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Dynamic Modeling and Control of Grid Connected Wind-PV Hybrid Generation System

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Abstract: ***This paper describes the Dynamic Modeling of a grid connected Wind and PV hybrid system with control strategy for the same. The Electrical Power received from hybrid wind-solar power system is transferred to the grid interface inverted by keeping common DC voltage as constant. In this paper a direct driven permanent Magnet synchronous wind generator (PMSG) is used for controlling strategy with variable speed control method, which is to capture the maximum wind energy below the rated wind speed.***

Keywords: Grid-connected hybrid system, modelling and controlling of Wind-PV System, power conditioning System (PCS), variable Speed wind turbine, PMSG, PI controller

1. Introduction

Energy demand is increasing day by day due to increase in population, urbanization and industrialization. The Energy plays a vital role in our daily routine life. The measurement of development and civilization of any country is measured by the amount of total energy consumed by human beings of that country. Sol that need for renewable energy source that will not harm the environment has been increased. The rate of energy consumption increasing and supply is depleting resulting in energy shortage. The depleting oil reserves, uncertainty and political and safety related issues concerning to nuclear generation, and the environmental concerns associated with coal and natural gas-fired generation are encouraging researchers, practitioners and policy makers to look for alternative and sustainable sources of energy. Some studies and projection indicate that the global energy demand will triple or may be higher by year 2050.

Renewable energy sources currently supply somewhere between 17% and 22% of the total world energy demand. Photovoltaic (PV) generation is the technique which uses photovoltaic cell to convert solar energy to electric energy. Photovoltaic energy is assuming increasingly important as a renewable energy source because of its distinctive advantages, such as simple configuration, easy allocation, free of pollution, low maintenance cost and among others[1,2] etc.

This paper presents a dynamic modeling and control of a grid-connected wind and PV hybrid system. Hybrid energy systems are inter-connected from wind power, photovoltaic power, fuel cell and micro turbine generator to generate power to local load and connecting to grid/micro grids. Because of the inherent nature of the solar energy and the wind energy, the electric power generations of the PV array and the wind turbine are complementary. The hybrid PV/wind power system has higher reliability to deliver continuous power than individual source. In order to draw the maximum power from PV arrays or wind turbines and to deliver the stable power to the load, a substantial battery bank is needed. However, the usage of battery is not an environmental friendly and there are some disadvantages like, heavy weights, bulky size, high costs, limited life cycles, and chemical pollution. Therefore one of the ways to utilize the electric energy produced by the PV array and the wind turbine systems is by directly connecting them to the grid.

2. Proposed System Configuration

Fig. 1 presents the configuration of the hybrid wind-PV power Generation system with its control system. The hybrid system consists of a wind turbine (PMSG), a PV array, power electronic converters for conditioning the power associated with the hybrid energy sources, and a grid-interface inverter.

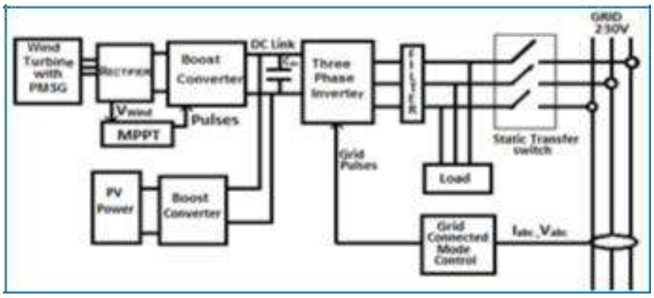


Figure 1: Proposed System's Configuration

3. MOdeling of Wind-PV Hybrid System

A. Wind Turbine Modeling

The wind turbine (WT) converts wind energy to mechanical energy by means of a torque applied to a drive train. A model of the Wind Turbine is necessary to evaluate the torque and power production for a given wind speed and the effect of wind speed variations on the produced torque. The torque T and power produced by the WT within the interval [V_{min} ,V_{max}], where V_{min} is minimum wind speed and V_{max} is maximum wind speed, are functions of the WT blade radius R, air pressure, wind speed and coefficients and coefficients C_p and C_q [3].

$$P_m = C_P\,(\lambda, \beta)\frac{\rho A}{2}\,V_{wind}{}^{3} \qquad (1)$$

C_p is known as the power coefficient and characterizes the ability of the WT to extract energy from the wind.

