DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

Simplified Approach for Modeling a PV/Wind Hybrid Renewable Energy systemusing Simulink/Matalab.

Ngang, N.B[1], ,E.N.C. Okafor[2],D. Nnadi[3]
Department of Electrical /Electronic Engineering,
Enugu State University of Science and Technology, Enugu.

Abstract
Photovoltaic (PV) array which is composed of modules is considered as the fundamental power conversionunit of a PV generator system. The PV array has nonlinear characteristics and it is quite expensive and takesmuch time to get the operating curves of PV array under varying operating conditions. In order to overcome these obstacles, common and simple models of solar panel have been developed and integrated to many engineeringsoftware including Matlab/Simulink. However, these models are not adequate for application involving hybrid energysystem since they need a flexible tuning of some parameters in the system and not easily understandable for readersto use by themselves. Therefore, this paper presents a step-by-step procedure for the simulation of PV cells/modules/arrays with Tag tools in Matlab/Simulink. A 200-Watt solar panel is used as reference model. The output characteristics curves of the model match the characteristics of the solar panel after simulation. The mathematical modeling of the PVwas demonstrated step by step, Wind Turbine performance was simulated and observed, the output voltage of the turbine was 240V matched the calculated value.
A step-by-step procedure for simulating a PV array with Tag tools, using friendly icons and dialogs in Matlab/Simulink block libraries is shown in this work. This modeling procedure serves as an aid to help people understand the I–V and P–V operating curves of PV module. The research is the first step to study a hybrid system where a PV power generation connecting to other renewable energy production sources like wind or biomass energy systems is applied and simplified.

KEY WORDS: Photovoltaic array, Matlab/Simulink, Hybrid, Tag

1. INTRODUCTION

Solar (PV) systems capture the sunlight and directly convert it into electricity. Photovoltaic (PV) cell is the basic element of a PV system. A photovoltaic cell is a semiconductor diode whose p-n junction is open to the light. When sunlight strikes the solar cell junction, free electrons and holes are generated and a current is delivered to the load when it is short circuited. A grouping of PV cells forms a solar panel. To obtain large output voltage solar panels are formed by connecting PV cells in series and to achieve large output current cells are connected in parallel. A function in Matlab environment was developed to calculate the current output from the following parameters: Voltage, solarirradiation and temperature in the study of [1].
A method which appliesMatlab m-file and C-language programming iseven more difficult to clarify [2].Another writerproposed amodel based onsolar cell and array's mathematical equations and builtwith common blocks in Simulink environment in [3,4,5 and 6].

Rated output power and rate output wind speed.

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly too. The limit to the generator output is called therated power outputand the wind speed at which it is reached is called therated output wind speed.At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. How this is done varies from design to design but typically with large turbines, it is done by adjusting the blade angles so as to keep the power at theconstant level.

2. MATERIALS AND METHODS

Components description

The configuration used in Fig. 1consists of wind energy and PV energy systems,DG, battery bank, charge controller, bidirectional converter, main load, and dummyload. The dispatch of this configuration is easy to be understood. The main load issupplied primarily from the WT and PV array through the bidirectional converter.

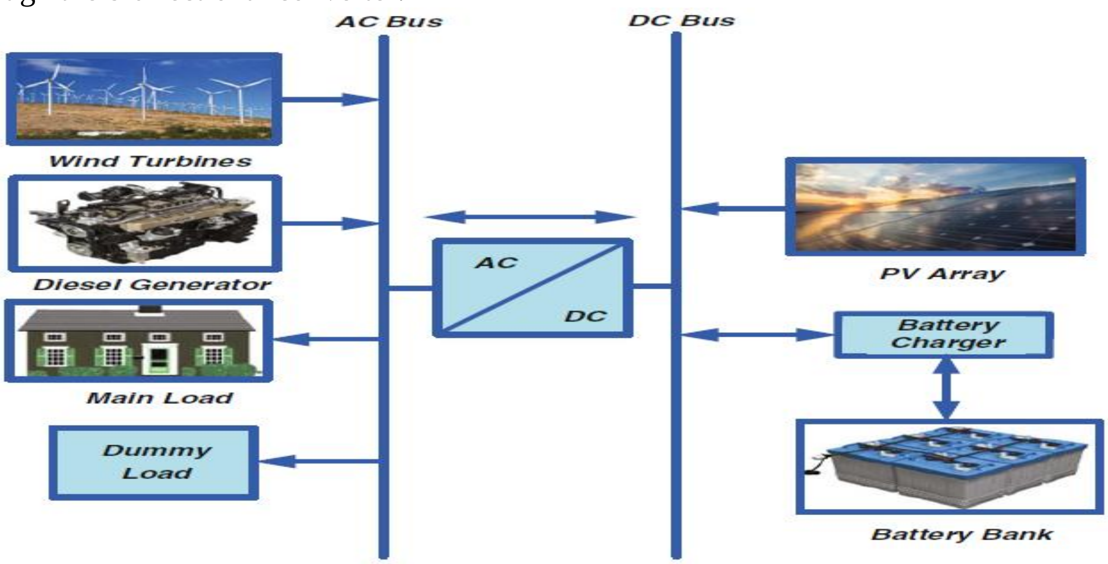

Fig. 2 Schematic diagram of the hybrid PV/wind/diesel/battery energy system courtesy of(SpringerInternational Publishing)

The excess power from the wind energy system and/or PV energy system above theload demand is stored in the battery bank until the batteries are completely charged.

If the battery storage is full; excess power (i.e., dummy power) will be used to supply certain special loads (i.e., dummy loads), such as loads for cooling and heating purposes, water pumping, and charging the batteries of emergency lights. used. Mathematical modeling of the proposed HRES parts is detailed in the following subsections. Among other authors, a proposed model is based on

solar cell and array's mathematical equations and builtwith common blocks in Simulink environment in [7,8,9 and 10]. In these studies, the effect of environmental conditions (solar insolation and temperature), and physical parameters (diode's quality factor, series resistance Rs, shunt was discussed and noted.

