Journal of Renewable Energy and Sustainable Development (RESD) Volume 3, Issue 3, December 2017 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2017.03.3.258

Practical Investigation for Road Lighting using Renewable Energy Sources

Sizing and Modelling of Solar/Wind Hybrid System for Road Lighting Application

Maged A. Abu Adma[1], Said S. Elmasry[1], Maram Ahmed[1] and Ahmed Ghitas[2]
[1]Dept. of Electrical Machine and Power Engineering, Faculty of Engineering, Helwan Univ., Egypt
[2]Dept. of Solar and Space Research, National Research Institute of Astronomy and Geophysics, Helwan, Egypt
Maram.kadous@hotmail.com[1]

Abstract - Hybrid renewable energy systems are recently used to counteract the limitations of solar and wind as solo renewable energy sources due to adverse weather conditions. This study explains a design of a fully independent -off grid- hybrid solar and wind road lighting system according to geography and weather conditions recorded from the National Research Institute of Astronomy and Geophysics. The computerized model is designed step by step by the aid of Simulink-Matlab and the simulation was successfully run to show the performance of each module.

Keywords - PV; Wind; Hybrid; Simulink; Matlab; Modelling*.*

I. INTRODUCTION

With the recent advances of research in the renewable energy field and the continuous development and innovation process to push the limits of such clean, environmental friendly energy sources, many methods are being developed to tackle the challenges continuously faced due to adverse weather conditions, e.g. clouds, rain, snow and hail which reduce the solar irradiation and low wind speed that affect the productivity from wind turbines. One of those methods is the use of hybrid designs which utilize more than one renewable energy source to overcome the limitations associated with the use of a single energy source to meet the load demand; such designs provide long term stability and efficient performance for the application intended [1].

The hybrid renewable energy system may also combine renewable and traditional energy sources, e.g. using a wind turbine connected to a diesel generator to reduce fuel consumption [2] can be a standalone off-grid or grid connected.

In this research, the researcher will present the sizing and modelling of hybrid solar and wind off-grid road lighting system using weather data and Matlab-Simulink software.

II. SIZE OPTIMIZATION

The size of each individual component of the system is optimized to meet the load demand while maintaining an economically feasible design with a long-term stability of performance. Sizing is conducted according to real time data measurements of solar irradiation and wind speed recorded throughout the year 2012 by the solar radiation and metallurgical station at the National Research Institute of Astronomy and Geophysics in Helwan, Egypt (Latitude = 29.5° N, Longitude = 31.2° E, Elevation=130 m) [3].

A. Photovoltaic module sizing

The mean monthly averages of solar irradiation are presented as bar chart Fig.1. The lowest average solar irradiation 343 W/m^2 was recorded in December, thus the sizing of the PV is designed according to the minimum solar irradiation, Fig. 2 represents the average variance of solar Irradiation per day during December 2012.

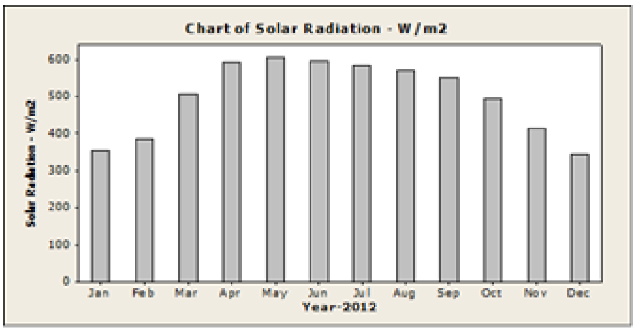


Fig .1. Monthly averages of solar irradiation during year 2012 at Helwan.

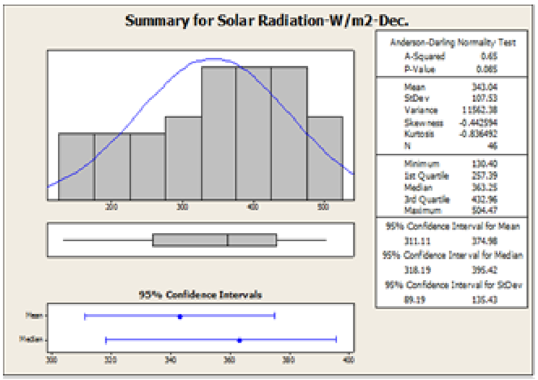


Fig .2. Average variance of solar irradiation per day during December 2012

As the system is required to power a 30 W luminar light for 13 hours, the total power demand equals 390 Wh/day; As 3.5 hours (the hours in the day during which maximum solar irradiation) provides 343 W/m^2; average solar irradiation with estimated 35% PV module efficiency, the size of the PV module was chosen accordingly to be 150WP as per the following equations:

