DESIGN AND ANALYSIS OF 1.4MW HYBRID SAPS SYSTEM FOR RURAL ELECTRIFICATION OFF GRID APPLICATIONS

Arpan Dwivedi* and Yogesh Pahariya**
*PhD Scholar, Department of Electrical & Electronics Engineering,
RKDFIST, SRK University, Bhopal, (M.P.) - India
**Principal, RKDFIST, SRK University, Bhopal, (M.P.) - India

Abstract

In this paper optimal design of Hybrid (PV/PMWTG/DG) SAPS (Stand Alone Power Supply System) system is done for off grid applications in remote areas where transmission of power is difficult. The SAPS system uses to primary renewable sources of energy solar and wind in addition to that a Diesel generator (DG) is hybrid with SAPS system for achieving power supply without interruption in case of any failure of wind or solar sources. This paper presents mathematical modeling of 1.4MW hybrid SAPS system for rural electrification. This paper firstly focuses on Mathematical modeling of PV module connected in a string, secondly focuses on modeling of permanent magnet wind turbine generator (PMWTG). These two systems are than hybrid with Diesel generator (DG) and for optimize system efficiency; a simple algorithm is developed for system sizing .The power output of Hybrid SAPS system is analyzed for meeting load demands at urban as well as for rural areas.

Keywords: SAPS, DG, PMWTG, Rural area, off grid, PV module.

***Corresponding Author**
E.mail: arpandwvd@gmail.com,ypahariya@yahoo.com
Mob.: +91-9770404077

Introduction

A Stand Alone Power Supply (SAPS) system can provide electricity independent of the local electricity network. A SAPS system allows households, farms or lodges, whether remote or urban, to generate their own electricity. These SAPS systems are usually based on a renewable energy resource and/or a diesel generating set. A SAPS system can be used to avoid electricity connection costs. The many residents Peoples are using SAPS systems. The type of system installed depends on specific energy requirements and the renewable energy resources available in area. There is many different SAPS system configurations- Solar, wind, micro-hydro or diesel engine generation sets; it can provide independent electricity supplies. Renewable energy sources are omnipresent, easily available, and environmentally friendly [1]. This is very useful in distant and remote area locations, that's by it is becoming very famous and can be used for rural electrification of remote areas. Rural electrification is the process of bringing electrical power to rural and remote areas. Electricity is used not only for lighting and household purposes, but it also allows for mechanization of many farming operations, such as threshing, milking, and hoisting grain for storage. Due to their geographical location and low demand compared to the area, rural areas are mainly suitable for renewable energy off grid applications. For achieving optimizing system efficiency algorithm is developed in MATLAB [2].

System Configuration

The PV module we are designing for SAPS system is of power rating 1 MW. Most solar panels on the market have power ratings in the range of **200 to 350 watts**. A higher power rating means that the panels are more effective at producing power. The WIND module designed for SAPS system is of power rating 0.4MW. Thus the total capacity of hybrid SAPS is 1.4MW. The electrical ratings are mentioned in table 1

Table1: IEEE Standard Electrical ratings for PV module & wind

Specification of PV Module			**Specification of Wind Turbine**			
1	Power Rating	P=200W	1.	Rated Power	10 KW at 11m/s(25 mph)	3 blade up wind
2	Voltage at maximum power	V(Pmax)=35.16V	2.	Rated Annual Energy	13600Kwh at 5m/s(11mph)	None, fixed pitch
3	Short circuit current	Isc=5.92A	3.	Max. Design wind speed	60m/s (134 mph)	240V Ac 1phase 50HZ
4	Open circuit voltage	Voc=43.75V	4.	Cut in wind speed	2.2m/s(5mph)	-40to +60deg C
5	Operating voltage	V(operating)=24V	5.	Nominal Power	10Kw at 12 m/s(27 mph)	Permanent magnet alternator

The electrical specifications are under test conditions of irradiance of 1 kW/m2, spectrum of 1.5 air masses and cell temperature of 25 °C. Hybrid SAPS power plant consists of mainly the solar cells, wind & diesel generator. The energy is produced from the combination and is fed to the load via hybrid controller; the function of hybrid controller is to allow the energy sources to supply the load separately or simultaneously depending on the availability of the energy sources. The functional block diagram of solar-wind hybrid power plant is shown in fig.1