A step-by-step procedure for simulating PV module with subsystem blocks with user-friendly icons and dialog in the same approach with Tarak Salmi and Savita Nema was developed by Jena, Pandiarajan and Muthu et al. However, the biggest gap of the studies mentioned above is shortage of

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

considering the effect of partially shading condition on solar PV panel's operation. In other researches, authors used empirical data and Lookup Table or Curve Fitting Tool (CFtool) to build P–V and I–V characteristics of solar module [11]. The disadvantage of this method is that it is quite challenging or even unable to collect sufficient datafor its application.From the work of[12] and [13], a solar cell block which hasalready been built in Simscape/Simulink environment is employed. With this block, the input parameters such as short circuit current, open circuit voltage, etc. areprovided by manufacturers. The negative point of this approach is that some parameters including saturation current, temperature,and so on cannot be evaluated.Solar model developed with Tag tools in Simulink environmentis recorded in the research of [14], and [15], etc. In these papers, only twoaspects (solar irradiation and temperature) are investigated without providing step-by-step simulation procedure. Hence,lack of presenting step-by-step simulation procedure is a concern for readers and researchersto follow and do simulation by themselves.Therefore, the study proposes an easy model built with Tag tools in Simulink environment. The proposed model shows strength in investigating all parameters' influence on solar PV array's operation. In addition, a unique stepby-step modeling procedure shown allows readers to follow and simulate by themselves to do research.

3.0 METHODS

Modeling the system with equations and Building the Simulink Block Diagram is the first step in realising the first objective.

(a) Modeling of the PV Array,1 shows the equivalent circuit of a PV cell.

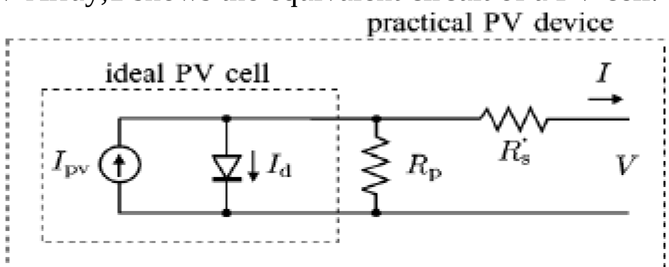

Fig.1: Equivalent circuit of a PV cell

The current source Iph is the PV cell photocurrent. Rsh and Rs are the shunt and series resistances of the cell, (internal resistance). The value of Rsh is always of large magnitude and that of Rs is usually very small, hence they may be neglected to simplify the analysis [16]. Practically, PV cells are arranged in larger segments called PV modules and these segments are connected in series or parallel to represent PV arrays which are used to produce electricity in Photovoltaic systems. The equivalent circuit for PV array is shown in Fig.1 The voltage–current characteristic equation of a solar cell is provided as [17].

Module photo-current,Iph = [Isc + Ki(T − 298)] × Ir/1000 (1)

Here, Iph: photo-current (A); Isc: short circuit current (A); Ki: short-circuit current of cell at 25 °C and 1000 W/m^2;T: operating temperature (K); Ir: solar irradiation (W/m^2).Module reverse saturation current $I_{rs}$is expressed as [18]

$I_{rs} = I_{sc}/[exp(qV_{OC}/NSknT) - 1]$ (2)

Here, q: electron charge, = 1.6 × 10^{-19}C; V_{oc}: open circuit voltage (V); Ns: number of cells connected inseries; n: the ideality factor of the diode;

k: Boltzmann's constant, = 1.3805 × 10^{-23} J/K.

Where Ipv, cell = incident light current (which is directly proportional to the sun radiation),

Id = Shockley diode equation

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

I_{rsat}, cell = reverse saturation or leakage current of the diode
q = electron charge (1.60217646 x 10-19 C)
k = Boltzmann constant (1.3806503 x 10-23 J/K)
T = temperature of the p-n junction
a = diode ideality constant
The module saturation current Isat varies with the cell temperature, which is given by [19] :

$$I_{sat} = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \tag{3}$$

Here, T_r: nominal temperature = 298.15 K; E_{g0}: band gap energy of the semiconductor, = 1.1 eV; The current output of PV module is:(Nguyen, 2015)

$$I = N_P \times I_{ph} - N_p \times 1_0 \times \left[\exp\left(\frac{V/N_s + 1 \times R_s/N_p}{n \times V_t}\right) - 1\right] - 1_{sh} \tag{4}$$

With:

$$V_t = \frac{k \times T}{q} \tag{5}$$

And (Nguyen,2015)

$$I_{sh} = \frac{V \times N_p/N_s + I \times R_s}{R_{sh}} \tag{6}$$

Here: N_p: number of PV modules connected in parallel; R_s: series resistance (Ω); R_{sh}: shunt resistance (Ω); V_t: diode thermal voltage (V).
Our reference model is a 200W solar power module that is specified for installation. The characteristics are obtained from the manufacturer as shown in table 1.

Table 1:Electrical parameters for PV array

S/NO	PARAMETERS	VALUES
1	Maximum Power	200W
2	Maximum Power Voltage	24.6V
3	Maximum Power Current	8.13A
4	Open Circuit Voltage	30V
5	Short Circuit Current	8.56A
6	Reference Temperature	25°C
7	Module Efficency	15.3%
8	Solar cell efficiency	17.2%
9	Maximum system voltage	1000V DC
10	Operating temperature	-40^{0}C – 85^{0}c (36^{0}C)
11	Total number of cells in parallel	72 (6x12)
12	Total number of cells in series1	

All electrical specifications are under test conditions of Irradiance of I kW/m^2,and cell temperature 25^0C.

