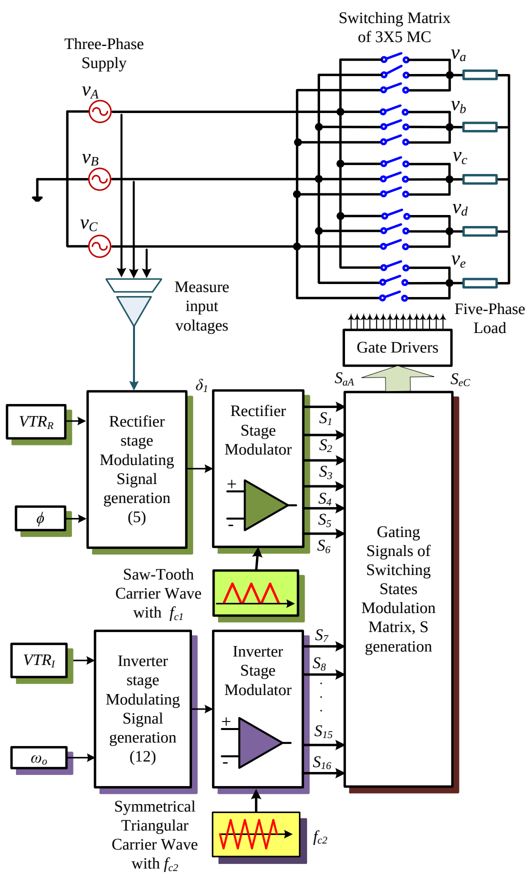


Fig .11. Layout of the implementation procedure of the proposed CBPWM technique

Finally, the generation of the overall gating signals of the 3×5 MC can be easily determined using (2) and (10). The final switching-state modulation matrix of the proposed 3×5 MC can be written as:

$$[S] = \begin{bmatrix} s_1 s_7 + s_2 s_8 & s_3 s_7 + s_4 s_8 & s_5 s_7 + s_6 s_8 \\ s_1 s_9 + s_2 s_{10} & s_3 s_9 + s_4 s_{10} & s_5 s_9 + s_6 s_{10} \\ s_1 s_{11} + s_2 s_{12} & s_3 s_{11} + s_4 s_{12} & s_5 s_{11} + s_6 s_{12} \\ s_1 s_{13} + s_2 s_{14} & s_3 s_{13} + s_4 s_{14} & s_5 s_{13} + s_6 s_{14} \\ s_1 s_{15} + s_2 s_{16} & s_3 s_{15} + s_4 s_{16} & s_5 s_{15} + s_6 s_{16} \end{bmatrix} \quad (16)$$

Fig. 12 illustrates the logic circuit that is used to generate the gating signals corresponding to phase-a of the 3×5 MC according to (20).

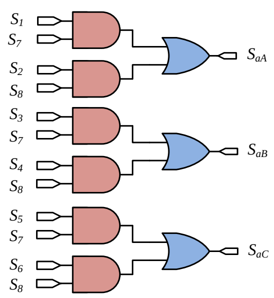


Fig .12. Generation of the gating signals of phase-a from the switching signals of the rectifier and inverter stages

VI. SIMULATION AND EXPERIMENTAL RESULTS

In order to verify the validity of the proposed modulation technique, a series of simulation and experimental results has been obtained in both linear and over-modulation operating modes. Firstly, to investigate the feasibility of the proposed modulation technique before compiling into a real-time system, the developed simulation models have been tested using Matlab/Simulink software. Then, a series of experimental tests were performed on the implemented 3×5 MC based on the dSPACE-DS1104 platform.

Fig. 13 shows a photograph of the complete experimental setup. In this figure, the host PC including the dSPACE controller, which is used to control and monitor the system variables by using the connector pins interface, is shown. Also, the power and interface circuits of the laboratory prototype of the proposed multi-phase MC are shown.

All measurements in this section are performed with a Tektronix MSO-2024B four-channel oscilloscope. The oscilloscope can also be logging the waveform data into the PC. These data can further be processed using MATLAB code in order to get the harmonic analysis of these waveforms.

In both the simulation and experimental processes, the 5-phase output terminals are connected to a series RL-load of 100 Ω and 0.25 H. In addition, A 100 V (peak), 50 Hz 3-phase voltage supply is applied to the 3-phase input terminals. In order to achieve a maximum available VTR of the 3×5 MC, the reference input current displacement angle has been adjusted to be equal zero.

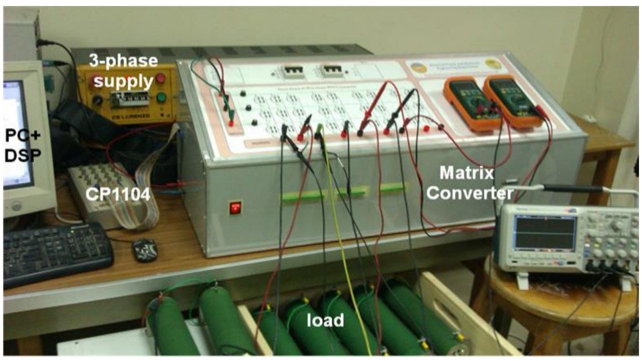


Fig .13. Photograph of the complete experimental set-up

On the other hand, the ratio of the carrier frequencies of both rectifier and inverter stages (f_{c1}/f_{c2}) is determined based on the Total Harmonic Distortion (THD) of the output current. Therefore, the operation of the 3×5 MC based on the proposed modulation technique is tested under a wide range of carrier-frequencies ratios and different frequencies of the output current. The THD of the output currents at different carrier-frequencies ratios (f_{c1}/f_{c2}) and different output-frequencies is shown in Fig. 14. The carrier-frequency range is changed from 1 kHz to 6 kHz.

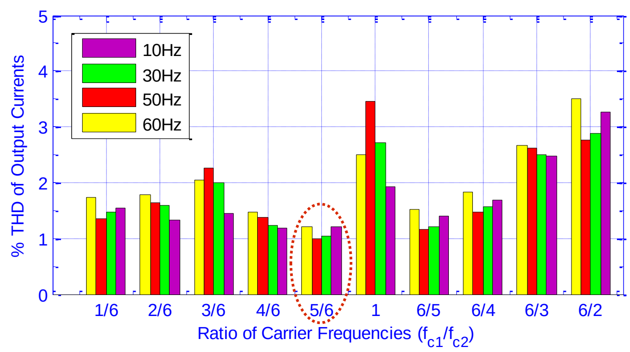


Fig .14. THD of output currents at different carrier-frequencies ratios and different output-frequencies

It can be noted from Fig. 14 that the THD of the output currents at different output-frequencies are in the acceptable limits (less than 5%) according to the specified standard of IEEE-519. In addition, it is observed that, in order to minimize the THD of the output currents, the ratio of the carrier frequencies should be selected as 5/6. Therefore, the simulation and experimental results, in both the linear and over-modulation modes, are obtained at carrier frequencies of the rectifier and inverter stages of 1.67 kHz and 2 kHz, respectively. In addition, the output frequency is set to 10Hz.

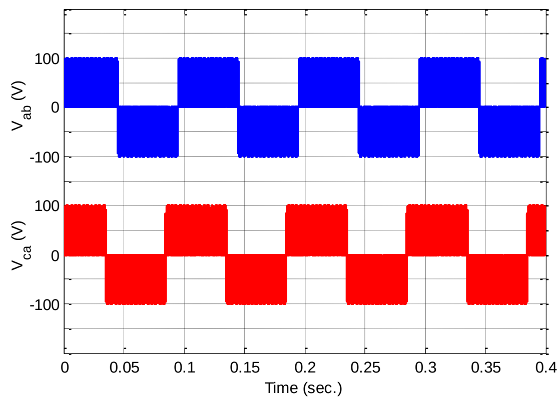
A. Modulation of Rectifier stage

The output line-line (adjacent and non-adjacent) and phase voltages generated by the 3×5 MC, in the linear modulation mode, are shown in Fig. 15 and Fig. 16, respectively. In order to achieve a maximum overall VTR of 0.7887 in the linear operating mode, both stages are operating with a maximum voltage transfer ratio in the linear operating mode (VTR_R = 1.5 and VTR_I = 0.5258).

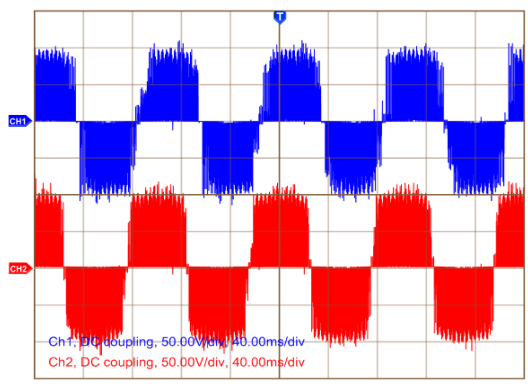
Fig. 17 shows the FFT (harmonics spectrum) analysis of the phase-a output voltage. From which, it can be noted that the fundamental component of the output phase-voltage equals 78.8 percent of the input phase-voltage. In addition, dominant harmonic components around the switching frequency (harmonics order of 200) and its multiples can be easily observed.

Furthermore, the corresponding load-current waveforms are shown in Fig. 18. Due to the capability of the used oscilloscope, only 4-phase current waveforms are obtained in the experimental process. Balanced load currents with approximately sinusoidal waveform can be easily noted from Fig. 18. This is due to the load inductive-nature and the proposed modulation technique.

On the other hand, Fig. 19 shows the input-phase voltage and current waveforms of the 3×5 MC. It can be observed that the input current has a pulse width modulated waveform. Due to setting the input-current displacement angle to zero, it is found that the fundamental component of the input current is in-phase with the input voltage. Therefore, a unity input power-factor operation is obtained.



(a) Simulation



(b) Experimental (50 V/div.& 40 ms/div.)

Fig .15. Output adjacent and non-adjacent line-line voltage in the linear modulation operating mode at f_o=10 Hz

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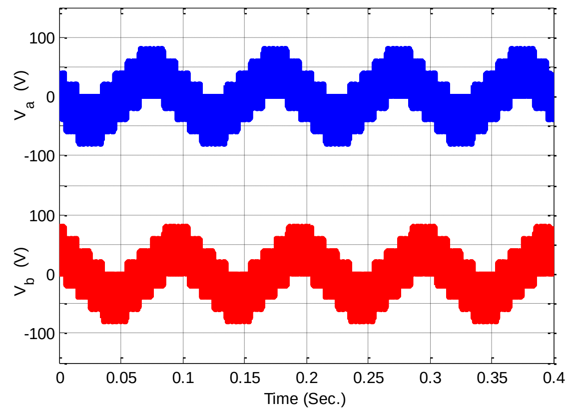
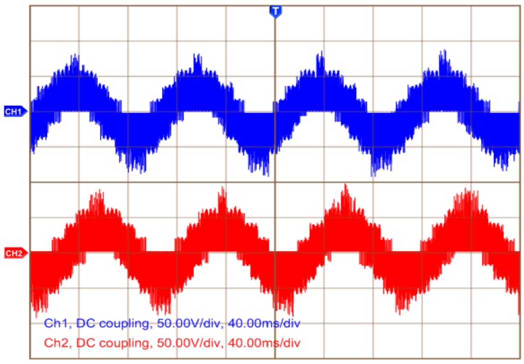


(a) Simulation



(b) Experimental (50 V/div.& 40 ms/div.)

Fig .16. Output phase voltage waveforms in the linear modulation operating mode at f_o=10 Hz

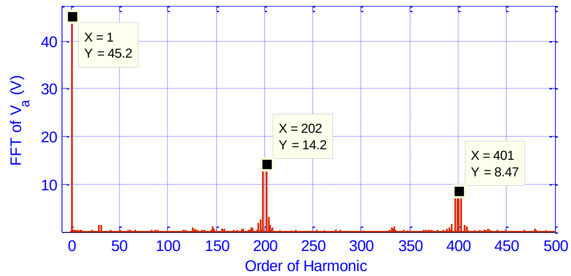


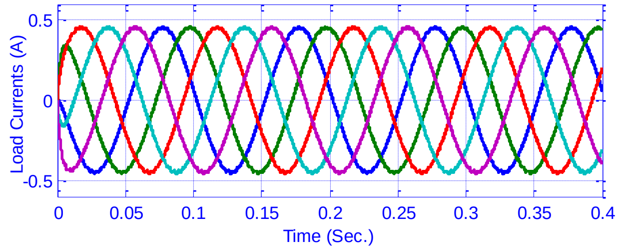
Fig .17. Harmonic spectrum analysis of phase-a of the output voltage in the linear operating mode at f_o=10 Hz

B. Over-modulation operating mode

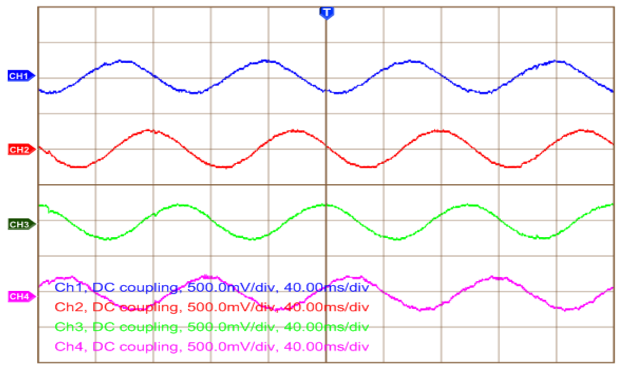
In this operating mode, both rectifier and inverter stages are operating with a maximum voltage transfer ratio (VTR_R=1.654 and VTR_I = 0.636) at an output frequency of 10 Hz.

The generated output line-line (adjacent and non-adjacent) and phase voltages in over-modulation mode are shown in Fig. 20 and Fig. 21, respectively. In addition, the corresponding harmonics spectrum analysis of the phase-*a* output voltage is shown in Fig. 22. The obtained results in this operating mode show that the fundamental component of the output phase-voltage equals 105 percent of the input phase-voltage and therefore a maximum overall VTR is achieved.

Moreover, it can be observed that the output phase-voltage waveform contain a considerable amount of lower order harmonics as illustrated in Fig. 22. It can also be noted that the magnitude of each harmonic component equals the inverse of its order as a percentage of the fundamental component.



(a) Simulation



(b) Experimental (1 A/div.& 40 ms/div.)

Fig .18. Load-current waveforms in the linear modulation operating mode at f_o=10 Hz

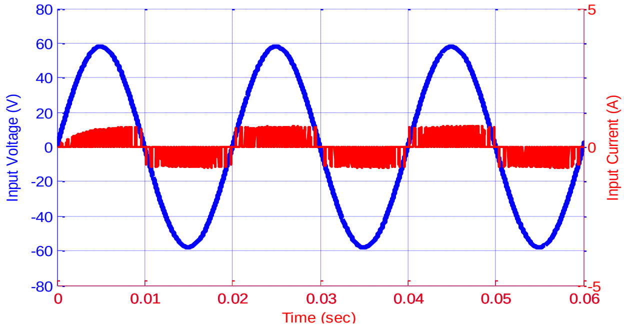
On the other hand, Fig. 23 shows the load-current waveforms in the over-modulation operating mode. The discrepancy between these current waveforms and that shown in Fig. 18 is due to operating in over-modulation mode. Therefore, it can be concluded that, in the over-modulation operating mode, the load currents contain a considerable amount of lower order harmonics as can be observed form Fig. 23. Furthermore, the input-phase voltage and current waveforms in the over-modulation mode are shown in Fig. 24. A unity input power-factor operation can be easily observed due to setting the input-current displacement angle to zero.

A close agreement between the presented simulation and experimental results can easily be observed in both linear and over-modulation operating modes which verifies the effectiveness of the proposed modulation technique.

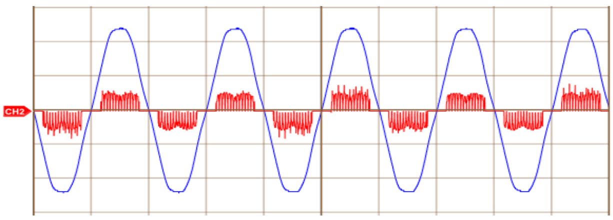
VII. COMPARISON BETWEEN THE PROPOSED CBPWM AND THE SVM TECHNIQUES FOR CONTROLLING 3×5 MC

In order to ensure the capability and effectiveness of the proposed modulation technique, a comparative study between the proposed CBPWM and the SVM techniques, given in [14], [15], for controlling the 3×5 MC is summarized in the following points:

- Unlike the SVM approach in [14], [15], the need for sector information for both input and output sides of the converter and the corresponding switching-tables are avoided in the CBPWM approach, thus highly simplifying the control of MCs, especially when the input or output phases are increased.

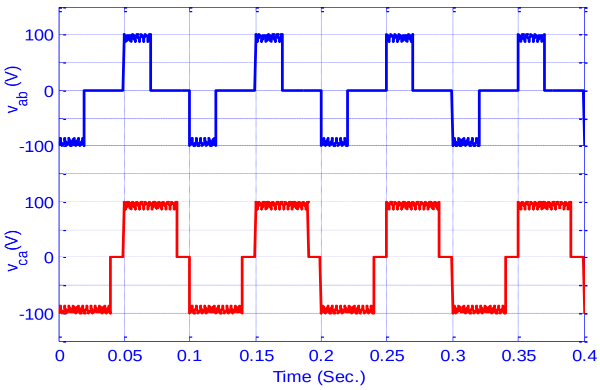


(a) Simulation

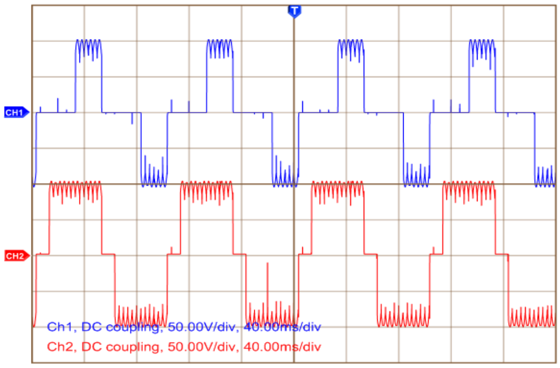


(b) Experimental (25 V/div., 1 A/div. & 40 ms/div.)

Fig .19. Input-phase voltage and current waveforms in the linear modulation operating mode.

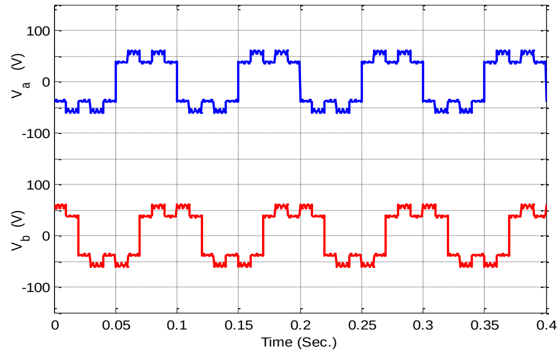


(a) Simulation

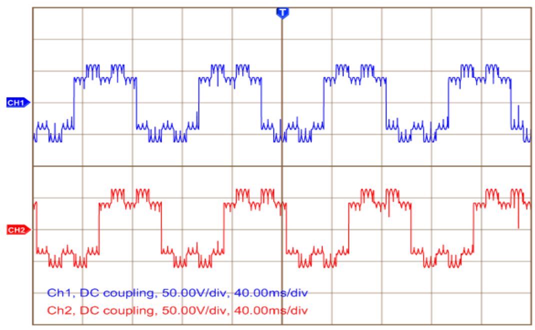


(b) Experimental (50 V/div.& 40 ms/div.)

Fig .20. Output adjacent and non-adjacent line-line voltage in over-modulation operating mode at f_o=10 Hz



(a) Simulation



(b) Experimental (50 V/div.& 40 ms/div.)

Fig .21 Output phase-voltage waveforms in over-modulation operating mode at f_o=10 Hz

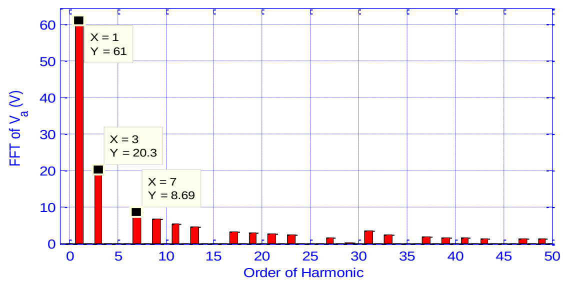


Fig .22 Harmonic spectrum analysis of phase-a of the output voltage in over-modulation operating mode at f_o=10 Hz

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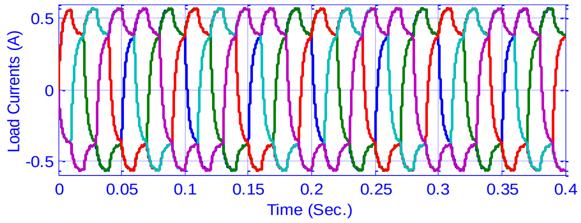
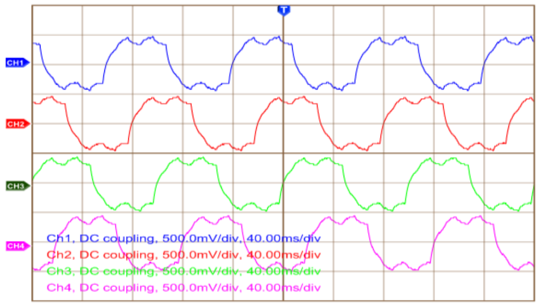


(a) Simulation

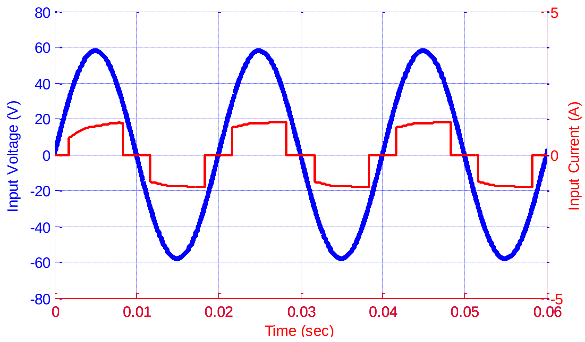


(b) Experimental (25 V/div., 1 A/div. & 40 ms/div.)