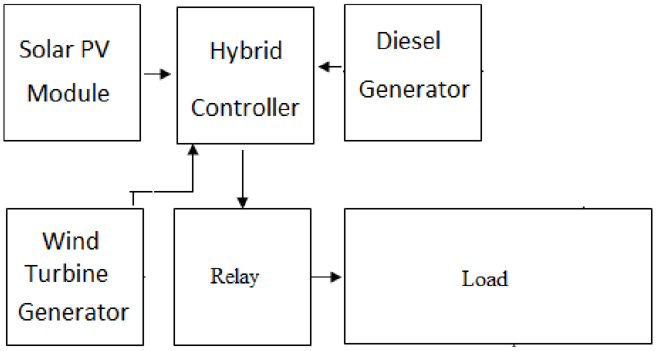

Fig.1: Functional Block Diagram of SAPS system

Mathematical modeling of SAPS system

Modelling of PV

The solar PV array includes six modules and each module has six solar cells connected in series. Therefore, the proposed model of solar PV array is given in Fig. 2

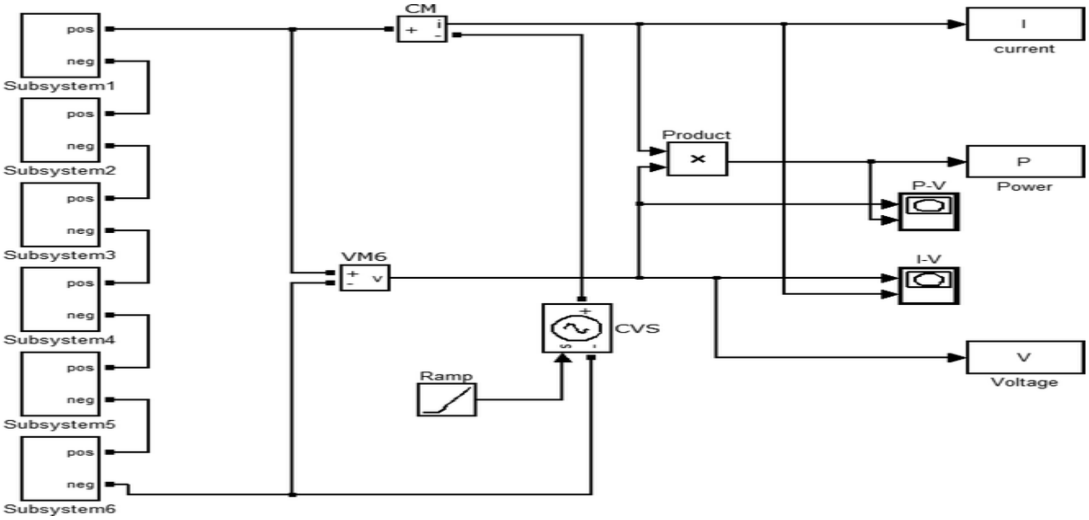

Fig. 2: Proposed model of solar PV

The voltage–current characteristic equation of a solar cell is provided as (Tu and Su 2008; Salmi et al. 2012). **Module photo-current Iph:**

$$Iph = [I_{sc} + Ki(T - 298)] \times \frac{Ir}{1000Iph} = [I_{sc} + Ki(T - 298) \times Ir/1000] \cdots\cdots \quad (1)$$

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/m2).

Module reverse saturation current Irs:

$$I_{rs} = \frac{I_{sc}}{\left[exp\left(\frac{qVOC}{NSknT}\right) - 1\right] I_{rs}} = I_{sc}/\left[exp\left(\frac{qVOC}{NSknT}\right) - 1\right] \cdots\cdots \quad (2)$$

Here, q: electron charge, = 1.6 × 10−19C; Voc: open circuit voltage (V); Ns: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805 × 10−23 J/K.

