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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.

Sustainable development is a multidisciplinary advancing to the center of energy research with the declaration of UN millennium development goals for the first time in 2000, and continued to constitute a challenge in energy technologies in the past decade. RESD is mainly interested in case studies of sustainable development and its relation to transition economies in the Middle East, Africa, Asia and Oceania.

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Photovoltaic: Perovskite fever: Is Perovskite the future of solar cells?

Professor Aziz Naamane

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Perovskites, this somewhat "barbaric" term derived from the name of a 19th century Russian mineralogist, Lev Perovski, is not yet known to the public. But in labs around the world researchers are feverishly active around this family of crystals that promise to revolutionize the conversion of solar energy into electricity.

Originally the perovskite is a crystal composed of calcium, titanium and oxygen. However, the term is now used to refer to other chemical compounds with identical structures. About ten years ago these materials, then used to make certain electronic components, suddenly emerged as potential candidates for the replacement of expensive silicon cells in solar panels. The hope was mainly based on the cost of perovskite cells, which are significantly lower than those made with silicon crystals and which currently equip most photovoltaic installations

Perovskite at a glance

- Perovskite solar cells are cheap, easy to implement and efficient, but their operation still lacks stability.
- The latest developments in research tend to move closer to the goal: solar cells with long-term high performance.
- To be successful, the new technology must be compatible with existing industrial manufacturing processes.
- A new technology is in the starting blocks: solar cells with perovskites. This generic term refers to new materials whose crystalline structure is similar to that of the natural material called perovskite.
- The solar cells with perovskites have undergone a flash development. Over the past decade, their output has literally exploded from just 3% to over 20%. Perovskites have remarkable properties: they absorb light particularly efficiently and evacuate the current produced well. In addition, they are both cheap and easy to manufacture and process. However, perovskite-based solar cells also have a significant drawback: they do not yet function consistently enough and are not durable enough for large-scale use. Researchers from the ETH Lausanne and the University of Freiburg are working to improve the stability and performance of this promising technology.

Perovskite rock in the Urals massif, Russia.
The discovery of the photovoltaic qualities of perovskites dates back only to 2012.

Conclusions:

In short, it would be tedious to describe all the research currently underway, but be aware that the results are there: lately not several weeks go by without a team proudly announcing that they have made progress towards the development of a photovoltaic technology based on perovkites, much cheaper than the current silicon cells and whose lifespan and efficiency are equivalent. Theoretically, the yield of perovskite-based panels could even be as high as 30%, but we are not there yet.

Another area of research concerns the manufacturing technologies of perovskite-based cells. Scientists are working on the possibility of placing thin-film materials on a flexible PET medium [1] using a process similar to inkjet printers. The solar module that we get is almost transparent, very flexible and offers a wide range of possibilities. For example, it could be integrated into building glazing or in complex shapes such as vehicle bodies. Some even plan to make clothes out of them.

The final issue is cost and marketing. According to media estimates, the price of perovskite-based solar modules is 4 to 5 times lower than that of current photovoltaic panels.

If all these hopes and promises come true, we may well be on the cusp of a solar revolution that would definitively sound the death knell for fossil fuels and nuclear power.

Shall we agree that Perovskites: these crystals will revolutionize solar energy? this question remains open.

[1] PET - polyethylene terephthalate: it is the plastic used to make bottles containing soft drinks

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Dr Abdelaziz Naamane obtained a M.Sc. in electronics, power electronics, and automatic control from the Université de Provence and a Ph.D. in electronics and physics from Aix Marseille University. He is currently a Professor at Aix Marseille Université and a senior researcher at Laboratoire d'Informatique & Systèmes (LIS UMR 7020 CNRS)

CURRENT INTEREST: Modelling, simulation and control of complex hybrid systems. Control-oriented modelling of nonlinear dynamical systems. Energy-based modelling (Bond Graphs, Euler-Lagrange, port-Hamiltonian methods) and control of nonlinear physical systems. Applications of nonlinear techniques to modelling, analysis and control of electrical machines, power electronics drives, and general mechatronic systems, including robotics. Energy management and control in micro smart grids.

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Renewable Energy and Sustainable Development

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Abstract:

As the contradiction between human development and environmental maintenance is increasingly prominent, sustainability has become a significantly important goal for future development. The renewable energy plays an essential role in the achievement of sustainable development, since it is relatively cleaner comparing with fossil fuels. The renewable energy has the advantages that it has fewer negative impacts on the environment than fossil fuels, so it is beneficial in improving the environment, increasing the diversity of fuels, ensuring stable energy supply, and promoting regional economic development. To improve the sustainability and development of renewable energy, countries worldwide set up goals and implemented relative regulations and policies. This keynote paper firstly introduced sustainable development; subsequently, summarized the roles of renewable energy on sustainable development; then, had an overview of the achievements on sustainable development and renewable energy; after this, investigated the barriers and in sighted; and concluded this paper. The results reveal that there is still a far way to go before all Sustainability Development Goals (SDGs) will be finally achieved although many progresses of sustainability and renewable energy development in technological, economic, environmental and social aspects have been made during the past 20 years with the efforts of all countries.

Keywords: Renewable energy, sustainable development, sustainability

1. Sustainable development

As the contradiction between human development and environmental maintenance is increasingly prominent, whether limited natural resources would meet the material needs and living needs of the growing population become a problem [1]. Due to the limitation of natural resources, the production of food, necessities and other products is expected to be restricted one day in the future. Insufficient amount of resources will inevitably cause the stagnation of economic growth, the allocation problem of social resources and the tension of social relations [2]. Also, the deterioration of land resources and environmental conditions limits the scope of human activities and living standards [3]. Therefore, endless production and consumption will inevitably lead to irreconcilable contradictions and serious consequences. When these problems were widely discussed and the solutions were attempted, the concept of sustainable development was put forward and received more attentions.

Sustainable development refers to a development model that can be endlessly used with limited resources. The term "sustainable development" uses the definition of sustainable development that has been most frequently cited by the Brundtland Commission: "*a development model that can meet our needs today without compromising future generations*." [4]. During the development process, the definition is constantly refined and updated. The current mainstream concept of sustainable development can be explained environmental, economic and social aspects. Environmental speaking, we shall minimize damage to the environment, including rational allocation and planned use of limited resources and reduction of pollutant emissions. In terms of society, some human physical and mental needs should be met for sustainable development, such as work needs, family security, comfort living environment, and human health. In the economic aspect, only those activities that could make profits could last for long and achieve sustainability.

In the process of continuous development, sustainable development is recognized as the joint efforts of all mankind. Therefore, the United Nations released eight Millennium Development Goals (DMGs) in 2000 [5], including "*extreme poverty and hunger eradication, universal primary education achievement, gender equality and empower women promotion, child mortality reduction, maternal health improvement, combating HIV/AIDS , malaria, and other diseases, environmental sustainability, and a global partnership for development*" [5]. Certain DMGs have been achieved during 2000-2015, but a more detailed goals should be clarified.

Therefore, the goals for sustainable development were adjusted and extended to 17 goals as known as Sustainable Development Goals (SDGs) in 2015 [6]. The scope and definition are broader and clearer, so that all countries have clear goals for common development in the next 15 years. The revised SDGs include "*no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation, and infrastructure, reducing inequality, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, justice, and strong institutions, and partnerships for the goals*" [6].

