Operation of Grid Integrated Wind/PV Hybrid System with Grid Perturbations

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Abstract - The wind and solar energies are the most available among other renewable energy sources in all over the world. In the present years, because of the rapid advances of power electronic systems the production of electricity from wind and photovoltaic energy sources have increased significantly. In this paper, the performance of the wind/PV hybrid system is studied under different grid perturbation conditions. The wind/PV hybrid system model has been implemented in Matlab/Simulink environment. The wind power system and PV arrays are controlled to attain maximum power output from them. The controller used for inverter maintains constant DC voltage at DC bus while injecting only active power to the grid. The common grid perturbations considered in this study are balanced voltage dip, voltage unbalance and harmonic distortions. The simulation results reported in this work also shows that, the performance of the presented hybrid system model is not affected by the grid disturbances considered.

Keywords – Wind power generation, PV power, maximum power extraction, inverter controller, grid perturbations

1. Introduction

Recently, much work has been focused on interfacing distributed generators (DGs) with the grid, mainly its control and operation. By integrating local power generations using non-conventional energy sources like photovoltaic arrays, wind energy, fuel cells etc., which may deliver power at several load centres and also to the main power grid. Interconnection of these DGs to distribution system will offer a number of assistances such as enhanced reliability, quality of power and improvement of system limits along with the ecological assistances [1]. Due to the rising momentum towards sustainable energy advances with these benefits, it is anticipated that a huge number of DG systems will be connecting to the utility grid in the coming years [2]. Interconnecting these large number of small rating DG systems with diverse characteristics to low voltage network causes many problems. Thus the hybrid configuration with clean, efficient and sustainable energy technologies such as wind and PV will be dominant in the future power supply network.

The grid integration of hybrid DG systems is expected to play a vital role in the future electrical power system. Multi-source hybrid renewable power sources to some extent overcome the uncertainty, intermittency and low availability of single-source renewable energy systems, which has made the power supply more reliable [3]. And hence, hybrid power systems have caught worldwide research attention. To build a hybrid power system, there are different combinations of renewable energy sources. The grid connected performance of fuel cell and PV based hybrid DG system is reported in [4]. In [5], a grid integrated hybrid wind/PV/fuel cell system with an optimal design for distributed energy production is presented. The detailed performance study of the hybrid power system with PV, wind and wave sources is reported in [6]. In [7], the design and economic analysis of grid connected hybrid PV/wind systems for the intermittent production of hydrogen. For performance of a grid integrated hybrid PV and fuel cell power plant with controller is maximized in [8]. From these listed hybrid power systems, it is observed that the main alternative energy sources employed are wind and PV power.

This study is orientated towards small-scale grid integrated wind/PV hybrid system under grid perturbations conditions. The primary power sources for the system chosen are wind and photovoltaic power to take complete benefits of renewable energy available around us. The hybrid system can supply power both to the utility grid and to local loads for a grid connected application. For grid connected operation mode of hybrid system, the utility grid behaves as backup energy source. The suitable power electronic converters are required to operate hybrid in grid connected mode of operation. The more power converter usage produces more losses. Some of the loads like battery, electronic equipment, DC drives require DC power which can be supplied from DC voltage directly from DC bus with proper dc-dc converter. A grid integrated hybrid system with wind and PV as the energy resources which can reduce the multiple conversion stages is implemented. The hybrid power system can supply both DC and three phase AC loads.

In this paper, the utility interactive performance analysis of hybrid wind/PV system is presented through simulation study under grid disturbance conditions. In this mode of operation of hybrid system, each DG will generate its maximum power and the grid will supply extra load demand requirements. The DC link voltage (V_{dc}) is regulated through inverter controller. In this study, the balanced voltage dip, polluted grid voltages and unbalanced grid voltages are considered as the grid perturbation conditions.

2. Hybrid System Configuration and Modeling

The block diagram of the wind/PV system for its grid connection is presented in Figure 1. The wind power system with PMSG with uncontrolled rectifier and dc-dc boost converter is connected to a DC bus. To connect the PV arrays are connected to DC bus, a dc-dc boost converter is used. The wind and photovoltaic generators are controlled locally to obtain the maximum power extraction. For the analysis of the grid connected hybrid system, both DC and AC loads are considered. The DC load is connected through a dc-dc buck converter to the DC bus. The rated voltages for DC load and AC load are 500 V and 415 V RMS respectively. In grid tied operation mode, the grid side inverter is responsible for stable DC bus voltage and injects only active power to the grid with zero reactive power.