Total appliance use = (30W x 13hours) = 390 Wh/day *(1)*

Total PV panel energy needed = 390 x 1.35 (Estimated losses) = 526.5 Wh/day. *(2)*

Total Wp of PV panel capacity needed = 526.5/3.5hrs=150Wp *(3)*

B. Wind turbine module sizing

Wind speed data collected throughout the same year in the same location is presented in Fig.3 with lowest average wind speed value of 4.33 m/s in November. The daily wind speed average values during the same month are represented in Fig.4

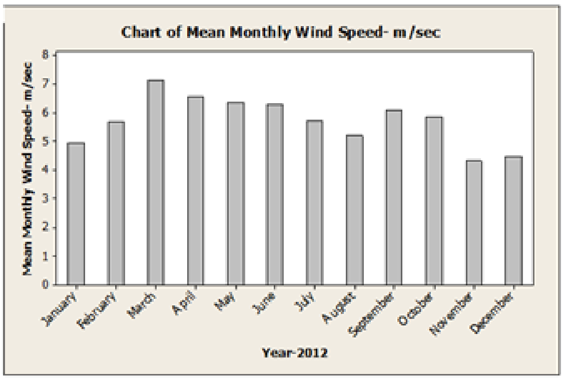


Fig .3. Mean monthly wind speed during year 2012 at Helwan.

The smallest wind generator WG available commercially is 420W (12V) and generates power equals to 25W (Fig. 5) at 4 m/s wind speed [4], 250Wh/day assuming 10 hours average running time at 4m/s or higher, which is sufficient to meet around 45% (250W from wind / 527 Load Demand) from the load demand.

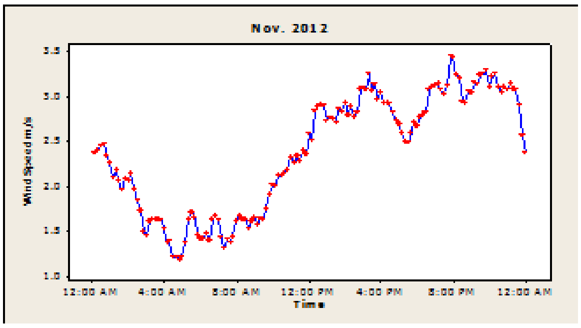


Fig .4. Average daily wind speed during November 2012.

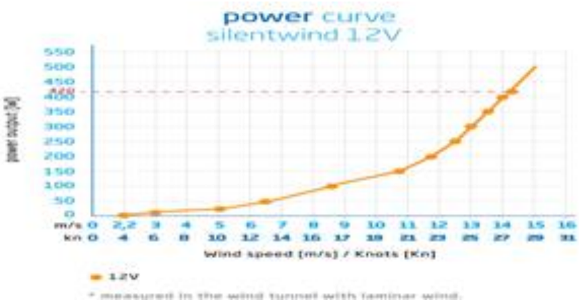


Fig .5. Output power curve for WT-420.

C. Battery module sizing

Finally, the battery sizing at nominal battery voltage 12V and Days of autonomy equal to 1.5 day with 30% deep of discharge, the size of battery capacity is chosen accordingly to be 100 Ah.

III. MODELLING

A computerized model of the system designed by the aid of Simulink/Matlab will be used to study different weather conditions and will be validated against the real-time data produced after installation of the system. Fig.6 shows a diagram of the main system components.

Journal of Renewable Energy and Sustainable Development (RESD) Volume 3, Issue 3, December 2017 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2017.03.3.258

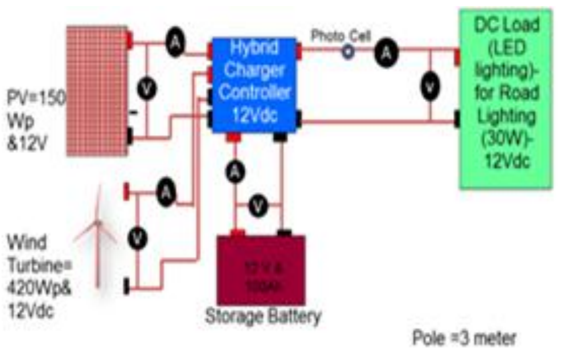


Fig .6. Diagram of main components of hybrid wind/PV road lighting system.