2. Renewable energy

Among all efforts made for promoting sustainable development, the renewable energy has played a significantly important role [7], [8]. Fossil fuels, such as coal, oil and natural gas, have been adopted as the major resources for energy generation for long in the history [9]. However, the use of fossil fuels causes land occupation, air pollution, and water pollution, which triggers damage to animals and plants, and climate change [10]. In addition, fossil energy is a non-renewable energy source, and its limited stocks on the earth will eventually be exhausted [11]. Renewable energy is naturally formed and can be repeatedly produced in the environment, such as solar energy, wind energy, ocean energy, biomass energy, water energy, and biomass energy [12]. Comparing with fossil fuels, renewable energies are clean energy sources that have fewer negative impacts on the environment than fossil fuels, and they are beneficial in improving the environment, increasing the diversity of fuels, ensuring stable energy supply, and promoting regional economic development [13]. In this case, the application of renewable energy has a direct positive effect on these SDGs including clean water and sanitation, affordable and clean energy, sustainable cities and communities, climate action, and life on land. In addition, the application of renewable energy also indirectly improves the development of the following goals by establishing more energy stations and providing more job opportunities: decent work and economic growth, gender equality, innovation, and infrastructure, no poverty, and zero hunger. Therefore, the development of renewable energy is an effective and important way to achieve sustainable development.

3. Achievements

After the concept of sustainable development has gained global recognition and attention, countries worldwide have formulated detailed goals at the national level according to their own development. The corresponding policies and supporting measures have been introduced and implemented to assist sustainable development. After 20 years, significant contributions for sustainable development in terms of technology, scope of application, economic benefit and environmental condition had been made [14]. The renewable energy has been widely applied and it accelerated environmental, economic, and social sustainability [15].

In recent years, the application of renewable energy has achieved technological innovation and improvement. Some relatively mature renewable energy power generation technologies, including hydropower, wind power and solar photovoltaic power generation, have been optimized and improved in energy generation efficiency, energy density and cost control [15]. The corresponding market has gradually matured and stabilized. 111 countries have designed and implemented feed-in tariffs (FIT) for renewable energy project. Some countries have gradually switched from FIT policies to more liberal and free market competition strategies, and there were more than 48 countries have replaced FIT by auction strategy [16]. It is expected that there will be more free market mechanisms explored in the future. In addition to the application of renewable energy mentioned above, other renewable energy sources such as geothermal energy, ocean energy have also been developed for power supply and heating in some areas, but they were not as popular as wind power, hydropower and photovoltaic energy [15]. In addition, many studies have also explored and studied the application of renewable energy in transportation, such as hydrogen batteries [17], solar cells [18], [19], and biomass fuel vehicles [20]. Furthermore, the optimization of the renewable energy supply chain, for example: energy storage [21], [22] and energy transmission [23], [24], have been widely studied.

The development of renewable energy has drawn attentions and has made great contributions with the efforts from all countries. Renewable energy targets had been adopted in 169 countries at the national or state level by the end of 2018, and the amount of annual investment rose from 177 billion USD in 2008 to 288.9 billion USD in 2018 [15]. In the past 20 years, the proportion of renewable energy power capacity has reached over 50% since 2015 [15]. The consumption of renewable energy has also reached 26% [25], which is a great achievement.

4. Barriers and insights

However, achievements of current sustainable development strategies are still far from that mentioned in the goal of global zero carbon emissions and other sustainable development goals. Following the current trend of CO_2 emission and temperature change, it is difficult to achieve net zero carbon emission in 2030 [15], [26]. After analysis, the following obstacles exist in global sustainable development and some insights are provided.

In the techno-economic aspect, the optimal energy system that best suits national conditions has not been determined by each country, but the amount of renewable energy investment that can be attracted is decreasing. While renewable energy technologies have room to upgrade, the energy mix of each country has not been optimized. Therefore, systematic and innovative studied should be conducted to develop and optimize an intelligent, mixed energy system.

Key development technologies suitable for the country should be analysed, evaluated, and selected according to national conditions, and the investment can be focused on cultivating key technologies due to the limited capital investment. The development of low-cost and accessible technologies for renewable energy provides more opportunities for countries to implement decarbonisation and to satisfy increasing energy needs. It can also provide more development possibilities for countries that do not have the advantages of existing renewable resources to reduce the impact of energy price fluctuations in other countries, and thus improve the energy security of their own countries. The existing renewable energy supply, such as wind energy, photovoltaic solar power, still requires investment and efforts, since there is still much room for upgrading. For example, the conversion rate of the latest photovoltaic cells has just reached 18% [27], which can be improved in further research.

Another technological improvement can be achieved by developing and optimizing mixed energy system of multiple energies. In some countries, the reserves and types of renewable energy resources have obvious regional characteristics and have the inherent advantages of diversified development. Regarding the development and utilization of renewable energy, the government should further promote the diversified development of renewable energy structure, strengthen the coordination between different types of renewable energy, and then improve the comprehensive energy utilization efficiency.

In addition, data analysis and computer information technology can be integrated into the renewable energy application system to predict and optimize control of uncertain information. Referring to the energy exchange between Denmark and the Nordic countries, every nation should continue to strengthen the construction of power infrastructure and power market, study the integration and dispatch technology of renewable energy, and realize the optimal allocation and efficient use of large-scale renewable energy resources.

In the policy-making aspect, the energy market regulations have not been perfected and optimized for every renewable energy in most of countries. There is no global energy optimization strategy which leads to a problem that some developed countries have transferred carbon emission to developing countries. In this case, the global net-zero carbon emission goal is hard to achieve. Therefore, policies and regulations should be adjusted accordingly to achieve global sustainability goals.

It is suggested to improve market policies, guide benign market competition, and gradually open up domestic and foreign market transactions. A mature energy market can attract more capital to enter the market, maintain the competitiveness in the market, help to reallocate energy allocation, and accelerate the technological development. Government departments should also further strengthen the system and mechanism of the integrated energy service market to help maintain the stable operation of the market. One country must also pay attention to the guiding role of laws and regulations in the comprehensive energy service business. The local goals should be coordinated with the national strategy to ensure that identical goals are achieved. The energy resource characteristics, energy supply and consumption characteristics of each nation should be fully integrated. Furthermore, multi-dimensional and multi-level relevant policies and laws and regulations are promulgated to ensure the implementation of comprehensive energy services. In terms of energy policy and regulations, the Danish practical experience shows that the government has effectively promoted the local comprehensive energy service business through the combination of comprehensive operation goal orientation, financial incentives, laws and regulations, technology development and other policies and regulations orderly development.

5. Conclusions

Sustainability is a significant goal for future development and the renewable energy plays an essential role in the achievement of sustainable development.

Although many progresses have been made during the past 20 years with the efforts of all countries, there is still a far way to go before all SDGs will be finally achieved. A mixed energy system is suggested to be developed and optimized according to the characteristics of each nation in techno-economic aspect. In policy-making aspect, more efforts should be made in energy market development for new renewable energy resources.

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Modelling and Methodology for Window Selection with Energy Efficiency Criteria in Chile

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***Abstract* -** This article presents the development of a methodology associated with the selection of windows with energy efficiency criteria in Chile. It provides the optimal option in a housing project, according to specific search parameters by region, commune, orientation, materiality, among others options. At the same time, it is possible to download the technical characteristics of the selected window instantly.

According to results obtained on the simulation, S2 showed better energy efficiency performance in the three cities studied (Antofagasta, Santiago and Concepcion). Mainly the transmittance value was slightly smaller than S1 solutions. In general, windows with lower thermal transmission (U) achieve better energy efficiency in homes. However, the selection of optimal windows for a project should always be based on the geographical area, the orientation of the facade or wall, the surface of the light, or the visibility to be projected (dimensions), and the thermal transmittance values (U).