C_q is the torque coefficient

Relation between C_p and C_q

$$C_q = \frac{C_P}{\lambda} \qquad (2)$$

Other relations

$$\lambda = \frac{R * \omega}{V_{wind}} \qquad (3)$$

$$T = \frac{P_m}{\omega} \qquad (4)$$

Where
Cp = Coefficient of performance
P_m = Mechanical Output power (watt)
β = Blade pitch angle
ρ= Air Density (kg/m^3)
V_{wind} = = Wind speed (m/s)
λ = Tip speed ratio
R = Radius of turbine blades (m)
T = Torque of wind turbine
ω = Angular frequency of rotational turbine (rad/sec)

The performance coefficient Cp (λ, β), which depends on tip speed ratio λ and blade pitch angle β, determines how much of the wind kinetic energy can be captured by the wind turbine system. A nonlinear model describes Cp (λ, β) as[4]:

$$C_p\,(\lambda\,,\beta)= C_1\left(\frac{C_2}{\lambda_i} - C_3\beta + C_4\right) e^{\frac{-C_5}{\lambda_i}} + C_6 \quad (5)$$

B. Modeling of PMSG

The synchronous generator model is expressed in d-q rotating reference frame Park's model. The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal. The generator is equipped with permanent magnets and has no damper winding. In order to simplify calculations the dynamic model of PMSG in the synchronous reference frame is transformed into d-q rotating reference frame using Park transformation [5].

$$V_{ds} = -R_s i_{ds} - L_d \frac{di_{ds}}{dt} + \omega L_q i_{qs} \qquad (6)$$

$$V_{qs} = -R_s i_{qs} - L_q \frac{di_{qs}}{dt} + \omega L_d i_{ds} + \omega\varphi_m \quad (7)$$

Where,
V_{ds} = Direct axis voltagof PMSG
V_{qs} = Quadrature axis voltage PMSG
i_{ds} = Direct axis current of PMSG
i_{qs} = Quadrature axis current of PMSG
R_s = Stator resistance,
ω = Angular frequency of rotor
L_d = Direct axis inductance
L_q = Quadrature axis inductance
φ = is the amplitude of the flux linkages established by the permanent Magnet Electrical Torque T_e is given by PMSG.
The Electrical Torque T_e is given by

$$T_e = \frac{3}{2}(P)\varphi_m i_{qs} \qquad (8)$$

Where, P = Number of pole pairs of the PMSG

Table1: Parameters and Specification of Wind Turbine

Parameter Name	Value	Unit
Rated Power	20	KW
Rated Wind Speed	12	m/s
Rated Rotor Speed	22.0958	Rad/s
Blade Radius (R)	2.7	M
Blade Pitch Angle (β)	0	degree
Air Density (ρ)	1.112	Kg/m^3

The parameters of the wind turbine model taken in this paper are shown in Table I. The aerodynamic torque is maximized at a given wind speed when the pitch angle of a blade(β) is 0 . Therefore, a constant pitch angle (β =0) is used in this study as shown in Table I

C. PV System Model

PV array are formed by combine no of solar cell in series and in parallel. A simple solar cell equivalent circuit model is shown in figure 2. To enhance the performance or rating no of cell are combine. Solar cell are connected in series to provide greater output voltage and combined in parallel to increase the current. Hence a particular PV array is the combination of several PV module connected in series and parallel. A module is the combination of no of solar cells connected in series and parallel.

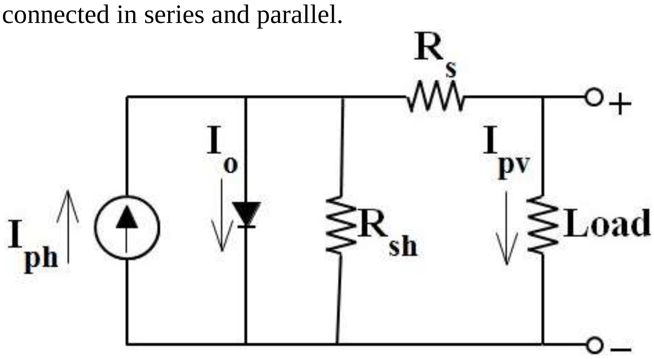


Figure 2: Circuit diagram of a single PV cell

The equation drive from ideal PV cell from its I-V characteristic. These equations mathematically describe the PV cells.

$$I = I_{PV.cell} - \frac{I_{0.cell}\left[\exp\left(\frac{qV}{aKT}\right)-1\right]}{I_d} \qquad (9)$$

$$I_d = I_{0.cell}\left\{\exp\left[\frac{qV}{A} * k * T\right] - 1\right\} \qquad (10)$$

Where
I_d = Diode Current (Amps)
$I_{pv.cell}$ = The Current generated by incident light (Amps)
$I_{o.cell}$ = the reserve saturation of the diode (amps)