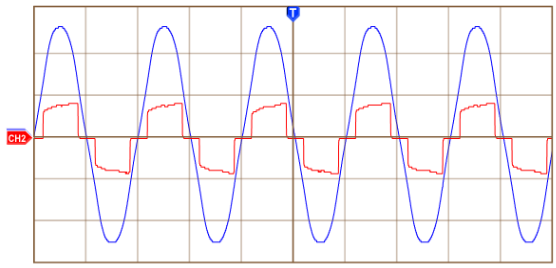
Fig .23. Load-currents-waveforms associated with over-modulation operating mode at f_o=10 Hz

- The maximum allowable VTR in the SVM approach in [14] and using scheme-II in [15] is 78.87%. The same value is obtained in the linear modulation mode of the CBPWM technique.

- In order to increase the VTR of the converter, both techniques push the converter to operate in the overmodulation region. The SVM approach in [15] increases the VTR to 92.3% using scheme-I, while the overmodulation-operating region in CBPWM is classified into three different modes (RSO, ISO and BSO). The maximum obtainable VTR of the converter is achieved using BSO mode to 105.2%.



(a) Simulation



(b) Experimental (25 V/div., 1 A/div. & 40 ms/div.)

Fig .24. Input-phase voltage and current waveforms associated with the over-modulation operating mode

Fig. 25 shows the THD of the output voltage and current using both techniques for a wide frequency range. The output frequency is changed from 5 to 100 Hz, with an incremental step of 5 Hz. it can be observed that the THD for both output voltage and current in SVM is lower than CBPWM at all frequencies. Moreover, the output current THD in both techniques are below the IEEE standard requirements.

VIII. CONCLUSION

In this paper, a proposed CBPWM technique for a 3×5 MC has been presented. The proposed modulation technique has been based on the indirect configuration of the 3×5 MC, which assumes the converter as a virtual three-phase rectifier followed by a five-phase VSI. The proposed CBPWM technique has been applied for each stage independently including both linear and over-modulation operating modes. In order to verify the validity of the proposed modulation technique, a series of simulation and experimental results has been obtained in both modes of operation. It has been observed that, in order to minimize the THD of the output currents, the ratio of the carrier frequencies should be selected as 5/6. In addition, a maximum overall VTR of 0.7887 has been achieved in the linear operating mode when both stages are operating with a maximum voltage transfer ratio. Dominant harmonic components around the switching frequency and its multiples have also been observed. On the other hand, in the over-modulation operating mode, the fundamental component of the output phase-voltage has been found to be equal 105 percent of the input phase-voltage and therefore a maximum overall VTR has been also achieved. However, it has been observed that the output phase-voltages as well as the load currents obtained in this mode of operation have contained a considerable amount of lower order harmonics. A unity input power-factor operation has been achieved in both operating modes due to setting the input-current displacement angle to zero. A close agreement between the presented simulation and experimental results in both linear and over-modulation operating modes has confirmed the effectiveness of the proposed modulation technique.

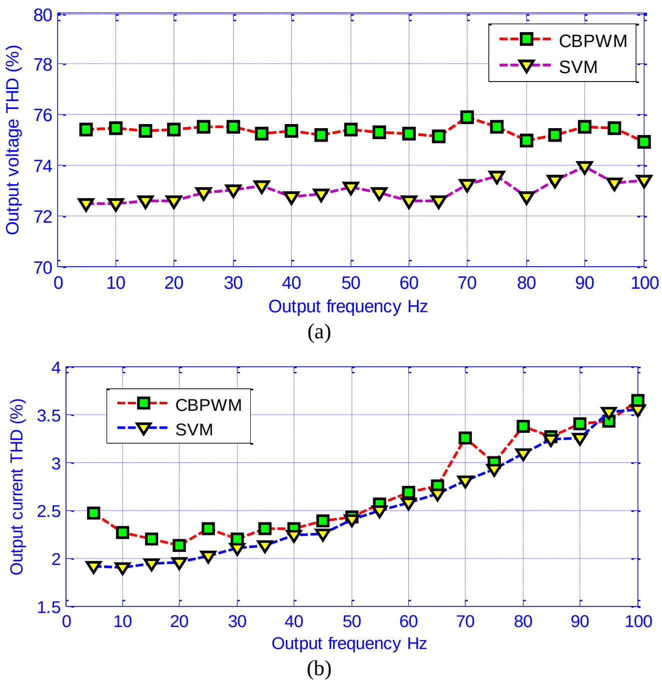


Fig .24. The THD for (a) Output voltage (b) Output current for the both CBPWM and SVM techniques

IX. BIOGRAPHY

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TRANSFORMER ISOLATED BUCK-BOOST CONVERTERS

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***Abstract* -** Of the single-switch dc-to-dc converters, those with the buck-boost voltage transfer function offer the best potential for transformer coupling, hence isolation, at the kilowatt level. This paper highlights the limitations of the traditional magnetic coupled, buck-boost topology. Then four split-capacitor transformer-coupled topologies (specifically the Cuk, sepic, zeta, and new converters) with a common ac equivalent circuit, that do not temporarily store core magnetic energy as does the traditional isolated buck-boost converter nor have a core dc magnetizing current bias as with the sepic and zeta transformer coupled topologies, are explored. Core dc bias capacitive voltage compensation is a practical design constraint in three of the four topologies, while all four must cater for stray and leakage inductance effects. Simulations and experimental results for the new converter at 408W that support the transformer-coupled, single-switch dc-to-dc converter concepts are investigated.

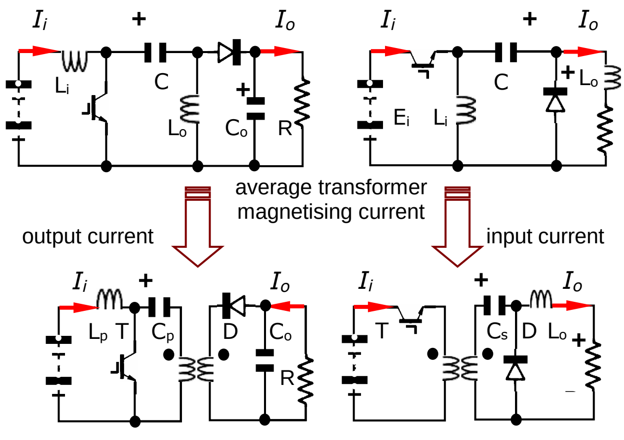
***Keywords* -** switched mode power supplies, smps, dc-to-dc converters, buck boost converters, transformer isolated buck boost converters, Cuk converter, sepic converter, zeta converter, inverse sepic converter.

I. INTRODUCTION

DC-to-dc converters are the enabling backbone of virtually all electronic systems, in industrial, consumer, and domestic products, like hand-held and portable electronics, and every computer. For safety, insulation, compatibility, and noise reasons, most applications require electrical isolation of the converter output from the energy source, where the transformer coupled flyback converter is a viable solution up to a few hundred watts. But higher power electrical isolation may be required by electric vehicles [1], battery chargers [2], fuel cell [3], [4], solar [5], [6], and wind energy, involving super-capacitors, smart grids and distributed generation [7], [8], electronic ballast [9], energy harvesting [10], and power factor correction [11], to name just a few application areas.

Various techniques are used to increase the power capabilities of the basic converters, including interleaved or multiphase converters, bidirectional dc-to-dc converters [12], [13], multiple input converters [14], cascaded output converters, high voltage supplies [15], [16], snubbers [17], and various control techniques [18]-[21]. Flyback circuits use an extra winding, namely a catch winding, and suffer from leakage effects and duty cycle limitations to ensure magnetic core flux reset. Eventually, electrical operating levels are reached where multiple switch topologies are used, like the push-pull converter or variations of the half and full H-bridge converters, where better utilization of the magnetic core is gained by high frequency balanced operation alternating between two magnetic B-H quadrants. Such techniques, although viable, require multiple switches and may resort to the complication of resonant techniques or passive and active snubbers to contain switch losses at ever increasing operating frequencies and through-put power levels.

The basic buck-boost converter output can be isolated via a coupled magnetic circuit [22]. Additional features to isolation are voltage matching and better semiconductor utilization, but the limitation is that magnetic energy is temporarily stored in the coupled circuit core. Thus for a given magnetic material, maximum energy transfer is restricted by core volume, viz. ½*BH*× Volume.



(a) (b)

Fig .1. Inductor coupled circuit magnetizing dc bias current of (a) sepic and (b) zeta converters.

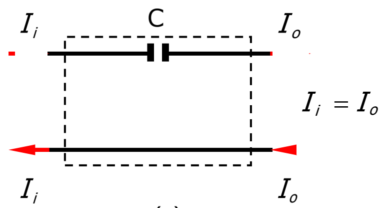
The core volume is utilized more effectively if magnetic energy transfer is through instantaneous transformer action rather than transfer with intermediate magnetic energy storage. The transformer coupling method commonly used for the sepic and zeta converters are shown in Figure 1, but these topologies result in a core dc flux bias attributable to the output and input average currents, respectively. A better approach is the split-capacitor transformer-coupled Cuk converter topology that utilizes the transformer transfer mechanism criteria without a dc flux bias. This paper identifies three further topologies, all with buck-boost transfer functions, that can operate in a transformer coupled mode, without a dc flux bias. As well as the Cuk converter, the other topologies are based on the sepic and zeta converters, with the fourth topology previously unidentified. Importantly, the common coupling of the circuit inductor in the sepic and zeta converter cases in Figure 1 is not that proposed in this paper, nor is the approach, the intermediate storage approach, used with the common buck-boost isolated converter. The split capacitor ac-mirroring approach adopted with the Cuk converter is employed in all four cases. The four considered topologies represent the four possibilities yielded from two possible transformer primary stage arrangements together with two possible transformer secondary circuit arrangements. A transformer allows all four converters to have the same buck-boost output polarity. The operating similarities and mechanisms of each of the four converters are evaluated and supported by time domain simulations and experimentation. No catch winding, as with a flyback converter, is used.

II. TRANSFORMER ISOLATED BUCK-BOOST CONVERTERS

The conventional isolated buck-boost converter, termed topology A5 in Table I, operates by temporarily storing energy, ½*BH*×Volume, in the magnetic core volume. The core volume is utilized differently if electrical energy transfer is through magnetic transformer action rather than core intermediate energy storage. If converter energy is transferred from the source to the load via ripple current (energy change) through a series capacitor, as in Figure 2(a), then that capacitor can be split so as to facilitate an interposed high magnetizing inductance shunt current transformer, as shown in Figure 2(b), and as with the Cuk converter, topology C5 in Table 1. AC-wise, if the output in Figure 2 is to be the same in both circuits, the secondary capacitor must electrically mirror the primary capacitor, so both are equal valued, if the transformer turns ratio $N_s/N_p = \eta_T$ is unity. The secondary capacitor is needed for supporting any dc bias associated with the secondary dc circuit conditions.

The common approach with the sepic and zeta converters is to replace a circuit inductor with a magnetically coupled inductor, as in Figure 1. Although its average voltages are zero, the core has an mmf bias (hence flux bias) due to a dc bias current component, which necessitates an air gap which adversely reduces the magnetizing inductance. The dc current bias, which is a maximum at full load, significantly decreases the allowable alternating flux and increases copper I^2R losses due to the increased number of turns. However, an air gap reduces coupling, which increases leakage inductance, with the associated store energy stressing the converter switch at turn off. Such coupling through circuit inductance can be summarized as a mechanism that requires enhancement of magnetic core imperfections (air gap increased mmf before current saturation onset), whilst split-capacitor transformer coupling relies on magnetic circuit perfection (infinite transformer magnetizing inductance).

A transformer offers voltage matching, hence better semiconductor device utilization by turns ratio variation (semiconductor duty cycle can be increased so as to decrease semiconductor peak current). Secondary circuit reactance can be transferred to the primary for ac analysis according to the turns ratio, squared.



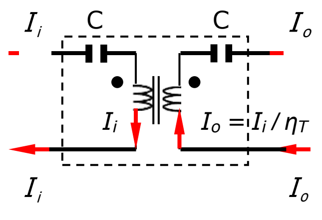


Fig .2. Capacitor ac circuit models:(a) series capacitor ac model and (b) equivalent ac capacitor model using transformer coupling.

Examination of the thirty-three known single-switch, single-diode, dc-to-dc converters [23] reveals that the

Cuk C5, sepic G6, zeta G5, and new buck-boost P5 converters, as shown in Table 1, all with a buck-boost magnitude transfer function, fulfill the series energy transfer capacitor requirement, shown in Figure 2(a). Although the transformer plus split-capacitor buffering approach is commonly used to isolate the Cuk converter output, its possible use on the sepic and zeta converters [24] has been virtually unexploited, with the coupled magnetic circuit with flux bias replacement of an inductor approach favored for these two converters, as in Figure 1. Both references [23] and [24] (c.f. Figure 11(b)) preclude the proposed new buck-boost topology P5, considered as being degenerate. However, with a dc-to-dc switched mode converter, energy transfer is ac circuit based (inductor current variation), while the transfer function is a dc level mechanism (average inductor current). Thus, analysis degeneracy only defines its transfer function, obliterating and masking any unique practical dc circuit features of the pre-degenerate topology. The independence of ac and dc circuit operating mechanisms and their superposition properties should be appreciated. This independence is illustrated by considering the inductor ac and dc currents in any of the basic three dc-to-dc converters. For a given duty cycle (output voltage), as the load is varied, the dc current in the inductor varies, but the superimposed ripple current magnitude remains the same. Conversely, the ripple current magnitude changes with duty cycle, as does the output voltage, yet the load can be adjusted to maintain a constant superimposed inductor, hence constant load and current.

All four converters (in fact all five in Table 1) are reversible (using two switch-diode anti-parallel connected pairs). The sepic G5 and zeta G6 converters are the reverse (or inverse) of each other, while due to circuit symmetry, the other two converters, Cuk C5 and P5, reverse to be the original topology.

Figure 3 shows how the one circuit topology can realize the four considered capacitor-coupled converter topologies in Table 1, by the appropriate reconnection of one end of each transformer winding. Conveniently, the switch emitter is at the zero volt level for all four converters. The ac equivalent circuit of each converter is the same, while the dc equivalent circuits only differ with the mirroring capacitors being dc voltage biased by the input and/or output voltages. The relative input and output voltage polarities remain fixed, as shown in Figure 3. The interposed shunt transformer acts in an ac current controlled mode where the voltage adjusts to meet the corresponding voltage requirement associated with the transformer equation ($I_p / I_s = V_s / V_p = N_s / N_p$), along with the converter current/voltage transfer function ($I_i / I_o = V_o / E_i = |\delta / (1-\delta)|$); both enforced since both equations comply with energy conservation. Because of the ac equivalent circuit similarities of the four converters, their component and operational design (including discontinuous conduction operation) and closed loop control design and performance, are all similar. Therefore, because of extensive pre existing research into Cuk, sepic, and zeta converter closed loop operation, such aspects need not be considered in this paper.

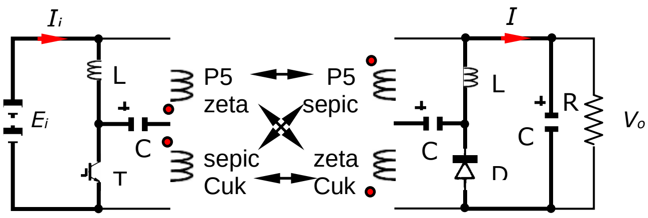


Fig .2. Four converters from a single circuit topology, with dot convention for each are shown, but reverse mode switch and diode are not shown..

III. TRANSFORMER/CAPACITOR DC BLOCKING

In the Cuk, sepic and zeta converter cases, the split-capacitor mirroring pair in Figure 2(a) must fulfill the important function of buffering, specifically blocking, a dc voltage component from the magnetic coupling element. Table 1 shows the dc component (the input and/or output voltage) each of the series split capacitors, C_p and C_s, must block, hence support. However, the split capacitors, the Cuk converter, C5, potentially experiences an additive dc component on both windings (E_i, V_o), while the sepic G5 (E_i, 0) and zeta G6 (0, V_o) converters potentially only experience dc voltage on one winding (primary and secondary, respectively). The dc voltage component is catered for and blocked, by using large capacitance, thereby preventing core saturation. Thus, in these three converters the series split capacitors serve a dual purpose, namely part of the ac energy transfer mechanism (usually associated with high ripple current) and dc voltage blocking. The new buck-boost converter P5 develops no potential dc voltage component on the primary or the secondary, because each winding is in parallel with inductance, which as for the zeta converter primary and sepic converter secondary, supports zero average voltage. In practice, in all four converter cases, any capacitor dc voltage bias is accentuated due to circuit non-ideal component voltage drops, including semiconductor, inductor and transformer winding resistance associated (current dependant) voltages. Large capacitance is therefore not necessary for the new converter P5 and such coupling is not applicable to the degenerate basic buck-boost converter A5 if transformer non-storage energy action is to be exploited.

IV. OPERATIONAL CONSTRAINTS

Because all five considered topologies have the same ac equivalent circuit (s/c dc supplies etc.), the switch, diode and inductor peak and average ratings are the same for all five, as are the capacitor ac characteristics for the four split-capacitor topologies. These common electrical characteristics are summarized in table 2. In each case, the average current in the input side (primary) and output side (secondary) inductors, L_p and L_s, are the input and output average currents, I_i and I_o, respectively. Only capacitor dc voltage ratings differ, as shown in Table 1. For analysis expediency, the transformer turns ratio is assumed unity ($\eta_T = 1$) and the dc blocking capacitors are assumed equal ($C_p = C_s = C$). Consequently, both capacitor ac voltages and ac currents mirror each other.

With an inductor in the transformer winding Kirchhoff voltage loop, the average winding voltage is zero, as is the case for one side of the transformer in the zeta (the primary) and sepic (the secondary) converters, and for both sides in topology P5. Since the capacitor on the zero average-voltage-side does not need significant dc blocking capability, the capacitance is dimensioned based solely on circuit ac voltage and frequency restrictions (as opposed to average voltage values plus a superimposed ripple component).

In each of the four transformer action coupled cases, circuit functionality requires that the input and output inductor currents are continuous. Specifically with a continuous conduction mode, CCM, the transfer function integrity and in particular the transformer volt-second (per turn) zero balance is maintained according to the average inductor current, and is not affected by the ripple current magnitude. Inductor ripple current magnitude only influences the minimum load, that is, the CCM-DCM (discontinuous conduction mode) boundary. Non-linear DCM operation is viable, without core saturation, since the magnetizing current falls to zero every cycle.

Energy is transferred in a single direction through the transformer: winding voltage polarities change depending on whether the capacitors are charging or discharging, but with zero average capacitor current.

Capacitance transfers between transformer sides in the turns ratio, inverse squared ($X_c \propto 1/C$). Thus in preserving equal energy change for both capacitors, with a turns ratio $N_s / N_p = \eta_T$, capacitance can be varied, with the voltage satisfying

$$V_o = \eta_T E_i \frac{\delta}{1-\delta} \qquad (1)$$

where the switch T is on, t_{on} and T is off, t_{off}, (such that $t_{on} + t_{off} = \tau = 1/f_s$ where f_s is the switching frequency) giving the switch on-state duty cycle as $\delta = t_{on} / \tau$.

- Capacitors, C_p and Cs

Decreasing split capacitance increases capacitor ripple voltage, but does not necessarily influence the CCM/DCM boundary. The ripple voltage peak-to-peak magnitude is independent of the capacitor dc bias level and is given by

$$\Delta V_{Cp} = (1-\delta)\frac{I_i \tau}{C_p} = \delta \frac{I_o \tau}{C_p} \qquad (2)$$

$$\Delta V_{Cs} = \delta \frac{I_o \tau}{C_s} = (1-\delta)\frac{I_i \tau}{C_s} \qquad (3)$$

Capacitor ripple voltage is independent of inductances L_p and L_s, and for unity turns ratio $\eta_T = 1$:

$$\Delta V_{Cp} = \Delta V_{Cs} \text{ if } C_p = C_s$$

Table 1. Five Buck-boost Topologies, Showing Inserted Transformer and Split-capacitor Theoretical dc Voltage Stress Levels in Four Cases.