A. Wind system modelling

Wind system consists of wind turbine to convert kinetic energy to mechanical energy, permanent magnet synchronous generator to convert mechanical energy to electric energy and a rectifier to obtain DC supply as shown in Fig.7 and according to the following equations.

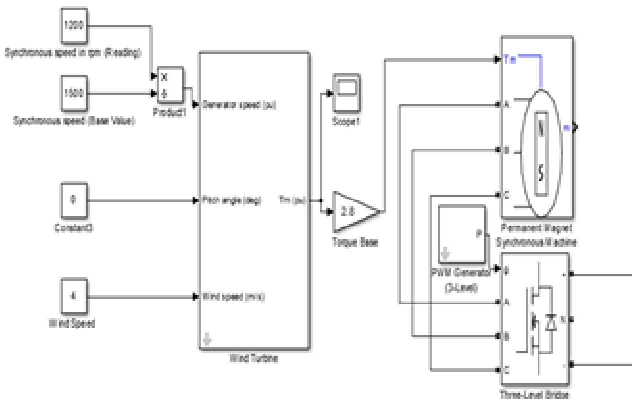


Fig .7. Wind system Model

1. Wind kinetic energy: [5]

K.E = 0.5 m v^2

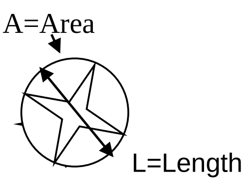
Where

1- m:mass = ρ V *(4)*

Where:

1.1 ρ = air density kg/m^3

1.2 V= volume = AL m^2.m



2- v: wind speed

Energy=power*time *(5)*

Power = energy/time

Power = 0.5 m v^2 /T

= 0.5 ρ V v^2 /T

= 0.5 ρ A L v^2/ T

Where:

T=time, L/T=v

Power in air =0.5ρAv^3 *(6)*

2. Wind turbine mechanical energy: [6]

The available energy part in wind is described by the power coefficient Cp.

P turbine = 0.5 ρ A v^3 Cp *(7)*

Where:

Cp is specification related and ranges from 0.4 to 0.5 for industrial turbines

The power coefficient is a function of the tip-speed ratio λ

$\lambda = r\,\Omega / v$ *(8)*

Where:

r is the rotor radius

Ω is the angular rotor speed.

3. Generator electrical energy:

Mechanical torque from the wind turbine is calculated by Simulink in pu of the nominal generator torque. The nominal torque of the generator is based on the nominal generator power and speed.

B. Photovoltaic modelling[7]

The equivalent circuit of a PV cell is as shown in figure 8.

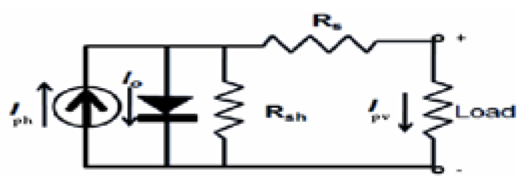


Fig .8. PV equivalent circuit

The current source Iph represents the cell photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis.

The photovoltaic panel can be modeled mathematically as given in equations (9) - (10) - (11) - (12).

Module photo-current:

Iph = [Iscr + Ki (T - 298)] * λ / 1000 *(9)*

Module reverse saturation current - Irs:

Irs = Iscr / [exp (q Voc / Ns K A T) - 1] *(10)*

The module saturation current Io varies with the cell temperature, which is given by

Io= Irs [T/Tr]^3 exp 〚 [(q*Ego)/(B K)〛 [1/Tr- 1/T]] *(11)*

The current output of PV module is

Ipv = Np * Iph - Np * Io [exp { (q * (Vpv + Ipv Rs))/(Ns A K T) } -1] *(12)*

Where:

Vpv is output voltage of a PV module (V), Ipv is output current of a PV module (A), Tr is the reference temperature = 298 K , T is the module operating temperature in Kelvin, Iph is the light generated current in a PV module (A), Io is the PV module saturation current (A), A = B is an ideality factor = 1.6, k is Boltzman constant = 1.3805×10^{-23} J/K, q is Electron charge = 1.6×10^{-19} C, R_s is the series resistance of a PV module ,I_{SCr} is the PV module short-circuit current at 25°C and 1000W/m^2 = 9.1A, Ki is the short-circuit current temperature co-efficient at I_{SCr} = 0.0017A /°C , λ is the PV module illumination (W/m^2) = 1000W/m^2 , Ego is the band gap for silicon = 1.1 eV, Ns is the number of cells connected in a series, and Np is the number of cells connected in parallel.