The basic Equation (10) of the elementary photovoltaic cell does not represent the I-V characteristic of a practical photovoltaic array. Practical arrays are composed of several connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic array requires the inclusion of additional parameters to the basic equation:

$$I_{PV} = \left(I_{pv,n} + k_I \Delta_T\right) \frac{G}{G_n} \qquad (12)$$

Where

I_{PV} , n is the light generated current at the nominal condition. The diode saturation current Io and its dependence on the temperature are expressed by:

$$I_0 = I_{o,n} \left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \qquad (13)$$

$$I_{o,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right) - 1} \qquad (14)$$

The $V_{t,n}$ is thermal voltage of Ns series connected cells at the nominal temperature Tn. The photovoltaic model described in the previous section can be improved if eq.(13) is replaced by

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{\exp\left(\frac{V_{oc,n} + K_V \Delta_T}{a\, V_t}\right) - 1} \qquad (15)$$

This modification aims to match the open circuit voltages of the model with the experimental data for a very large range of temperatures. The eq.(15) is obtained from eq.(14) by including the current and voltage coefficients KV and KI.

D. MATLAB/Simulink Modeling of PV Array

A typical KC-200GT PV module is taken into account. The KC-200GT PV module has 54 cells in series. For desired output current and Voltage, the proposed solar PV power generation system (6kW) consists of 30 PV modules with 10x3 series-parallel arrangements. Each module can produce 200W of DC electric power. Typical electrical characteristics of a KC-200GT PV module are shown in Table II at solar radiation of 1000W/m2 and cell temperature of 25ºC (STC).

Table II: Parameters of a KC-200GT Solar Array Under STC

Parameter Name	Value	Unit
Maximum Power	200	W
Maximum Power Voltage	26.3	V
Maximum Power Current	7.61	A
Open circuit Voltage	32.9	V
Short circuit Current	8.21	A
Voltage .Temp coefficient	-0.1230	V/K
Current Temp Coefficient	0.0032	A/K
Series Connected Cells	54	Nos

E. Model of Grid Connected WIND/PV Hybrid System

The hybrid energy system is a photovoltaic array coupled with a wind turbine which is shown in Figure-2.

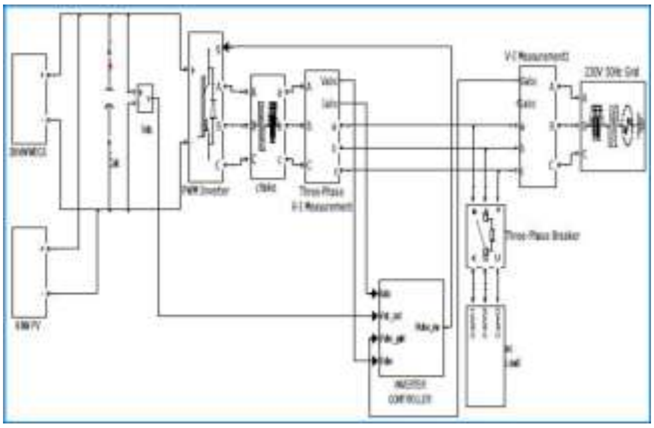


Figure 2: MATLAB/Simulink diagram of Grid connected wind /PV hybrid system

4. Control Strategies

a) Power conditioning system

Renewable Energy Sources (RES's) will generate energy in the form of DC/AC with different voltage and frequency levels. Power electronic interface is to inter-connect RES with grid. The photovoltaic system will give us unregulated DC output voltage due to change in input parameters like irradiation and temperature. By using boost converter we can control the output of PV system. The regulated DC output which is connected to the grid through VSI.

AC output is generated from wind turbine generator. The output of generator is converted to DC by using uncontrolled rectifier. The boost converter is used to control the DC link voltage due to change in wind speed. Then the regulated DC output is inter-connected to the grid through VSI. The VSI is controlled by PQ-controller.

In hybrid wind and PV energy system, the rectified wind energy and the output of PV system is connected to the boost converter to regulate DC link voltage. The regulated DC supply is connected to the grid through DC link and VSI. The VSI is controlled by PQ-controller. The power conditioning system for hybrid energy systems includes DC/DC boost converter, Inverter, PQ-control and RL filter.

b) Modeling and control of grid side converter

Since the machine is grid connected the grid voltage as well as the stator voltage is same, there exists a relation between the grid voltage and DC link voltage. The main objective of the grid side converter is to maintain DC link voltage constant for the necessary action. The voltage oriented vector control method is approached to solve this problem.