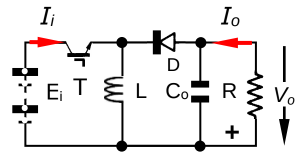
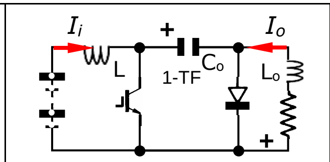
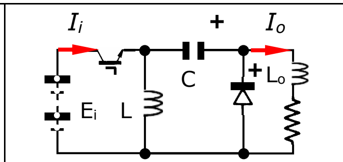
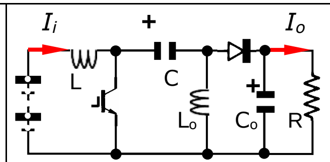
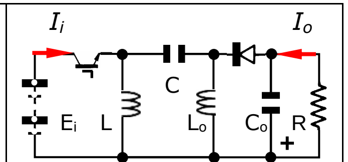
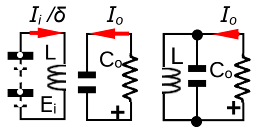
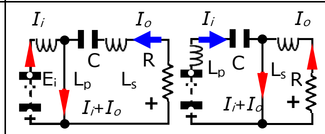
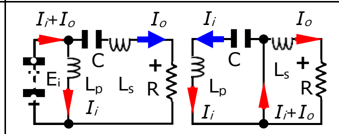
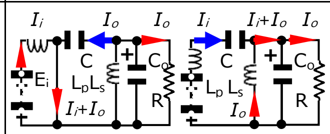
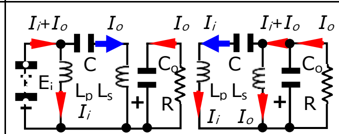
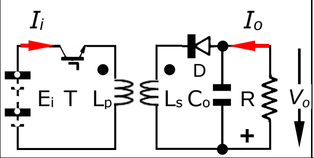
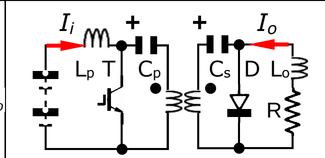
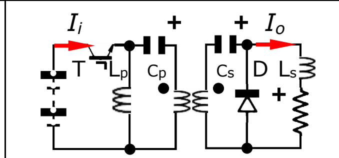
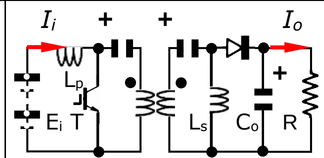
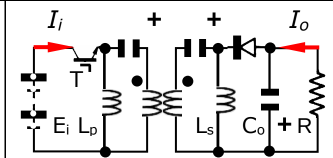
voltage sourced converters					
switch T state	switch T ON / switch T OFF	switch T ON / switch T OFF	switch T ON / switch T OFF	switch T ON / switch T OFF	switch T ON / switch T OFF
Two operating states					
Loop equations	$L\times\Delta i_L=\int v_L dt = t_{on}\times E_i= -t_{off}\times V_o$	$C\times\Delta v_C=\int i_C\, dt = -t_{on}\times I_o= t_{off}\times I_i$	$C\times\Delta v_C=\int i_C\, dt = t_{on}\times I_o= t_{off}\times I_i$	$C\times\Delta v_C=\int i_C\, dt = -t_{on}\times I_o= -t_{off}\times I_i$	$C\times\Delta v_C=\int i_C\, dt = t_{on}\times I_o= -t_{off}\times I_i$
Average capacitor voltage	-	$E_i+\lvert V_o\rvert$	V_o	E_i	**0**
Classification $\delta= t_{on}/\tau$ voltage transfer function $f_v(\delta)$	**A5** BUCK-BOOST **(a)** $-\frac{\delta}{1-\delta}$	**C5** Cuk **(b)** $-\frac{\delta}{1-\delta}$	**G6** ZETA **(c)** $+\frac{\delta}{1-\delta}$	**G5** SEPIC **(d)** $+\frac{\delta}{1-\delta}$	**P5** NEW **(e)** $-\frac{\delta}{1-\delta}$
features	Discontinuous input current voltage source output	Continuous input and output current	Discontinuous input current Continuous output current	Continuous input current voltage source output	Discontinuous input current voltage source output
Magnetic coupling (1:1 and $C_p=C_s$)					
Coupling mechanism	*Magnetic storage coupling*	*Transformer coupling*	*Transformer coupling*	*Transformer coupling*	*Transformer coupling*
Primary dc bias	I_i	E_i	**0**	E_i	**0**
Secondary dc bias	$I_i(1-\delta)/\delta$	V_o	V_o	**0**	**0**

Table 2. Common Component Characteristics.

$\delta = t_{on} / \tau = t_{on}\, f_s$	$\eta_T \left\lvert \frac{\delta}{1-\delta} \right\rvert$	Buck-boost converters	
$\eta_T = N_s / N_p = 1$		single inductor	two inductors
$C_p = C_s$	topology	A5	C5, G6, G5, P5
average voltage switch and diode	V_T , V_D	E_i , V_o	E_i , V_o
maximum voltage switch and diode	V_T , V_D	$E_i + V_o$, $E_i + V_o$	$E_i + V_o$, $E_i + V_o$
switch current average and peak	I_T , I_T	$I_o\,\delta / 1\text{-}\delta$, $I_o / 1\text{-}\delta$	$I_o\,\delta / 1\text{-}\delta$, $I_o / 1\text{-}\delta$
diode current average and peak	I_D , I_D	I_o , $I_o / 1\text{-}\delta$	I_o , $I_o / 1\text{-}\delta$
average inductor current input and output	I_{Lp} , I_{Ls}	I_i / δ	I_i , I_o
inductor ripple current input and output	$\Delta I_{Lp} = \Delta I_{Ls}$	$\delta E_i \tau / L$	$\delta E_i \tau / L_p$, $1\text{-}\delta\, V_o \tau / L_s$
capacitor ripple voltage	$\Delta v_{Cp} = \Delta v_{Cs}$	--	$\delta I_o \tau / C$

Capacitor maximum *dv/dt* stress depends on the smaller of t_{on} and t_{off}, that is the duty cycle δ: when δ < ½ the maximum *dv/dt* stress is

$$\left.\frac{\Delta V_{Cp}}{\Delta t}\right|_{max} = \frac{I_o}{C_p} \quad \text{and} \quad \left.\frac{\Delta V_{Cs}}{\Delta t}\right|_{max} = \frac{I_o}{C_s} \tag{4}$$

when δ < ½ the maximum *dv/dt* stress is

$$\left.\frac{\Delta V_{Cp}}{\Delta t}\right|_{max} = \frac{I_i}{C_p} \quad \text{and} \quad \left.\frac{\Delta V_{Cs}}{\Delta t}\right|_{max} = \frac{I_i}{C_s} \tag{5}$$

The capacitor dc bias voltage is the input and/or output voltage, or zero, depending on the dc topology. If dc biased, the capacitor voltage reaches zero during the off-period (hence DCM) when:

from equation (2), for the primary side capacitor biased by E_i

$$I_i = 2\frac{E_i}{(1-\delta)\tau}C_p = 2\frac{V_o}{\delta\tau}C_p \tag{6}$$

corresponding to a critical minimum load resistance of

$$R_{DCM} < ½\,\frac{\tau\delta^2}{C_p(1-\delta)} \tag{7}$$

from equation (3), for the secondary side capacitor biased by V_o

$$I_o = 2\frac{V_o}{\delta\tau}C_s = 2\frac{E_i}{(1-\delta)\tau}C_s \tag{8}$$

corresponding to a critical minimum load resistance of

$$R_{DCM} < ½\,\frac{\tau\delta}{C_s} \tag{9}$$

Hence C5 has two capacitor discontinuous constraints, the zeta and sepic converters one capacitor constraint, while P5 has no capacitor constraints because of the juxtaposition of two inductors, L_p and L_s. Since the input and output currents are related by the transfer function, in the case of a non-reversible Cuk C5 converter, with η_T =1, both capacitors enter DCM simultaneously at a specific duty cycle, when

$$C_p = \frac{\delta}{1-\delta} C_s \qquad (10)$$

- Inductors, L_p and L_s

DCM also occurs when an inductor current ripple reaches zero during the switch off period t_{off}, at which instant the associated capacitor maintains a constant dc bias voltage for the remainder of the switching period τ.

In each case, the primary-side inductor L_p average current is the average input current I_i, while the secondary-side inductor L_s average current is the output average current I_o. Operation assumes that both inductor currents are not discontinuous. The (current hence voltage) transfer function integrity is based on the average inductor current, independent of the ripple current magnitude. The ripple current specifies a DCM boundary, thus two CCM-DCM boundaries exist, viz. one for each inductor, L_p and L_s. The optimum design is the case where both inductors enter the discontinuous current mode at the same load current level, but unexploitably, this is only possible for a specific duty cycle.

For a given set of operating conditions and circuit component values, the input inductor L_p ripple current is the same for all four topologies, since each experiences the input voltage E_i for the same period of time t_{on}, that is

$$\Delta i_{Lp} = \frac{E_i t_{on}}{L_p} = \delta \frac{\tau E_i}{L_p} = (1-\delta)\frac{\tau V_o}{L_p} \qquad (11)$$

Similarly, for each topology, the output inductor L_s ripple current is the same in all four cases and can be expressed in terms of the output voltage V_o and switch off time t_{off}; specifically

$$\Delta i_{Ls} = \frac{V_o t_{off}}{L_s} = (1-\delta)\frac{\tau V_o}{L_s} = \delta \eta_T \frac{\tau E_i}{L_s} \qquad (12)$$

Inductor ripple current is independent of split capacitance C_p and C_s, and for unity turns ratio $\eta_T = 1$:

$$\Delta i_{Lp} = \Delta i_{Ls} \text{ if } L_p = L_s$$

Since the output inductor average current is equal to the load current and all four converters have the same output inductor ripple, the critical maximum load resistance R_{crit} for DCM is the same and can be determined from equation (12), as

$$R_{DCM} > \frac{2L_s}{(1-\delta)\tau} \qquad (13)$$

or if the input inductor enters discontinuous conduction before the output inductor, from equation (11)

$$R_{DCM} > \frac{2\delta L_p}{\tau (1-\delta)^2} \qquad (14)$$

Equating (13) and (14) gives the boundary condition as to which inductor enters DCM first, and like the capacitor DCM condition, is purely duty cycle dependant:

$$L_s = \frac{\delta}{1-\delta} L_p$$

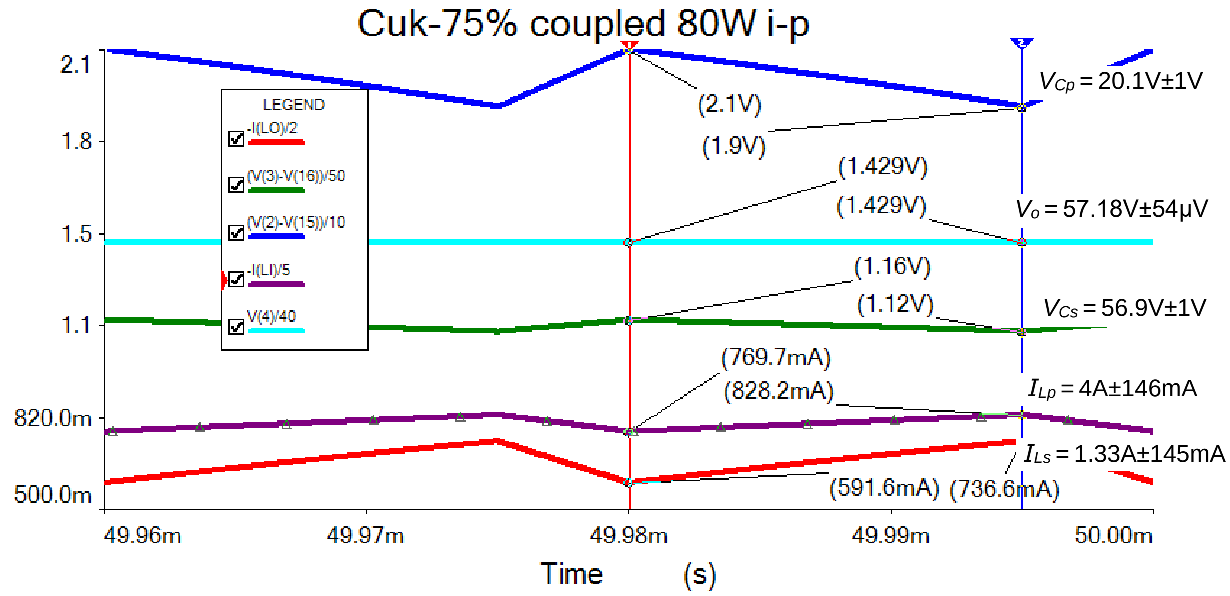
The ripple current (voltage) magnitude, hence inductance (capacitance), trades rapid response with large ripple current (voltage) against closed loop stability reduction and a higher DCM boundary.

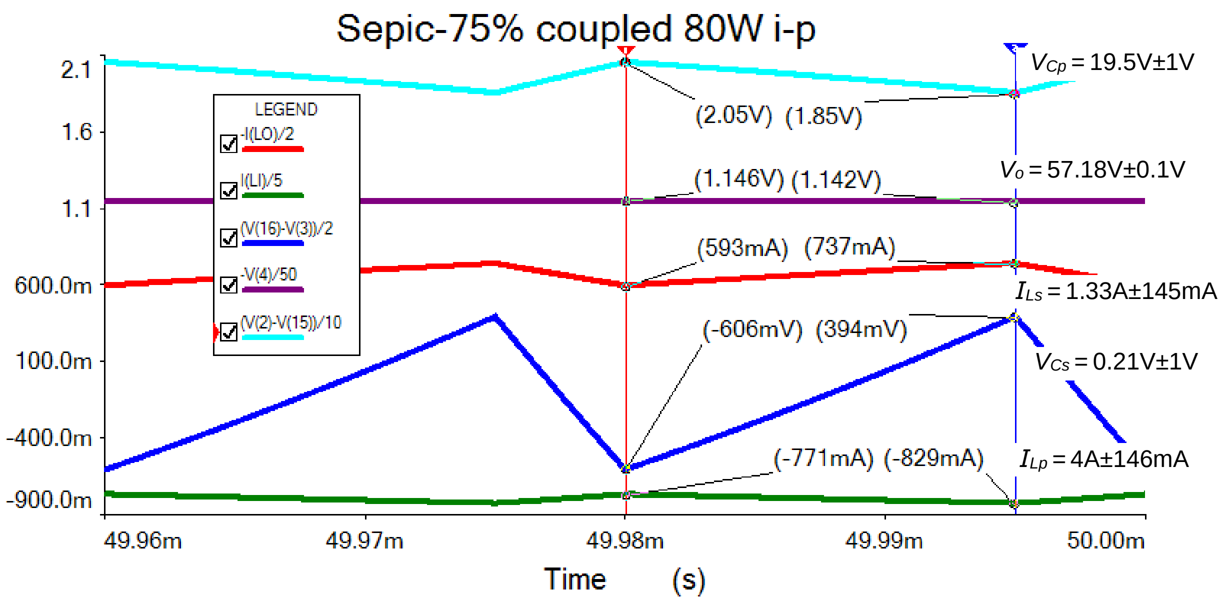
V. CONVERTER SIMULATIONS

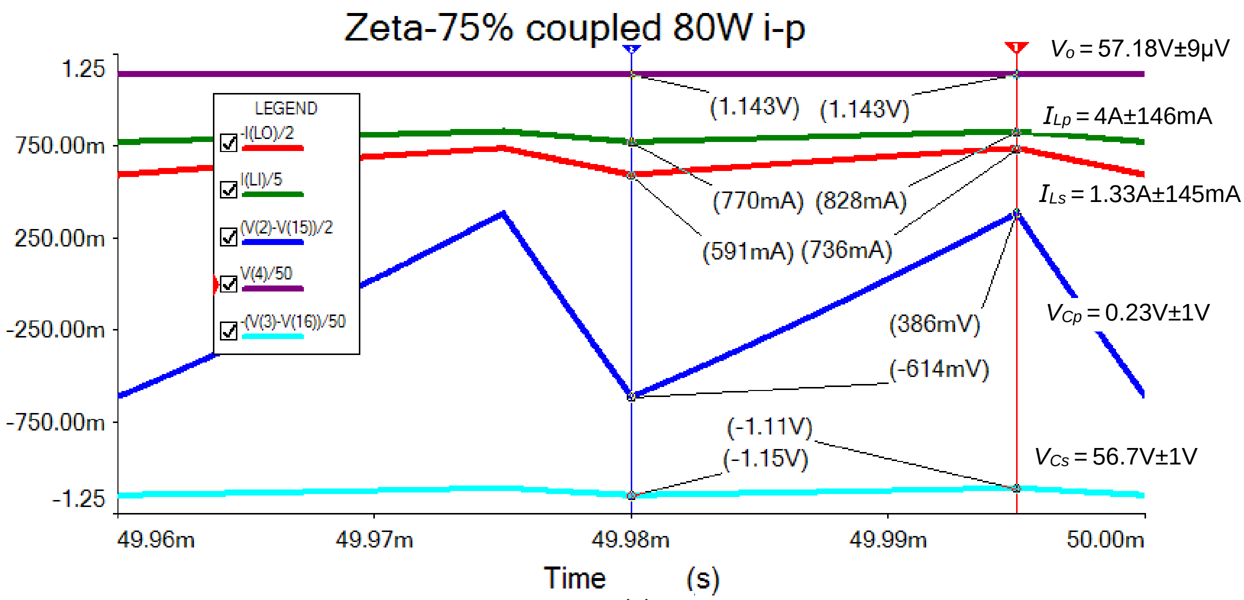
Table 3 summaries the component values used for the time domain transient simulations (and practically), with typical simulation results for each converter shown in Figure 4. Perfect transformer coupling, k =1, is assumed, with the practical consequences and remedies for leakage effects considered in subsequent sections.

Table 3. Component Values

E_i	20V	T, mosfet	200V, 54mΩ
L_p	1.0mH, 74mΩ, 10A	D, SiC	600V, 10A
L_s	1.0mH, 74mΩ, 10A	t_{on}	15μs
C_p C_s	10μF, 10μF	Δ	75%
C_o	100μF	f_s	50kHz
η_T	1 (100mH:100mH)	K	1


Cuk-75% coupled 80W i-p
2.1
1.8
1.5
1.1
820.0m
500.0m
LEGEND
-I(LO)/2
(V(3)-V(16))/50
(V(2)-V(15))/10
-I(LI)/5
V(4)/40
(2.1V)
(1.9V)
(1.429V)
(1.429V)
(1.16V)
(1.12V)
(769.7mA)
(828.2mA)
(591.6mA) (736.6mA)
VCp = 20.1V±1V
Vo = 57.18V±54μV
VCs = 56.9V±1V
ILp = 4A±146mA
ILs = 1.33A±145mA
49.96m
49.97m
49.98m
49.99m
50.00m
Time (s)
(a)


Sepic-75% coupled 80W i-p
2.1
1.6
1.1
600.0m
100.0m
-400.0m
-900.0m
LEGEND
-I(LO)/2
I(LI)/5
(V(16)-V(3))/2
-V(4)/50
(V(2)-V(15))/10
(2.05V) (1.85V)
(1.146V) (1.142V)
(593mA) (737mA)
(-606mV) (394mV)
(-771mA) (-829mA)
VCp = 19.5V±1V
Vo = 57.18V±0.1V
ILs = 1.33A±145mA
VCs = 0.21V±1V
ILp = 4A±146mA
49.96m
49.97m
49.98m
49.99m
50.00m
Time (s)
(b)


Zeta-75% coupled 80W i-p
1.25
750.00m
250.00m
-250.00m
-750.00m
-1.25
LEGEND
-I(LO)/2
I(LI)/5
(V(2)-V(15))/2
V(4)/50
-(V(3)-V(16))/50
(1.143V) (1.143V)
(770mA) (828mA)
(591mA) (736mA)
(386mV)
(-614mV)
(-1.11V)
(-1.15V)
Vo = 57.18V±9μV
ILp = 4A±146mA
ILs = 1.33A±145mA
VCp = 0.23V±1V
VCs = 56.7V±1V
49.96m
49.97m
49.98m
49.99m
50.00m
Time (s)
(c)

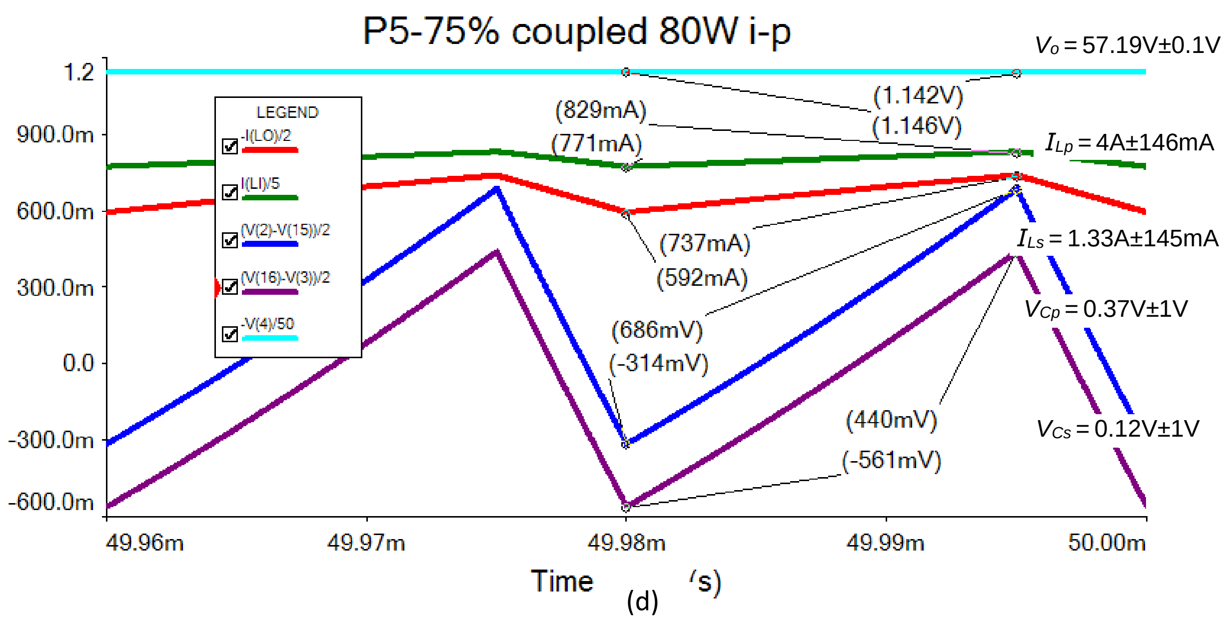


Fig .4. Simulation results at 20Vdc, 80W input, with δ=¾:(a) Cuk - C5, (b) sepic - G5, (c) zeta - G6, and (d) new - P5, converters.

Table 4. Simulation Results for the Four Transformer Coupled buck-boost Converters.

E_i = 20V δ=¾ R_o = 49.2Ω		Cuk	sepic	zeta	New
topology		C5	G5	G6	P5
ave I_i	A	4.00	4.00	4.00	4.00
P_{in}	W	79.90	80.00	79.91	80.01
ave $I_{Lp} \pm \Delta I_{Lp}$	A	4.00 ± 146m	4.00 ± 146m	4.00 ± 146m	4.00 ± 146m
ave $V_{Cp} \pm \Delta V_{Cp}$	V	20.1 ± 996m	19.54 ± 998m	0.23 ± 1.00	0.373 ± 1.00
ave $V_{Cs} \pm \Delta V_{Cs}$	V	56.9 ± 997m	0.21 ± 999m	56.7 ± 999m	0.122 ± 1.00
ave $I_{Ls} \pm \Delta I_{Ls}$	V	1.328 ± 145m	1.330 ± 145m	1.328 ± 145m	1.330 ± 145m
$V_o \pm \Delta V_o$	V	57.18 ± 54μ	57.18 ± 0.1	57.17 ± 9μ	57.19 ± 0.1
P_{out}	W	76.21	76.21	76.17	76.23
efficiency η	%	95.38	95.27	95.32	95.27

The open-loop simulation results in Figure 4, summarized in table 4, albeit at the same operating point for all four converters, confirm that the ac operating conditions are identical. The differences are in the split-capacitor dc bias and the ripple in the input current (discontinuous/ discontinuous) and output voltage ripple, due to discontinuous output current. The low output voltage ripple for the Cuk and zeta converters, because of continuous output current, illustrates that the 100uF output capacitance C_o could be reduced. Nonetheless, output capacitor equivalent series resistance, ESR, not accounted for in the simulations, would tend to dominate the output ripple voltage. Generally, the small simulation variations are due to the different Joule losses in the various operating Kirchhoff voltage loops.