The module saturation current I0 varies with the cell temperature, which is given by:

$$I0 = I_{rs}[TTr]3exp[q \times Eg0nk(1T - 1Tr)I_0 = I_{rs}[TTr]3exp[q \times Eg0nk(1T - 1Tr)]] \ldots$$

(3)

Here,

Tr: nominal temperature = 298.15 K; Eg: band gap energy of the semiconductor, = 1.1 eV;

The current output of PV module is:

$$i = NP \times I_{ph} - NP \times I_0 \times \left[\exp\left(\frac{V}{NS} + I \times \frac{R_s}{NP_n} \times V_t\right) - 1\right] - I_s h_I = NP \times Iph - NP \times I_0 \times \left[\exp\left(\frac{V}{NS} + I \times \frac{R_s}{NP_n} \times V_t\right) - 1\right] - Ish$$

… (4)

With

$$V_t = k \times T_q V_t = k \times T_q \ldots\ldots\ldots\ldots \quad (5)$$

and

$$Ish = V \times NP/NS + I \times RSRshIsh = V \times NP/NS + I \times RSRsh \cdots\cdots\cdots \quad (6)$$

Here: Np: number of PV modules connected in parallel; Rs: series resistance (Ω); Rsh: shunt resistance (Ω); Vt: diode thermal voltage (V).

Step 1

Provide input parameters for modeling:

Tr is reference temperature = 298.15 K; 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 = 6.11 A; Voc is PV module open circuit voltage at

25 °C and 1000 W/m2 = 0.6 V; Eg0 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

Module photon-current is given in Eq. (1) and modeled as Fig. 4 (Ir0 = 1000 W/m2).

$$I_{ph} = \frac{[I_{sc} + K_i(T-298)\times]I_r}{1000\,I_{ph}} = [I_{sc} + K_i(T - 29i8] \times I_r/1000\ldots\ldots.. \qquad (7)$$

Modeling of PMSG

In order to develop the mathematical model for a PMSG, it is essential to make the following assumptions (Arroyo E.L.C. 2006):

- The conductivity of the permanent magnet is zero
- Saturation is neglected
- Induced electromotive force (EMF) is sinusoidal
- Eddy currents and hysteresis losses are negligible
- There are no field current dynamics

With the assumptions above, the wind turbine causes the rotor of the PMSG to rotate.

This can be represented in the direct-quadrature (DQ) coordinate system, which is described as follows

$$V_{qs} = -r_s i_{qs} + L_{qs}\frac{d}{dt}i_{qs} - \omega_r L_{ds} i_{ds} + \omega_r \frac{dy}{dx}\psi d_s$$

$$V_{ds} = \;-= -r_s i_{ds} + L_{ds}\frac{d}{dt}i_{ds} + \omega_r L_{ds} i_{ds}$$

Where,

Vqs is the quadrature-axis (q-axis) stator terminal voltage in *volt*

Vds is the direct-axis (d-axis) stator terminal voltage in *volt*

ids is the d-axis stator current in ampere *A*

iqs is the q-axis stator current in ampere *A*

ωr is the angular velocity of generator rotor in *rad/sec*

rs is the equivalent resistance of the stator winding

Lds is the stator equivalent inductance in d-axis

Lqs is the stator equivalent inductance in q-axis

$\frac{d}{dt}\psi\ ds$ is the amplitude of the flux linkages in *v/rad/sec*

In the rotor reference frame, the electromagnetic torque can be described by

$$T_e = \frac{3P}{4}\left[i_{ds} i_{qs}\left(L_{ds} - L_{qs}\right) + i_{qs}\frac{d}{dt}\psi ds\right]$$

Where,

Te is electromagnetic torque in *Nm*

P is the pole number of generator stator

The relationship between the angular velocity of the generator rotor and the mechanical angular velocity of the wind turbine rotor is given as follows

$$\omega = 2\omega_r / PG$$

$$\frac{d}{dt}\omega_r = \frac{P}{2j}\left(T_m - T_e\right)$$

Where,

G is the gear ratio

Tm is the input torque to the generator rotor in *Nm*

J is the inertia of the generator rotor in *kgm2*

The input torque to the generator can be obtained by means of the torque of wind turbine rotor divided by the gear ratio

$$T_m = \frac{T_t}{G}$$

Here it is assumed that the torque loss through the mechanical transmission system is neglected. For a direct-driven PMSG wind turbine, *G*=1, and *Tm* = *Tt*.