Reference model:

150W PV module is taken as the reference module for simulation and the name-plate details are given in Table 1.

Table 1. Electrical Characteristics of 150 W PV Module.

Rated Power	150 Wp
Voltage at maximum power (V_{mp})	18.1
Current at maximum power (I_{mp})	8.26
Open circuit voltage (V_{OC})	21.6
Short circuit current (I_{SCr})	9.1
Total number of cells in series (Ns)	36
Total number of cells in parallel (Np)	1

The electrical specifications are under test conditions of irradiance of 1 kW/m^2, and cell temperature of 25°C. By using the equations given with the Simulink modeling to be done in Fig.9.

C. Hybrid boost charger controller modeling

Hybrid charger controller is boost converter to convert variable DC to constant DC from both wind and PV systems as shown in Fig.10 [8].

D. Battery modelling

The lead acid gel battery is implemented with 30% state of charge (SOC) and resistive load lead system 12VDC, 2.5 amps, 30 watt, as shown in Fig.11.

The mechanism of the battery for charging and discharging is explained as follows: when SOC of the battery goes under 30%, the connected load with the battery will be removed; while when SOC goes to between 40% and 100%, the load is applied, so the battery only supplies the 2.5 amps load as shown in Fig.12.

http://dx.doi.org/10.21622/RESD.2017.03.3.258

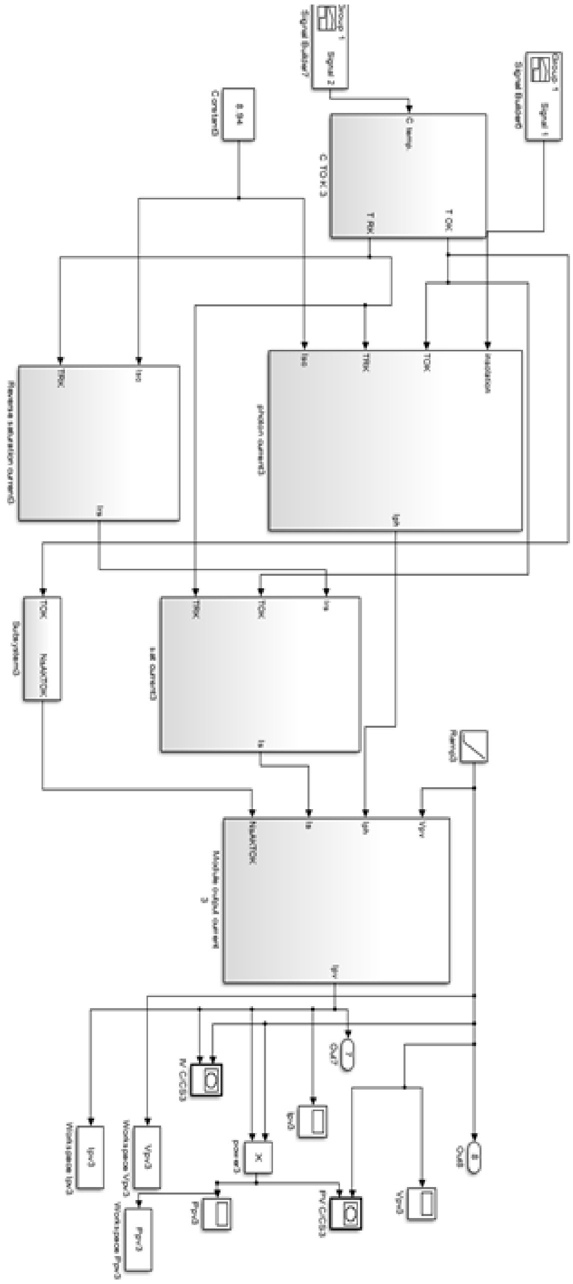


Fig .9. PV Simulink Model

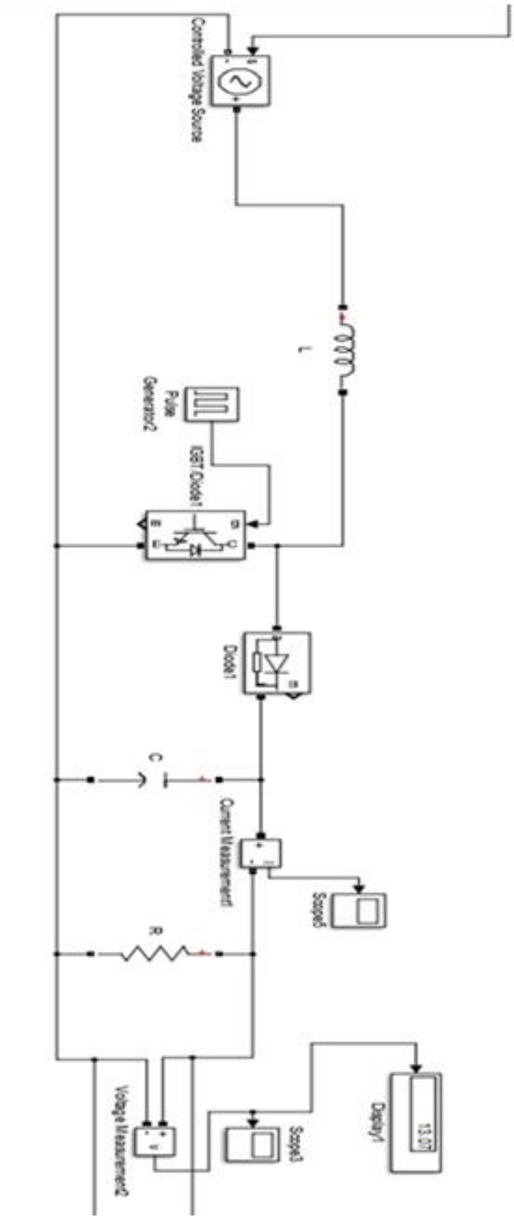


Fig .10. Hybrid boost charger controller modeling.

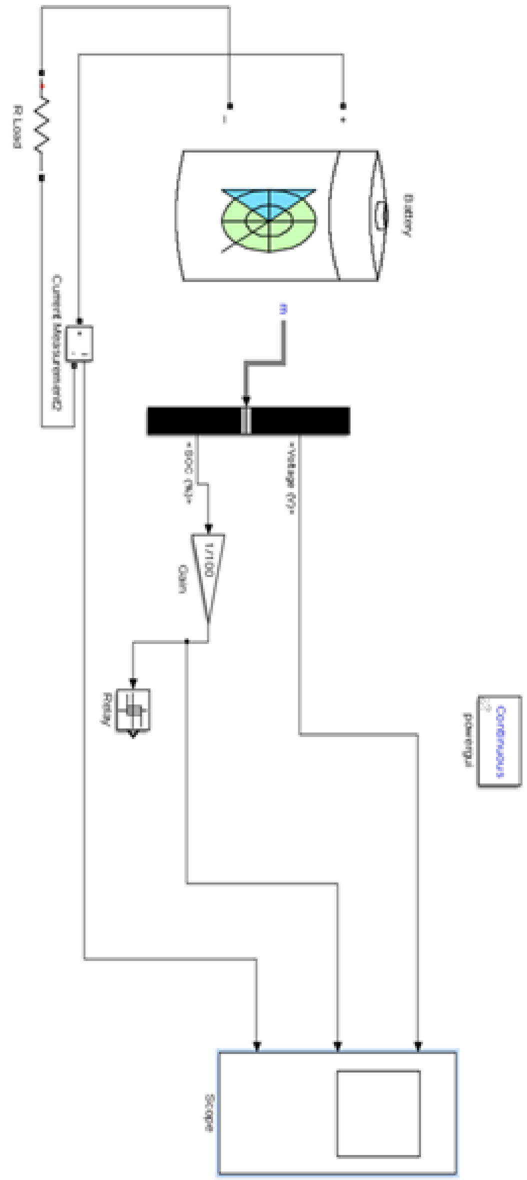


Fig .11. Lead-acid battery Simulink model.