VI. EXPERIMENTAL RESULTS

Figure 3 illustrates that all four split-capacitor converters can be practically assessed with a single hardware arrangement, with facilities to reconnect the transformer winding terminations. With the transformer winding terminal connected to the each of the split capacitors fixed, the output voltage polarity is fixed, independent of the connection (0V or E_i / V_o) of the remaining winding terminals. Also, Figure 7 will show that the same commonality exists for the necessary switch leakage energy clamping snubber circuit.

Since no mmf bias is required of the coupling transformer, the high relative permeability (>30,000) and high saturation flux density >1.2T, of low-loss, high Curie temperature, nanocrystalline strip core material can be exploited, with switching frequencies in excess of 100kHz. The high permeability justifies the high transformer magnetizing inductance (100mH:100mH) used in the simulations.

Experimental results are open loop. Because the ac circuit is identical for all four converters, the 408W practical result in Figure 5 is indistinguishable between the four converters, including the overshoot and ringing components. The RCD snubber uses ½nF of capacitance, amounting to 0.05W of loss (at E_i=20Vdc and 50kHz); which is insignificant to the overall converter efficiency.

Differences (36.2W in 408W) between simulated and experimental results in Figure 5 are accounted for by non-modeled core losses, winding proximity and eddy (Foucault) current created copper losses, plus switching and RCD snubber losses that are not modeled.

VII. SUMMARY OF PRACTICAL RESULTS

Figure 6 shows the open-loop dependence of capacitor voltage and ripple, output voltage and current regulation (droop), and efficiency, on average input current magnitude I_i. The converter circuit component values are as shown in Table 3. Without exception, these graphs show that the ac characteristics of the four converters are indistinguishable, expected given all four have the same ac equivalent circuit. Any differences are due to losses in the output capacitor due to different ripple currents, hence ESR I^2R losses.

The efficiency and voltage regulation deteriorate (near linearly) with increased load/input current. In confirming the inductor ripple current equations in Table 2 and equations (11) and (12), the inductor ripple currents are independent of load current - figures 4 and 5. Figure 6c shows that converter efficiency decreases with load.

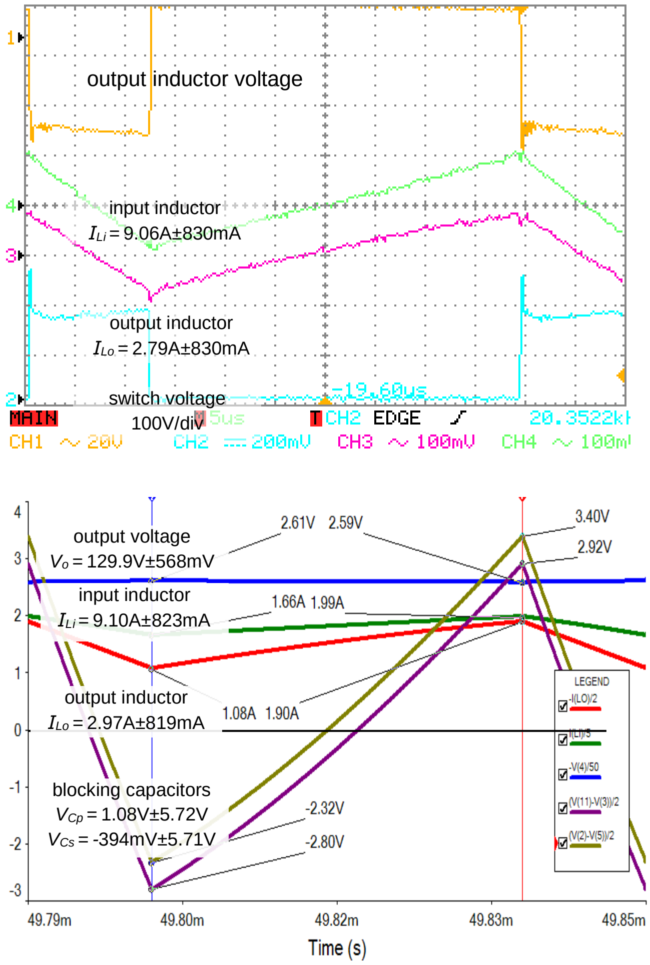


Fig .5. Simulation and experimental results for the transformer coupled buck-boost converter P5, at 20kHz, 45Vdc, 9A ave (408W) input, η = 85.7% (output 125.3Vdc, 2.79A).

Also in accordance with the theory, equations (2) and (3) and table II, the capacitor ripple voltage Δv_c in Figure 6(d) increases linearly with increased load current (for a given δ, etc.) and is independent of terminal input/output voltages. Due to circuit Kirchhoff loop losses, specifically the unequal inductor resistive component voltages, not included in the theory, the capacitors have a current-dependant small dc bias (in addition to any input/output dc blocking voltage), which is duty cycle and load dependant, as shown in Figure 6(a). Figures 4 and 5 show that if the inductances are equal ($L_i = L_o$), with a transformer 1:1 turns ratio, the ripple current magnitudes are equal. From Table I, the relative average current magnitudes in both inductor windings (which equal the average input/output currents), change-over at δ=½, when V_o=E_i.

In contrast to the poor open-loop output voltage regulation, the converters exhibit good output current regulation characteristics, as shown in Figure 6(b). The voltage regulation in Figure 6(b) deteriorates because semiconductor voltages and *IR* drops detract from the effective input and output voltages. On the other hand, the current transfer ratio is largely unaffected by voltage components; it is purely a relation between the input and output current, independent of the input voltage. Hence, at the modest input voltage of 20V dc, the current regulation is significantly better than the voltage regulation. Such a regulation feature is common to all dc-to-dc converters.

Increasing the input voltage from 20V dc to 30V dc to 45V dc, for a given input current results in improved efficiency (as shown in Figure 4c), hence better voltage regulation, since the Joule *IR* type voltage drops become less significant. For example, at 8A average input current, the efficiency increases from 73% to 75.5%, corresponding to the open-loop output voltage droop decreasing from 26% to 16.5%, for 20V dc and 30V dc, respectively. As shown in Figure 5 and plotted in Figure 6, the efficiency at 45Vdc and 9A average input improves to 85.7%, at 20kHz. Switch RCD snubber losses at a few tens of milliwatts, are insignificant.

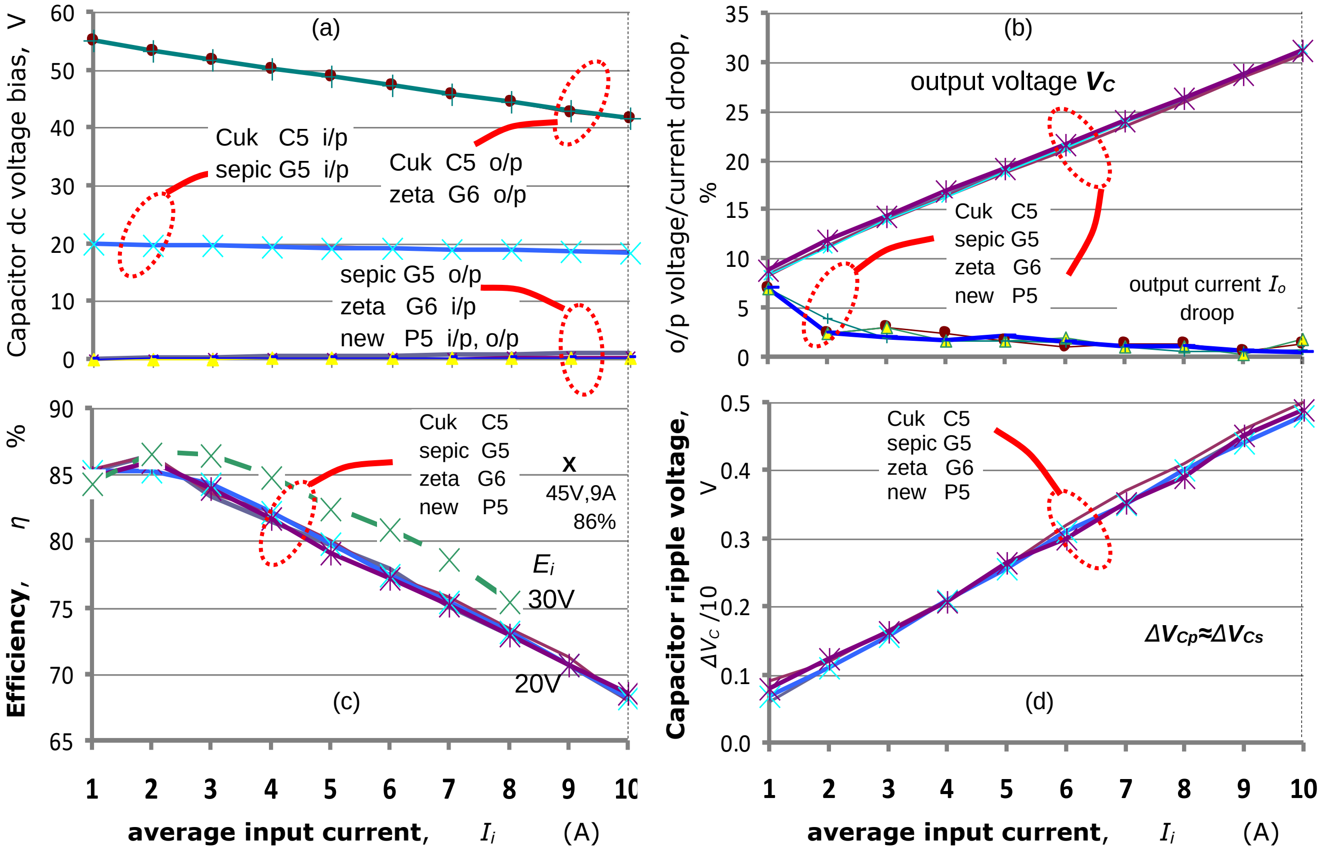


Fig .6. Experimental results at 50kHz, δ=75%, E_i = 20V and varied average input current, for the four transformer-coupled buck-boost dc-to-dc converters (C5≡Cuk, G5≡sepic, G6≡zeta, P5≡New): (a) capacitor C_p and C_s dc voltage bias, (b) output voltage V_o and current I_o regulation (droop), (c) efficiency, and (d) capacitor C_p and C_s ripple voltage/10.

VIII. OPERATIONAL CONSTRAINTS

Each circuit configuration (coupled and uncoupled) has leakage and/or stray inductance, hence it suffers from trapped energy switch and diode over voltage at commutation. The key physical design aspect is to minimize stray/leakage inductance, accomplished by using transformer bifilar windings and a core with as high as possible permeability (low core reluctance). Since stray/leakage inductance inevitably remains, current commutation overlap occurs, whence switch turn-on snubbering is inherent. Switch/diode turn-off clamping/snubber energy if not dissipated, any energy recovered should feed back to the supply rather than the output, which is variable, so as not to affect the output regulation and more importantly not to upset the transformer Vµs balance, which is hyper-critical in single-switch converter configurations, if core saturation is to be avoided.

The inevitable leakage in itself is not a problem, nor is a high converter power rating. Converter topology physical construction and electrical isolation are similar up to about 1kV. That is, leakage and stray inductance are largely independent of voltage up to 1kV. Trapped energy is determined by the current magnitude, squared. Thus, the lower the voltage for a given power rating, the higher the current, which results in significantly higher trapped energy being proportional to current squared $\frac{1}{2}LI^2$. Therefore, low-voltage high-current converter design is challenging. A single power semiconductor clamping device (5W transient voltage suppressor) but not a metal oxide voltage suppressor (high capacitive energies at high frequencies) is adequate for a few Watts of losses, as shown in Figure 7(a). At higher dissipation levels, an RCD snubber as shown in Figure 7(b), not only controls inductive leakage current induced voltage levels, but also reduces switch turn-off losses. At even higher current levels, the complication of snubber energy recovery may be viable, where active techniques are required, as shown in figures 7(c) and 7(d). The switch T_r in Figure 7(c) is self synchronized, its gate being ac coupled via an auxiliary auto-transformer winding on L_i. The main switch T and recovery switch T_r are gated together, and the topology in Figure 7(d).i can use a common gate driver (with T_r gate ac coupled as in Figure 7(c)). The minimum reset time (minimum switch on-time), $t_{on} \geq t_1 + t_2$, comprises a fixed period $t_1 = \frac{1}{2}\pi/\omega_o$ where $\omega_o = \sqrt{L_r C_{sn}}$, at which time the snubber capacitor retains zero voltage, provided $\eta_{Xc} < \frac{1}{2} V_{Csn\ max} / E_i$. The interval t_2 is source voltage and trapped energy dependant ($V_{Csn\ max}$), specifically $t_2 = (V_{Csn\ max} - \eta_{Xc} E_i) / \eta_{Xc} \omega_o E_i$, where η_{Xc} is the reset transformer turns ratio, effectively ηXc is unity for Figure 7(c) analysis.

The leakage energy associated with the recovery transformer in Figure 7(d), is also recovered, and the series inductance L_r function may be fulfilled by recovery transformer leakage. The same snubber topology is employed on the switch/diode on both sides of the transformer, which then also caters for bidirectional converter operation.

Attempts at passive energy recovery are hampered since the switch supporting voltage V_o+E_i is more than the supply voltage E_i but less than the peak voltage $V_{Csn\ max}$, produced by capacitor storage of the trapped energy.

Previous active recovery circuits [25] use a floating switch gate/source, that experiences high *dv/dt*'s. Also the main switch experiences the recovery current at switch turn-on [25] and energy is fed into the output circuit, which is a variable voltage; therefore portion of the reset period is not only load current dependant but also duty cycle dependant [25].

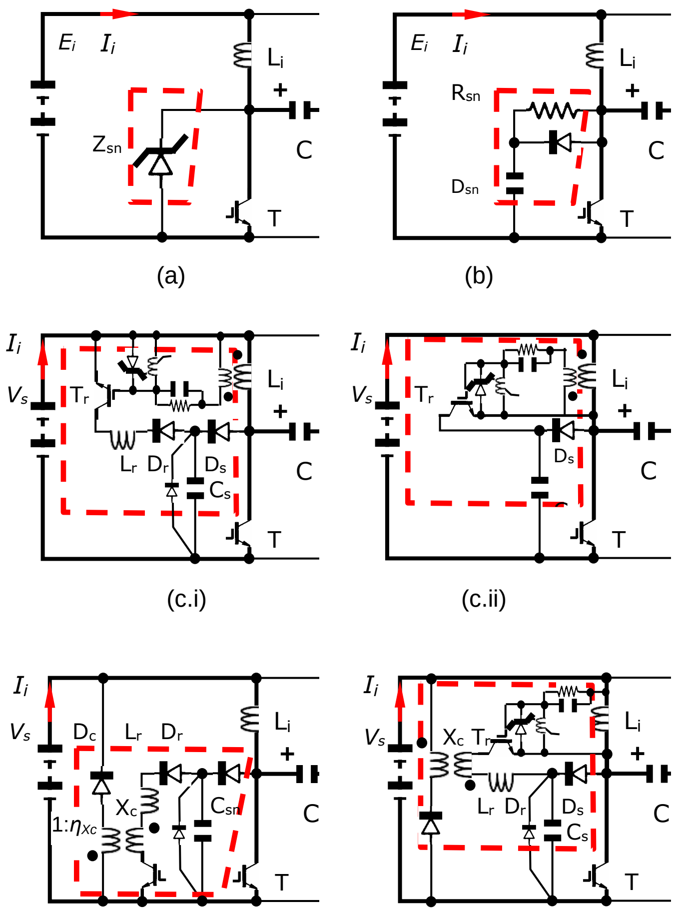


Fig .7. Stray/leakage inductance energy clamping techniques: (a) Zener clamp, $V_z > E_i + V_o$, (b) RCD/soft clamp snubber, (c) active regenerative turn-off snubber, and (d) isolated active recovery.

IX. CONCLUSIONS

Four single-switch, transformer-coupled buck–boost converters have been analyzed and assessed theoretically, in simulation and experimentally. This paper has highlighted the ac circuit equivalence of the Cuk, sepic, zeta and new converters. All four converters use two inductors and two split mirroring capacitors with a shunt transformer interposed, and have identical ac characteristics, but differ in terms of mirroring capacitor dc bias. The external input and output ac current conditions differ, being combinations of either continuous and/or discontinuous. The voltage transfer function is independent of inductor ripple current, being dependant on average inductor currents. Specifically, the primary-side inductor average current is the average input current, while the secondary-side inductor average current is the average output current, in the ratio $\delta/(1-\delta)$, independent of current ripple. Discontinuous conduction is inductor ripple current magnitude dependant, while capacitor constant voltage mode characteristics (capacitor equivalent to inductor DCM) are induced by inductor DCM (and vice versa).

The transformer dc current (hence flux) bias in the conventionally coupled sepic and zeta converters under utilizes the core two quadrant flux swing capability and increases the total copper losses. The copper losses are increased because of the reduced allowable flux swing, and with an air gap the number of turns for a given inductance increases, hence resistance increases. By separating transformer and inductor functions, each can be optimally and independently designed.

Practically, the only limitation in realizing a high-power single-switch, transformer-isolated dc-to-dc converter, is trapped energy associated with stray and leakage inductances. Four clamping/snubber circuits, to cater for the leakage trapped energy at switch turn-off, have been proposed, which facilitate operation from a few watts output to over 2kW.

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Recent Positioning Techniques for Efficient Port Operations and Development of Suez Canal Corridor

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Abstract - The majority of positioning systems for marine traffic are satellite based such as GPS. The developments of Real Time Kinematic Networks and their applications such as Virtual Reference Station are considered one of the recent high precision techniques for Global Navigation Satellite Systems (GNSS). These techniques will have great impacts on construction and operation of smart and efficient ports.

The advantages of using virtual reference station technique in different port operations and constructions have been discussed in this paper. To apply this technique in Suez Canal corridor zone, a design of GNSS Continuously Operating Reference Station network has been proposed. This network could be used during different construction and operations phases of Suez Canal Corridor project. The recommended system could reduce the time and cost of project constructions and improve navigation and safety through the Suez Canal.

Keywords - Suez Canal Corridor, RTK GPS, VRS, smart ports, vertical datum, dredging, under-keel clearance

I. INTRODUCTION

One of the main objectives of port authorities is maintaining safe movements of ships during entry, exit and inside the water area of the port. The efficient ports should perform continuous and economic services to ships without delay. The current development in satellite based positioning systems and their applications such as Virtual Reference Station (VRS) provide three-dimensional high precise positions which are critical for efficient ports.

The International Maritime Organization (IMO) issued minimum maritime user requirements for positioning for marine navigation as in Table (1). To meet these requirements, augmented GNSS is required in ports and port operations [1].

Table 1. Minimum Maritime User Requirements for Positioning.

	System level parameter			
	Absolute accuracy	Integrity		
	Horizontal/Vertical (Meters)	Alert limit (Meters)	Time to alarm (Seconds)	Integrity risk* (per 3 hours)
Ocean/ Costal/ Port approach / restricted waters	10 (H)	25	10	10^{-3}
Port	1 (H)	2.5	10	10^{-3}
Inland waterways	10 (H)	25	10	10^{-3}
Track control	10 (H)	25	10	10^{-3}
Automatic docking	0.1 (H)	0.25	10	10^{-3}
Ship-to-ship/-shore	10 (H)	25	10	10^{-3}
Search and rescue	10 (H)	25	10	10^{-3}
Hydrography	1-2 (H) 0.1(V)	2.5-5	10	10^{-3}
Oceanography	10	25	10	10^{-3}
Dredging	0.1 (H) 0.1(V)	0.25	10	10^{-3}
Construction works	0.1 (H) 0.1(V)	0.25	10	10^{-3}
Container/Cargo management	1 (H) 1(V)	2.5	10	10^{-3}
Cargo handling	0.1 (H) 0.1(V)	0.25	1	10^{-3}

*Integrity risk is the probability of providing a signal that is out of tolerance without warning the user in a given period of time.

The high accuracy GNSS techniques such as Real Time Kinematic (RTK) and network-based applications such as VRS are considered very efficient tools for precise port operations such as dredging, real-time under-keel clearance monitoring, hydrographic survey, terminal asset management, and other applications. With the draft of ships increasing mega ships capable of carrying more than 20000 TEU containers are now coming into service, it is now more crucial than ever that ports operate as efficiently as possible.

The network-based RTK positioning is very effective for port construction and developments such as Suez Canal corridor development project. This mega project in Egypt aims to increase the role of the Suez Canal region in international trading and to develop the three canal cities. In this paper a design of GNSS Continuously Operating Reference Station (CORS) network has been proposed. This network can be utilized during different construction and operations phases of the project. The efficient operations can be achieved in Suez Canal and all ports in the area by using the different applications of the proposed CORS network such as VRS.

II. POSITIONING SYSTEMS IN PORTS AND WATERWAYS

Presently, the use of land based positioning systems for waterways such as Loran-c is becoming uncommon due to its cost and low accuracy. The accuracy specification for Loran-C is a 95 percent probability of a radial error within 400m over water. However, differential Loran can achieve accuracies of order 10m at selected locations, such as airports and harbors [2]. The majority today use satellite based systems such as GPS. The IMO has recognized that Global Navigation Satellite System (GNSS) will improve, replace or supplement existing position fixing systems since some of which have shortcomings with regard to integrity, availability, control, and system life expectancy.

A. Differential GPS Positioning

Differential Global Positioning System (DGPS) is an improvement to navigation solution of a standalone GPS receiver. The position accuracy might improve from the 15-meter nominal GPS accuracy to reach decimeter level in case of the best implementations [2].

DGPS uses a network of fixed, ground-based reference stations to broadcast the difference between the positions determined by the GPS and the known fixed positions of the stations. These differences are received by the users as corrections which can be applied to improve the accuracy of their GPS positions as in Figure 1.

