Performance of Grid Connected Hybrid System with Maximum Power Optimization Algorithms

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Abstract: Energy is an essential part of our lives and is used in various fields such as agricultural land, transportation, domestic and industrial applications. Further, the renewable energy (RE) sources are becoming more popular now a days due to limited fossil fuel and more eco-friendly. Two RE sources i.e. Solar PV and Wind energy conversion system are considered in this paper to fulfill the energy demand. The conversion efficiency of PV and wind power systems is very low due to different weather conditions. Therefore, maximum power extraction schemes are implemented to extract maximum power during different weather conditions. Two different maximum power schemes i.e. P&O for solar PV system and ANN for Wind energy have been accomplished to find maximum power from these resources. Each component of system is modeled in MTLAB/Simulink and hybrid system is developed by integrating individual model. A 15 kW PV and 15 kW WECS is designed for grid integration. Extensive results are taken and different operating conditions, which validate the developed hybrid model.

1 INTRODUCTION

Non-conventional energy sources are now more popular due to limited fossil fuels and more environmentally friendly. The RE sources produce energy from natural sources that replace themselves again in a short span of time (Edenhofer et al., 2011). These sources incorporate solar, wind, small hydro, biogas, tidal energy, geothermal etc. The RE sources are freely available, pollution free, inexhaustibility are the main advantages and can be used for electricity generation as well as other applications such as air and water heating (Yazdani-Chamzini et al., 2013; Rana, Ansari and Chauhan, 2020). The RE sources are unpredictable in nature such as solar PV provides energy during sunlight, and the wind energy is also unpredictable which depends on the flow of air, so the RE sources are not active every time. The performance of the RE sources are affected by several environmental conditions. The total energy generated from renewable energy sources (RES) is 91153.81 MW i.e. 24.28% of the total installed energy as on 31 December 2020 (CEA, 2020).

Solar energy is the most emerging RE source because of its various advantage such as pollution free, low maintenance, long lifespan, low cost etc., so this source is very reliable and congenial to use. Semiconductor materials are used to convert sunlight into electricity for solar PV cells (Rana, Chauhan and Ansari, 2016; Breyer et al., 2018). The efficiency of solar cells is very low, because of environmental conditions such as shading, clouding, dust accumulation effects etc. For maximum efficiency and power, different maximum power extraction algorithms methods are used. Perturb and observe (P&O) algorithm is used to find the maximum energy during variable irradiance.

Wind power is the oldest RE source for the use of grinding grains and steer ship. Now a days, wind energy is used to produce electricity generation with various generator technology. As the wind speed changes, the output power also changes accordingly (Chinmaya and Singh, 2018; Saini, Ansari and Rana, 2019). For maximum power, wind turbine parameters such as blade pitch and tip speed ration are changed. Wind energy technology has experienced significant growth and progress over the past few decades. Today, wind energy is found as an increasing RE source. Wind energy can be used for various purposes

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such as transportation in river and sea, grinding of grain and electricity generation (Breyer et al., 2017).

For a hybrid power system, two or more power sources are connected together. The hybrid power system is highly efficient and more reliable than the conventional energy sources (Kumar et al., 2018). The hybrid power system is suitable for remote areas due to various benefits such as constant power flow, more durable etc. Hybrid power system is more popular due to the continuous power flow between load and source. The gird integration system is more popular now a days due to various advantages such as 24 hours electricity, high reliability and increased reserve plant capacity, but it is very challenging task for the researcher to integrate the RE source with grid due to the intermittent power of RE based sources (Rehmani et al., 2018). The integration can be possible in two different ways i.e. transmission level integration for large power and distribution level integration for small power generation.

In this paper, the performance of hybrid energy sources (PV and Wind) are analyzed with the help of maximum power extraction schemes i.e. P&O for solar PV system and ANN for WECS. With the help of a voltage source inverter, the generated energy of the hybrid power system is fed to the grid.

This paper is mainly distributed in five sections. In section I, introduction of RES is covered. In second section, System description is described. In section-three, the modeling of the proposed hybrid system is discussed. In Section IV, the results of the hybrid (PV and WECS) system are discussed. The conclusion of the hybrid energy system is discussed at the end of this paper.