3.1 (a)Procedure for Modeling Solar PV Step by step

The modeling of the PV array has to do with the diode equivalent circuit fundamentalequations;this will cover diode current source,series resistor,and parallel resistor. The entire modeling will be done with tags in simulink environment.The simulation will be based on the equations stated above,that is (1) Module photocurrent (2) Module reverse saturation current,(3)Module Saturation current(4)The current output of PV model. (5) Vt thermal voltage, (6) shunt current I_{sh}

The equation given in[19] for Isat =$I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]$

A mathematical model of PV array including fundamental components of diode, current source, series resistor and parallel resistor is considered with Tags and modeled in Simulink environment. (http://mathwork.com). The simulation of solar module is from the equations given in the previous section and will be followed sequentially.

Step 1:Provision of input parameters

Input parameters for modeling are required,: These values are: Tr is reference temperature = 298K that is(273+25);n is ideality factor = 1.2; k is Boltzmann constant = 1.3805×10^{-23} J/K; q is electron charge = 1.6×10^{-19}; Isc is PV module short circuit current at 25 °C and 1000 W/m2 = 8.56A; Voc is PV module open circuit voltage at 25 °C and 1000 W/m^2 = 30 V; E_{g0} is the band gap energy for silicon = 1.1 eV. Rs is series resistor, normally the value of this one is very small, = 0.0001 Ω; Rsh is shunt resistor, the value of this is so large, = 1000 Ω.

3.2 Step 2

Module photon-current is given in Eq. (3.1) and modeled as Fig.3.8 (Ir0 = 1000 W/m2).

Iph = [Isc + Ki(T − 298)] × Ir/1000 (7)

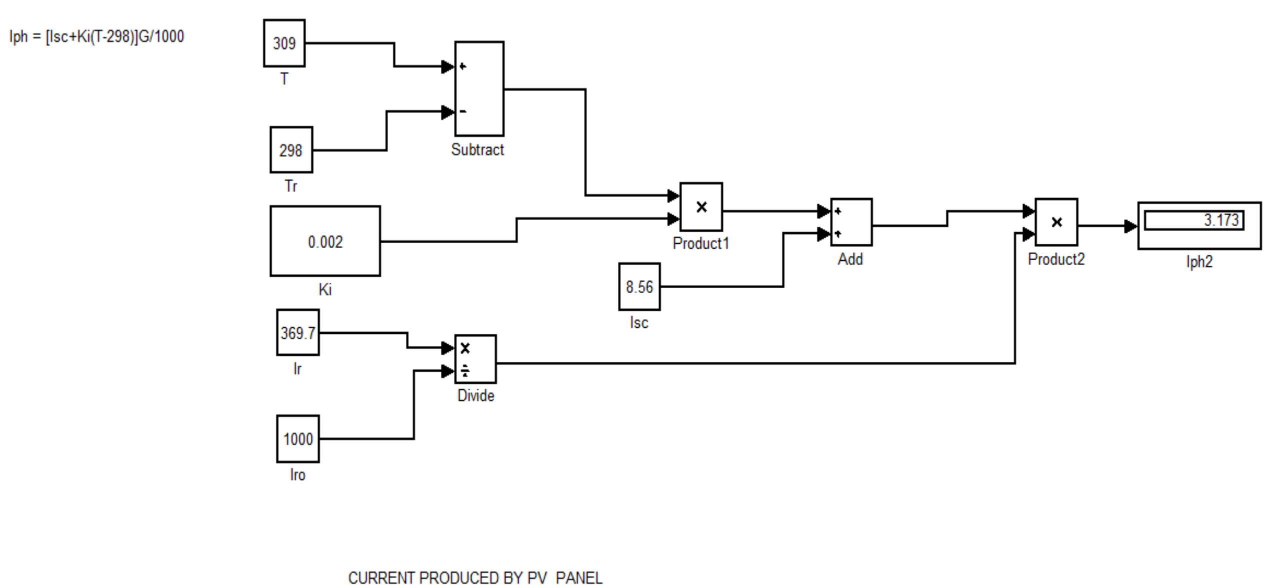

Fig. 2: Modeled circuit of equation 1 PV photo current.

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

3.3 Step3: Module reverse saturation current from equation 2 $I_{rs} = I_{sc}/[exp(qV_{OC}/NSknT) - 1]$
Module reverse saturation current is given in Eq. (2) and modeled as Fig 9.