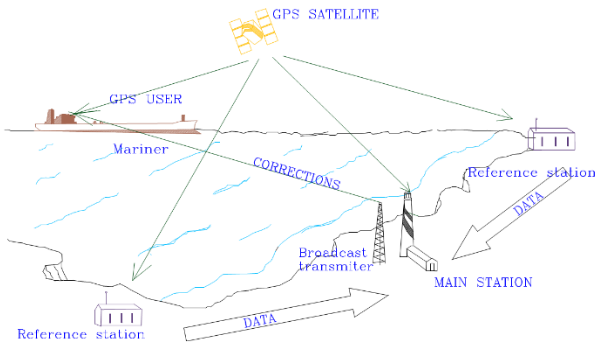

Fig .1 Concept of DGPS

The DGPS network in Egypt consists of six control stations, each has one reference station and radio beacon broadcast site with integrity monitoring and communications links. Along the Mediterranean, three sites (Mersa Matruh, Alexandria, and Port Said) provide coverage for Egypt's north coast. The three southern sites (Ras Umm Sid, Ras Gharib, and Quseir) provide coverage from the northern end of the Gulf of Suez south to Egypt's border with Sudan as shown in Figure 2. Port Said and Ras Gharib together also provide full and overlapping coverage of the Suez Canal and the oil fields in the Gulf of Suez.

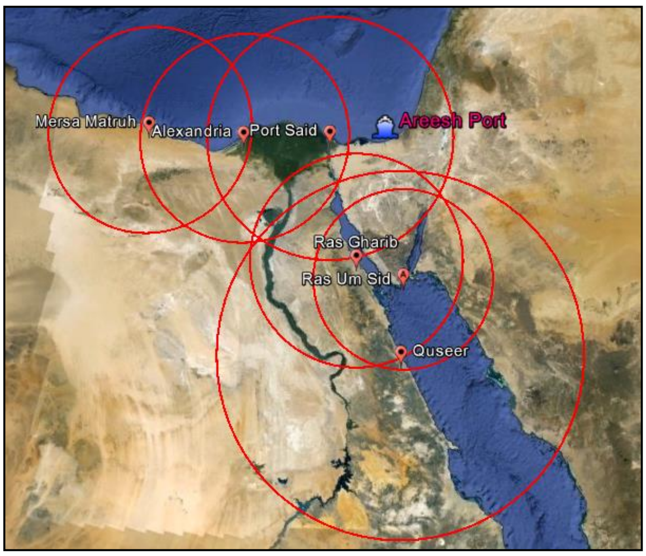

Fig .2. Coverage of DGPS service in Egypt [3]

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B. Real Time Kinematic GPS Positioning

Real Time Kinematic GPS allows the user to obtain centimeter-level positioning accuracy in real-time. The basic concept behind RTK is that a base station receiver is set over a known point and sends the observed GPS data to other rover receiver [4]. The rover receiver is equipped by a controller which has software capable to process the double difference GPS data of both receivers and resolve the integer phase ambiguities. Once the integer ambiguities are correctly resolved, the position of the rover station can be determined with accuracy reach centimeter level in real time while the station is in motion [5]. The base station data is normally sent via UHF or spread spectrum radios that are built specifically for wireless data transfer as in Figure 3.

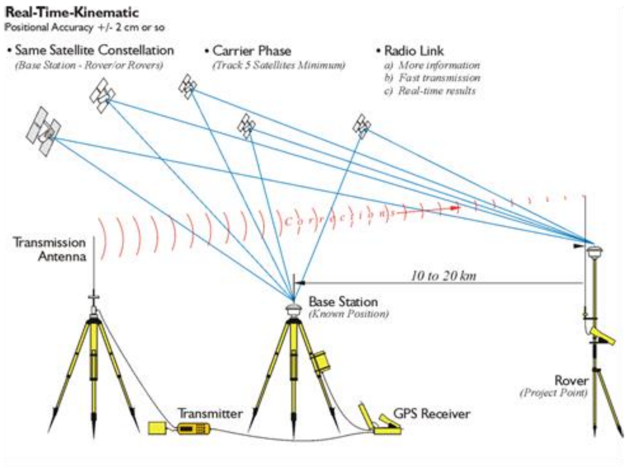

Fig .3. Real Time Kinematic GPS technique

C. Network RTK and Virtual Reference Stations

The Virtual Reference Station is a concept which helps to reach centimeter-level, or even better accuracy of positioning by using single receiver. It requires the use of dual-frequency carrier phase observations using a network of reference stations. These observations are usually processed using a differential GPS algorithm, such as RTK.

GPS network configuration such as CORS networks often makes use of multiple reference stations. This approach allows a more precise modeling of distance-dependent systematic such as ionospheric and tropospheric refractions, and satellite orbit errors [5]. The network of receivers is linked to a main control center, and each station contributes its raw data to create network-wide models of the distance-dependent errors. The computation of errors based on the full network's carrier phase measurements involves the resolution of carrier phase ambiguities and requires knowledge of the reference station positions. At the same time, the rover calculates its approximate position and transmits this information to the computation server, via Internet Protocol. The computation center generates in real time a virtual reference station at or near the rover position as shown Figure 4. This is done by geometrically translating the pseudorange and carrier phase data from the closest reference station to the virtual location and then adding the interpolated errors from the network error models. When VRS data received, the rover receiver uses standard single-baseline algorithms to determine the coordinates of the user's receiver, in RTK or post-processed modes [6].

In the VRS positioning, many techniques can be employed such as the virtual reference station method (VRS) and the area correction parameter technique. These methods have differences in the amount of data to be sent to the user, the processing strategy, amount of computations at the station, and the type of communications between the network and the rover receiver. The objective is to avoid the distance dependent decrease of accuracy and the equivalent increase of the required time to fix ambiguities.

In order to dominate the distance dependent errors in real-time applications, it is necessary to perform a real-time data analysis using all data from the participating reference stations. In practice, this means that all reference stations need a data link to a computing server where the analysis is executed in quasi real-time, and the distance dependent errors coming from the orbit, the ionosphere, and the troposphere are estimated. This information is then used to correct the results at any given station within the working area. The technique could be named "interconnected reference network", "linked network", or "coupled network". The main advantages of the Network RTK can be summarized as follows [7]:

- Cost and labor reduction, as there is no need to set up a base reference station for each user.

- Accuracy of the computed rover positions is more homogeneous and consistent as error mitigation refers to one processing system.

- Accuracy is maintained over larger distances between the reference stations and the rover.

- The same area can be covered with fewer reference stations compared to the number of permanent reference stations required using single reference RTK. The separation distances between networks stations are tens of kilometers, usually kept less than 100 km.

- Network RTK provides higher reliability and availability of RTK corrections with improved redundancy, such that if one station suffers from malfunctioning, a solution can still be obtained from the rest of the reference stations.

- Network RTK is capable of supporting multiple users and applications.

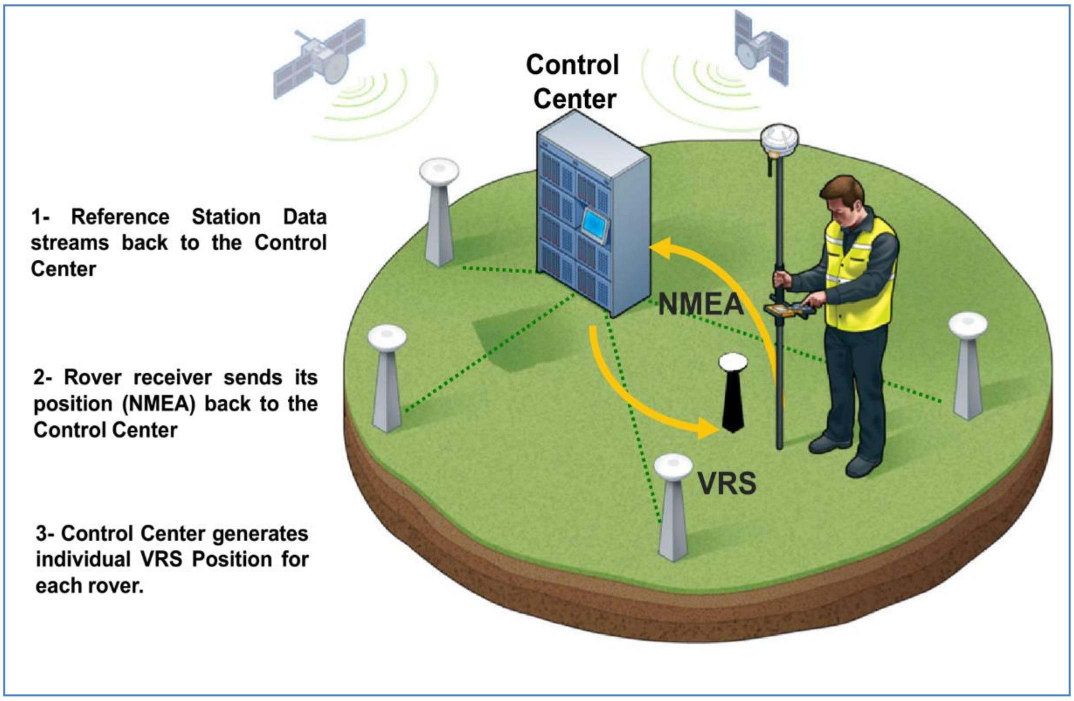

Fig .4. Virtual Reference Station concept

III. RTK APPLICATIONS IN PORT OPERATIONS

A RTK system is a precise and accurate system for both horizontal and vertical measurements and centimeter-level accuracy could be obtained over a large site. The RTK systems have many benefits and applications which can be used in numerous activities at ports such as:

- Hydrographic surveying of the ports water area and navigation channels.

- Precise and economic dredging and construction of quay walls and coastal protection.

- Ship under-keel clearance monitoring, berth docking and piloting systems.
- Precise tracking for position and speed to feed into the vessel tracking systems.

- A positioning system infrastructure for terminal asset management.

This paper focuses on the advantages of using RTK network and its application VRS in hydrographic surveying, dredging, and real time under-keel clearance monitoring.

A. Advantages of Using RTK in Hydrographic Surveying

The hydrographic survey mainly depends on measuring the horizontal and vertical position of the survey vessel. The accuracy of the vessel positioning directly affects the accuracy of the seabed survey.

Conventional hydrography determines a chart depth by measuring the distance from the sounding transducer to the bottom and then applying corrections for draft and tide. RTK GPS receivers can measure the latitude, longitude and height above the WGS-84 reference ellipsoid to within a few centimeters. Using this vertical accuracy, water level corrections (tide corrections) can be determined. This eliminates the need to use conventional tide gauges or to assign personnel to monitor tide staffs. The separation between the WGS-84 reference ellipsoid and the appropriate chart datum of the survey as it has to be pre-determined area. Figure 5 illustrates the relationship between different vertical datums in hydrography.

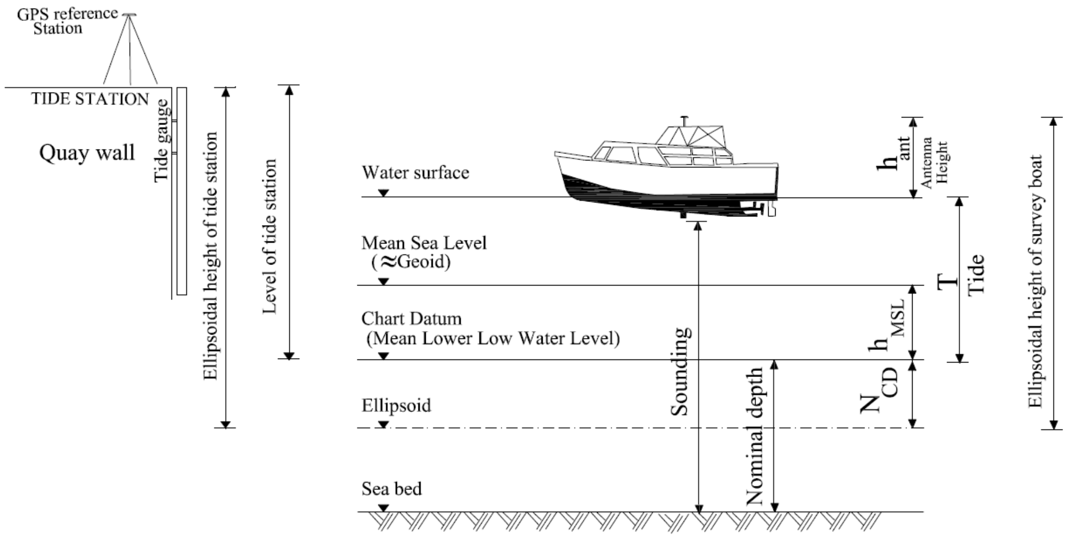

Fig .5 Relationship between different vertical datums in hydrography.

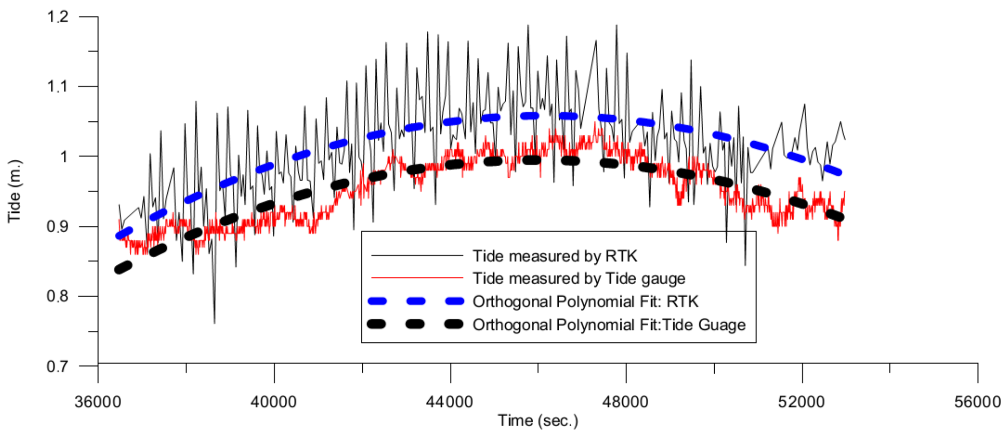

Fig .6 Tide values measure by the tide gauge and by RTK GPS [3].

Tide gauges can only report the tidal condition at the place where they are installed and they cannot measure other long waves at the vessel position. In case of projects located far from the tide gauge, significant differences may occur. To investigate these differences data obtained during a maintenance dredging project in Port Said East Port were utilized [3]. Figure 6 depicts the tide values measured by both the tide gauge and RTK GPS for an area about 10 km away from the tide gauge. Data obtained during a maintenance dredging project in Port Said East Port were utilized. It becomes clear that there is nearly a 10 cm gap between the measured values in each case. Tide measurements at the location of tide gauge diverge from the tide values at the project site due to the change in the sea state conditions and other factors. The limitation of using RTK GPS for measuring tide is the assumption that the separation between ellipsoid and CD for the project area is constant where the gradient of chart datum is considered zero.

Many errors associated with GNSS positioning can be eliminated through careful calibration procedures prior to each survey. The remaining errors affect the measured coordinates depending on the type of equipment and measurements technique. Figure 7 illustrates an example of effect of error in horizontal position of survey vessel on the measured depth and consequently on the calculated dredged volume. In areas with flat bottom, this effect may not be significant.

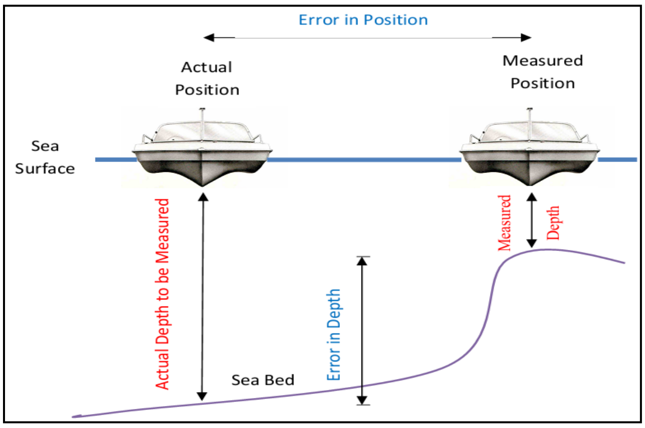

Fig .7 Example of effect of errors in position on the measured depths

B. *Precise and Economic Dredging and Construction*

Using the RTK network provides centimeter-level accuracy for both horizontal positioning and depth. Therefore, possibilities of missing spot shoals are decreased. Also, knowing accurate draft of the vessel enables increased accuracy for dredge cuts. In addition, the improved accuracy makes dredging around piers and pilings easier [8].

To inspect the effect of the used positioning equipment on the estimated dredged volume, an experiment has been carried out in Arish Port. Hydrographic survey has been performed using two different positioning equipment RTK GPS model Leica 1230 and DGPS model Trimble DSM132. ODOM ECHOTRACK single frequency Echo-Sounder is used for depth measurements and HAYPACK MAX Hydrographic survey software V.6.2b is used for data collections and processing [3].

Figure (8) shows spot height differences of Areesh Port obtained using RTK GPS and DGPS positioning systems. The spot height differences range from -2.56 m to 1.48m with -0.03 m mean and 0.32 m standard deviation. The estimated dredging volume to level (-13 m) is 977603 and 974474 cubic meters in case of using DGPS and RTK GPS, respectively. Considering the average cost of dredging is 7$ per cubic meter, the direct difference in cost is 21903 $, which is nearly the difference between the purchasing cost of RTK GPS and DGPS.

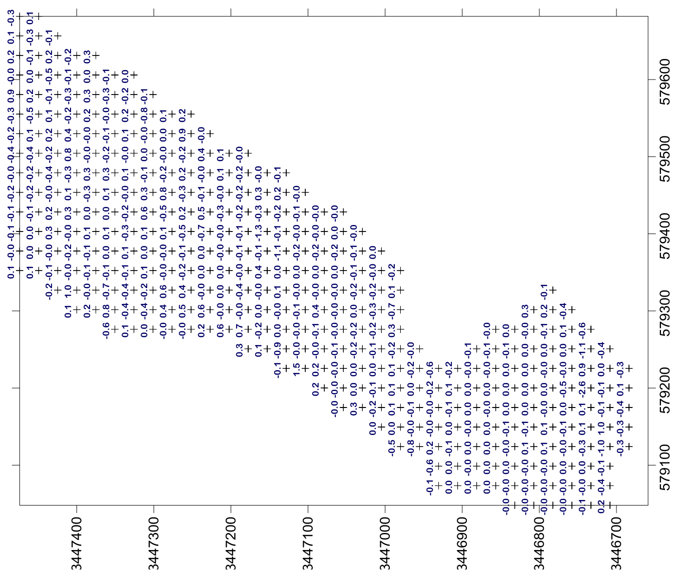

Fig .8 Differences in hydrographic survey results using DGPS and RTK (all dimensions are in meters)

To investigate the effect of using RTK GPS in tide measurements, the volume of the dredged materials of Port Said East Port maintenance dredging project has been calculated. The volumes of the dredged materials were 1,874,363 and 1,610,095 cubic meters estimated by using RTK GPS and tide gauge, respectively. The difference in volumes is a considerable amount and has a significant impact on the project cost.

C. Real-time Ship Under-keel Clearance Monitoring

Under-keel Clearance (UKC) is the most important factor which determines the possibility of ship hull touching the bottom; therefore it is one of the basic elements which decide navigation safety in restricted waters. The basic navigator's responsibility is to keep under-keel clearance safe in any conditions. Typically, a channel is dredged to a defined depth and any deep draft vessel exercises a margin of safety such as entering port in high tide, or exiting with a lighter load. It is recommended to reduce UKC without compromising safety for less cost and reduce possible environmental impact of dredging [9]. The total allowance or Gross UKC can be diagrammatically represented in Figure (9).

In addition to the conditional factor allowances identified in Figure (9), most real-time UKC calculations include a "Bottom Clearance", which refers to the remaining clearance allowance required after all other conditional factor allowances are removed. The Bottom Clearance allowance is based on internationally accepted guidelines, and is intended to be a representation of the Gross UKC value.

There are a few technologies available for UKC measurement using GPS. Dynamic UKC technique characterizes the performance of each class of ship in the port area. This is carried out by using precise GPS while sailing in and out. For following up port entries, that data are used plus wave buoy information, nominal draft, vessel speed and wind data and report in real-time on the actual draft. Another technique is to install RTK GPS receivers on deep draft vessels so that the precise absolute depth of the keel is known independent of tide gauges and changing vessel draft. When combined with an accurate digital terrain model of the navigable depth of the port , the UKC can be determined.

The ability of RTK GPS receivers to determine the altitude of fixed points on the vessel relative to a known vertical datum means that the potential exists to bypass the measurement of tide heights, ship drafts and local sinkage in determining the elevation of a ship's keel relative to chart datum. When combined with charted bathymetry, the under-keel clearance can then be obtained. The RTK GPS concept for monitoring real-time ship under-keel clearance is shown in Figure 10 and Equation 1&2 [11].