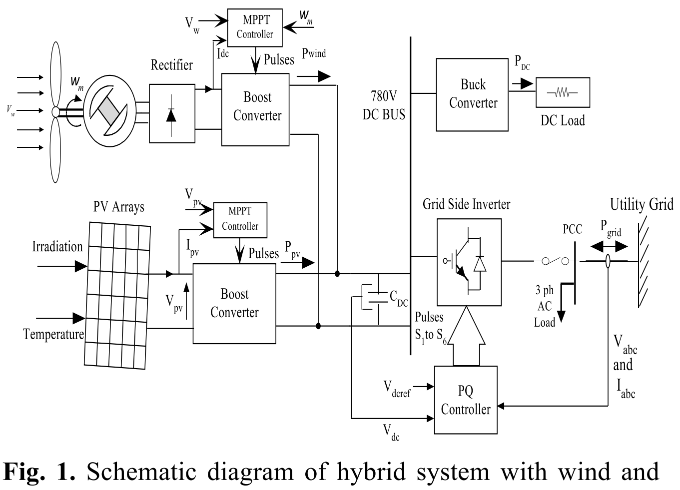

Fig. 1. Schematic diagram of hybrid system with wind and PV based DG system

The principal parts of a typical recent wind energy system are turbine rotor, gearbox, generator and tower. Also, the wind turbine mechanical power is given by [9]

$$P_m = \frac{1}{2}\rho A V_w^3 C_p(\lambda,\beta) \tag{1}$$

Where A = rotor swept area, P_m = Power in watts, V_w= speed of wind in m/sec, ρ = air density, C_p is performance coefficient. From the power available, the torque on the wind turbine shaft can be calculated [10]

$$T_m = \frac{P_m}{\omega_m} = \frac{1}{2}\rho\pi R^5 \frac{\omega_m^3}{\lambda^3} C_p(\lambda,\beta) \tag{2}$$

The PV modules are made up of silicon cells. In order to get a solar PV module these cells are connected in series. The basic equation describing the nonlinear current-voltage relationship of the PV cell is [11]

$$I = I_{ph} - I_d - I_{sh} \tag{3}$$

$$I = I_{ph} - I_s\left[\exp\left(\frac{q(V + IR_S)}{akT}\right) - 1\right] - \frac{V + IR_{se}}{R_{sh}} \tag{4}$$

Where I_s is saturation current of diode; R_{se} is the equivalent series resistance and R_{sh} is the equivalent parallel resistance; I_{ph} is photocurrent of the PV cell.

3. Power Conditioning System and Control

Figure 2 represents the main control unit of grid integrated hybrid wind/PV power system. Both wind and PV system consists of maximum power point tracking (MPPT) controllers. A MPPT algorithm increases the efficiency of power conversion [12]. The maximum power point (P&O technique) algorithm is functioned at without measurement values of wind speed and suitable for large inertia systems.

The MPPT algorithm keeps the power coefficient C_p at its maximum, C_p=C_{pmax}, corresponds to λ_{opt}.

$$\text{Where } \omega_{ref} = \frac{V_w \lambda_{opt}}{R} \tag{5}$$

$$\text{and } P_m = 0.5\rho A C_{p\max}\left(\frac{R\omega_{ref}}{\lambda_{opt}}\right)^3 \tag{6}$$

The MPPT code generates reference turbine speed (ω_{ref}) by using perturb and observe technique.

The incremental conductance method on is used for PV system to get maximum power output. By using the MPPT algorithm, the PWM control signal for the dc-dc boost converter is controlled [13].