2 SYSTEM DETAILS

The Simulink diagram of grid connected solar PV and WECS is shown in Fig. 1. A common 200 V DC bus is made to connect the hybrid RE system. In the case of PV system, a dc voltage is generated through PV panel and then increased through boost converter. In case of WECS, three phase voltage is converted into DC voltage through a bridge rectifier to make a common dc bus as shown in Fig. 1. The dc voltage is converted into ac voltage (three phase) with the help of VSI and the connected to the Grid through transformer.

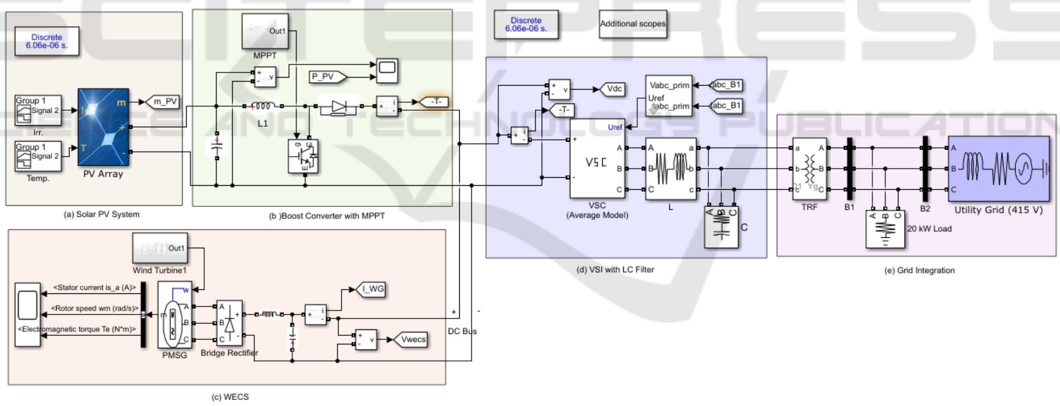

Figure 1: Simulink Diagram of Grid Connected PV and WECS

3 SYSTEM MODELLING

3.1 Modeling of Solar PV System

The series and parallel combination of the PV cells is used to make the PV system to produce specified output power (El-Khattam and Salama, 2004; Rana, Ansari and Chauhan, 2019). The circuit diagram of PV cell is described in Fig. 2.

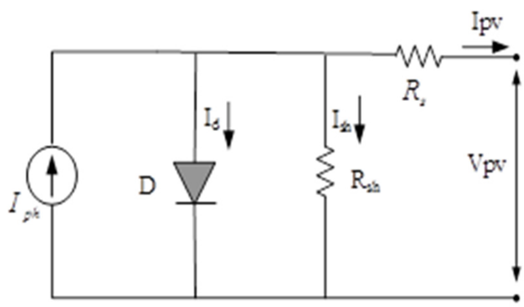

Figure 2: Equivalent circuit of a PV cell

The voltage and current of the photovoltaic system are shown in (1-3),

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

$$I_{pv} = I_{ph} - I_0 \left[exp\left(\frac{q(V_c + R_s I_{pv})}{AkT_c} \right) - 1 \right] - \left(\frac{V_{pv} + R_s I_{pv}}{R_{sh}} \right) \tag{2}$$

$$V_{pv} = \frac{AkT_c}{q} \left(\frac{I_{ph} + I_0 - I_{pv}}{I_0} \right) - R_s I_c \tag{3}$$

The V_{oc} and I_{sc} of the PV cell are described in (4) and (5) as,

$$V_{oc} = \frac{AkT_c}{q} ln\left(\frac{I_{ph} + I_0}{R_{sh}} \right) \tag{4}$$

$$I_{sc} = I_{ph} - I_0 \left[exp\left(\frac{qR_s I_{sc}}{AkT_c} \right) - 1 \right] - \left(\frac{R_s I_{sc}}{R_{sh}} \right) \tag{5}$$

Where, T_c is PV cell temp. (K), q charge of electrons (1.602x10-19 C), I_d is diode current (A), I_{ph} is photo current (A), I_{sc} is short circuit current, I_o is diode reverse saturation current (A), k is Boltzman constant (1.38 × 10-23 J/K), V_{oc} is open circuit voltage (V) and A is ideality factor (1.1).