***Keywords* -** Sustainability, Energy efficiency, Window, Thermal transmission, Transmittance values.

I. INTRODUCTION

Currently, Chile has joined multiple sustainable agreement and due to this, Chile actively participate such as a member of the Organization for Economic Cooperation and Development (OECD), Asia Pacific Economic Cooperation (APEC) and the United Nations Framework Convention on Climate Change (UNFCCC). Consequently, a series of national strategies is laid down, for the short and medium-terms, which seeks to favour the transition to a more sustainable and efficient country. [1] [2] [3]

For the development of these, the European reality was studied, which had a successful work program and extensive experience. One of the initiatives that stood out in this area was Directive 2010 / 31 / EU of the European Parliament [4], which is the basis for the energy rating of homes. It also defines the objectives and standards of energy efficiency in buildings by 2020.

Then, the study and analysis of the different energy sectors of Chile began, to know the state of the country in this matter and determine what the gap that exists with high-standard countries is.

In this regard, each the residential and the mining sectors represent 15% of the total national energy consumption. This indicates the magnitude of the context, taking and into account the importance of mining in Chile. [5] [6]

On the other hand, the National Energy Strategy 2012-2030 stipulates an Energy Efficiency Action Plan 2012-2020 that aims to achieve a 12% reduction in projected energy demand in the year 2020 [7] [8]. Additionally, national law No. 20,257 was also enacted, which states that non-conventional renewable energy sources must generate 10% of the energy by 2024 [9].

Notably, the residential sector has sustainable construction standards [10] [11] [12], according to the Handbook of Housing Energy Qualification [13] and the General Law of Urbanism and Constructions of Chile [14]. As a result, there is a need to innovate in this area, creating a methodology that allows selecting windows with energy efficiency criteria.

II. METHODOLOGY

A. *Study Areas*

Three research areas are involved in the study development, namely Laws and Standards, Market Research and Technical Characteristics. The investigative process is detailed in Fig. 1.

1. Laws and Norms

First, all information on national laws and regulations related to window selection was collected, as well as additional information, such as manuals and proposed standards — notably, the General Ordinance of Urban Planning and Construction [15].

On the other hand, the thermal zones of the cities of Chile, they were defined by maps proposed by MINVU [16]. Alternatively, the MINVU update on the communes that have the Air Decontamination Program was incorporated [17] [18]. Also, there is complementary information associated with sustainable construction standards [10] [11] [12] according to the Handbook of Housing Energy Qualification [13], and Climate Explorer [19].

After searching for the applicable legal and regulatory information, the parameters for the methodology were established and defined. Those parameters are necessary to generate an algorithm that allows simulations of different window configurations.

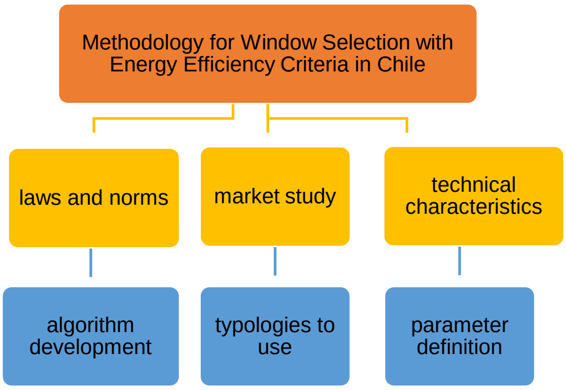

Fig .1 Flowchart to obtain the methodology for the selection of windows with energy efficiency.

2. Market study

At this point, the market window that includes recurring characterization patterns in different types of windows available. However, the windows present technical information and tests. These are fully available to be selected by the methodology database to ensure effectiveness during implementation. These involve the articles consulted from MINVU [20] [21], as well as suppliers [22]. Moreover, it includes a sample of twenty-eight windows, with all the relevant information.

Subsequently, the windows are added to the methodology and three types are defined; bringing down, sliding and projecting. Each of them has a subdivision according to the frame and thermal background.

Regarding the Chilean window market, it is correct to affirm that investments in the real estate sector have been in a constant growth throughout the years [23] [24] producing an increase in the demand for windows.

However, the products with the most significant presence in the market are Aluminium and PVC. The First is the most frequent for having a lower manufacturing cost, for the number of companies that distribute it and for its age in the market. On the other hand, PVC has only been gaining ground until recently, since public policies use it as a baseline for all their projects in order to generate energy savings in homes, lower maintenance costs, better acoustics [25]. The market distribution is represented by Fig. 2, that reflects an approximation of the growth of both over the years.

Window Type	Amount of money in the window industry per year (M / USD)		
	2017	2018	2019
Aluminium	120,5	126,5	131,5
PVC	31,6	31,0	32,8
Total (M / USD)	152,1	157,5	164,3

Fig .2 Amount of money in the window industry per year.

Characteristics	Window Type	
	Aluminium	PVC
Corrosion resistance	High	High
Electrochemical corrosion risk	Low	Null
Vulnerability to thermal bridges	Half	Low
Vulnerability to cuts or scratches	Half	Low
Degradation by saline environment	Half	Null
Risk of condensation inside	Low	Null
Difficulty cleaning	Low	Low
Window weight	Low	High
Maintenance	Half	Low

Fig .3 Factors influencing both durability and window maintenance.

On the other hand, the acquisition of a window brings with it a subsequent installation. Under this circumstance, the Chilean market generally delivers a price to the buyer that includes the installation value. The latter may vary due to the dimensions of the window and the distance or location of the destination. However, the type of window material does not influence this cost, in other words, that a window made up of one material or another will not increase or decrease the installation value.

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Nevertheless, in the stage of exploitation or use of the window, there are economic differences related to the material composition. Since the durability and maintenance are not the same in all cases, as shown in Fig. 3. For this reason, has been used the two most recurring window compositions, aluminium and PVC, have been used to identify the variables that can influence the maintenance costs, as well also as in the useful life of them [26]. The latter being an essential factor in determining when to make a replacement.

3. Technical Characteristics

The methodology explicitly uses the following types of variables; region, commune, thermal zone, facade surface according to orientation, frame material, window type and thermal transmittance (U) [27] [28] [29] [30]. All of these options allow recreating the conditions of the home better. After entering the information, there is an optimal solution for our case through a technical file, which implicitly contains information such as; glass-framed ratio, glass thickness, inner chamber space, the filling inside the chamber, the rail thickness and air permeability [31] [32]. In summary, have to adjust the data at the beginning, to later know in detail the characteristics of windows.

Additionally, a graphic representation of them allows the user to use as a means for the quotation, manufacture, and implementation of the windows. All this information ensures a correct and quick selection of windows for the case in question.

B. Methodology of the Verification Process

According to Fig. 4, the simulation considers housing in different climatic zones (Antofagasta, Santiago, Concepción) to which improvements are subsequently implemented in its windows. It is important to note that energy demand is calculated based on passive systems and does not include equipment (No HVAC). However, the HAP program [33] was used to simulate housing, which uses ASHRAE Std. 62.1 - 2010 [34], ASHRAE Std. 90.1 - 2010 [35] and LEED 2009 [36] as a regulatory framework.