The detail mathematical modeling of grid side converter is given below. The control strategies are made following the mathematical modeling and it is shown in Fig.3.The PWM converter is current regulated with the direct axis current is used to regulate the DC link voltage whereas the quadrature axis current component is used to regulate the reactive power. The reactive power demand is set to zero to ensure the unit power factor operation [9].

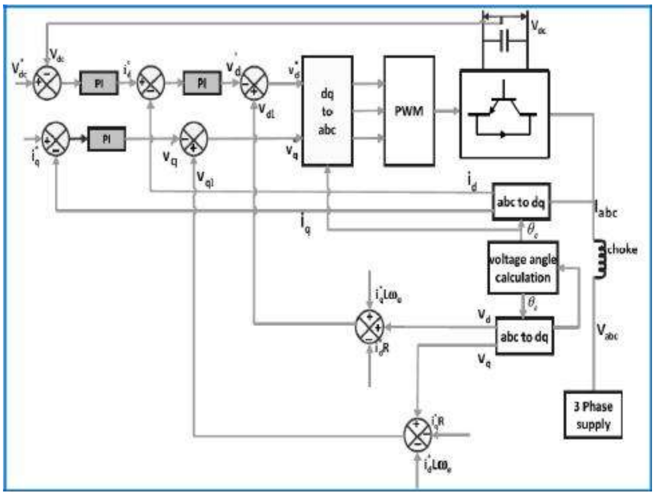


Figure 3: Control block diagram of grid side converter

The voltage balance across the line is given by eq.(16), where R and L are the line resistance and reactance respectively. With the use of d-q theory the three phase quantities are transferred to the two phase quantities

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} V_a{}' \\ V_b{}' \\ V_c{}' \end{bmatrix} \qquad (16)$$

For the grid side converter the mathematical modeling can be represented as

$$V_d = Ri_d + L\frac{di_d}{dt} - \omega_e L i_q + V_{di} \qquad (17)$$

$$V_q = Ri_q + L\frac{di_q}{dt} - \omega_e L i_d + V_{qi} \qquad (18)$$

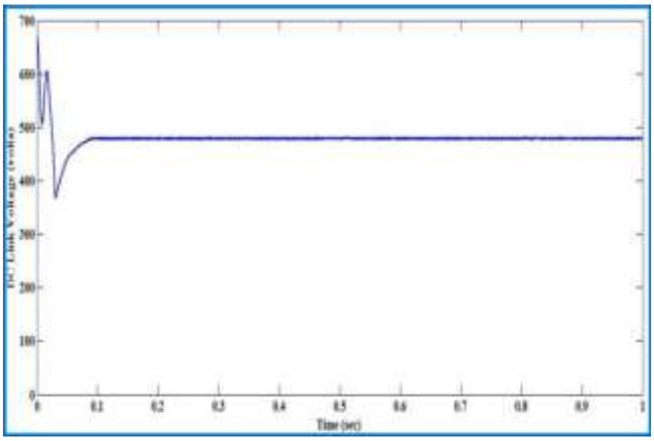
Where V_{di} and V_{qi} are the two phase voltages found from V_a , V_b , V_c using d-q theory

5. Results and Discussions

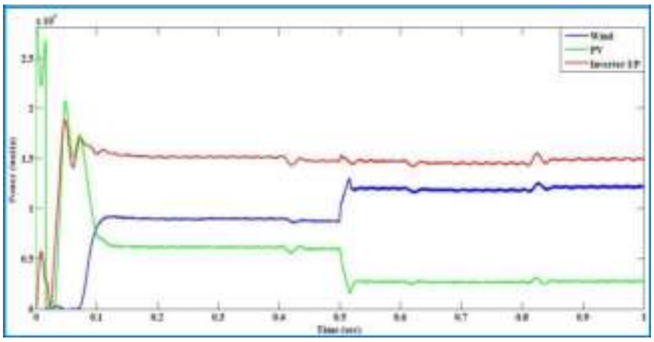
Model of wind turbine coupled with PMSG and model of Photovoltaic (PV) energy system are inter-connected with grid through full scale power electronic devices by using MATLAB/Simulink. The performance study is done for the simulated system under input variations at RES's and load variations