The fill factor and efficiency of panel is shown in (6) and (7) as,

$$Fillfactor = \frac{I_{mpp} * V_{mpp}}{I_{sc} * V_{oc}} \tag{6}$$

$$Efficiency = \frac{V_{oc} * I_{sc} * FF}{P_{in}} \tag{7}$$

Where, P_{in} ispower input to the PVpanel i.e. P_{in} = solar cell area*Irr.

In Fig.3, modeling of the solar PV system based on the above equation is described.

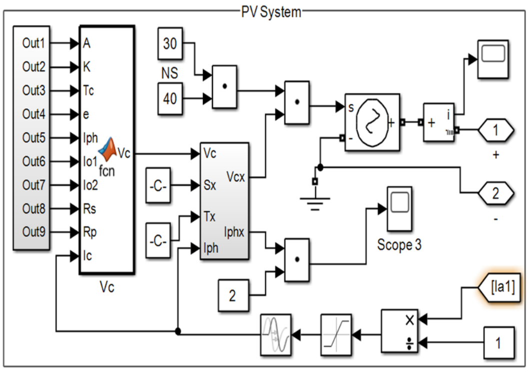

Figure 3: PV Cell Modeling Details

3.2 Modeling of WECS

The mathematical modeling of a WT (Mahdi et al., 2010; Ben Ali, Schulte and Mami, 2017) is described in (8) to (14) as:

$$P_w = \frac{1}{2}(\text{air mass per unit time}) * (\text{Wind velocity})^2 \tag{8}$$

$$P_w = \frac{1}{2}(\rho A v) * v^2 = \frac{1}{2}\rho A v^3 \tag{9}$$

$$C_p = \frac{\text{Output power of WT}}{\text{Wind power}} = \frac{P_{WT}}{P_w} \tag{10}$$

$$P_{WT} = C_p(\lambda, \beta) * P_w = C_p(\lambda, \beta) * \frac{1}{2}\rho A v^3 \tag{11}$$

$$TSR(\lambda) = \frac{\text{Linear speed of blade}}{\text{wind velocity}} = \frac{\omega.R}{v} \tag{12}$$

$$C_P(\lambda, \beta) = M_1 \left(\frac{M_2}{\lambda_i} - M_3.\beta - M_4\beta^x - M_5 \right) e^{-\frac{M_6}{\lambda_i}} \tag{13}$$

$$\text{Where, } \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\,\beta} - \frac{0.035}{\beta^3 + 1} \tag{14}$$

Where: P^w is the output power (W), A is the area of rotor (m^2), ρ is the air density (1.224 Kg/m^3 at 15^{oC} and normal pressure), v is wind velocity (m/s), ω is the rotor speed, λ is the tip speed ratio, R is radius of rotor, β is the blade pitch angle and M_1 to M_6 are the coefficients and the values of these coefficients are constant. The Simulink model of WECS based on ANN is shown in Fig. 4 as below:

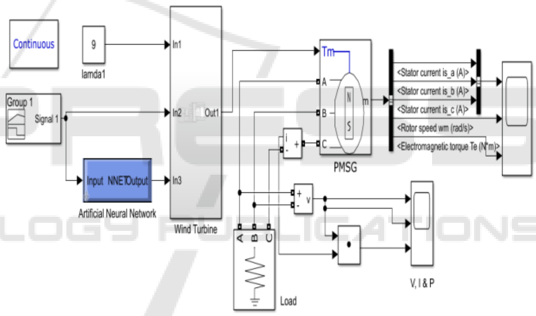

Figure 4: ANN based Simulation Model of WECS

An ANN control scheme is used to control tip speed ratio and pitch angle of wind turbine. The error between reference torque and actual torque is minimized very fast by using ANN based control algorithm. The training of ANN is based on the wind speed variation. The difference between calculated output and the desired output is minimized through the delta learning rule(Asghar and Liu, 2018). The different steps are used to train the ANN algorithm as:

Step I: First initialize the weight.
Step II: Optimize the hidden layer
Step III: Compute the output.
Step IV: Calculate the error.
Step V: Wight updated and calculate the output by using (15).
Step VI: Go to step II and iterate this calculation till the error between output and desired output is minimum.