Mathematical inverse Park and Clarke transforms

The discussion above is based on the rotating reference frame. A practical generator produces 3-phase AC power. For this reason, the inverse Park and Clarke transforms are introduced to implement the 3-phase AC output from the generator model.

As Fig.3 shows, the transform from the stator axis reference frame (αβ) to the rotating reference frame (dq) is called the Park transform (Texas Instruments 1997). The Clarke transform is the transformation of the 3-phase reference frame to the 2-phase orthogonal stator axis (αβ).

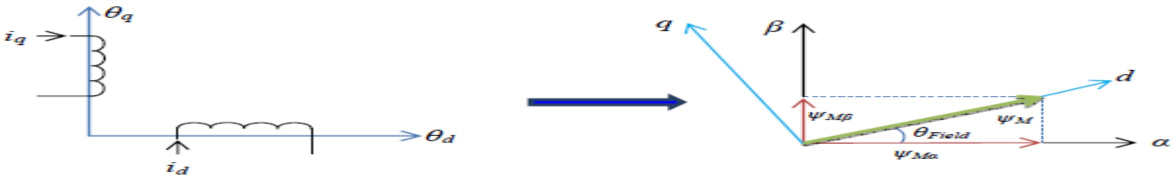

Fig. 3: Inverse Park transform

As Fig.3 illustration, assumes the αβ frame has an angle θ Field with the dq frame, the inverse Park transform (dq - αβ) which can be expressed as follows:

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = \begin{bmatrix}\cos\theta_{field} & -\sin\theta_{field}\\ \sin\theta_{field} & \sin\theta_{field}\end{bmatrix}\begin{bmatrix}d\\ q\end{bmatrix}$$

The mathematical inverse Clarke transform is given as follows

$$\begin{bmatrix}V_a\\ V_b\\ V_c\end{bmatrix} = \begin{bmatrix}1 & 0\\ -1/2 & \sqrt{3}/2\\ -1/2 & -\sqrt{3}/2\end{bmatrix}\begin{bmatrix}\alpha\\ \beta\end{bmatrix}$$

In order to simulate the power generation from the wind turbine, it is necessary to model the wind and obtains the power coefficient of the wind turbine rotor using MATLAB. Fig. 4 shows the modeling of PMSG.

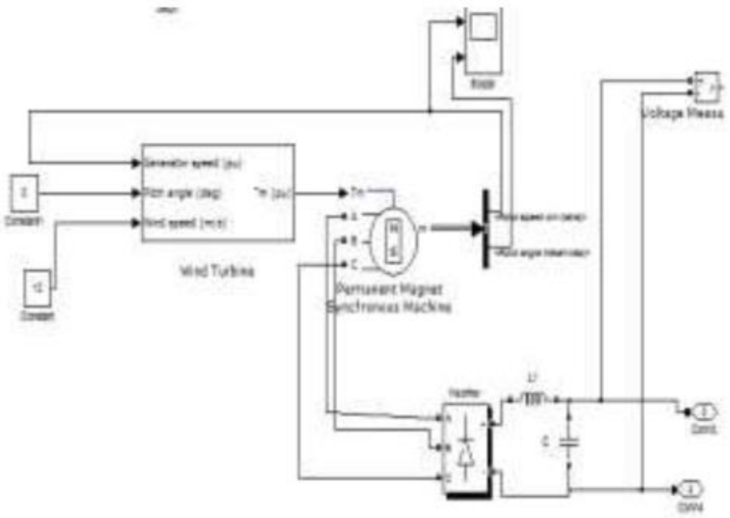

Fig. 4: Mathematical modeling of PMSG

Modeling of diesel generator

Diesel generator set converts fuel energy (diesel or bio-diesel) into mechanical energy by means of an internal combustion engine, and then into electric energy by means of an electric machine working as generator. The generator we are adopting in our system is DC generator. Fig 5 shows the modeling of Diesel generator