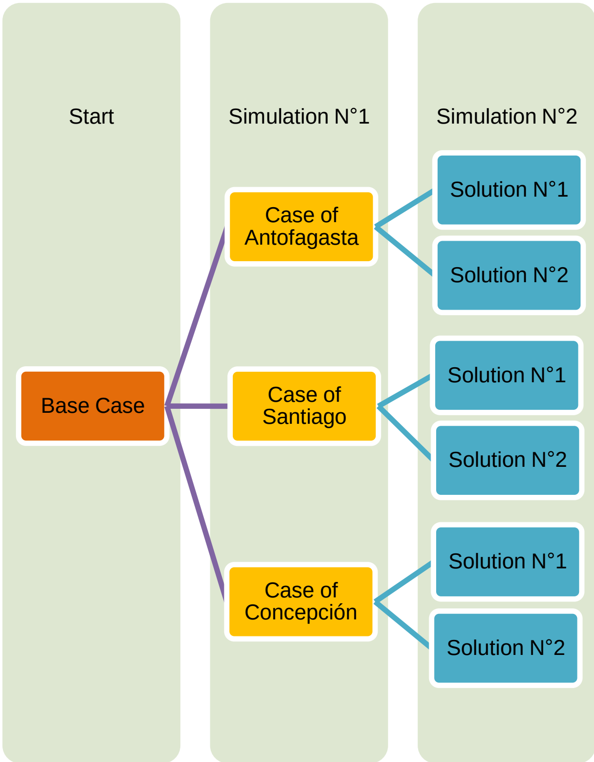

Fig .4 Flowchart to obtain case analysis.

1. Characteristics of Base Cases

The base cases are made up of the technical specifications exemplified in Figs. 5, 6 and 7.

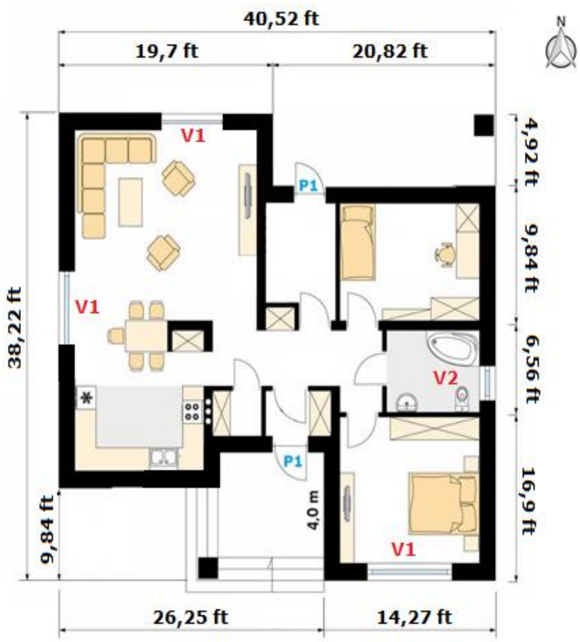

Fig .5 General architecture plant for base cases.

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City	Element	High (ft)	Surface (ft2)	U (BTU/hr/ft2/F)
Antofagasta	Facade N	7,55	304,62	0,29
	Facade S	7,55	292,78	0,29
	Facade E	7,55	248,65	0,29
	Facade W	7,55	249,72	0,29
	Roof	-	1337,95	0,06
	Floor	0,49	1145,28	0,52
Santiago	Facade N	7,55	304,62	0,29
	Facade S	7,55	292,78	0,29
	Facade E	7,55	248,65	0,29
	Facade W	7,55	249,72	0,29
	Roof	-	1337,95	0,06
	Floor	0,49	1145,28	0,52
Concepción	Facade N	7,55	304,62	0,29
	Facade S	7,55	292,78	0,29
	Facade E	7,55	248,65	0,29
	Facade W	7,55	249,72	0,29
	Roof	-	1337,95	0,06
	Floor	0,49	1145,28	0,52

Fig .6 Structural elements of the base cases.

City	Element	High (ft)	Width (ft)	Surface (ft2)	U (BTU/hr/ft2/F)
Antofagasta	P1	6,6	2,8	18,3	0.32
	V1	5,2	5,2	27,6	1,02
	V2	1,6	1,6	2,7	0,53
Santiago	P1	6,6	2,8	18,3	0.32
	V1	5,2	5,2	27,6	1,02
	V2	1,6	1,6	2,7	0,53
Concepción	P1	6,6	2,8	18,3	0.32
	V1	5,2	5,2	27,6	1,02
	V2	1,6	1,6	2,7	0,53

Fig .7 Non-structural elements of the base cases.

2. Characteristics of the Solutions to Simulate

The solutions for the simulations appear from replacing the initial windows V1 with others with better performance, through the methodology. As a summary of the improvement selection process, Figs. 8 and 9 show all the information necessary to prepare the simulations.

City	Solution N°1			
	Window V1			
	Frame Type	Window opening	Surface (ft2)	U (BTU/hr/ft2/F)
Antofagasta	Aluminium	Side-hung	19,4	0,63
Santiago	Aluminium	Sliding	17,8	0,63
Concepción	Aluminium	Sliding	12,9	0,63

Fig .8 Summary of solutions No. 1 to simulate.

City	Solution N°2			
	Window V1			
	Frame Type	Window opening	Surface (ft2)	U (BTU/hr/ft2/F)
Antofagasta	PVC	Side-hung	19,4	0,53
Santiago	PVC	Sliding	24,2	0,42
Concepción	PVC	Sliding	12,9	0,28

Fig .9 Summary of solutions No. 2 to simulate.

III. RESULTS

Figure 10 shows the cooling or heating energy required by a window V1. Indicating that the cities of Antofagasta and Concepción have cooling gains with their negative statistics. This is not the case in Santiago, whose values show an additional demand for it. As for heating, all windows require other energy input. The window that achieved the best performance was the solution n ° 2 in the city of Concepción. Since it has a favourable contribution of cooling energy (- 16 BTU / hr) and its heating demand is the lowest (126 BTU / hr).

Figs 11 and 12 indicate the amount of variation and heating energy required by the total windows of the house in comparison with the total area of these houses. In particular, the heating demand values are much higher than the cooling figures, with a difference between them that ranges 87 % and 93 %. On the other hand, the window that obtained better performance in both graphics. Is the S2 solution in the city of Santiago because it has the smallest reduction in surface area, 11% compared to the base case. Also, it manages to reduce the cooling and heating needs by 64% concerning its base case.

Figs 13 and 14 it show the heat that flows per unit of time and surface area (U) in the windows compared to the total demand for cooling or heating energy of the house. The cooling demand values are much higher than those required for heating as there is having a difference between them that ranges between 70% and 86%. Moreover, the city that presented the most significant energy demands was that of Santiago — reaching differences of up to 9% in cooling and 56% in heating. However, the city that shows the lowest energy savings is Antofagasta, decreasing only 1.5% in cooling and having a maximum of 9% in heating. In comparison, the city that achieved the best energy performance was the city of Concepcion with solution S2 since it managed to reduce cooling energy by 3% and 12% for heating.