The mathematical modeling of ANN system is shown in (15).

$$O_q^h = \sum_{p=1}^{n} w_{pq} x_p + \theta_p^h \; and O_{q+1}^o = \sum_{q=1}^{p} w_{q(r+1)} O_q^h + \theta_q^o \quad (15)$$

Where, θ_p^h and θ_q^o are the bias value ofhidden layer and output layer, Wpq, and Wq(r+1) are the hidden layers weights, x_p and O_q^h are input and output of the hidden layer.

4 RESULTS AND DISCUSSION

As the temperature of the panel increases, the PV panel output decreases and vice-versa. In case-1 (0-2 sec), the irradiation level and temperature are 1000 W/m^2 and 35^{o}C respectively. Case-2 (2-4 sec), both the irradiation level and temp both are reduced and reached to 600 W/m^{2}and 29^{o}C.The irradiation level and temperature in case-3 (4-6 sec), decreases again upto 400 W/m2 and 26^{o}C respectively. In case-4 (6-8 sec), the irradiation level and temp increases to 800 W/m^2 and 32^{o}C. In case-5 (8-10 sec), the irradiation level and temp of the panel is 1000 W/m^2 and 35^{o}C respectively. The variation of irradiation level and temperature of the PV panel is shown in Fig. 5.

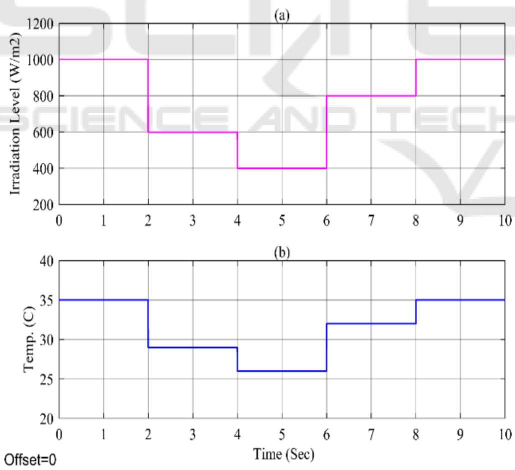

Figure 5: Irradiation Level and Temperature Variation over PV Panel

A 15 kW WECS is considered for hybrid energy system. Different wind speeds are considered for analysis because the wind speed is variable in nature. Five different cases are considered for variable wind speed i.e. case-1 (0-2 sec) - wind speed is 12m/s; case-2 (2-4 sec) - wind speed is 9 m/s; case-3 (4-6 sec) - wind speed is 6 m/s; case-4 (6-8 sec) - wind speed is 8 m/s and wind speed is 12m/s in case-5 (8-10 sec) is shown in Fig. 6.

The voltage, current and power of the grid connected hybrid system at the inverter terminal are shown in Fig. 7. The inverter voltage is 200 V which is constant. The inverter voltage is controlled by a DC.As the wind speed and irradiation level changes, the output current of the inverter also changes.The power output of hybrid system also varies accordingly.