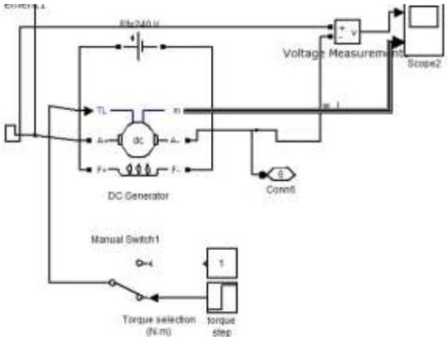

Fig. 5: DC Generator set module

1.4 MW hybrid SAPS system

The proposed system for the purpose of rural electrification is presented in this section. The mathematical modeling of PV module/wind/Diesel (DC generator) hybrid SAPS system is done in MATLAB/SIMULINK shown in Fig 6. The validation of results i.e. performance of all the sources for power generation is already discussed in previous section. Now the hybridization is done here by consideration that the output voltage of all the three system must be same and of same ratings (1.4 MW). So that the output voltage of hybrid system can be fed directly for the off grid applications.

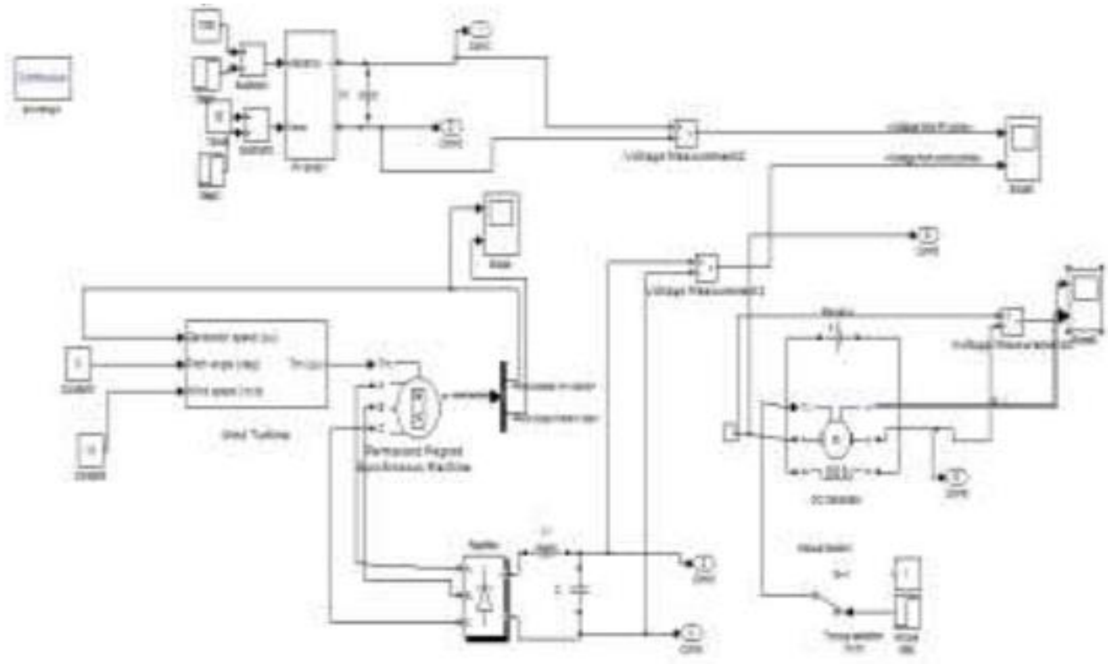

Fig.6: Simulation model of Hybrid SAPS system

Results and Discussion

Hybrid SAPS system

Fig 7 shows the variation of angular frequencies of the rotor of wind turbine with respect to time. This output of wind turbine generator is compared with the standard 1KW rated turbine & found near by the same characteristics for off grid applications.