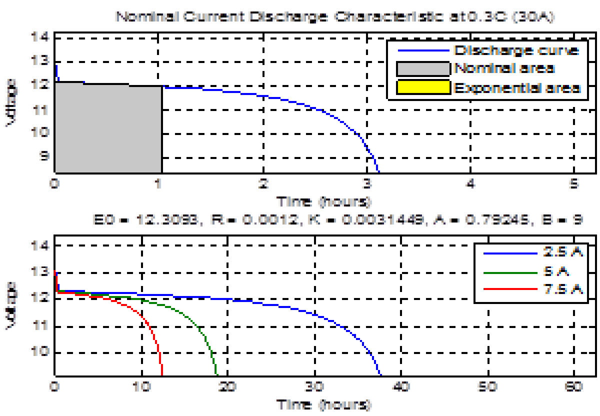


Fig .12. Battery discharge characteristics.

E. The hybrid PV / Wind / battery modeling with the load

Finally, all models are connected together as shown in Fig.13 to show the final waves formed from wind turbine and PV, their effects on the R load and storage of the extra energy in lead acid battery to maintain the system performance even in the worst weather conditions expected throughout the year.

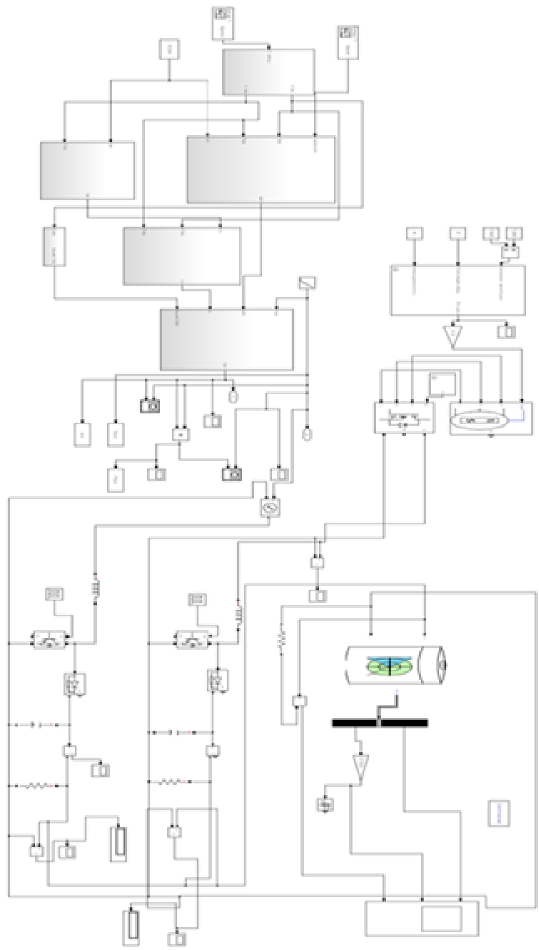


Fig.13 Full system Model

IV. RESULTS

The final model includes wind speed of 4 m/sec, temperature 25°C and irradiation of 600 watt/m^2 as input and gives the output for each module as follows:

A. Wind system modelling

For different wind speeds and for blade pitch angle β = 0 degree is illustrated below. Figure 14 is obtained with the default parameters (base wind speed = 4 m/s, maximum power at base wind speed = 0.06 pu (kp = 0.73) and base rotational speed =0.8 pu).

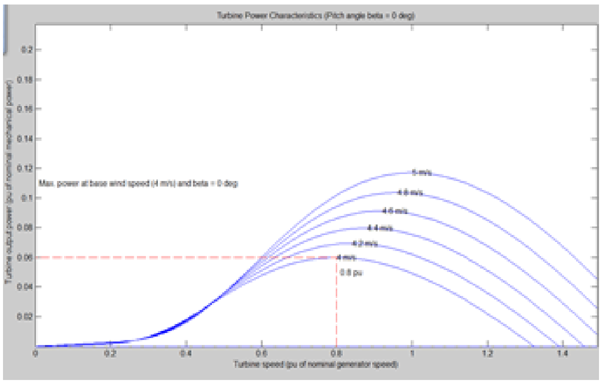


Fig .14. Turbine power characteristics with pitch angle = 0 degree

The mechanical power Pm as a function of generator speed,

For converting from P.U:

ns=120*f/p=1500r.p.m *(13)*

where p= no. of poles = 4 *(14)*

P.U=Reading/Base

Max. Power at 4 m/s acts 25 watt where P.U power = 0.06 at base power 420 watt

Torque=power/ω *(15)*

Where ω = 2 л ns / 60

Then torque base = 2.8 n.m

The mechanical torque is the output from wind turbine as shown in Fig.15 in negative mode, the negative torque is applied to the permanent magnet synchronous machine so it acts as a generator mode, the three-level bridge block is then used as AC-DC converter.