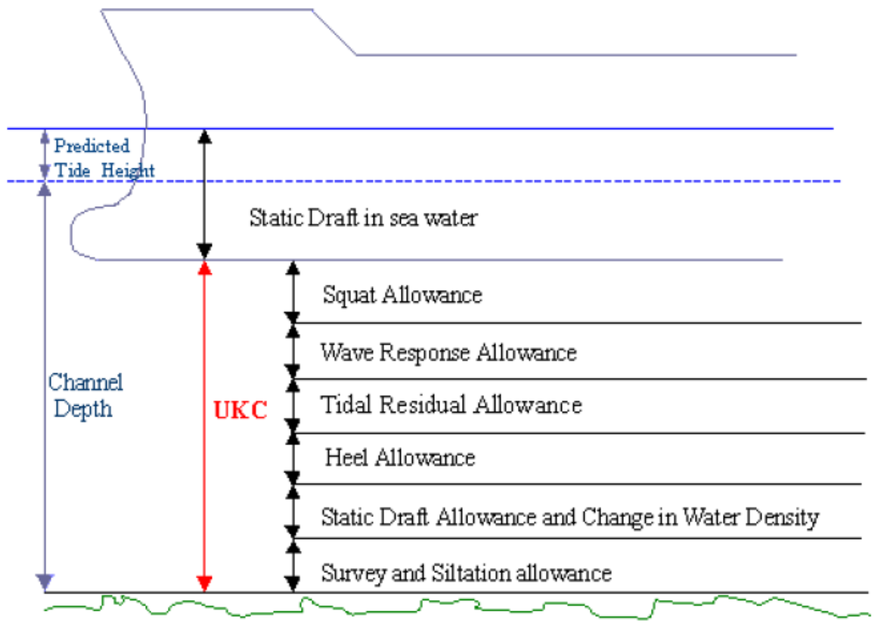

Fig .9 Factor allowances associated with a Gross UKC Calculation [10]

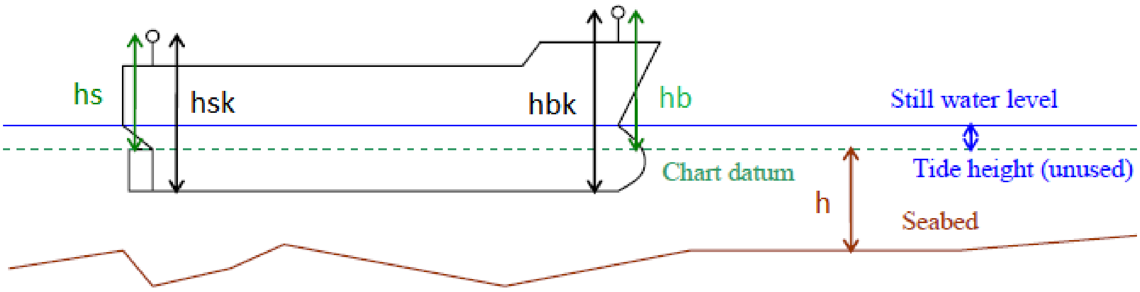

Fig .10 GPS concept for monitoring ship UKC [7]

Real-time UKC at bow = h+hb-hbk (1)

Real-time UKC at stern = h+hs-hsk (2)

Where hs is stern GPS altitude, hsk is stern GPS altitude above keel, hb is bow GPS altitude, hbk is bow GPS altitude above keel, and h is water depth. Similar relations are used at other points on the ship.

Overseas operational experience confirmed that applying a real-time UKC monitoring systems give greater understanding of the margin of navigational safety and increase the potential for economic benefit to the users by permitting increased cargo uplift [10].

IV. APPLICATIONS OF CORS NETWORKS IN DEVELOPMENT OF SUEZ CANAL CORRIDOR

The Suez Canal Corridor Area SCCA Project is a mega project in Egypt. The project's aim is to increase the role of the Suez Canal region in international trading and to develop the three canal cities: Suez, Ismailia, and Port Said. The project involves building new Ismailia city, an industrial zone, fish farms, completing the technology valley, seven new tunnels between Sinai and Ismailia and Port Said, and improving five existing ports.

Such a mega and promising project could benefit from the advantages of GNSS networks during the construction and operation phases. There is an endless number of potential applications that might benefit by VRS and GNSS networks. Figure (11) shows the proposed CORS network for SCCA.

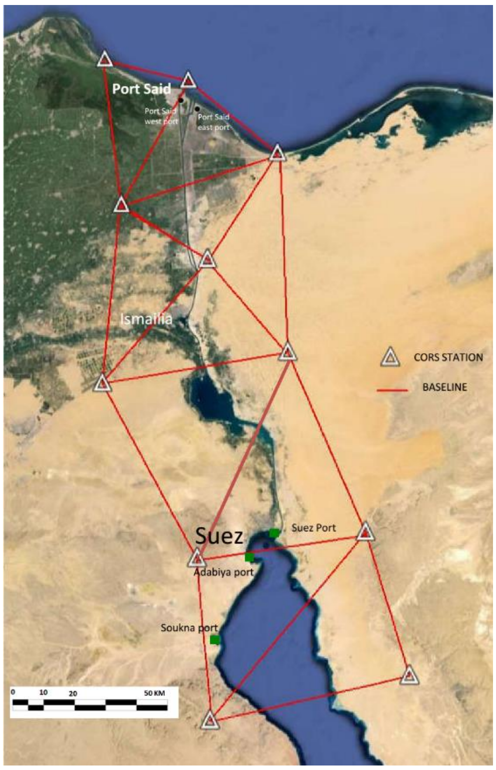

Fig .11 The proposed GNSS network in Suez Canal Corridor Area

CORS Station location follows some requirements needed to provide a good network in terms of geometrical arrangement around the area of interest. This was done by carefully selecting locations which were strategically viable for installing this kind of technology. The proposed baseline lengths for the network range from 30 km to 70 km. Some factors need to be considered before a Base Station can be installed in a particular location and these are following:

- Location where the instruments receiving antenna can clearly view the sky above and no obstruction hindering them from gathering satellite data. 360o view of the horizon and 5o elevation mask is recommended.
- Locations where one can get good geometrical network by positioning it to an evenly spaced network forming an interconnected triangular polygon in each and every location.
- Locations far away from the nearby transmitters, it is recommended to position it 300 meters or more away from these structures.
- Avoid locations where there are unstable environmental conditions such as: thermal expansion that can cause shifting of position, excessive wind forces that can bend materials that are supporting the receiving antenna and condition where there is an unstable ground that can generate structure settlement and shift the original position because of excessive tilt.
- Locations where security procedure is tight enough to guard this kind of installation.
- Accessibility of the installation must be in good condition as much as possible in order to get into this installation directly whenever there are troubleshooting issues that needs to be addressed immediately.

A. Benefits of CORS in SCCA during Construction Stage

The construction stage of SCCA project includes the building of roads, highways, tunnels, quay walls, terminals, factories and water and electricity infrastructure and many other constructions. There are numerous existing and potential applications of GNSS technology in this area. The majority of major construction projects now utilize precision guidance in site surveying and earthmoving. With regard to earthmoving, adoption rates of machine control systems are steadily increasing and information obtained from suppliers of precision GNSS equipment indicates very high degree of accuracy at the growth in sales of machine control systems in construction that are among the highest of any precision product line.

VRS technology allows surveyors to determine critical coordinates instantly without the need for calculations with centimeter-level of accuracy. The high accuracy obtained from the use of VRS means fewer mistakes are made and checking processes can be performed quickly and easily. Importantly, the accuracy and reliability obtained by GNSS means that less site rework is required thus benefiting both surveyors and construction parties relying on the survey information.

The application of machine guidance technology to earthmoving machinery has been one of the biggest growth areas for precision GNSS equipment. Precision GNSS technology allows for site plans to be programmed into earthmoving equipment, such as bulldozers, excavators and graders. The earthmoving equipment can then be controlled to conform to the site plan via the use of continuously
updated GNSS positioning information. Conventional earthmoving involves a significant amount of rework, or machine passes, to provide an accurate finish. In addition, conventional methods require surveyors to be continually on site to stake out routes. Precision GNSS technology, however, significantly reduces the amount of rework and in some cases completely negates the need for surveyors to stake out routes.

CORS network and its application VRS, as applied to construction earthmoving, results in significant benefits. These benefits are outlined in Table 2 and Table 3 [12].

Table 2. Benefits of CORS/VRS in Land Surveying [12].

Time savings	• Negates the need to set up control points when starting a new project – 0.5-1 day saved per project • Reduces time spent doing manual calculations • Reduces time spent in the office – from 40% to around 10% per project • Time savings of up to 75% for large projects and 60% for small projects are possible
Labour savings	• Reduces the number of surveyors required for a project from 50 to about 10 for large projects • Allows for the use of non-survey staff to do simple mapping tasks that would otherwise require a qualified surveyor
Infrastructure savings	• Reduces the need for traffic disruptions, such as lane closures, and associated risk to survey and road workers
Safety improvements	Reduces the need for maintenance of ground marks

Table 3. Benefits of CORS/VRS in earthmoving in construction [12]

EARTHMOVING IN CONSTRUCTION	
Time savings	• Reduces project time significantly – savings of between 30% and 80% are possible • Negates the need for surveyors to physically stake out routes • Negates the need to navigate machines around stakes and pegs • Reduces the frequency with which dirt is moved around a site by up to 60% • Reduces the time spent conducting as-built surveys
Capital savings	• Productivity of bulldozers, excavators and graders is significantly increased • Reduces the amount of re-work up to 70% • Reduced need for support machines • Reduced downtime
Labour savings	Fewer workers are required for a project
Safety improvements	• Reduces the number of workers on a site and in close proximity to machines, particularly workers with grade stakes and string lines
Quality improvements	• Work is generally more accurate – e.g. grader trimming

B. 2 Benefits of CORS in SCCA during Operation Stage

CORS applications and benefits during operation of SCCA projects are varied. There are many applications in ports operations as mentioned before. The proposed CORS network could improve navigation through the Suez Canal and permit vessels to transit in all weather condition, which keeps the Canal open all times for ship transits. Using VRS technique through Suez Canal will provide real-time 3D monitoring of the vessel position and UKC improving navigational safety. The proposed network will keep controlled piloting and berthing, so minimal damage to infrastructure and ships occurs.

CORS may have relevant benefits and applications in operation of SCCA projects such as container terminals management, intelligent transport systems, assets management,etc. [13].

V. CONCLUSION

This paper shows the current development in GNSS positioning techniques and its impact on both construction and operations of ports. The benefits of

RTK GPS in hydrographic surveying, dredging and UKC monitoring are discussed and examined. The results agree with the previous studies and showed that using RTK GPS networks and its application VRS could be more economic and accurate than other positioning system such as DGPS.

In this paper a design of GPS Continuously Operating Reference Station network has been proposed. The benefits for this network have been discussed for different construction and operations phases of the project. The efficient operations could be achieved in Suez Canal and all ports in the area by using the different applications of the proposed CORS network such as VRS.

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Importance of Communication and Information Technology and Its Applications in the Development and Integration of Performance in Seaports

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***Abstract* -** The maritime industry is a global transporter of the goods of modern globalized economies. Shipping plays a vital role in today's economy, with over 90% of the world's trade carried by sea. The efficient transportation of cargoes impact on both consumers and the global economy.
In order to improve the safety and efficiency of maritime transport and the protection of the sea and marine environment, it is inevitable to use modern information and communication technologies when collecting, storing, processing, presenting and distributing relevant data and information to the participants in maritime transport. The Smart Port used information technology (IT) extensively to create a high-tech port.

The key factors contributing to the success of the IT and communication infrastructure in the Smart port are the ability to meet the changing demands of users and to keep up with the rapid developments in IT and the ability to accommodate new technology developments without having to constantly restructure.

This paper presented the key issues related to navigation systems, communication networks and information technology and its applications to secure the ships and the development of business performance for the transfer and circulation of goods within the seaports with high efficiency and the impact of this on the national economy.

***Keywords* -** Communication networks and information technology; Navigation Systems; Smart Ports.

I. INTRODUCTION

Navigating the seas safely is not just important for the lives of the people on board; shipping plays a vital role in today's economy, with over 90% of the world's trade carried by sea[1].

The maritime industry is regulated by the International Maritime Organization (IMO) which is responsible for the safety, security and efficiency of shipping and the prevention of maritime pollution. Technology and innovation, such as the Internet of Things (IoT), are said to be a driving force behind smart port productivity. This type of technology, in the form of physical and IT infrastructure could be the best way to see benefits in a smart port environment. The ultimate smart port may be the fully automated port where all devices are connected via IoT. In port operations, the integration of various infrastructures, both physical and IT, includes different network technologies like radio, LAN, WAN and WLAN, RFID and positioning technologies. The effectiveness of the smart port environment may lie in the technology and smart practices' ability to be able to work together to effectively share information, both for the benefit of ports and for its customers.

A key element to all this is some sort of internal cloud gathering information about all events related to the port. When analyzed and presented in a smart way, that data can help to achieve the goal of doing things smarter.

The efficient transportation of cargoes impact on both consumers and the global economy. The correct planning and execution of operations on a container-carrier vessel is a decisive element in the strategy of a seaport. The operational process of a container terminal can be considered as a large productive process where the final element is not a physical product but rather a specified service. The handling and storage of the containerized goods of a particular customer need to be delivered as rapidly as possible to enable the vessel to spend the minimum time necessary in port and, consequently, to obtain maximum economic utilization and to be both Energy and Environmentally efficient.

Communication networks and Computers technologies and all their associated equipment present the technical foundation of smart ports. Computer technology is experiencing a rapid development geared towards increasing processing speed, increasing capacity of the memory, mobility and the use of all media designed for receiving and storing data, greater compatibility and continuous price cuts, etc.

In order to improve the safety and efficiency of maritime transport and the protection of the sea and marine environment, it is inevitable to use modern information and communication technologies when collecting, storing, processing, presenting and distributing relevant data and information to the participants in maritime transport.

In order to meet rising customer expectations and stay ahead of the competition, the overall port operation services can be enhanced by moving to a paperless environment and providing a valuable and relevant solution that completely restructures the manual process of documents exchange among port community members. Automation aimed at and achieved the optimization of the Port Management processes by decreasing the vessel and cargo turn-around time to making available the necessary real time data for yard operations and performing all statistical and data analysis for decision makers.

This paper is organized as follows: Section 2 outlines wireless and satellite communications networks for maritime sector; Section 3 presents navigation and tracking systems and their applications; Section 4 outlines sensing technologies and services provided for the maritime sector; Section 5 presents a glance at some of the technological applications and services offered in Smart ports; Section 6 presents information technologies and integration between different Maritime services; and Section 7 concludes the paper.

II. WIRELESS AND SATELLITE COMMUNICATIONS NETWORK

The communication infrastructure currently available in the maritime sector has enabled shipping companies to integrate their ships within their own overall IT networks. However, integration technology for the shipping industry must take into account the communication systems in use today and the ones which will be available in the foreseeable future.

Communication systems available to and used by the maritime and transport industries cover the terrestrial networks (HF/VHF/UHF radio, land lines, fiber optics) and satellite communication systems; the availability of these has enabled the use of the internet, web-based processes and the possibility of real time information flow. The choice and availability of the different types of communications depend on the geographic location.

Wireless and satellite communications are keys to the success of the maritime industry because they provide the medium by which maritime safety information, ship position reporting and weather forecasts, as well as other information, can be passed to ships at sea. For a vessel in trouble, the accuracy and update rate of the reporting of the ship's position aids rescue, potentially avoiding the loss of the ship, saving the lives of the crew or preventing an environmental disaster.

Seaports are relying more and more on wireless technologies to enhance the flexibility of operations and improve efficiency. Wireless network equipment is used for better handling of equipment, to improve cargo integrity, real time surveillance, effective administration through building connectivity etc. Radio data communications are widely used within the port environment today. Common use includes communication from a central computer to mobile computers, such as those that are hand held or fixed and used by personnel on site or drivers of trucks, cranes and straddle carriers.

The significant benefit from using radio data communication is that it allows transfers within the container terminal to happen in real time, with the immediate updating of container movements. The central computer can assign a carrier to do a particular job based on what equipment is most suitable. The radio data communication link can also be used to transmit sensor data from the container moving equipment to the central computer, for example giving details about its location obtained using positioning techniques and satellite communications.

In a world where most workers still record container numbers on clipboards, wireless solutions can drive significant cost savings and faster operations. Smart Port is set to strengthen significantly through a range of innovative communication technologies, which will increase interconnectivity and enhance the port's overall competitiveness.

Smart Port can harness the use of mobile technology and wireless connectivity to enhance communications, productivity and crew welfare at the maritime center. These include providing 3G/4G broadband mobile telecommunications technology access for vessels operating within waters of the port and the immediate maritime community. The low-cost, secure wireless 3G/4G broadband service and WiMAX network will be available to users within 15 km of the coastline to further enhance network coverage across the port to benefit the maritime community[2]. Wi-Fi services at the port and launching new mobile application for the maritime community and members of the public to conveniently access maritime information and services on their mobile phones will further enhance passenger experience and business operations at ports.

III. NAVIGATION AND TRACKING SYSTEMS AND THEIR APPLICATIONS

The global navigation satellite system (GNSS) is a navigational system of satellites that provides autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) within a few meters using time signals transmitted from navigational satellites. GNSS technology is the backbone of traffic management and modernization at seaport container terminals. One of the most important properties of GNSS-enabled systems is the ability of tracking container arrivals and their docking at the port [3].

GNSS improves navigation, transport economics and consumption at sea; on the other hand. it can avoid casualties like collisions helping to limit risk to safety and the environment and has an effect on transport quality, loading factor and service. The ability to accurately determine and communicate one's position at any moment, thanks to GNSS, is starting to have a major impact on the management of ship and lorry fleets, road and rail traffic monitoring, the mobilization of emergency services, the tracking of goods carried by multimodal transport and air traffic control.

A Smartphone application can use GNSS to capture information about location, speed, acceleration and driving times. Based on the specific freight, vehicle weight and predefined reference profiles, this data can then be used to calculate the exact fuel consumption, which can then be integrated with the specific route parameters. The logistics company and the driver will immediately receive these metrics via the specific server. This will help reduce emissions and save fuel, which in turn will help to reduce the overall costs for the providers of logistics services. An additional benefit will be that an efficient driving style also reduces the amount of maintenance required on vehicles and can thereby help to increase their periods of active usage.

There are obvious examples used as application for tracking and monitoring vessels during sailing in the sea such as long range identification and tracking system (LRIT) and automatic identification system (AIS).

A. Automatic Identification System (AIS)

The Automatic Identification System (AIS) is a ship-borne transponder system designed in the first instance for maritime safety and, in particular, for collision avoidance. It consists of a transponder unit including GPS, VHF transmitter/receiver and display/terminal. The unit broadcasts a message at regular intervals containing its identification, position, speed, course plus a number of detailed items about the ship and its cargo. The broadcast carries VHF range which is basically line of sight[4]. It is used for identifying and locating vessels by electronically exchanging data with other nearby ships and VTS stations. AIS displays incoming vessel information on a suitable device, collects vessel movement information and assembles it into an AIS compliant data sentence, and initiates and controls the flow of data sentences between participating units. Figure.1 depicts AIS tracking system for vessels.

The AIS sender and receiver are generally present on the big ship and the information is often available through dedicated internet sources. An AIS system has limited coverage based on radars specifications but this problem will be overcome with the implementation of satellite AIS.

AIS information supplements marine radar, which continues to be a vital method of collision avoidance for waterborne transport, hence it avoids marine casualties and environmental pollution.

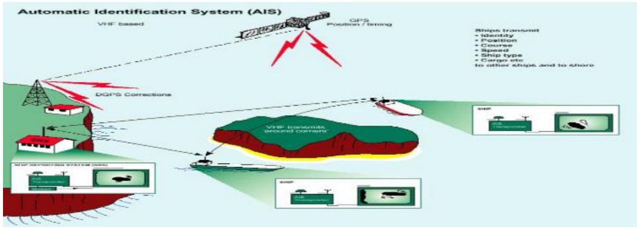

Fig .1. AIS tracking system for vessels.

B. The Long Range Identification and Tracking (LRIT) System

LRIT system is a designated International Maritime Organization (IMO) system designed to collect and disseminate vessel position information received from IMO member states ships that are subject to the International Convention for the Safety of Life at Sea (SOLAS). LRIT consists of the ship borne LRIT information transmitting equipment, the Communication Service Provider(s), the Application Service Provider(s), the LRIT Data Centre(s), including any related Vessel Monitoring System(s), the LRIT Data Distribution Plan and the International LRIT Data Exchange. Certain aspects of the performance of the LRIT system are reviewed or audited by an LRIT coordinator acting on behalf of all contracting governments. LRIT regulation requires operators of ships regulated by SOLAS contracting governments and engaged on international voyages, including passenger ships, cargo ships of 300 gross tons and above, and Mobile Offshore Drilling Units, to provide compliant ship borne equipment for the transmission of LRIT information. Inmarsat-C equipment already installed on the majority of vessels is frequently used for LRIT compliance[5]. Figure.2 depicts LRIT tracking system for vessels.

LRIT is available to all vessels having the appropriate equipment and comply with the IMO regulation for the system. LRIT information can be used for security, safety and environmental protection.

The main distinctions between AIS and LRIT are first that AIS is line of sight while LRIT is global, and second that AIS is broadcast whereas LRIT is only sent to specific recipients for confidential treatment. Furthermore, the AIS message contains much more information than LRIT systems.

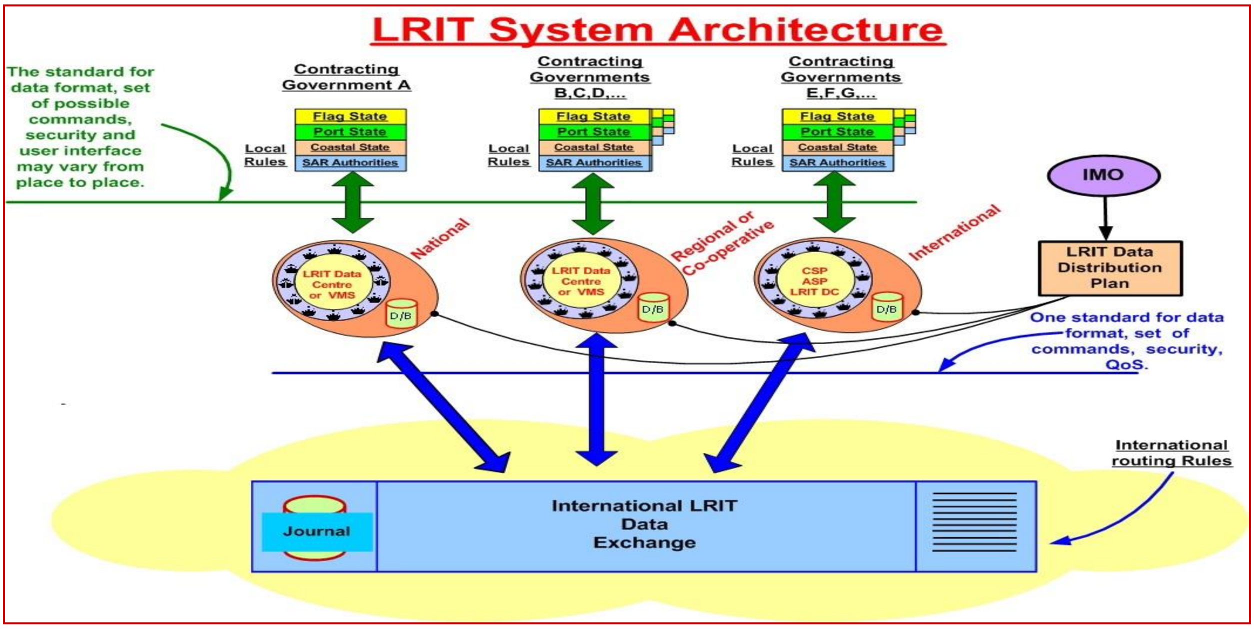

Fig .2. Long range identification and tracking (LRIT) system for vessels.