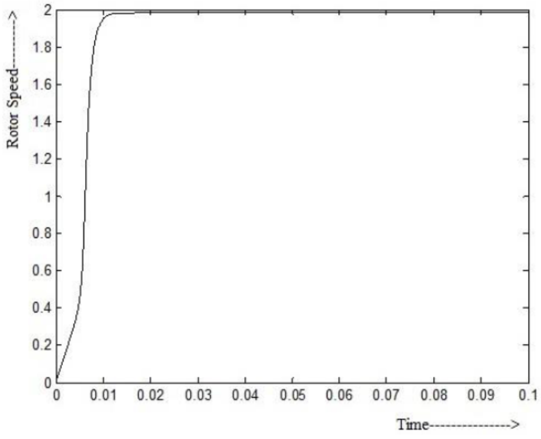

Fig. 7: Plot between angular frequency (rad) with respect to time

Fig 8 shows the variation of rotor angle displacement of wind turbine rotor with respect to time. This output of wind turbine generator is compared with the standard 1KW rated turbine & found near by the same characteristics for off grid applications

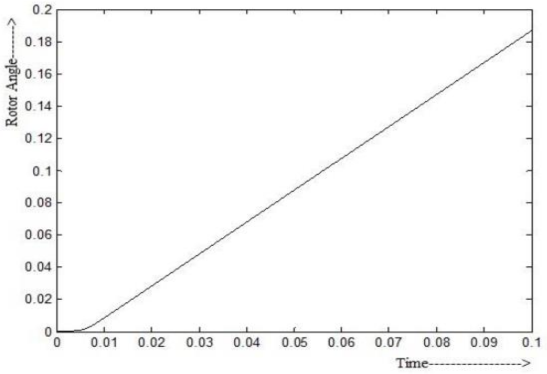

Fig. 8: Plot between rotor angle with respect to time

Fig 9 shows the plot between voltage outputs of wind turbine generator set with time. The value of the voltage output coming from our proposed wind turbine generator set is when compared with the voltage output of the standard wind generator as shown in fig 36, it is found that both the turbines show similar characteristics and nearly equal values of voltage is achieved.

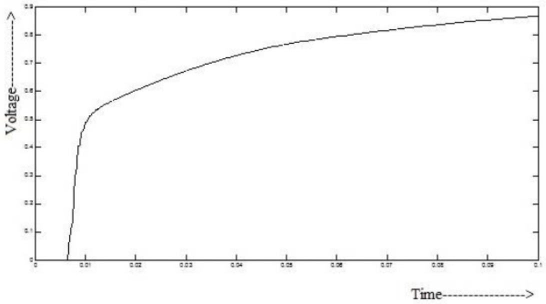

Fig. 9: Plot of voltage (volt) with time (sec)

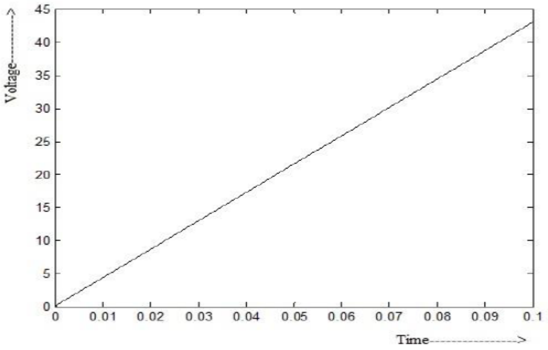

Fig. 10: Plot of output voltage (volt) with respect to time (sec)

Fig.10 is the output voltage of Wind/PV/Diesel is hybrid & is used as input voltage for the multi level inverter, for power quality improvement in, off grid applications. Table No. 2 shows the output of Hybrid SAPS system.

Table 2: Output of Hybrid SAPS system

S.No.	Terms	Ratings
1.	Total SAPS power output	1.4MW
2.	Output Voltage Solar Module	24 V DC
3.	Output Voltage Wind Turbine Generator	230 V AC
4.	Output Voltage Diesel Generator	24 V DC
5.	Load Current	100 A
6.	Transformer (for wind output)	1:10 Stepped Down
7.	Converter	3 Phase (IGBT), 24 V DC

Conclusion

The Proposed hybrid SAPS system consists of PV/ wind/diesel generator is presented in the paper and their standard ratings are mentioned for the purpose of rural electrification and remote areas. The total capacity of the system is 1.4 MW at full load this system will be adopted for off-grid applications i.e. directly feeding to the load.

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