In a 3-phase system, the total instantaneous value of power is given by

$$p(t) = v_a i_a + v_b i_b + v_c i_c \tag{7}$$

In synchronous reference frame, the powers are given by

$$P = \frac{3}{2}(V_{gd} i_d + V_{gq} i_q) \tag{8}$$

$$Q = \frac{3}{2}(V_{gq} i_d - V_{gd} i_q) \tag{9}$$

If the voltage vector for grid is $V_g = V_{gd} + j0$, the active and reactive power equations are given by

$$P = 1.5(V_{gd} i_d) \text{ and } Q = 1.5(V_{gd} i_q) \tag{10}$$

The purpose of the inverter control strategy is to maintain the fixed DC bus voltage and to deliver the total maximum power produced to the grid. In this control scheme, by regulating the direct and quadrature currents with PI controllers both power control can be achieved. For regulating active-power, the outer loop of voltage control is used to get the *d*-axis current reference. In order to get zero reactive power injected to the grid the reference current for *q*-axis is specified as zero [14]. The following equation at a unity power factor is used to determine the lower bound on the DC bus voltage [15]

$$0.6124 m_a V_{DC} \geq \sqrt{(V_{acLL})^2 + 3(\omega L_f I_{ac})^2} \tag{11}$$

Where V_{acLL} = Line to Line RMS voltage on inverter side.

I_{ac}= RMS value of the load current.

m_a= Inverter modulation index.

L_f= Inductance of filter.

The DC link voltage is 780 V for RMS voltage of 415 V on inverter side. For power decoupling between the hybrid system and the grid, the electrolytic DC link capacitor is included.

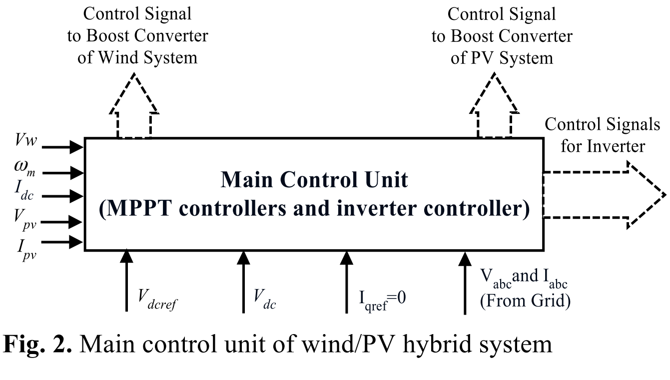

Fig. 2. Main control unit of wind/PV hybrid system

4. Results and Discussions

In this section, the simulated results of the hybrid wind/PV system are presented. The simulation duration of 3 sec has been selected. For modeling, the wind generation system [16] and the Solarex MSX-60 PV module [17] parameters are given in Table 1. The simulation tests were carried out with different perturbations initiating from the grid. In order to assess the ability of the inverter controller, three typical perturbations are considered. The first case deals with hybrid operation under balanced dip in grid voltages. The second case with heavy distorted grid voltages and the third is hybrid system operation under unbalanced grid voltages. The wind speed (12 m/sec) and irradiation (1000 W/m^2) are constant and total generation is 60 kW. A DC load connected to DC bus is 25 kW and three phase AC load is drawing a power of 20 kW at 0.9 p.f. lagging.

Table 1: Simulation parameters of the studied wind/PV hybrid system

Wind Turbine	Blade Radius=3.7m; air density=1.225kg/m^2; number of blades=3; C_{pmax} =0.47
PMSG	Stator Phase Resistance = 0.1764Ω; Inertia = 0.00065Kg-m^2; L_d=L_q=4.245mH; Torque constant=13.91N-m/A peak; Pole pairs = 18; P_{out}=20kW, V_{wrated} = 12m/sec;
PV Arrays	k = 1.38e^{-23}; q = 1.6e^{-19}; n=1.2; V_g = 1.12; P_m=60W; N_S = 32; N_P=21; V_{oc} = 21.1V; I_{sc}= 3.8A; G=1000W/m^2; P_{out}=40kW;
DC link voltage	780V; DC link capacitor=5000μF;
DC load	Resistive Load, 500V
AC load	3-Ph RL loads at 0.9 p.f.;
Grid Parameters	415V, 50Hz, X/R ratio=7;
Filter	R=3e^{-3}Ω; L=250e^{-6}H;

Case 1: Balanced Voltage Dip

The performance of hybrid system with balanced voltage dip is depicted in Figure 3. By using a three-phase programmable voltage source available in the Matlab/Simulink, in the grid voltages, balanced voltage dip of 20% is introduced at t = 1.4 to 1.6 sec as shown. The DC link voltage waveform is shown in Figure 4 and DC bus voltage due to the grid balanced voltage dip is constant. The variations of powers injected to the grid are depicted in Figure 5. It is seen that both powers injected to the utility grid remains the same with regards to the perturbation. This is due to the constant current control scheme used for the grid side inverter operation.