IV. SENSING TECHNOLOGIES AND SERVICES PROVIDED FOR THE MARITIME SECTOR

Technological advances in telecommunications and information technology, coupled with ultramodern/state-of-the-art microchip, RFID (Radio Frequency Identification) and inexpensive intelligent beacon sensing technologies, have enhanced the technical capabilities that will facilitate motorist safety benefits for intelligent transportation systems globally. Sensing systems for ITS are vehicle- and infrastructure-based networked systems, i.e., intelligent vehicle technologies. Infrastructure sensors are indestructible devices that are installed or embedded in the road or surrounding the road (e.g., on buildings, posts, and signs), as required, or by sensor injection machinery for rapid deployment. Vehicle-sensing systems include deployment of electronic beacons for identification communications and may also employ video automatic number plate recognition or vehicle magnetic signature detection technologies at desired intervals to increase sustained monitoring of vehicles operating in critical zones. Some examples for sensing technologies are RFID, OCR and CCTV.

A. Radio Frequency Identification and Tracking (RFID) Technology

RFID are deployed to support the identification and tracking of assets typically associated with operations within a facility, to automatize processes, to improve operational productivity and equipment utilization as well as for safety of people and assets and security of containers.

RFID is a technology that uses radio waves to transfer data from an electronic tag, called RFID tag or label, attached to an object, through a reader for the purpose of identifying and tracking the object. RFID can be applied to all transport modes and to all transport and supply chains. With RFID transport, chains can significantly improve loading factors as well as increase cost efficiency.

RFID technology can be used efficiently in container ports to improve container security and regulatory compliance, improved quality, container identification, location and tracking, and access control. Human errors can be reduced by up to 70% and in-port transaction completion time can be reduced by up to 50% [6]. RFID real-time data allows for dynamic optimization yielding better planning, higher efficiency and overall performance as a whole. An important advantage is that it enables dynamic optimization in container ports, a much needed tool for solving increasingly complex problems. The high level of flexibility and dynamic optimization allow the achievement of real time solutions that could have neither been obtained nor reached otherwise. The following figure.3 is an example of used RFID with GPS and mobile network technologies in order to track containers in Chennai Port of India.

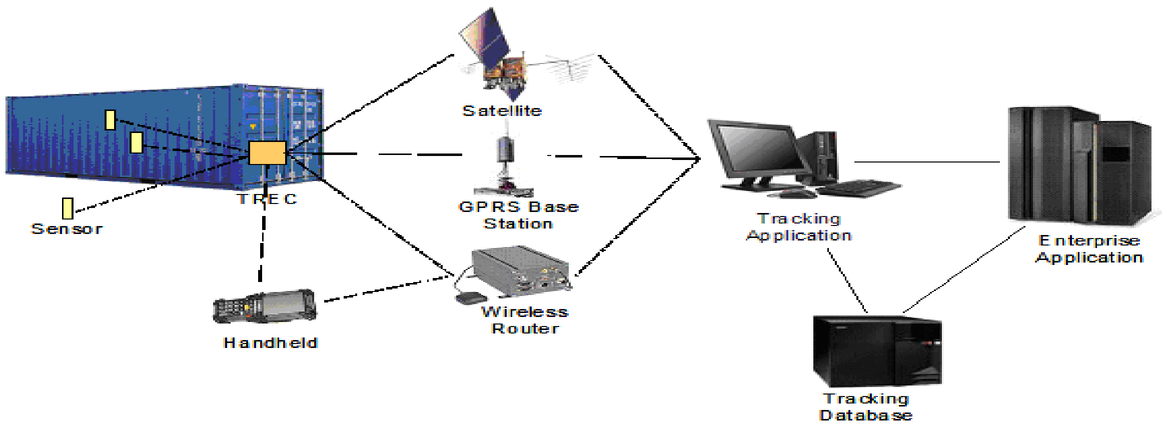

Fig .3. RFID in container[3].

The container freight station operator based in Chennai India, A.S. Shipping Agencies, is mixing both RFID with GPS/ GPRS technologies in order to track containers throughout its yard, situated 16 kilometers away from the Port of Chennai. RFID interrogators, antennas, and GPS receivers are fixed on cranes. Once a container arrives at the storage yard, it is weighed and by means of a small touch-screen device, the crane operator enters its information into the system. Then, a passive RFID tag is linked with the container number and mounted on the top of the container. The tag data is updated with the GPS latitude and longitude information, and then conveyed via GPRS to a central server database. The container's location is then visualized on a Web application. The container's location is thus updated automatically as the container moves through the yard area [7]. The main advantages of this system are the clear reduction in the container's location time in the yard, better yard capacity planning and accurate customer billing knowing the exact storage time. Moreover, container information can be accessed, through a Web application, by clients anywhere in the world. All these factors increase the service level provided by the company. However, this system still needs to be integrated with the company's billing system [7].

A joint venture of IBM and Maersk Logistics resulted in a development of a system for tracking shipping containers around the world. This system goes beyond RFID technology and uses it just as a part of a collection of wireless technologies to transmit location and sensor data [8]. This system, called later the

Secure Trade Lane (STL) solution, is using tracking devices called TRECs (Tamper-Resistant Embedded Controllers), which are small intelligent wireless monitoring boxes mounted on containers [9] and making them smarter.

TRECs perform an automatic container events data collection including physical location based on GPS and state of the container (temperature, humidity, acceleration, door status.., etc). TRECs' communication can be achieved through communicating over a satellite, a cellular system (GPRS/3G), or a Wireless Personal Area Network (WPAN) based on ZigBee3 /IEEE 802.15.4 radio. A handheld device can also communicate with the TRECs over a WPAN for the automatic creation of the container manifest, invoices, bills of lading, etc. The Shipment Information System (SIS) ensures that the information provided by the TREC is available to the supply chain authorized actors with the appropriate information sharing among them [9]. This STL platform enables real-time access, tracking and monitoring of containers each participant with its authorized view, thus granting a full visibility of the supply chain from the manufacturer to the store.

B. Optical Character Recognitions (OCR)

In addition to the RFID, optical character recognitions (OCR) is one of many technologies now available for asset identification and process automation in ports and terminals. The key advantage is that it enables not only the automated 'hands free' identification and locating of assets, but also the recording of an object's visual condition at that time. It also provides a deviceless method of identification, without requiring the application of any tag or device to the asset. OCR scans the ID numbers while the truck is in motion, based on a set of sensors. It automatically operates the illumination, takes pictures from a number of cameras, extracts the ID numbers, classifies the type of containers, verifies the results, then outputs the results to the Port Automation and Control System or a local terminal operating system.

C. Closed Circuit TV(CCTV)

The Port Management Entity can supplement both perimeter and access control systems with new arrays of high resolution, low-light and/or infrared closed circuit television (CCTV) cameras to determine the nature of any alarm or intrusion and to guide response by law enforcement personnel. The CCTV deployment can be extended to other perimetral sensitive locations in and around the ports and can be fully integrated with port operations and control centers Advance Perimeter Security Improvements. The Port Entities can deploy a combination of advanced security technologies to support surveillance of port perimeters and to improve detection of unauthorized intrusions. This package of technologies can include the innovative use of ground-based radar and state-of the-art motion sensors that can activate alarms at Port Security Centers, indicating the specific location of a potential intrusion of persons or vehicles.

V. A GLANCE AT SOME OF THE TECHNOLOGICAL APPLICATIONS AND SERVICES OFFERED IN SMART PORTS

Port e-services can be categorized as based on the functionality offered, their integration/maturity level, and their business and organizational sophistication. Regarding their integration and maturity level, port e-services can be divided to informational and transactional. Informational are the services that only provide information regarding the port and the provided services. Transactional are the services that enable the users to perform transactions, payments, bookings and to interact with the port authority or other port service providers.

The services can be further "functionally" distinguished to navigation, ship, cargo, logistics, business intelligence, security and environmental safety related. Navigational services are the services that assist the navigation of the ships to and from the port. Ship services help the communication of the ship with the port authority and port service providers regarding ship and crew related documentation, supplies and parts. Cargo related services concern cargo documentation and cargo handling/tracking. Logistics e-services assist the connection with the logistics chain. E-services regarding business intelligence assist the shipping companies' and industry actors' decision making by providing information and management supporting tools. Security and environmental safety related e-services provide information regarding security and environmental safety matters in port area.

- Vessel Traffic Management and Information System (VTMIS): Addressing traffic congestion was one of the initial motivations to look at intelligent transport systems solutions for a better utilization of transport capacity through the exchange of real-time information on infrastructure and traffic conditions. Since then, new transport applications based on ICT have emerged and continue to emerge, ranging from basic traffic management systems (e.g. navigation, traffic control) to management of containers; from monitoring applications such as closed-circuit television (CCTV) security systems to more advanced applications integrating live data and feedback from a variety of information sources.

A common structure of the VTMIS system consists of the VTMIS functions and VTMIS subsystems. VTMIS functions are grouped into operational and complementary roles, while VTMIS subsystems include communication networks, sensors (the automatic identification subsystem and a marine radar subsystem), operator consoles, servers, databases, system software, application software and web services. The integration between various port entities is very important.

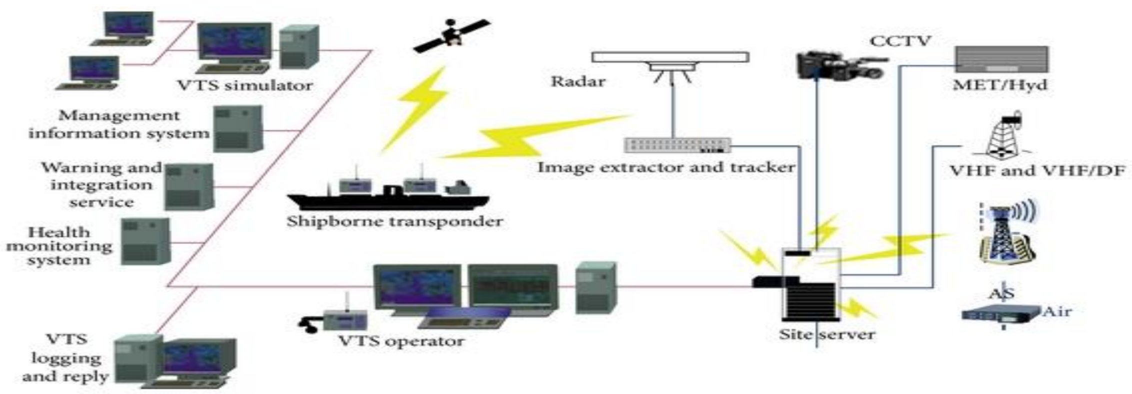

Fig .4. System architecture of VTS service.

This includes conducting all necessary studies to reorganization procedures among different parties in order to regulate the operational cycle for integration purposes.

In general, the elements composing VTS are shown in Figure.4. VTS is the system in which the followings are connected to one another: the VTS center on the land, the base station site on which various sensors (sensing devices such as CCTV, Radar, DF, MET, etc.) and AIS are installed, the control center that actually operates VTS, and it is a complicated system consisting of various types of telecommunications networks that connect ships, satellites, and sensing devices [10].

Technologies provide a broad range of sophisticated systems for wide area security, automated surveillance and instrument controls for the private sector and for governments. Artificial intelligence-driven digital security systems integrated with actionable video-based surveillance intelligence are technical solutions with potential to be tailored for the maritime industry includes:

- Security Corridor Systems: This system could easily be adapted to isolated fence line perimeters as well as rail lines entering and exiting port facilities both overland and also across water. The Virtual Fence is based on digital video recorders driven by the innovative intelligent sensor detection suite which integrates fixed and high resolution, color, day/night cameras, RFID active scanners and other sensor types, positioned at strategic locations along the line of the asset. The system establishes virtual fence lines within the field of view of each of the cameras. Live streaming video is interpreted to deliver low false alarm, real-time vigilance for common behaviors that can indicate a security breach. Data is encrypted and transmitted using TCP/IP based communication either via a chain of Wi-Fi radio transmitters, satellite, and fiber optic or hard-wire connectivity to local and remotely located command and control centers. The Virtual Fence is fully integrated with all other system components to provide centralized command unity [11].

- Virtual Gates: Virtual gates are installed in conjunction with the Virtual Fence application.
These are installed at a pre-determined distance from the actual port/marine facility entry point, thus creating a buffer zone. The Virtual Gate serves as a remote controlled advance checkpoint for inbound traffic. Gates include vehicle presence

sensors, cameras, chemical detection sensors, radiation detection sensors, and I/O controllers. Vehicles and personnel approaching the Virtual Gates are detected and the real time video together with potential rule breaches are presented and routed simultaneously to the command and control center and other locations where operators can view live, streaming video images and alarm events in real time.

- Smart Yard Digital Management System: Port facilities are typically large, asymmetrical activities dispersed over hundreds of acres of land and water so that they can simultaneously accommodate ship, truck and rail traffic, petroleum product/liquid offload, storage or piping, and container storage. Like a rail yard, they are crowded, and with huge stacks of containers, warehouses and cranes, and often have limited visibility.

  Installation of a Smart Yard Digital Management Solution in the port area provides robust, fully scalable live video with real-time, intelligent video capability. This enables the central port authority to coordinate the activities of its personnel and assets day-to-day by monitoring critical road or rail transit areas, checkpoints, or container offload/stack locations. Unprotected crossings can be monitored and critical navigational assets can be monitored for operation or critical change.

  SMART Yard employs a network of fixed and digital video cameras connected to digital video servers. Each digital video recorder includes the rule-based intelligent vision suite to automatically deploy audio and visual alarms, process live video feed and create a video digital archive. The cameras also function as intrusion detectors providing live streaming video of vulnerable security areas and potential threats to vulnerable areas within the facility viewed on a customized Graphical User Interface (GUI). The GUI shows intrusion points and critical port locations so that port authority controllers can simultaneously view and control cameras positioned throughout the facility to analyze incoming video and sensor feeds, and thus maintain a real time situational awareness of container operations, truck transport on-load/off-load activity, crane operation, warehouse security, and shipping movement in and out of the port facility and adjacent areas[10]. In addition to remote real-time viewing of events, images are also automatically digitally recorded, time stamped, and stored for later retrieval. A powerful video search engine allows for easy retrieval of stored video files.

- Intermodal Container Exit System (ICES): Port security and operations are particularly vulnerable to theft, smuggling and vandalism. Terrorism is also an increasingly significant concern, particularly with respect to the movement and identification of containers and contents. Technologies have developed a system that can identify and track containers and link them to transport companies, drivers and specific vehicles. The system gives law enforcement a significant tool to track containers of concern, and at the same time allows port authorities to keep their operations running smoothly.

- ICES is a completely automated application for tracking and recording intermodal containers exiting, or entering, a container yard. The core technology of the system is the Video Optical Character Reader (VOCR) which takes video imagery from moving containers, extracts relevant data (user defined) and populates a database with the extracted data. ICES will capture and store the following information in a simple user interface: Container numbers; Trailer numbers; Front and rear license plates; Driver's license data; Video of vehicle and container; Video and audio of driver and guard interaction at the port; Biometric capture of fingerprints.

- Friend or Foe Detection System (FFDS): This system component is achieved and can be incorporated into a Port Authority's overall security plan by adding an RFID technology layer. It can be an especially important element of protection of critical infrastructure and hazardous material or loading points within the port. All personnel and visitors authorized to access the facility would receive an active RFID tag, which is constantly scanned by an array of scanners installed throughout the facility. Tag geo-spatial information (achieved through scanner triangulation) is displayed on the GUI, thus revealing the location of each person at any time. If the Virtual Fence is breached, FFDS automatically validates approaching "authorized" personnel to prevent false alarms [11].

VI. INFORMATION TECHNOLOGIES AND INTEGRATION BETWEEN DIFFERENT MARITIME SERVICES

Information systems are used to enhance the efficiency of terminal operations and improve turnover. The important competitive advantage of a port is to move cargo quickly and safely through the port. Ports face increasingly complex range of operational challenges in management of highly complex, multi-tenant port environments. From the operational point of view, a consolidated, reliable, flexible and secure flow of information is vital in order to provide quick, reliable and cheap services at seaports.

Container and other marine terminals require increasingly versatile terminal operating and other IT systems to plan, schedule and manage operations for efficient cargo handling. Terminal Operating System (TOS) is key part of the supply chain and primarily aims at controlling the movement and storage of various types of cargo in and around a container terminal or port.

Ports are natural bottlenecks in the transport chain. Port Community Systems have played a major role in facilitating the most efficient movement of goods, while allowing Customs and other government departments to maintain effective controls. Such systems reduce the overall amount of administrative work by providing some means of capturing information at once and allowing controlled access by all appropriate members of the port community. Wasted effort is avoided because duplication of entry and storage of data is reduced to a minimum. The time required to release cargoes is reduced because the necessary information is instantly available to those who may need it.

It is important to integrate the electronic business workflow in the port community via port single window including Port Authority, customs, shipping agents, transportation companies, etc.; the system simplifies and accelerates data exchange between different entities by providing the needed tools and procedures including message exchange system and portal that enable a single authorized entity to collect all business documents from customers and coordinate document processing with other entities until reaching Custom Declaration/Cargo Release or Cargo Shipping/Vessel Departure.

Integration between various port entities is very important. This includes conducting all necessary studies to re-engineer procedures among different parties in order to regulate the operational cycle for integration purposes. In order to meet rising customer expectations and stay ahead of the competition, the overall port operation services can be enriched by moving to a paperless environment and providing a valuable and relevant solution that completely restructures the manual process of documents exchange between port community members.

Automation aimed at and achieved the optimization of the Port Management processes from decreasing the vessel and cargo turn-around time to making available the necessary real time data for yard operations and performing all statistical and data analysis for decision makers.

The agent of the shipping company access the web-based system to prepare and sent the necessary documentation to customs office and port authorities. The customs office receives through the web-based system the documentation and processes it to provide customs clearance. Through the system the customs office sends the clearance to the agent and the port authority. The port authority enters the cargo data into the port management system which automatically assigns personnel and equipment to discharge the cargo according to port's current condition and shipping company's needs. The system auto arranges storage and sends data through the wireless system to stevedores and warehouse. The port authority also forwards information to the agent.

Through the web interface, the agent tracks the procedures and the cargo current position with the use of the port's container tracking system. Through the web interface it contacts the logistics provider and sends the information regarding the ships location as well as the necessary documentation. Through the web interface the agent has access to a database of suppliers.

During the procedures we can see the interaction between the various actors with the use of the two distinguished information systems. The web interface enables the shipping company agent to interact with the Port Authority, the Customs Office and the logistics provider, while the integrated management system supports the port authority's decision making and communication with the stevedores and the warehouse.

VII. CONCLUSION

The growth of e-business is having major effects on the maritime transportation industry including increasing pressures for advanced integrated, intermodal transportation and logistics systems and technology applications. The growth of maritime transportations and port services requires highly flexible, information-intensive and efficiently integrated transport systems. Key elements for developing such systems are the development of integrated applications of Intelligent Transportation Systems and the creation of electronic business applications for intermodal transport, with port being a major node of the transport value chain.

At the same time, ICT technologies in ports and terminals are becoming a key to absorb the growth linked to world trade expansion to achieve the integration of ports in logistics and intermodal transport systems. With the advent of ICT enabled network business models, port product and processes are considered as "augmented" products and processes, as their traditional, physical nature is overplayed with an informational and electronic transactions component. Thus, inter-organizational network models provide a great opportunity towards the 'smart networking' of the plurality of port actors, including public port authorities, terminal service providers, shipping companies, customs, logistics and transportation companies and other third parties.

Overall, 'networking' as based on the advancement of a rational coordination, for operating and strategically developing a port can renovate port authorities in a new blended virtual agency role, that is a combined physical and electronic mode of operation. Against this background, a classified port services for systematic identification, assessment and selection of individual port e-services is presented, as based on port e-service categorization by the level of integration, sophistication and functionality.
Deployment of consolidated technological solutions based on the IT is considered as a crucial factor in sound and efficient operation of the ports that considerably contribute to the ports' competitiveness and efficiency. The ongoing revolution in ICT, smart devices and IoT can interconnect port with high-speed internet, extensive use of data analytics and innovative mobile solutions to enhance services in the Smart Port and this will benefit all users at the Smart Port.

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ENVIRONMENTAL COMPENSATION FOR PORT EXTENSION: THE CASE OF ROTTERDAM HARBOUR AND NATURE COMPENSATION, POLICY AND PRACTICE

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***Abstract* -** The paper focuses on two aspects often forgotten when dealing with smart ports: ecology and compensation of damage. The port of Rotterdam (The Netherlands) recently built a large extension, Maasvlakte 2. It was built in an area with valuable coastal ecosystems belonging to the EU Natura 2000 network of European conservation areas. The construction and use of Maasvlakte 2 causes considerable damage to existing Natura 2000 sites. According to EU regulations, this damage should be compensated by creating new nature. In the case of Rotterdam, the compensation was twofold: a marine and a terrestrial part. The paper describes the design and the actual lay-out of the compensation works. It also reports on the monitoring that is ongoing to assess the damage to existing nature and the quality of the new (compensated) nature.

***Keywords* -** port extension, environmental damage and compensation, EU Natura 2000, building with nature.

I. INTRODUCTION

The Dutch government decided in 2003 to develop a policy which enabled a new harbour extension (called Maasvlakte 2), in order to receive and handle the world's largest containerships, starting from 2015. Maasvlakte 2 (net 1000 ha, which is 20% of the already existing harbour area) was build between 2008 and 2014 by reclaiming part of the North Sea with foreshore nourishment (365 Mm3). It is expected that the new harbour will be in full operation by 2030.

Maasvlakte 2 extends in the middle of an environment with valuable coastal and marine ecosystems. They are under protection of the EU-Natura 2000 network. In such a case, EU-regulations state that construction is only allowed when there are imperative reasons of overriding public interest to carry out the plan, when there is no alternative, and when the submitter of the plan commits himself to compensate for the damage it causes. It concerns the environmental damage to Natura 2000 sites that will be caused by the new harbour and its activities.