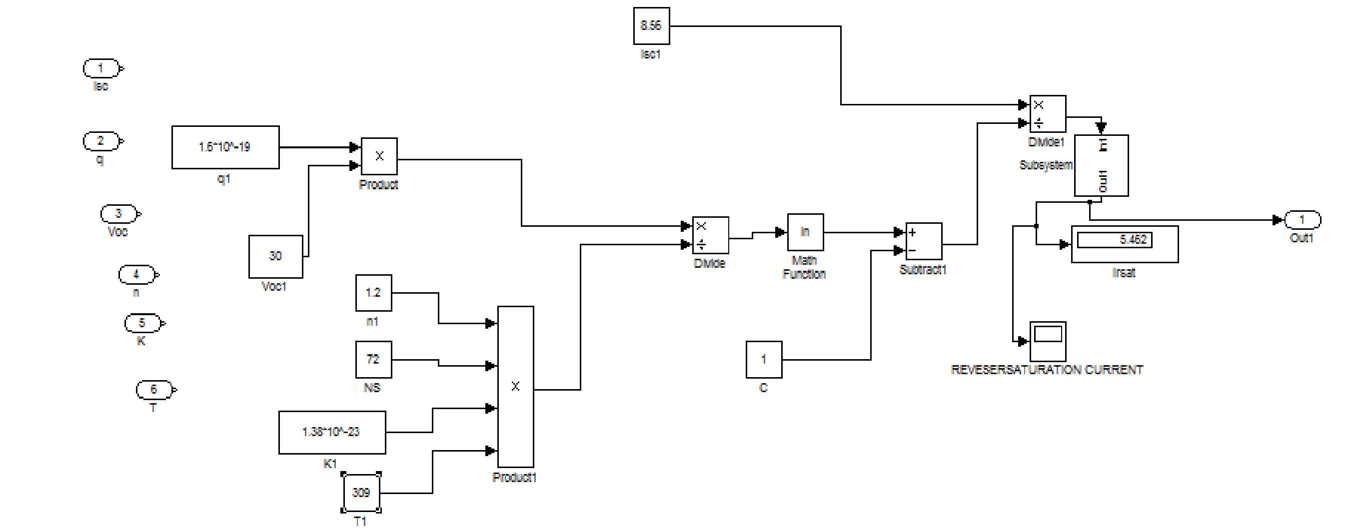

Fig.3 Modeled circuit for equation 2 reverse saturation current $I_{rsat} = I_{sc}/[exp(qV_{OC}/NSknT) - 1]$

3.4 step 4 to calculate the module saturation current I_{sat}, as given in equation3
$I_{sat} = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]$ and modeled as figure 4

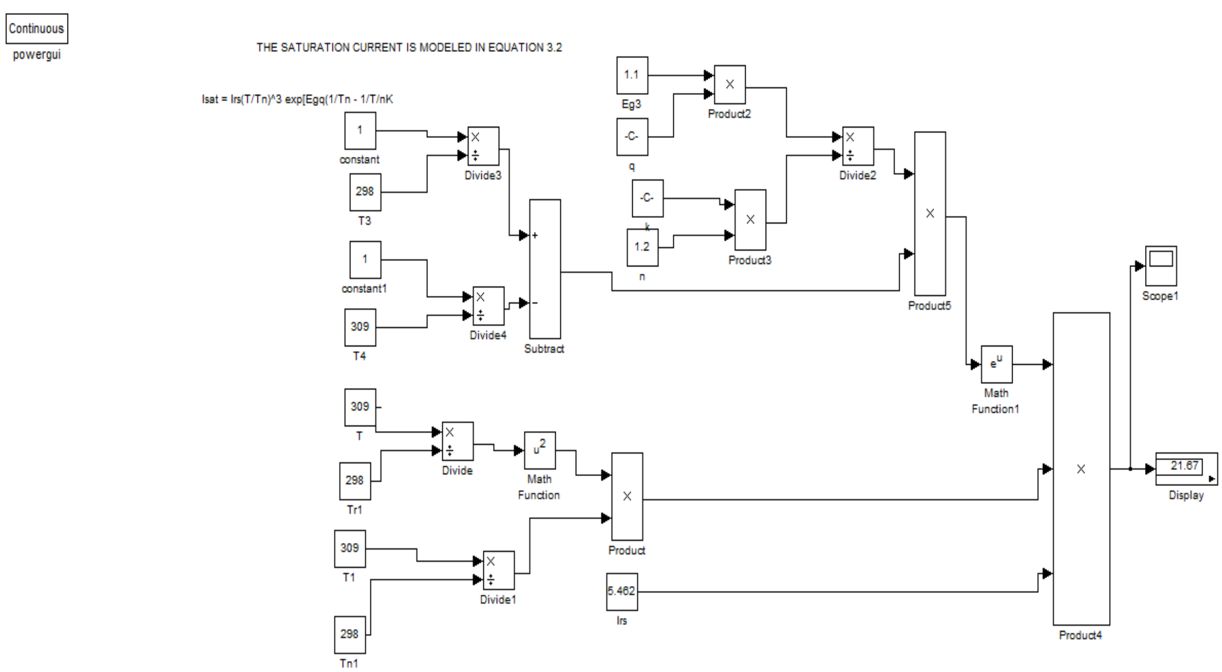

Fig.4: Modeled circuit for equation 3

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

3.5 Step 5

A modeled circuit for equation 3.6 is shown in figure 3.11,where the inputs are expressed in order to calculate the shunt current given as $I_{sh} = \frac{V \times N_p / N_s + I \times R_s}{R_{sh}}$

In this equation,N_p is the number of PV modules connected in parallel;R: series resistance in ohms;R_{sh} is the shunt resistance while Vt is the diode thermal voltage(v_t).The 200W solar panel is chosen as the reference module for simulation and the detailed parameters of module expressed as in table 3.