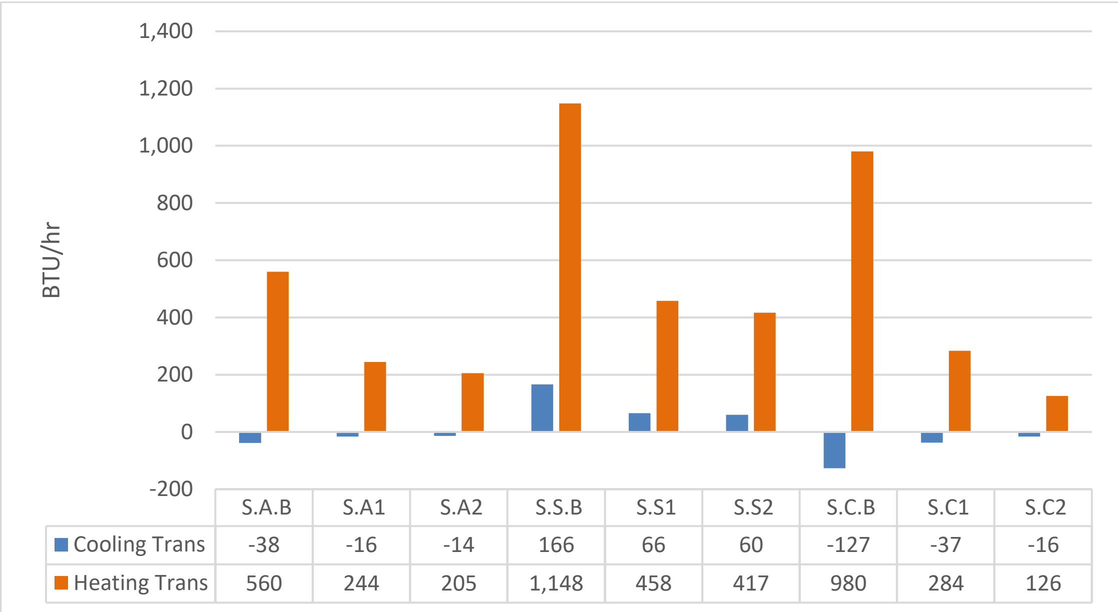


Fig. 10. Cooling vs heating energy required by a V1 window.

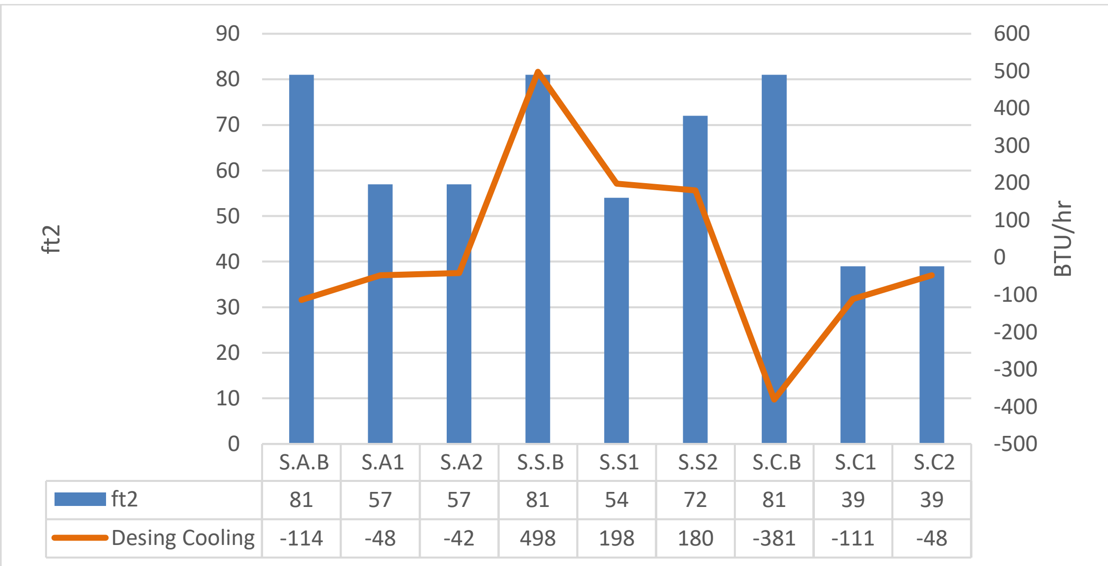
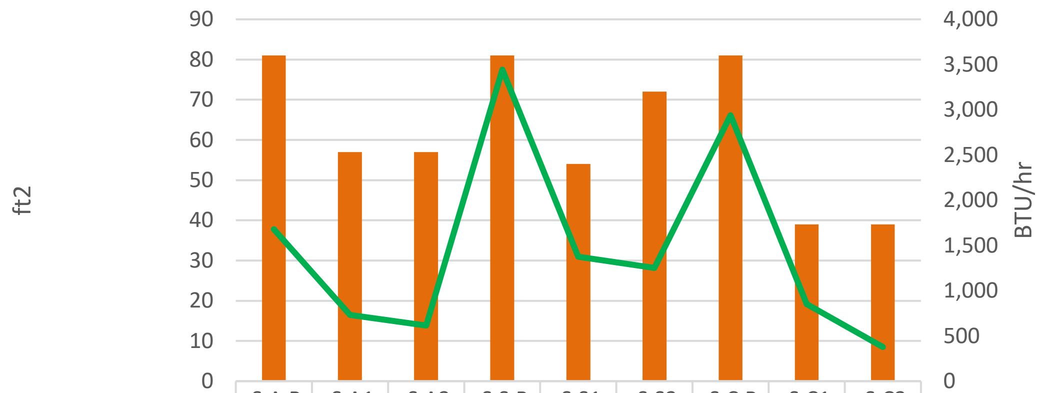
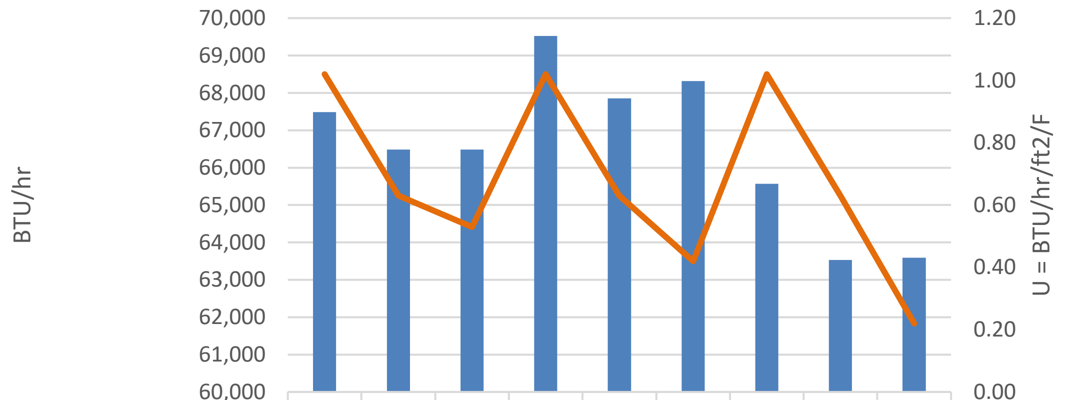


Fig. 11. Total surface of the V1 windows vs energy supply for cooling them.