It is important to understand that the compensation activities should start at the same time and parallel with the activities for the new harbour, and not, if at all, afterwards.
To convince possible opponents it was decided by the EU-permits to start with the compensation measures before or at least at the moment of beginning the extension.
Compensation is realized at other locations nearby the port extension (Figure 1). It involves marine ecosystems (fish, sea bottom fauna and bird communities) as well as land ecosystems (beach and dune ecosystems).

Marine compensation is necessary because the new harbour was reclaimed from the sea, causing loss of habitats and foraging areas. Beach and dune compensation was necessary because the EIA predicted that important existing dune ecosystems nearby will be damaged by the use of the new harbour (extra air pollution by more harbour traffic). In order to assess whether the predicted environmental damage indeed will occur and whether, in the future, the quality of the new nature indeed will compensate for this damage, an extensive monitoring program is running.

The case of Rotterdam is of importance to mirror with harbour development worldwide to achieve innovative smart solutions in a more sustainable way. Key concepts are compensation of irreversible damage to nature and building with nature.

Fig .1. The Netherlands (inset) and part of the south western Delta coast of the North Sea. In the middle the new harbour extension (Maasvlakte 2) in outline. The dunes of Voorne's Duin, Kapittelduinen and Solleveld are nearby Natura 2000 areas that will suffer expected environmental damage. Spanjaards Duin, in the north, is the new dune and beach compensation area. In the south in the Voordelta (a shallow sea in front of the coast, also a Natura 2000 area) is the area where marine compensation measures are taking place (yellow boundary). Image: Google Earth..

II. METHODOLOGY

Monitoring of the compensation was done using the latest techniques. In the case of dune compensation: terrain morphology (GPS transects and laser altimetry), groundwater (piezometers and chemical analyses), vegetation (vegetation samples and individual species records) and in the case of marine compensation: sea bottom fauna, hyperbenthos and fish, countings of indicator sea birds, countings of trawl activities, and countings of water recreation activities.

For both compensation activities a special monitoring scheme was developed. This contains main evaluation questions with factsheets per question. Each factsheet contains sub questions, the kind of information required to answer the sub question and the strategy needed to acquire this information [8]

- EU Natura 2000

Natura 2000 is a network of specially protected areas, both on land and sea, in the 28 member states of the EU, meeting the requirements of the EU-Habitat Directive. It is the largest coordinated network of protected areas in the world.

When Natura 2000 sites are predicted to be damaged by construction of a project, and the project is of outstanding national economic importance ("imperative reason of overriding public interest, without a proper alternative"), the damage needs to be compensated (article 6.3 and 6.4 of the EU-Habitat Directive)(ec.europe.eu/environment/nature2000).

III. DUNE COMPENSATION

(project being carried out with dr Bert van der Valk, Deltares, Delft, The Netherlands)

- Damage to existing dunes and compensation targets

The EIA[1] for the extension of Maasvlakte 2 predicted that the use of the new harbour would damage important dune ecosystems in the nearby existing dunes. These ecosystems belong to the EU Natura 2000 network and, under European Habitat Directive regulations, have to be compensated. They are: H 2190 (nutrient poor calcareous moist dune valleys, or dune slacks) and H 2130 (nutrient poor, more or less calcareous dry dunes, so-called "Grey dunes") [2]

In the European context, The Netherlands have a special requirement when it comes to maintaining the surface and improving the quality of these nutrient poor (N, P) dune environments. The predicted damage in existing dunes and the compensation targets in the new dunes are given in Table 1.

Table 1. Dune Compensation Targets in New Constructed Dunes of Spanjaards Duin in Relation to Predicted Losses in Existing Natura 2000 Dunes. See also Figure 2.

Dune compensation targets	**loss (ha)**	**compensate (ha)**
Moist dune valley (H 2190)	1,3	6,5 (x5)
Grey dune (H2130)	4,2	9,6 (x2)
Species: Fen orchid *Liparis loeselii*	1 population	1 population
Loss of nutrient poor habitats		Compensate nutrient poor habitats

The damage to these ecosystems occurs because the use of the new harbour will cause an increase in traffic and industrial activities. This will raise the level of NOx emissions. The extra airborne N-load will affect the nutrient household of the nutrient poor dune ecosystems. The higher nutrient level will cause some common plant species to encroach and take over the space of several rare plants that are characteristic of H2190 and H2130.

- Dune compensation and nourishment

In order to compensate for this loss, a new dune and beach area was constructed by beach and foreshore nourishment. The work was done in 2008 in combination with a larger regular nourishment works along the Dutch Delfland coast. The new area covers 35ha and involves 6,5 x 10million m3 of sand.

The nourishment was done by dredging the sand some 19km offshore and piping it onshore from a close-by connection point (Figure 1). Subsequent shovel work formed the basic shape according to its design (Fig 2): an elevated (5-7m above MSL) dry and undulating ridge, the new frontal dune, and a flat depression (ca. 2.5m above MSL) or dune valley, later to become moist due to rising fresh groundwater level. Because of sand mobility (see paragraph below), part of the nourished material had to have a specific grain size (180-250μ), which is slightly smaller than the average sea bottom sediment in front of the coast. However, earlier surveys showed that there was enough material present in the neighbourhood.

Fig .2. Top left: construction of the compensation area in front of the existing coastal fore dunes (at right) by beach and foreshore nourishment. The contours of the designed elongated moist dune valley, a flat depression, are already visible in the middle (photograph courtesy Nico Bootsma, Rijkswaterstaat). Top right: design of the new dune area in front of the Delfland coast. Grey=existing dune, yellow=new beach, orange=new dry dune, green=new moist dune valley. From Veeken et al.[3] Bottom: compensation targets grey dune (left) and moist dune valley (right). The Fen orchid occurs in the latter.

- Dune compensation and building with nature

Building with nature is a technique that is being used more and more when constructing, restoring or reshaping landscapes, also at the coast. Applying this technique means that the characteristics and spontaneous forces, materials and elements of the local environment are used as much as possible [4]. For example, to strengthen a sandy coast with sand nourishment and not with hard materials like concrete or basalt, can be considered building with nature. In the case of the compensation area, building with nature was applied [4, 5].

- Phases of new dune development

The ecosystems that have to be compensated take time to develop. Grey dunes take 15-20 years. A moist dune valley about five years (partly because of settlement of the appropriate groundwater dynamics and quality). The development of the area was foreseen in four phases (Table 2) and started from the design (Figure 2). Some phases run successively, like the development of the abiotic habitat conditions first, followed by the biotic elements.

First the basic foundation was laid out by sand nourishment. After this basic foundation, free movement of sand and spontaneous sand transport (erosion and accumulation by wind) were allowed to take place. This causes some remodelling of the basic shape and also the formation of appropriate Aeolian initial dune soils, the appropriate condition for colonisation and growth of vegetation. During this phase, the salt/brackish sand material has gradually been desalinated by precipitation; and consequently a fresh groundwater lens will develop in the subsoil, also fed by infiltration of freshwater from the (thin row of) mainland dunes (Fig 2, right). After some time (expected 4-6 years in this case), the phreatic level of this lens will rise up to the valley floor, creating habitat requirements for a moist dune valley, and, eventually, moist dune slack vegetation (H2190). Because of sand mobility, part of the nourished material had to have a specific grain size (180-250μ), which is slightly smaller than the average sea bottom sediment in front of the coast.

Table 2. Phases of Dune Development and Building with Nature

Phases of development	Natural elements and processes involved
Construct basic foundation	Sand that is characteristic of the region
Remodelling of sand by wind transport Development of appropriate groundwater dynamics and quality	Building of natural dunes and valleys by erosion and accumulation Desalinisation of sand by precipitation
Successive colonisation of plants and development of plant (and animal) communities	Allow spontaneous, natural colonisation, no active, deliberate planting of dune species
Management to steer if needed	Aim at compensation targets

- Monitoring

In order to assess whether the dune area develops in the right direction of the target habitats, a monitoring program was established. It concerns dune geomorphology, groundwater and vegetation. Also, there are monitoring activities in the existing dunes especially concerning their nutrient (N,P) status.

- Overall results

About seven years after construction, the area is still very dynamic (Figure 3). Vegetation is scarce. However, the abiotic conditions for the development of the compensation targets, the nutrient poor dune grasslands, are nearly in place. Signs of the development towards grey dunes can be seen. The area functions in a number of ways: for coastal defence, nature conservation and also recreation. In the densely populated environs of Rotterdam harbour in the Dutch Delta, this is regarded as a very positive situation. To ensure that nature development can take place, free access is not allowed. The new area is already under Natura 2000 protection.

Fig .3. The new area development of Spanjaards Duin (2013). Wind activity is clearly visible. Former (existing) coastal fore dunes are to the left. New embryo dunes formed by wind and sand captured by Marram grass are in the middle. Prospective wet dune valley and new fore dune ridge are to the right. Harbour of Rotterdam (Maasvlakte 1) is in background. North Sea is (just visible) to the right.

IV. MARINE COMPENSATION

- Damage and compensation targets

Maasvlakte 2 was reclaimed from the sea, in this case the Voordelta, a shallow marine environment of high nature value, belonging to the EU Natura 2000 network (H1110, shallow seas with sand flats permanently inundated and tidal inundations).

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Maasvlakte 2 has taken away 2,000ha of sea. Rather than creating more new sea, it was decided to improve the quality of existing waters nearby in the Voordelta with ca 10%. Besides the loss of sea environment and sea (bottom) fauna (fish, benthos), there was also an expected damage to resting and foraging areas of seabirds (common scoter, sandwich tern, and common tern). These birds are most sensitive to disturbance in their habitats. In time after the construction of Maasvlakte 2, it was expected that currents will create a sea bottom pit (near the sea defense wall surrounding the harbour) of 500 ha, which also needs to be compensated.

The following marine compensation targets were set: (i) create a marine protection area of 2,500x10 = 25,000ha in the Voordelta and within the protected area, and (ii) establish resting places for the three most sensitive seabird species, common scoter, sandwich tern and common tern (Figure 4) (Table 3).

Fig .4 Top: Marine compensation in the Voordelta (orange boundaries) and the marine protection area (red) and the resting areas for seabirds (yellow). Bottom: from left to right common scoter, sandwich tern and common tern.

Table 3. Marine Damage and Compensation Targets. See Figure 4.

Damage	Compensation target
2,500ha sea(bottom) lost	Establish 25,000ha marine protection area to restore sea bottom (communities) and fish.
Resting and foraging places for seabirds lost	Create new resting places within protection area to restore sea bird populations

- Compensation measures and monitoring [6,7]

In the protection area bottom trawling with vessels >260 hp were stopped. It was expected that this would improve the numbers of fish and of sea bottom fauna. And that this would favor the bird numbers because of an increase in food source. In the resting areas all human activity was banned.

Monitoring was set up to see whether the predicted damage could be sufficiently compensated. The monitoring concentrated on (i) benthos (sea bottom fauna), (ii) birds, (iii) fish, (iv) abiotics and (iv) human use of the area. The first phase (T_1) of the monitoring period was from 2009-2013. Before this, a T0 period was monitored between 2004 and 2007. During T_1 the reference area was the Voordelta area outside the protection area.

- Monitoring results

The following results have been obtained after four years of measuring. (i). It was not possible to find a significant correlation between the stopping of fisheries activities and trends in the sea bottom. One possible reason for this is that already in 2004 fisheries activities were reduced by 80%. (ii) It was not possible to find a significant correlation between numbers of the three bird species (and their spatial distribution) and the establishment of new resting places. These results are valid for comparison of the compensation areas both with the reference area and with the T_0.

As a consequence, at the moment a clear sign that the damage to the marine environment is sufficiently compensated cannot yet be seen.

V. DISCUSSION

There are several factors that can play a role to explain the results in the Voordelta. Since the closing of the large sea inlets in this Delta area (1960-70ies) as part of the Dutch Delta Plan, this area has not yet reached its new equilibrium. Because of this and by the nature of the environment itself, the area has a high degree of hydrodynamics. There are great autonomous spatial and temporal changes in abiotic conditions of water and soil. These may cause differences in benthos and fish per time lap, which are larger than the consecutive monitoring differences.

Also, the data on numbers of birds and their spatial distribution show large differences between the years, larger than those between the compensation and the reference. In this case, also the monitoring period (four years) is too short to detect significant effects.

Another important factor is that birds and fish do not stay in the same protected area and reference area. They move to other areas and (may) come back. So, their population dynamics is influenced, not only by ecosystem changes in the area itself, but also in other areas (far away). Thus, it is difficult to attribute changes only to the compensation measures in the marine protected area.

Finally, monitoring is being done not only to assess whether the compensation is going to be sufficient, but also to understand more about the relationship between the various elements (birds, fish, benthos, nutrients, and water conditions) in this marine ecosystem.

The monitoring will continue for at least another 4-year period. This will give more insight in the ecosystems itself (life strategies, carrying capacity, food chains, and resilience). It is expected that new answers can be given to evaluate the compensation efforts.

VI. CONCLUSIONS

Large-scale technical activities for harbour extension always damage coastal nature. The EU compensation principle can contribute to restoration and new nature development and to more sustainable overall coastal solutions. Key concepts are compensation and building with nature.

Success of a project like this depends on a multidisciplinary cooperation and patience. Close cooperation between civil engineers, policy makers and ecologists is necessary.

Time should be given to nature to develop itself. This time is often longer that politicians can wait. Area protection is necessary to allow for undisturbed developments of new nature.

The case of Rotterdam harbour is of importance to mirror with harbour development worldwide. It is a case that considers, at the same time and right from the beginning, economic development and ecological quality.

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Cad and Distributed Manufacturing Solutions for Pellet Boiler Producers

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***Abstract* -** The paper is summarizing the research activities that had been carried out for defining an appropriate manufacturing concept and the system architecture for a manufacturing plant of pellet boilers. The concept has been validated through the implementation of a solution of computer integrated manufacturing that includes a CAD platform and a CAM facility including laser cutting machines, rolling and welding machines and advanced technologies for assembly, quality control and testing.

***Keywords* -** computer integrated manufacturing, distributed manufacturing, pellet boilers.

I. INTRODUCTION

The manufacturing concepts may be considered as the core characteristic of the modern human civilization. At the same time, mankind is now facing a series of social challenges such as non-precedence growth of population, closely related to the increase of consumption, the rise of emission levels, environmental degradation and the scarcity of resources.

In the last decades, the manufacturing value chains reached a global scale. It is estimated that 80% of the global manufacturing output is concentrated in just 3 regions [1].

There are many options and there is a convergence of opinions that humanity has to move towards localized, closed loop manufacturing cycles.

For the closed loop manufacturing to be considered, it requires a fundamentally paradigm shift, from the current paradigm that starts with design, reacting at a certain scale, mass production and further to product distribution, towards the new paradigm which is called mass customization that means to design for use, to define the economic targets based on scope, to customize products and to manufacture on a distributed base all around the world.

Experts in this field are considering that researchers have to pass from current 3rd industrial revolution, which is based on extensive use of controls, IT and electronics, in order to obtain an automated and highly productive environment, towards the 4th industrial revolution [2], which is considered to be smart and based on integration of virtual and physical production systems.

In this context, what the experts call now the industry 4.0 will be based on three basic strategic goals, as convergence of applications which will form conditions of new advancements, energy efficiency and sustainability to gain greater business focus, greater presence of mobility and web-based information systems.

From the technology point of view, the 4th industrial revolution will integrate wireless technologies, internet of things, big data and cloud platforms. From the collaboration point of view, it means integrated industries, IP centralization and social innovation. In addition, from the processes perspective, it means sustainable manufacturing, integrating internet of services and life-cycle assessment.

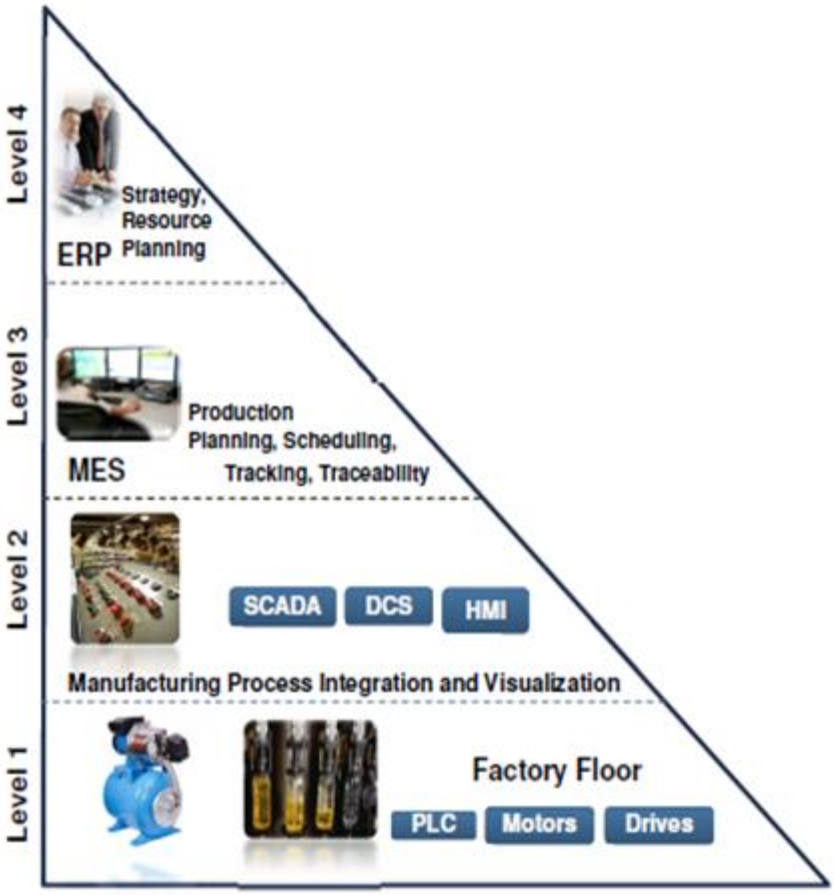

Fig .1. The enterprise pyramid [1].

According to the current status of technologies, the architecture of a manufacturing enterprise will be shaped as a pyramid with four layers. The Enterprise Pyramid is a comprehensive representation of different operational layers at their respective positions. This includes factory floor at Level 1, followed by controls and automation in Level 2, MES at Level 3, and ERP at Level 4. In a new development, product life cycle management is expected to be included in the future of enterprise hierarchy, between Levels 3 and 4.

The companies structured following the pattern from figure 1 will be much more flexible and adaptive in integrated enterprise ecosystems. At the factory floor level, the wireless technologies will push for intelligent devices. All the industrial control systems will integrate new smart services based on mobile technologies, enabling intuitive control rooms. The manufacturing execution systems will be pushed by enterprise integration and cloud computing. The enterprise resource planning shall include software as a service and social media integration.

II. EVALUATION OF THE CURRENT STATUS

As a first phase in the implementation of modern enterprise architectures, a comprehensive analysis regarding the enterprise ecosystem and the specific characteristics of the existing value chain should be carried out.

For this purpose, in the specific case of the project Ecopellet, the analysis has been centered on a company specialized on manufacturing and installing of pellet boilers.

The evaluation of the enterprise ecosystem has been initiated with a SWOT analysis by the evaluation of the internal and external connectivity, including the suppliers of different components and the distribution and market delivery of the final products.

In this evaluation the market trends had been analyzed and the growth opportunities identified. The initial status of the infrastructure has been evaluated as well as the requirements for the transition to the modern architecture, defining optimal alternative solutions to the manufacturing phases and the evaluation of the new solutions from the technical and economical point of view.

Based on the initial evaluation, the choice for the adopted solution has been substantiated.

The project consists of three components as follows: Ecopellet Soft - is the soft component that regards the acquisition procedures, technical assistance and studies, Ecopellet core project that includes the upgrade of the manufacturing value chain and the inquiry of infrastructure components, and Ecopellet R&D that is the research component.

Ecopellet Soft project is aiming to provide technical assistance for the implementation of the investment project EcoPellet and research EcoPellet R&D, by contracting specialized firms to carry out feasibility study, technical design, construction documentation and business plan, which will enable the efficient implementation of projects provided above.

Ecopellet core project is the investment component, aiming to develop a manufacturing line for pelletized biomass incineration system components. The new infrastructure enables accumulation of expertise by R&D activities that provide competitive advantages to the partners.

EcoPellet R&D is associated with the Ecopellet core project. The R&D component includes industrial research, to acquire knowledge allowing the development of a competitive advantage for the partner companies. The objectives also include organizing of research activities in line with market requirements and the exploitation of research results into innovative products and services nationally and internationally competitive.

On the short term, the project aims to complete the infrastructure elements required to carry out R&D activities in the field of manufacturing pelletized biomass incinerators thus to offer competitive advantage in developing future business. This infrastructure will enable collaboration with businesses, universities and individual inventors, provision of R&D services and implementing innovation projects. The project is also aiming to increase the performance of the manufacturing processes, the development of competitive advantages through the acquisition of high performance equipment to complement the production line, improve the quality and safety of the operation of systems for burning biomass pelleted, reduce costs and increase product competitiveness of the partner companies.

On the medium term, the project will identify specific market segments in EU countries and emerging economies. There will also be prospected emerging markets of Azerbaijan and the countries of the Caspian region, Jordan and the Middle East, Algeria and North African countries, markets with high growth potential such as Turkey, Ukraine and countries of the former Yugoslav space for the development of an expansion infrastructure.

III. IMPLEMENTATION AND RESULTS

In the two years of project implementation, the activities had been carried out by the project team of the two partner companies with no significant delays or setbacks.

All the steps had been carried out for the completion of the manufacturing infrastructure that included the inquiry of a laser cutting machine, a rolling machine and an advanced automated welding robot, thus assuring the optimal performance, best quality and competitive production costs.

The design department was equipped with state of the art graphic stations, running CAD CAM software. After commercial solutions have been studied, PTC Creo has been adopted as the CAD CAM software solution, for being versatile and integrating all the elements of the production process, from sketch and design, simulation, manufacturing and assembly.

Research activities have been carried out, including simulation and optimization of the burning processes, experimental research on the product range, technological planning for the new manufacturing processes. Also a test bench have been conceived and certified for the testing of various conditions of load and input of the pellet boilers.

As a result, the Ecopellet project fulfilled almost all the key point indicators and the project implementation project has ended successfully.

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