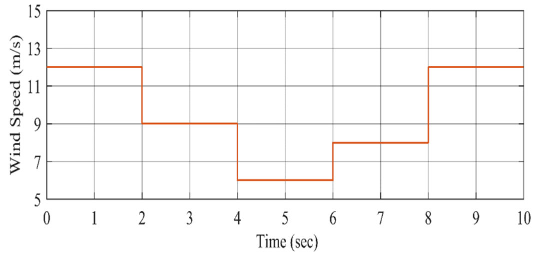

Figure 6: Variation of Wind Speed for WECS

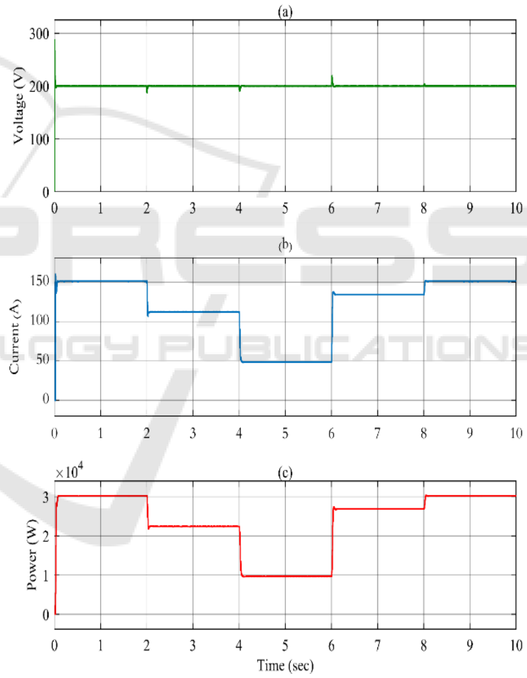

Figure 7: V, I & P of Grid Connected Hybrid (PV and WECS) System

In case-1 (0-2 sec), when the solar irradiation and wind speed is 1000 W/m^{2}and 12 m/s respectively, then V, I and P are 200V, 151.20 A and 30.24 kW respectively. In case-2 (2-4 sec), V, I and P are 200 V, 112.50 A and 22.50 kW respectively, when then irradiation level and wind speed decreases. The output voltage, current and power at the inverter terminals are 200 V, 48.6 A and 9.71 kW respectively in case-3 (4-6 sec). When the wind speed and irradiation levelincreases in case-4 (6-8 sec), the voltage, current and power across the inverter terminals are 200 V, 134.2 A and 26.84 kW respectively. In case-5 (8-10 sec), When the wind speed and irradiation level again reach to 12 m/s and 1000 W/m^2, then V, I and P at the inverter terminals are 200 V, 151.2 A and 30.24 kW respectively.

The power flow between inverter and grid are shown in Fig. 8. For hybrid energy system, 20-kW fixed load is considered. In case-1, the power at the inverter bus is 29.40 kW out of which 20 kW power is consumed by the load and the remaining 9.40 kW power is transferred to grid. The inverter bus power is 21.94 kW in case-2, when both irradiation level and speed are decreased. A 20-kW power is consumed by the load and remaining 1.94 kW power is transferred to grid. In case-3, the total power at the inverter is 9.48 kW. To fulfil the load demand, 10.52 kW power is taken from the grid. When the irradiation level and wind speed increase, the inverter power becomes 26.20 kW out of which 20 kW is supplied to the load and remaining 6.20 kW is fed to the grid in case-4. In case-5, the total power transferred to the inverter bus is 29.40 kW. Out of which 20 kW power is supplied to the load and remaining 9.40 kW power is fed to the grid.

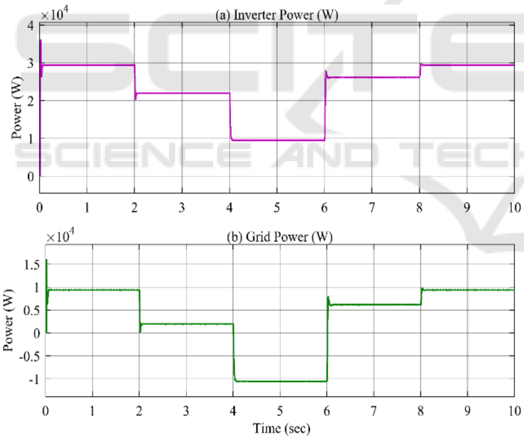

Figure 8: Inverter bus and Grid bus Power

The frequency variation of grid connected energy system is between 50.04 to 49.96 Hz which is very much useful for grid integration as per IEEE standards *(IEEE P 1159.1)*. The frequency and THD variation with respect to irradiation level and wind speed for grid connected hybrid energy system are shown in Fig. 9. The THD of the hybrid system is also with in the permissible limit as per IEEE standards *(IEEE 519)* for integration. The THD is 0.4% in case-1. In case-2, the THD of the grid connected hybrid system is 0.6%, when the speed and irradiation both are decreases. The THD is 0.9% in case-3, when wind speed and the irradiation level both are increased. The THD is 0.5 and 0.4 in case-4 and case-5 respectively. The frequency and THD of the proposed RE based hybrid system change due to modulation index changes to make the constant output voltage of VSI.