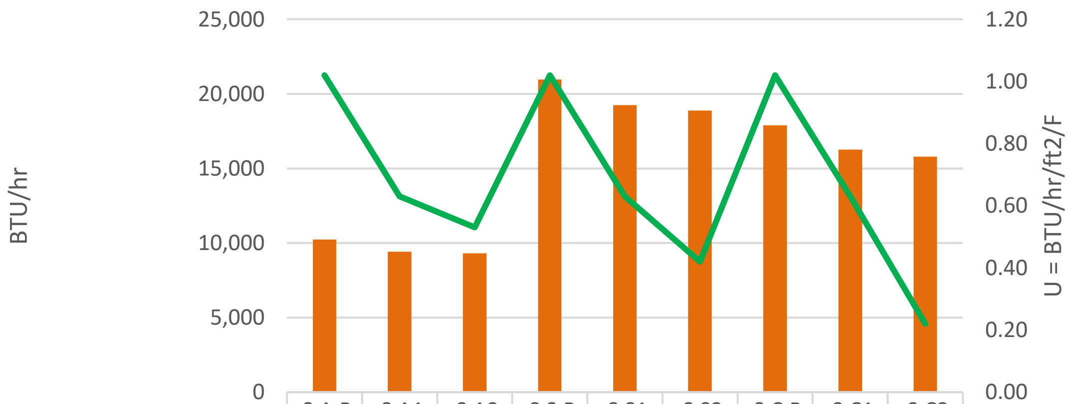
	S.A.B	S.A1	S.A2	S.S.B	S.S1	S.S2	S.C.B	S.C1	S.C2
ft2	81	57	57	81	54	72	81	39	39
Desing Heating	1,680	732	615	3,444	1,374	1,251	2,940	852	378

Fig. 12. Total surface of the windows V1 vs energy supply for heating them.



	S.A.B	S.A1	S.A2	S.S.B	S.S1	S.S2	S.C.B	S.C1	S.C2
Total Desing Cooling	67,489	66,481	66,488	69,523	67,856	68,317	65,567	63,527	63,588
U	1.02	0.63	0.53	1.02	0.63	0.42	1.02	0.63	0.22

Fig. 13. Thermal transmittance of the window (U) vs total energy demand for cooling.



	S.A.B	S.A1	S.A2	S.S.B	S.S1	S.S2	S.C.B	S.C1	S.C2
Total Desing Heating	10,227	9,422	9,306	20,964	19,248	18,889	17,897	16,262	15,789
U	1.02	0.63	0.53	1.02	0.63	0.42	1.02	0.63	0.22

Fig. 14. Thermal transmittance of the window (U) vs total energy demand for heating.

IV. CONCLUSION

After evaluating the passive energy performance of homes, it is concluded that the highest energy demands were recorded in cooling and they were much higher than those required for heating. As a result, the double airtight glass allows reducing the solar gain but fails to eliminate overheating in high-temperature seasons.

Other relevant data provided by the simulations correspond to the relationship between the thermal transmittance (U) of the windows and the total energy demand of the house (BTU / hr). Specifically, when using windows with small values of U in geographic areas where high temperatures prevail, great energy and economic performance are not obtained. Radiation control measures are more practical to combat these situations.

In geographical areas where low temperatures are recurrent, the strategy is of using very high-quality windows is not always viable. That is to say, using thermal transmittance values that are very low or close to 1.0 BTU / hr / ft2 / F. Together with decreasing their dimensions, they singularly favour the heating demand reduction. However, this situation is not entirely profitable because the natural light surface is lost, and the implementation costs are too high.

In temperate climates, it is where the correct selection of the windows has a higher incidence. Because, if windows with U values ranging between 2.0 and 3.0 BTU / hr / ft2 / F are used, a considerable reduction in the energy demands of the house is obtained, with a reasonable implementation cost. For example, in cold months, the solar radiation decreases, allowing the double airtight glass to limit heat transfers between the interior and exterior of homes in addition to avoiding condensation in the interior glass.

In contrast, in months of high temperatures, the same windows allow cooling through cross ventilation caused by opening them. In the case of having a ventilation, heating and air conditioning system (HVAC) the windows with the indicated characteristics allow encapsulating or retaining the comfortable temperature inside the enclosure, avoiding energy loss.

In general, it is confirmed that windows with lower thermal transmittance (U) achieve better energy performance in homes. However, the selection of optimal windows for a project should always be based on the geographical area, the orientation of the facade or wall, the surface of light or visibility to be projected (dimensions) and the values of thermal transmittance (U). For example, the simulations showed that the S2 solution obtained a better performance of energy efficiency in the three cities mainly because it had U figures and slightly smaller surfaces than the S1 option.

As for the users of homes in Chile and around the world, the following inferred; usually, they do not know the energy demand of homes, much less about the selection of doors or windows with excellent performance. Because these responsibilities transferred to government authorities, this means that it is the governments that generate the energy efficiency and sustainability strategies, according to the political, social and economic reality that they live. However, the difference is that Europe, unlike Chile, has more experience and track record on this issue. Instead, Chile is in the process of transition, since its policies and regulations are recent or in the development stage.

About the above and the evidence collected, it is possible to affirm that this methodology can effectively provide support to users, allowing them to know when it is profitable to change their windows for one that has a better performance. On the other hand, the implementation of this in the design stage allows knowing the cost and benefit relationship that exists between the windows, a critical factor in projects where resources are minimal, such as social projects. Furthermore, it favours the country's energy transition process in a transversal manner. In other words, it involves all the stages of a project; design, construction, operation and demolition or replacement in this case. It can be implemented free of charge, with high possibilities of application in the market and with national coverage. However, the successful integration of this in the field depends on the improvement of the current legal and technical framework that surrounds it, a modest initial investment, additionally a process of information and standardization of the market.

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Smart Electric Grids Three-Phase Automatic Load Balancing Applications Using Genetic Algorithms

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***Abstract* -** Smart grid is to be the future grid. Smart Electrical Grids require nowadays a large interest in the electrical load distribution balancing problem. This problem is well known for not having an optimal solution for large-scale systems, where the number of single-phase consumers connected to three phase systems increases especially in very large-scale electrical distribution system. This paper presents a new control technique for an automatic circuit phase change as well as an optimisation approach using Genetic Algorithms (GA) used to enhance the solution of electrical load distribution balancing problem. In the first part of the paper, the system under study and the various solutions adopted are introduced. In the second part of the paper a GA formulation and implementation of the solution are presented. The efficiency of the GA solution is also discussed.

***Keywords* -** Smart Electric Grids, Genetic Algorithms, Electric Load Balancing.

I. INTRODUCTION

Most domestic supplies at households and semi-industrial premises are supplied by single-phase AC with a phase and neutral wire. However, most electricity is generated and transmitted as three-phase AC. Rather than having a single coil rotating in a magnetic field, three-phase generators have three coils fixed at 120° from each other; thus three voltages, that are 120° out of phase with each other, are produced in three separate circuits. The phases are normally called red (R), yellow (Y) and blue (B). Using three phases is a standard issue nowadays due to the numerous known reasons from power constancy, copper wire utilisability, zero neutral currents for balanced systems, etc … [1, 2].

Over time, distribution feeders have a tendency to increase in load unbalance due to the following reasons[1-4]:

1. Loads on single-phase lines gradually increase.
2. Single-phase lines arbitrarily get manually switched to other phases.
3. Unequal distribution of single phase loads on three-phase lines.
4. Lack of planning.
5. Asymmetrical transmission impedances (due to untransposed lines).
6. Asymmetrical transformer winding impedances.
7. Blown fuses on phases of capacitor banks.
8. Unbalanced three-phase loads, such as arc furnaces.

The results are [1-5]:

1. Voltage phase shifts deviating form the 120°.
2. Increased return currents in the neutral conductor.
3. Increased losses due to excessive unnecessary currents.
4. Physical ramifications of the connections.
5. The unbalance in current creates a neutral point voltage shift.
6. Over-voltages and under-voltages occurring at different points of the feeder.
7. Unbalance in current dictated by placement of load on feeders.