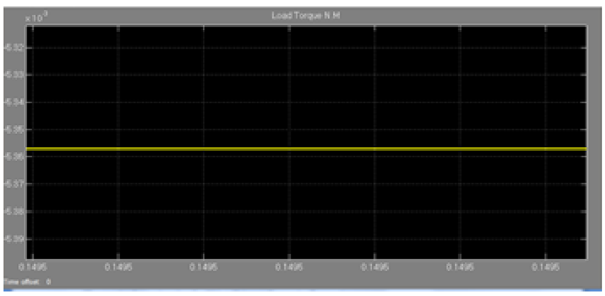


Fig .15. Wind turbine mechanical torque in negative mode.

B. Photovoltaic modelling

The PV module characteristics are estimated at different conditions as follows:

- I-V and P-V characteristics under different irradiation starting from 200W/m² to 1000W/m² at constant temperature 25ºC are obtained as shown in ffigures 16 and 17, respectively.

- I-V and P-V characteristics under different temperatures starting from 25ºC to 45ºC at constant irradiation are obtained as shown in

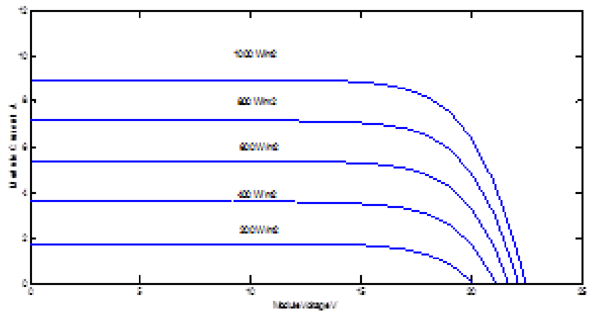


Fig.16. I-V characteristics under different irradiation at 25 ºC.

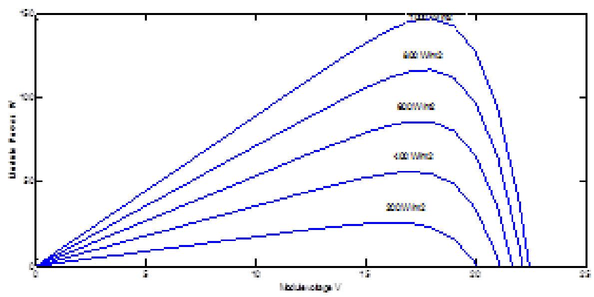


Fig.17. P-V characteristics under different irradiation at 25ºC.

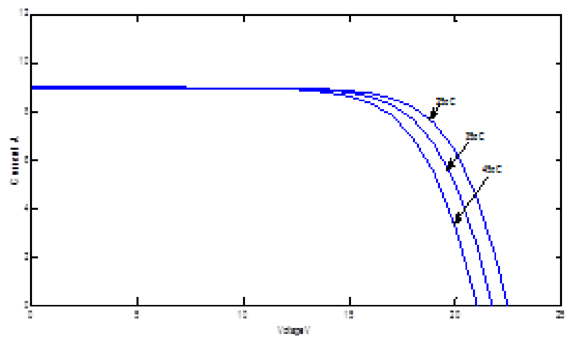


Fig.18. I-V characteristics under different temperatures.

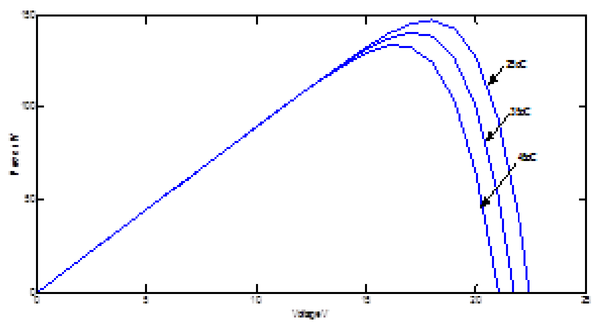


Fig.19. P-V characteristics under different temperatures.

C. Battery modelling

The power of the battery is dissipating through resistor and simultaneously charged by a DC voltage source from wind/PV module. The value of SOC (state of charge) is varying with changing the value of DC voltage source around 13V. If the DC voltage is more than the nominal voltage of battery, SOC will remain the same, while if the DC voltage is less than the nominal voltage of battery, SOC will decrease.