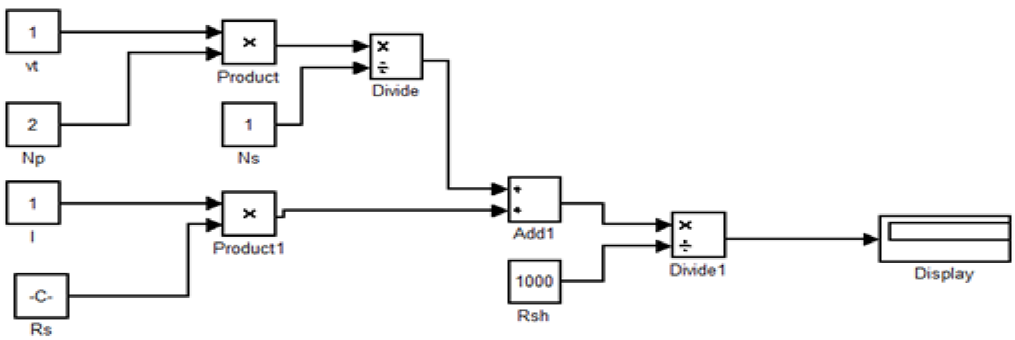

Fig.5: Modeled Circuit for shunt current of Equation 3.6

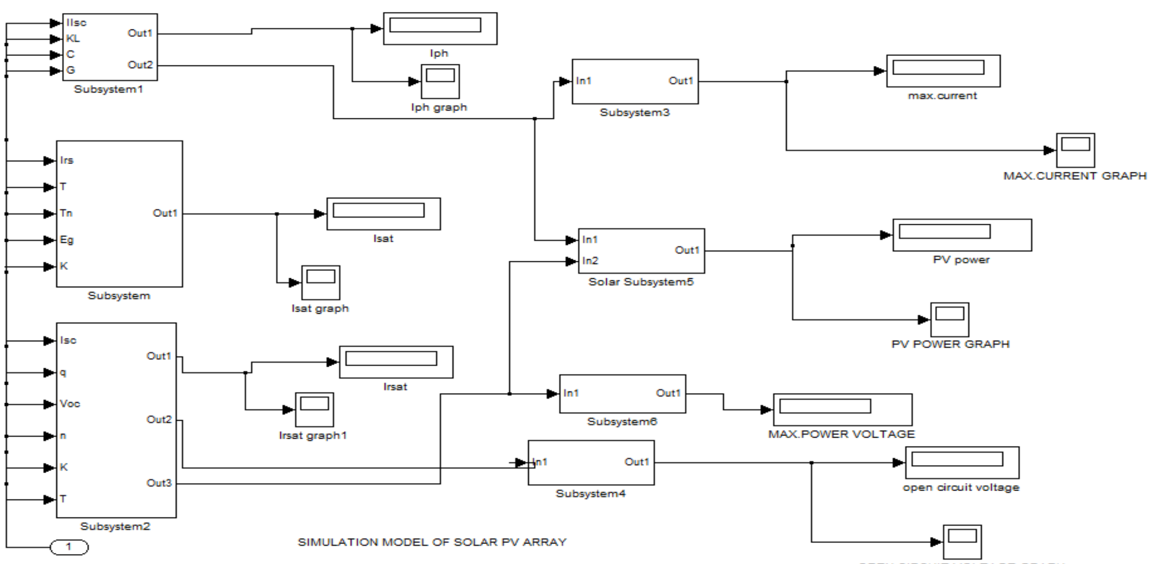

Fig.6: Interconnection of all subsystems of PV Module.

(b) Modeling of Wind Turbine

Wind energy falls under the class of a clean, friendly and endless source of energy. Therefore, a wind energy system is one of the preferred sources of alternative energy for the future demand. A wind turbine changes the, kinetic energy of wind into mechanical energy. The amount of this converted mechanical energy depends on the air density and the wind velocity. The power developed by the wind comes from the turbine and is expressed as

$1/2Cp(\lambda,\beta)\rho AW^3$ (8)

Where

P_m power captured by wind turbine

ρ=Air density,β=Pitch angle (in degrees),r = Blade radius (in meters)

W= Wind Velocity (in m/s), the term λ is the tip-speed ratio, given by the equation

$\lambda = wr/V$ (9)

Where w = rotor speed of rotation in (rad/sec)

Cp can be expressed as the function of the tip speed ratio (λ)[20](Ochieng, 2014)

$$C_p = 1/2\left[\frac{116}{\lambda 1} - 0.4\,\beta - 5\right] \exp^{-165/\lambda} \quad (10)$$

$$\lambda_1 = \left(\frac{1}{\frac{1}{\lambda + 0.089} - \frac{0.035}{\beta^3 + 1}} \right)$$

(Ochieng, 2014) (11)

λ =Tip speed ratio

λ_1= constant

Where CP = performance coefficient of turbine

ρ = air density (kg/m3)

A = area of turbine blades (m3)

w = wind velocity (m/sec)

λ = tip speed ratio of the rotor blade tip speed to wind speed

β = blade pitch angle (deg)

The coefficient CP is the fraction of kinetic energy which is converted by wind turbine into mechanical energy. It is
related to the tip speed ratio (λ).Wind turbine output torque (T_m) can be calculated using equation [21](Anjali Rana,2015):