Normally, unbalanced loads cause unbalanced distribution systems naturally [2]. The smart grids are nowadays targeted everywhere in three-phase electrical power systems of modern countries. The various problems arising with electrical power distribution grids arise from the fact that consumer loads are not perfectly predictable and do not balance out when different loads are distributed over the three phases [2].

This in effect renders the distribution problem of the loads on the corresponding phases rather difficult in order to reach the case of balanced loads. The proper choice of which loads gets connected to which one of the three phases is in effect very important in order to render the neutral conductor current to minimum [2, 3]. The problem then simplifies to an ordinary constrained optimisation problem that can be solved by several techniques.

The proposed solution in this paper treats the phase unbalance and the large value of neutral conductor current. Subsequently all over- and/or under-voltage problems are then greatly reduced. It is to be noted that no consideration was given to the feeder impedances in the work presented herein as this is outside the scope of this paper.

Section II of this paper presents the three-phase load balancing problem with the proposed circuit while section III presents the proposed control technique. Section IV presents the formulation of the objective function along with the constraints, followed by section V, which describes the GA formulation of the problem. The results are discussed in section VI followed by the conclusion in section VII.

II. THREE-PHASE LOAD BALANCING TECHNIQUES

The first and most basic solution is the use of special transformers, such as "Scott" and "Steinmetz" transformers [4]. In such cases, the three-phase grid sees a balanced load resulting from the single phase loads connected to the transformers. This is a rather expensive solution which increases to a great extent the initial installation cost of the system.

Another type of mitigation technique is to rearrange or redistribute the loads in such a way that the system becomes more balanced. For certain applications, there is a possibility of reducing unbalance by changing the operating parameters such as the line and short circuit impedances of the system at the point of connection [4-8].

Classically, the selection problem of which load is to be connected to which phase was treated manually by anticipating the average amount of current magnitude. No consideration for the respective load power factors was taken into consideration. The change of phase was then performed manually per load across the terminal wiring [4]. The problem in this case lies within the constraints of load disconnection and the following change of phase.

Another solution technique makes use of the fast-acting power electronic circuits, such as 'Static-VAR-Compensators', which can be configured to limit the unbalance [4-8]. These behave as if they were rapidly changing complementary impedances, compensating for changes in impedance of the loads on each phase. They are also capable of compensating unwanted reactive power. However, these are expensive devices and are only used for large power loads when other solutions are insufficient.

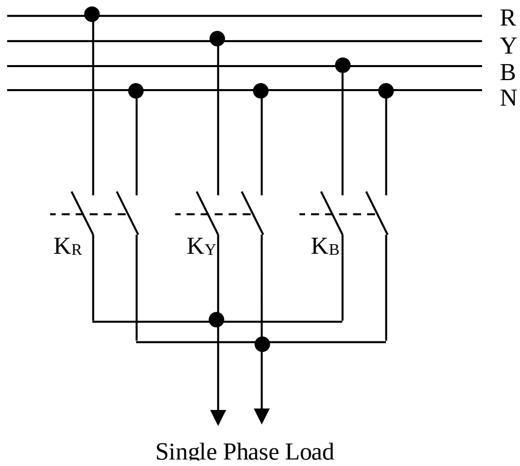


Fig .1 Three-contactor method.

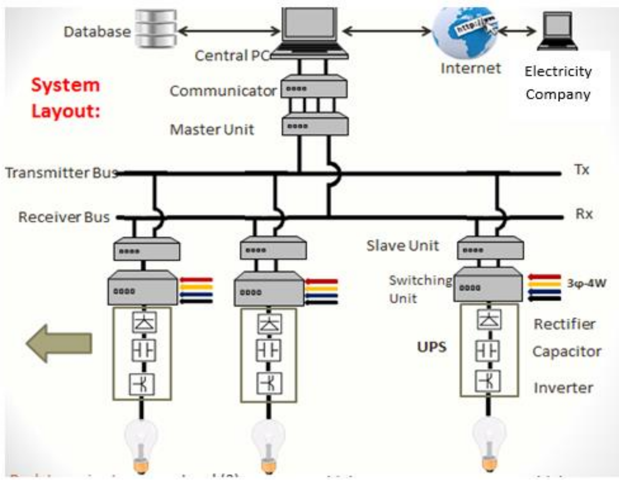


Fig .2 Automatic Phase changing system under consideration.

Finally, another method making use of three-single-phase contactors each connected to a different phase (R, Y and B) solves the problem at a fraction of the expense of the other previous techniques [4-8]. Figure 1 shows the connection of the three contactors with the three-phase supply and the single-phase load. Very good care must be taken in order to ensure that only one contactor is allowed to close its contacts at a time otherwise a line to line electrical short circuit would occur. Load balancing is one of the famous NP-complete problems [3].

The optimisation techniques for such circuits ranged from fuzzy logic, genetic algorithms, and several other heuristic techniques [5-8].

III. THREE-PHASE AUTOMATIC PHASE CHANGE TECHNIQUES

Figure 2 shows a proposed networked system capable of implementing the process presented in Figure 1 automatically and dynamically during the normal system operation. Three different loads are shown in the figure. For each of these load systems, a measuring device computes the load current and its corresponding power factor (*pf*) angle and transmits these readings from the slave unit through the communication network bus (using RS-485) to the master unit. These data are then processed by the central computing device (Industrial PC) which can be connected through the internet to the electricity distribution company. The central PC collects the data from all the loads under its control. It is then responsible for deciding which load is to be connected to which one of the three phases according to the optimisation technique implemented in its software. The decision for each load is then sent back from the master unit to each one of the corresponding slave units at the corresponding loads. Note that this system may include a UPS in order to eliminate the switching transient from the load supply during the transition from one phase to the other. This is of course dependent upon the importance of the load and its sensitivity to voltage interruptions. The details of the system description are outside the scope of this paper.

The advantages of the automatic system presented in Figure 2 for the smart load balancing problem are as follows:-

1. Providing an up-to-date balanced operation of three-phase systems by continuous metering of individual single-phase loads.
2. Helping to continuously avoid unbalance problems and losses.
3. Easy to be installed on any system with almost no significant changes in the distribution system.
4. Allowing the user to monitor the load current and its phase angle at any time.
5. Allowing the central computer to monitor all the individual single-phase loads at any time.
6. Allowing the central computer to generate an alarm when there exists a fault in any single-phase load.
7. Providing a database for the historical values of each load at the central PC.
8. Providing a remote monitoring of the system status and history using a web interface.
9. Power factor correction can be achieved by connecting lag power factor loads with lead power factor loads on the same phase.
10. The harmonic content can be reduced by the concept of useful harmonics; negative harmonics with positive harmonics on the same phase eliminate each other.

It is to be noted that only the load balancing technique is to be considered in this paper.

IV. OBJECTIVE FUNCTION FORMULATION

The main task of applying any solution to the system relies on the formulation of the problem. It is important in this case to address the problem formulation.

The first task is to identify the control variable. In this case, it is the balancing of phase loads in order to reduce the neutral current to minimum. This in effect is adopted under the consideration that the interconnecting electrical cable line impedances are neglected due to the fact that such loads are so close to each other as in the case of commercial or residential building blocks where the distances and hence the cable lengths between each two consecutive consumer loads are very small.