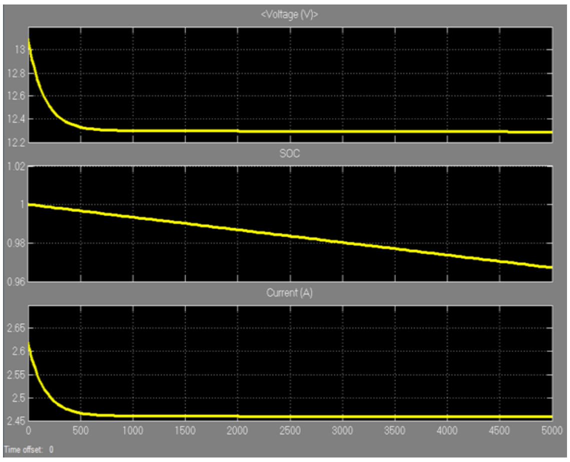


Fig.20. Results and system performance.

V. RESEARCH IN PROGRESS

The results generated by Simulink/Matlab model will be compared and validated against the real-time data produced by the system currently being installed in Faculty of Engineering, Helwan University facility, the differences – if any - found between the computerized model and the practical application will be used to either apply correction factor or refine the model to give more accurate estimation. The model will then be used to adapt the system to different weather conditions in different geographical locations. The possibility of diverting the extra energy to be used to power an advertisement installed on the pole is also under research.

VI. CONCLUSION

The step-by-step procedure for sizing and modeling a PV/wind hybrid road lighting system is presented, the performance of the hybrid PV/Wind system was investigated to utilize road lighting pole with DC - R load by using Matlab/Simulink simulation at starting wind speed of 4 m/sec and solar irradiation of 600 W/m^2 at constant temperature 25^{o}C after analyzing the geography and weather data from National Research Institute of Astronomy and Geophysics. The system components were optimized and chosen to be 150W photovoltaic module, 420W wind generator, 100Ah acid gel battery and LED lighting luminar 30W - 12VDC. Simulink/Matlab model results showed that the system will perform efficiently even under the worst environmental condition. After the current work in progress, the researchers can compare and present accurate dynamic performance of solar and wind energy system of each case to validate the sizing and the modeling system with the real-time system implementation to develop a unit sizing method which avoids complexity in the design of the hybrid system.

REFERENCES

[1] V. Khare, S. Nemaand P, Baredar. “Solar–wind hybrid renewable energy system: A review,” Renewable and Sustainable Energy Reviews, vol. 58, pp. 23–33, 2016.

[2] H. Ibrahim, M. Dimitrova, Y. Dutil, D. Rousse, A. Ilincaand J. Perron. "Wind-Diesel hybrid system: Energy storage system selection method ",Innostock 2012 The 12th International Conference on Energy Storage, INNO-S-14.

[3] A. E. Ghitas, A. Abulwfa and Y.A. Abdel-Hadi. "An assessment of wind energy potential as a power generation source in Helwan," Journal of Clean Energy Technologies, vol. 4, no. 6, pp 453-456, November 2016.

[4] www.silentwindgenerator.com

[5] K.R. Ajao, O.A.Oladosu and O.T. Popoola. “Using Homer power optimization software for cost benefit analysis of hybrid-solar power generation relative to utility cost in Nigeria,” Available: www.arpapress.com/Volumes/Vol7Issue1/IJRRA S_7_1_14.pdf [April 2011].

[6] A. Pachori and P. Suhane. “Design and modelling of standalone hybrid power system with Matlab/Simulink,” International Journal of Scientific Research and Management Studies (IJSRMS) ISSN: 2349-3771 vol. 1, Iss. 2, pp 65-71, May 2014.

[7] N. Pandiarajan and R. Muthu. “Mathematical modeling of photovoltaic module with Simulink,” International Conference on Electrical Energy

Systems (ICEES 2011), pp. 314-319, 3-5 Jan. 2011.

[8] R. Silva-Ortigoza, M. Antonio-Cruz, M. Marcelino-Aranda, G. Saldaña-González ,C. A. Merlo-Zapata and P. Pérez-Romero. ‘‘DC/DC Boost-Boost power converter as a didactic system: Experimental results with Matlab/Simulink via current and voltage probes,’’Available: http://dx.doi.org/10.5772/58243 [2014]