$$T_m = \frac{1}{2}\rho A C_p \frac{w}{\lambda} \quad (12)$$

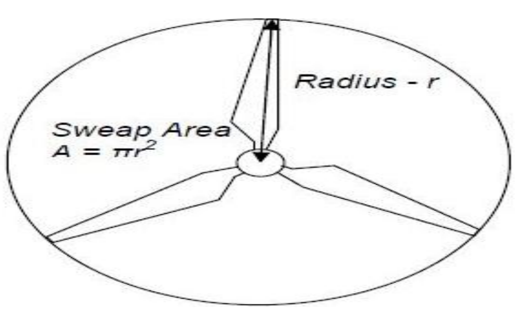

Fig. 7: Wind Turbine Blade

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

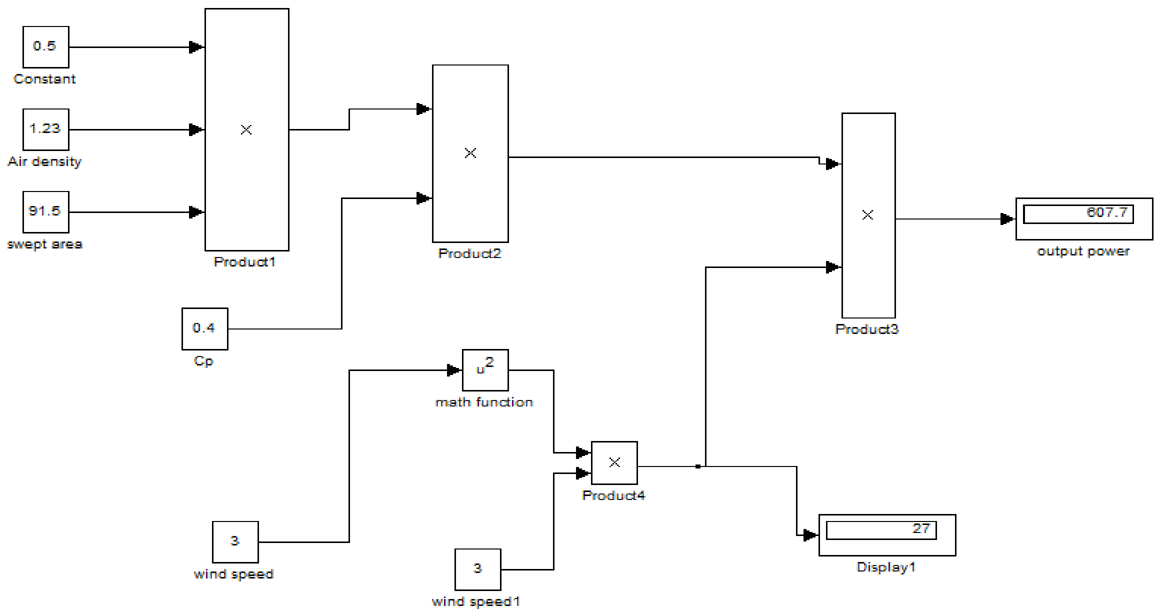

Fig. 8: Wind Turbine Model in Simulink equation 8.(1/2Cp(λ,β)ρAW^{3})

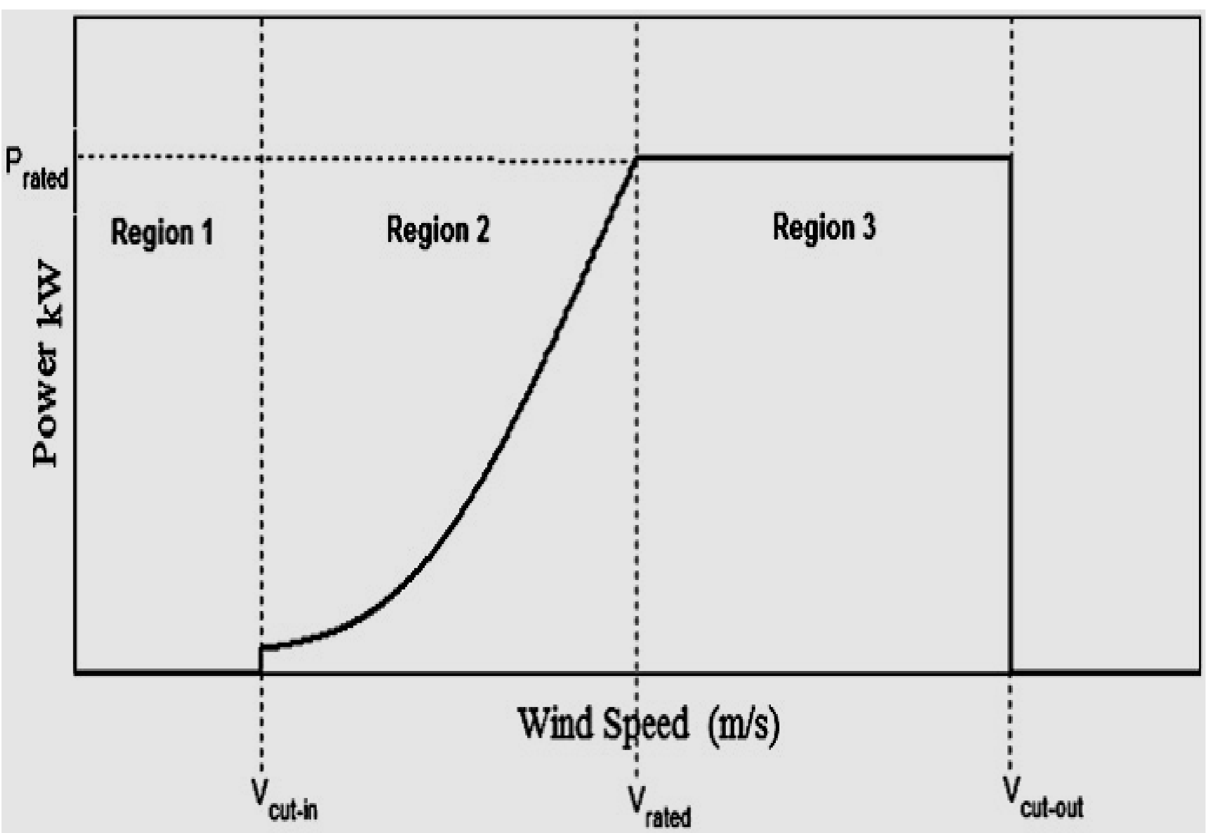

Fig. 9: Ideal power curve of wind turbine courtesy of (Anjali Rana,2015)

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

This wind turbine is connected to a three phase synchronous generator which converts this mechanical power into electrical power. A single turbine is used in this work.

(c) Modeling of Hybrid PV/Wind System

A collection of Wind and PV energy system into a hybrid generation system can increase their efficiency by boosting their overall energy output, by reducing energy storage requirement. This makes system less costly and more reliable as compared to individual energy system.