The currents magnitude of load k is given by I_k at each node (load) as well as its corresponding power factor angle (φ_k). This current in phasor format is added to the total current of each phase depending upon its corresponding connection. The three total phase currents ($\bar{I}^{A}_{tot}$, $\bar{I}^{B}_{tot}$ and $\bar{I}^{C}_{tot}$) are given by

$$\bar{I}^{A}_{tot} = \sum_{k=1}^{N_{ld}} A_k \cdot \bar{I}_k \tag{1}$$

$$\bar{I}^{B}_{tot} = \sum_{k=1}^{N_{ld}} B_k \cdot \bar{I}_k \cdot a \tag{2}$$

$$\bar{I}^{C}_{tot} = \sum_{k=1}^{N_{ld}} C_k \cdot \bar{I}_k \cdot a^2 \tag{3}$$

where, $a = 1\ \angle 120^{\circ}$ and A_k , B_k and C_k are three binary variables (0 or 1) corresponding to the whether the corresponding load current at node k is connected (value = 1) or not connected (value = 0) to that particular phase. The values of a and a2 are only considered here to compensate for the 120° and 240° phase shifts between phases A, B and C. It is to be noted that the quantities in equations 1 to 3 are phasor quantities added vectorially with respect to each other in order to preserve the phase angles of each load with respect to its corresponding phase voltage.

In order to reach the balanced loading condition, the neutral current is given by the equation:

$$\bar{I}_N = \bar{I}^A_{tot} + \bar{I}^B_{tot} + \bar{I}^C_{tot} \tag{4}$$

In equation (4), only the total neutral current of all loads is considered for the optimisation. The optimisation (in this case a minimisation of I_N) is subject to the constraint that it should only consider moving each load as a whole from one phase to another in determining the optimal distribution of the load currents across the three phases of the electric feeder. Another constraint applied to the system is that the three phases should be loaded almost equally; i.e., the current magnitudes in the three phases must be almost equal to within a certain percentage of unbalance determined by the operator of the electric power system.

V. GA SOLUTION APPROACH

Genetic Algorithm (GA) is a popular solution for solving NP-Complete problems. GA belongs to the class of evolutionary algorithms, which generate solutions inspired by natural evolution [3]. In order to implement a GA [5-10] solution for the above optimisation problem, it is required to clearly identify the following definitions:

A. Gene

The implementation of the gene (k) in this modelling includes three parts:

- Load current magnitude at node k given by Ik.
- Load current phase angle at node k given by φ k.
- Phase at which this particular node is to be connected (1, 2 or 3) corresponding to phases (R, Y or B).

The first two values of the gene are fixed during the whole optimisation problem since it includes the original system data. The only variable that is allowed to change is the phase connection of each gene. The following table shows the values of the phase connection and the corresponding values of A_k, B_k and C_k.

Phase	Ak	Bk	Ck
1	1	0	0
2	0	1	0
3	0	0	1

B. Chromosome

The chromosome includes a number of genes equal to the total number of loads in the electrical power system (N_{ld}). The chromosome will include its own solution for the phase selection of each of the loads at the different nodes.

C. Population

The population of the genetic algorithm system is the collection of valid chromosomes with a total number of N_{chr}. Each element in the population has to have its fitness evaluated. The population is then sorted in ascending order according to the fitness of each chromosome since this is a minimisation problem as discussed in the previous section. The crossover and mutation operators are applied to the chromosomes to generate new off-springs. The cycle then repeats until stabilisation or a maximum number of generations (N_G) is reached.

D. Fitness function and chromosome validity

The fitness of each of the chromosomes of the population is to be evaluated using a fitness function given by

$$Minimise\ \{I_N\} \qquad \text{Subject to}$$
$$If \begin{cases} difference(I^A_{tot}, I^B_{tot}, I^C_{tot}) > Tolerence & fitness = 10^6 \\ otherwise & fitness = I_N \end{cases} \tag{5}$$

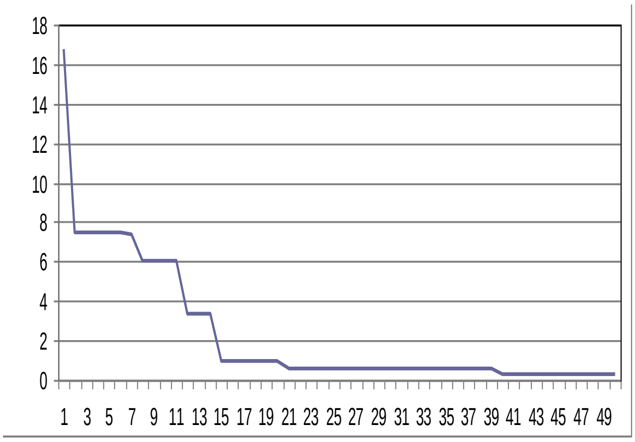
The fitness function described herein ensures the elimination of the chromosomes, which do not satisfy the conditions discussed in the previous section, by assigning very large values to the non-valid ones.

E. GA operators

Cross-over is applied to each pair of the chromosomes in order to generate the new off-springs subject to the constraints. This is effectuated onto a certain percentage of the chromosomes. The remaining chromosomes are subjected to mutation. A basic roulette randomisation technique selection mechanism is adopted in order to decide the point of crossover or mutation application at a certain gene. It is worthwhile to iterate here that the changes resulting from the two above operators are only applied to whole genes.

VI. RESULTS AND DISCUSSION

The GA program was applied to a system of $N_{ld} = 100$ nodes. The population size was chosen to be $N_{chr} = 50$ chromosomes. The system was allowed to run for a maximum of $N_G = 50$ generations or until a certain minima is reached. The crossover is effectuated onto 80% of the population and the mutation is performed on the remaining 20%. Figure 3 shows a typical fitness variation curve against the generation number.



Iteration Number

Fig .3 Fitness Variation Curve.

Eight different random loading conditions were applied to the system and the GA program was run for each of the cases. Table 1 shows the minimum number of iterations required for each set of loads with the best fitness (I_N) reached as well as the normalised values I_N relative to the equal share of the per-phase load current for each of them. The last row of Table 1 shows the average of each column.

It can be easily spotted that the maximum percentage error (relative uncompensated neutral current) is less than 0.4% in all cases. This is quite acceptable for the case of an electrical power system phase balancing.

Table 1. Fitness Comparison for 8 Different Loading Conditions.

Iteration	Generation No.	Best Fitness	Total Phase Current	% error
1	25	0.6967	307.76	0.23
2	33	0.3685	293.50	0.13
3	31	1.1655	311.25	0.37
4	22	0.9619	291.92	0.33
5	19	0.8293	313.41	0.26
6	22	0.7874	258.07	0.31
7	43	0.6018	284.29	0.21
8	39	0.2850	272.36	0.10
Average	29	0.7120	291.57	0.24

It is worthwhile to note here that the computation times of GA algorithm is generally large compared to other computation technique. The technique used in this paper took around 10.1 minutes in order to perform the computation. This in effect depends on a large number of factors such as the population size and the computation accuracy. This time is relatively large for fast varying application and renders the system impractical for such load cases. On the other hand, loads such as computer loads in commercial company buildings do not change that fast. The lighting and ventilation would amount to the same as well. Such computation times obtained in this paper would be rather suitable. Other techniques and measures would be considered in order to accelerate the computation process. This would be the subject of other research.

VII. CONCLUSION

A proposed control system for automatic transfer of electrical loads across phases in order to reach a minimum unbalance condition; i.e., minimum neutral current, was presented in this paper. The accompanying optimisation algorithm using Genetic Algorithms was also presented. The problem formulation as well as the GA implementation was discussed. The system was proven to reach minimum unbalance of less than 0.4% for all the eight different loads of 100 nodes each. The maximum number of iterations reached was 39 generations, which is quite reasonable from the point of view of system hardware implementation.

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