Variable Generation & Change in Load

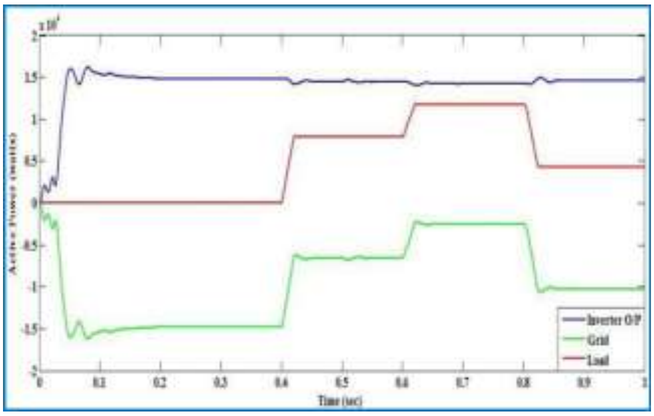
In this case both the inputs parameters like irradiation and wind speed are varied with a change in ac load near Grid are considered for simulation. Change in Generation is achieved by changing the irradiation of PV system and Wind speed of WECS. In our simulation we consider a change of irradiance from 900 W/m2 to 600 W/m2 at 0.5 second, Similarly for WECS the change in speed from 6m/s to 8m/s at 0.5 second. Change in Load is illustrated by connecting a Load 1 of 7.5 kW active power, 5.0404 kVAR Inductive reactive power at 0.4 second, here the breaker 1 closes and at 0.8 second the breaker is opened. Load 2 of 4 kW active power, 3.3143 kVAR connected through breaker 2 at 0.6 second. So from 0.4 second to 0.6 second the Load will be 7.5 kW, 5.0404 kVAR; from 0.6 second to 0.8 second the Load will be 11.5 kW, 8.3547 kVAR and from 0.8 second to 1 second the Load will be 4 kW active power, 3.3143 kVAR. These local ac loads are connected to 230 V, 50 Hz Grid. The system is simulated for 1 second. The results are as follows:



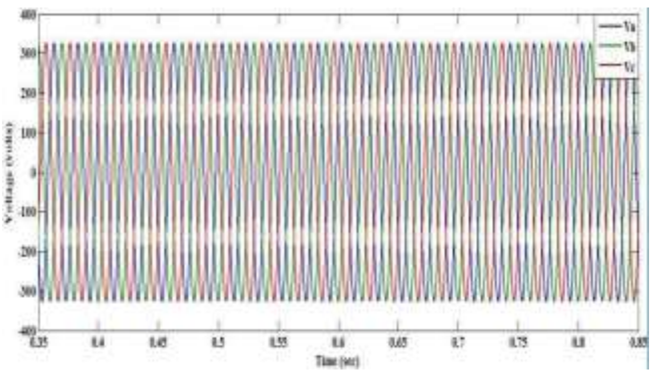
DC Link Voltage



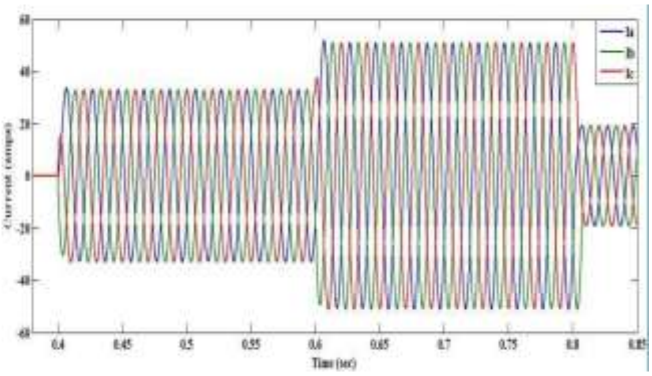
Power of Hybrid System



Active Power Distribution



Grid Voltage



Load current

Hybrid Wind/PV generation the input parameters are varied, irradiance of PV is changed from 900 W/m2 to 600 W/m2 at 0.5 second, Similarly for WECS the change in speed from 6m/s to 8m/s at 0.5 second. Change in Load is achieved by using 2 Breakers for connecting Loads. The Power required by the Load is supplied by the Hybrid system and remaining power is fed in to the Grid.

6. Conclusion

The modeling of hybrid Wind and PV for power system configuration is done in MATLAB/SIMULINK environment. The present work mainly includes the grid tied mode of operation of hybrid system. The models are developed for all the converters to maintain stable system under various loads and resource conditions and also the control mechanism are studied. The dynamic performance of Hybrid Wind and operation of hybrid system. The models are developed for all the converters to maintain stable system under various loads and operation of hybrid system. The models are developed for all the converters to maintain stable system under various loads and resource conditions and also the control mechanism are studied. The dynamic performance of Hybrid Wind and operation of hybrid system. The models are developed for all the converters to maintain stable system under various loads.

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