A hybrid system of wind and PV connected together is simulated. It consists of a converter with PWM generator and voltage source converter which convert DC to AC of grid frequency. A Simulink model of hybrid system is shown in fig.10

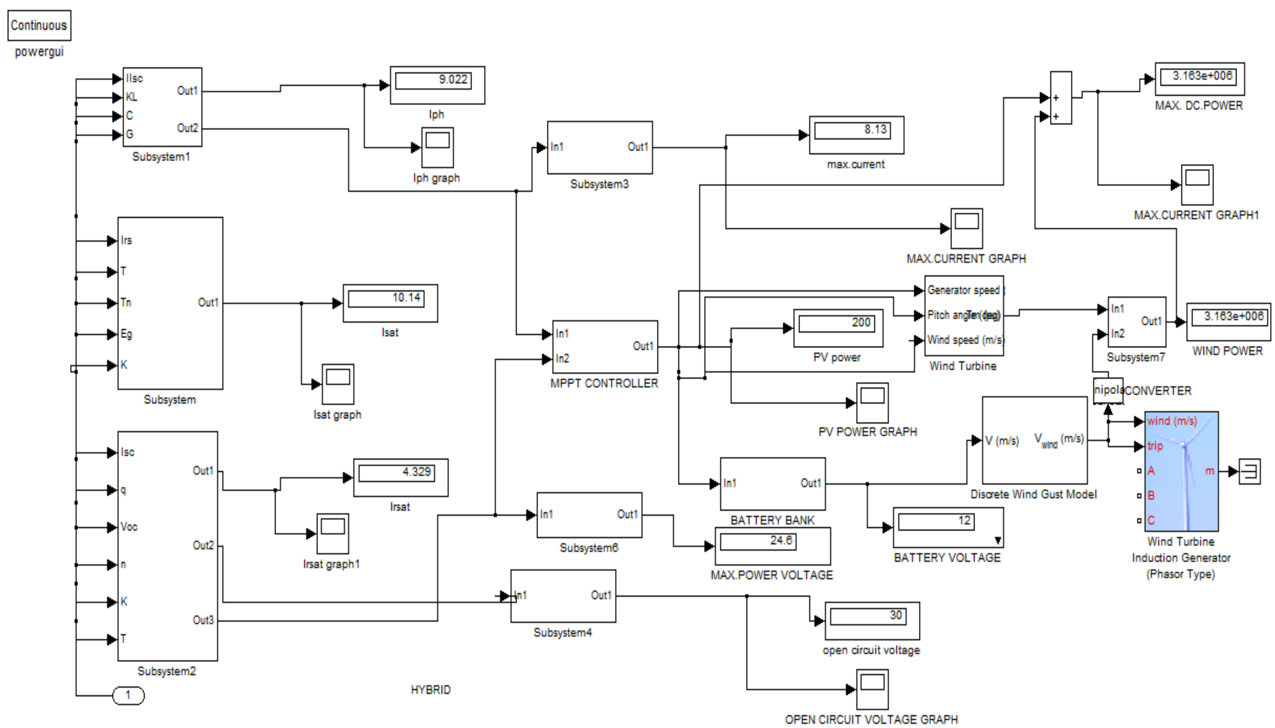

Fig. 10: Complete Simulink model of HRES wind/PV/Battery hybrid system

1. PV model in SIMULINK was simulated.
2. Wind Turbine performance was simulated and observed.
3. Battery Bank was modeled and simulated for charging and discharging capability.
4. The Hybrid Renewable Energy SystemHRES) was used to power or supply electric energy to the residential Area. Simulation was done using and inductive motor that consumed the same load current as the residential load equivalent in rural area,.

The graphs of figures11 and 12 showed the output curves of the generated parameters