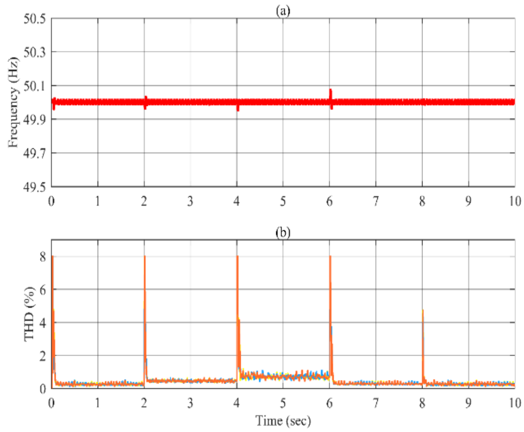

Figure 9: Frequency and THD of Grid Connected Hybrid Energy System

The comparative investigation hybrid energy system for grid integration is summarized in Table 1.

Table 1: Comparative Analysis of Grid Connected hybrid PV and WECS

Cases	1	2	3	4	5
Time (Sec)	0-2	2-4	4-6	6-8	8-10
Irradiation (W/m^2)	1000	600	400	800	1000
Temp. (°C)	35	29	26	32	35
Wind Speed(m/s)	12	9	6	8	12
Voltage (V)	200	200	200	200	200
Current (A)	151.20	112.50	48.6	134.20	151.20
Power-PV (kW)	15.50	9.52	6.40	12.67	15.51
Power-WECS (kW)	14.80	12.96	3.37	14.24	14.80
Generated Power (kW)	29.40	21.94	9.48	26.20	29.40
Load (kW)	20	20	20	20	20
Power to Grid (kW)	+9.40	+1.94	-10.52	+6.15	+9.40
Frequency (Hz.)	50	50	50	50	50
THD (%)	0.4	0.6	0.9	0.5	0.4

The different cases are considered to analyses the hybrid system with variable irradiation level and wind speeds.

5 CONCLUSION

In this paper, A 30-kW hybrid renewable energy sources have been designed and implemented in Matlab/Simulink. ANN and P&O based maximum power extraction schemes have been implemented to extractmaximum power during variable environmental conditions.In RE based hybrid system, the PV and WECS both are connected together with grid integration. A30-kW power is generated by the hybrid energy system and 20-kW load is considered to analyse the behavior of the generation system. The total power generated from the hybrid system is 30 kW when the system is operating at irradiation of 1000 W/m2 and 12 m/s wind speed. The hybrid system generates 9.48 kW when the irradiation is 400 W/m2 and wind speed is 6 m/s. The frequency of hybrid energy system is same as the grid frequency i.e. 50 Hz with 0.9 % THD.The advantage of the proposed system is that the storage system is not required and the maintenance cost of the proposed hybrid system is very low, as it does not require any storage system.

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APENDIX

Table-2: System Details of 15 kW Grid connected PV panel

Components	Specifications
PV array output	15 kW
P_m	250 W
V_{oc}	37.32 V
I_{sc}	8.66 Amp.
V_{mp}	30.71 V
I_{mp}	8.15 Amp.
R_{sh}	224.18 Ω
R_s	0.237 Ω
No of series connected panel (Ns)	5
No of parallel connected panel (Np)	13
Grid Voltage and Frequency	415 50 Hz

Table-3: Parameters of Wind turbine and PMSG

WT Operating Parameters	**Specifications**
No. of blades	Three
Radius of Blades	4.5 Meter
Gear ratio of turbine	40
β	Variable Pitch
ρ	1.2 kg/m^3
V_w	10-18 m/s
λ	9
C_p	0.45
M1, M2, M3, M4, M5, M6	0.5176, 116, .4, 5, 21, .0068
PMSG Operating Parameters	Specifications
Rs	0.4250 Ω
Ld, Lq	0.0086, 0.0086 H
Jg	0.00146 $Kg.m^2$
FF	0.0003036 N.m.s.
Poles	2
T	-17 Nm
Rated voltage & current	1140 V, 7.15 A