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

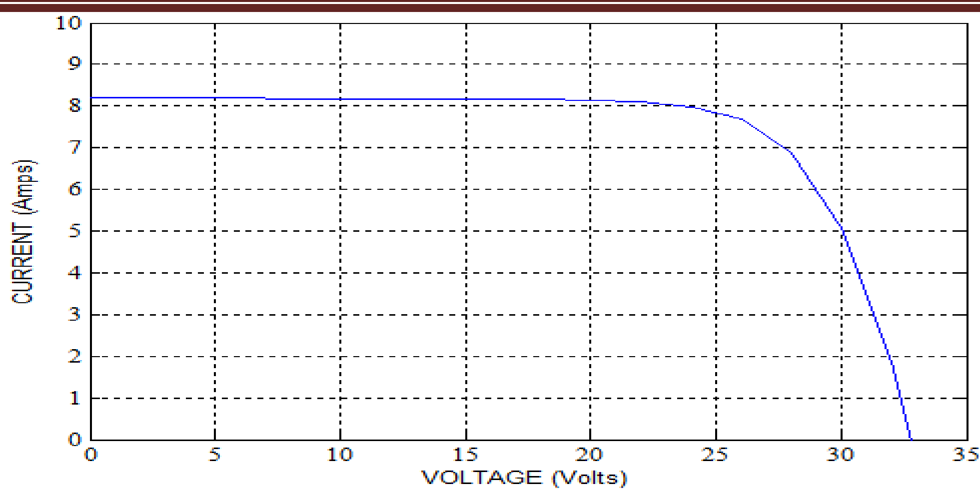

Fig.11: current –voltage curve of Photovoltaic Module

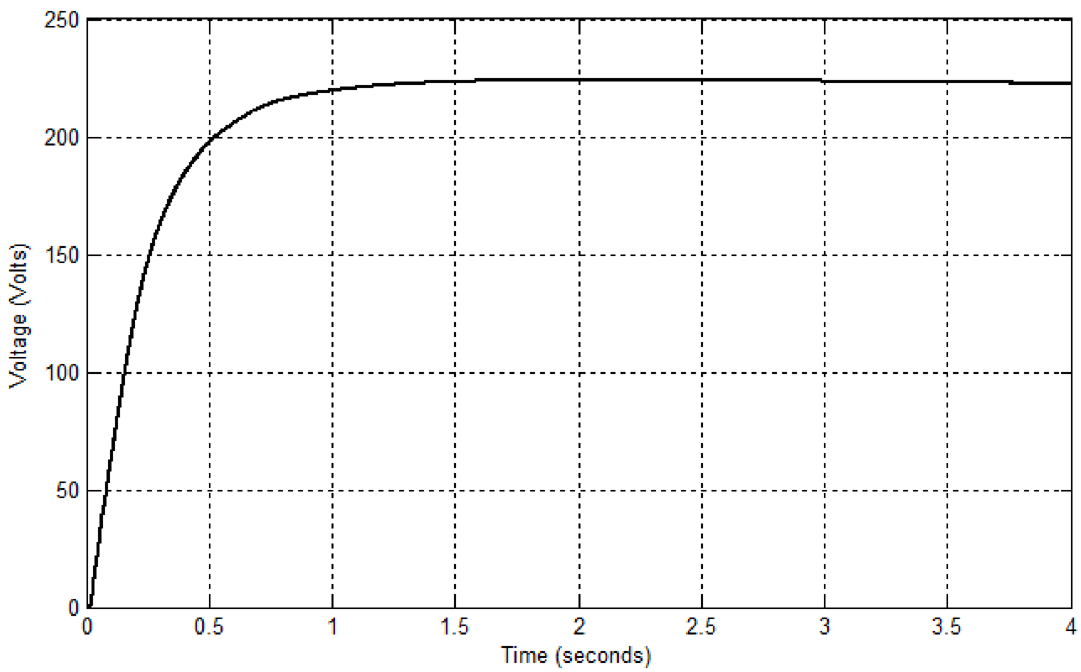

Fig. 12:Output voltage of a wind turbine

4.0 RESULTS AND DISCUSSION

The mathematical modeling of the PV was done step by step from fig.2 to fig.8, Wind Turbine performance was simulated and observed, the output voltage of the turbine was 240V, matched the calculated value.

A step-by-step procedure for simulating a PV array with Tag tools, using friendly icons and dialogues in Matlab/Simulink block libraries is shownfig5 and 6 respectively, where the simplified procedure was explained using SIMULINK.

5.0 CONCLUSION

A step by step method for simulating PV array and wind turbine with tag tools and user friendly icons and dialogs in Matlab/Simulink block libraries is illustrated.This modeling approach serves as an aid

DOI : https://dx.doi.org/10.26808/rs.ed.i9v6.05
International Journal of Emerging Trends in Engineering and Development Issue 9, Vol. 6(Oct-Nov 2019)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

to help people to have a deeper understanding of I-V and P-Voperating curves of PV module.This paper is a step to study a hybrid system where a PV power generation connecting to other renewable Energy production sources like wind or biomas energy system are applied.

References

[1] Walker G (2001) Evaluating MPPT converter topologies using a Matlab PV Model, j electrical engineering Aust 21(1):7

[2] Gow JA, Manning CD (1999) Development of a photovoltaic array model for use in power-electronics simulation studies. IEEE Proc Electr Power Appl 146(2):8

[3] Salmi T, Bouzguenda M, Gastli A, Masmoudi A (2012) Matlab/simulink based modelling of solar photovoltaic cell. Int J Renew Energy Res 2(2):6

[4] Panwar S, Saini RP (2012) Development and simulation photovoltaic model using Matlab/Simulink and its parameter extraction. International conference on computing and control engineering (ICCCE 2012)

[5] Savita Nema RKN, Agnihotri Gayatri (2010) Matlab/Simulink based study of photovoltaic cells/modules/arrays and their experimental verification. Int J Energy Environ 1(3):14

[6] Sudeepika P, Khan GMG (2014) Analysis of mathematical model of PV cell module in Matlab/Simulink environment. Int J Adv Res Electr Electr Instrum Eng 3(3):7

[7] Salmi T, Bouzguenda M, Gastli A, Masmoudi A (2012) Matlab/simulink based modelling of solar photovoltaic cell. Int J Renew Energy Res 2(2):6

[8] Panwar S, Saini RP (2012) Development and simulation photovoltaic model using Matlab/Simulink and its parameter extraction. International conference on computing and control engineering (ICCCE 2012)

[9] Savita Nema RKN, Agnihotri Gayatri (2010) Matlab/Simulink based study of photovoltaic cells/modules/arrays and their experimental verification. Int J Energy Environ 1(3):14

[10] Sudeepika P, Khan GMG (2014) Analysis of mathematical model of PV cell module in Matlab/Simulink environment. Int J Adv Res ElectrInstrum Eng 3(3):7

[11] Banu I-V, Istrate M (2012) Modeling and simulation of photovoltaic arrays. World energy system conference, p 6 Gonzalez-Longatt FM (2005) Model of photovoltaic module in Matab. II
CIBELEC 2005, vol 2005, p 5

[12] Ibbini MS et al (2014) Simscape solar cells model analysis and design. In: Zaharim A, Sopian K, Bulucea A, Niola V, Skala V (eds) 8th International conference on renewable energy sources (RES' 14), 2nd International conference on environmental informatics (ENINF'14), Kuala Lumpur, Malaysia,
23–25 April 2014, WSEAS Press

[13] Venkateswarlu G, Raju PS (2013) Simscape model of photovoltaic cell. Int J Adv Res Electr Electr Instrum Eng 2(5):7

[14] Varshney A, Tariq A (2014) Simulink model of solar array for photovoltaic power generation system. Int J Electr Electr Eng 7(2):8

[15] Mohammed SS (2011) Modeling and simulation of photovoltaic module using Matlab/Simulink. Int J Chem Environ Eng 2(5):6

[16] Pandiarajan N, Muthu R (2011) Mathematical modeling of photovoltaic module with Simulink. International Conference on Electrical Energy Systems (ICEES 2011), p 6

[17] Salmi T, Bouzguenda M, Gastli A, Masmoudi A (2012) Matlab/simulink based modelling of solar photovoltaic cell. Int J Renew Energy Res 2(2):6