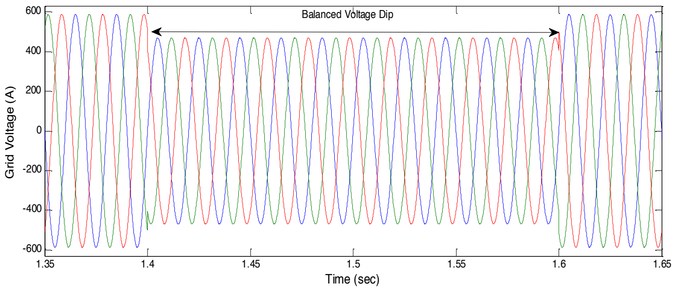

Fig. 3. Balanced voltages dip in grid voltages

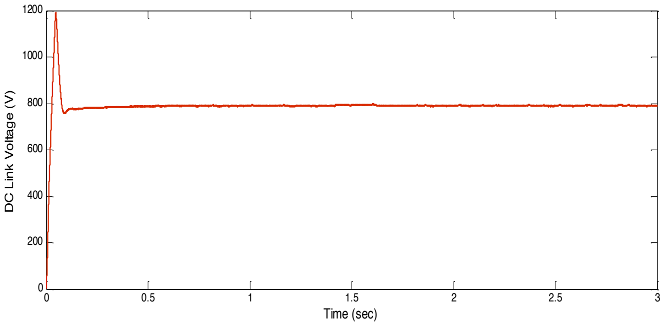

Fig. 4. DC link voltage

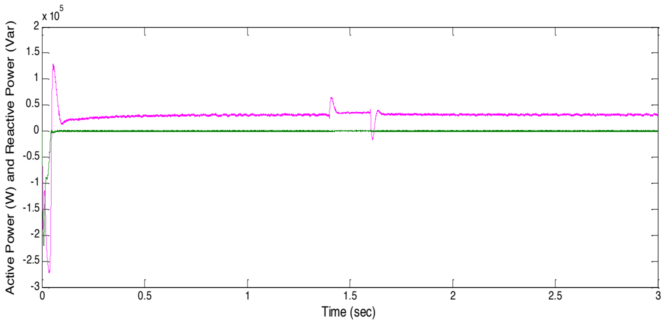

Fig. 5. Active and reactive power injected to the grid

Case 2: Polluted Grid Voltages

For grid integration of renewable sources, the THD of voltage is kept lower than 5 % according to the standard prescribed [IEEE Std. 1547 (2003)]. But in and factories and industrial plants it can however surpass this recommended value due to both line impedances and transformers in existence of nonlinear load currents. To represent this situation as shown in Figure 6 total harmonic distortion of utility voltage considered is 10 % (6 % of 7^{th} harmonic and 8 % of the 11^{th} harmonic). The waveforms of polluted three-phase grid voltages are presented in Figure 7. The corresponding variations in *d* and *q*-axis current by hybrid system are reported in Figure 8. Figure 9 shows the injected active and reactive powers to the utility grid. Figure 10 shows % THD for injected grid currents. We note a major increase in % THD of line current injected to the grid to 4.57 % if the grid voltage is polluted strongly.

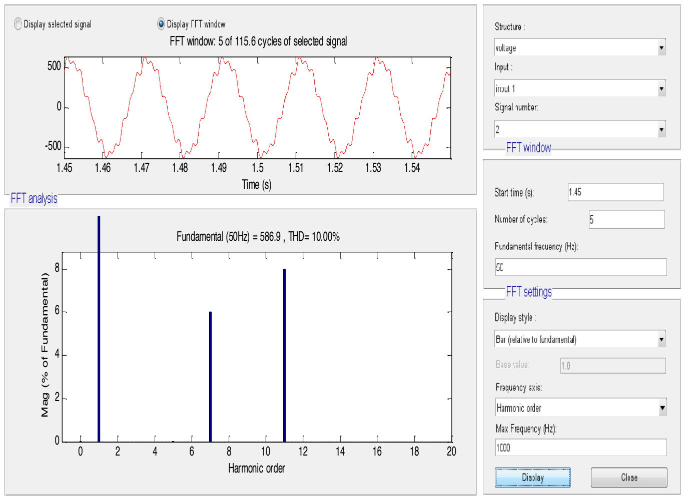

Fig. 6. THD (%) in polluted grid voltages

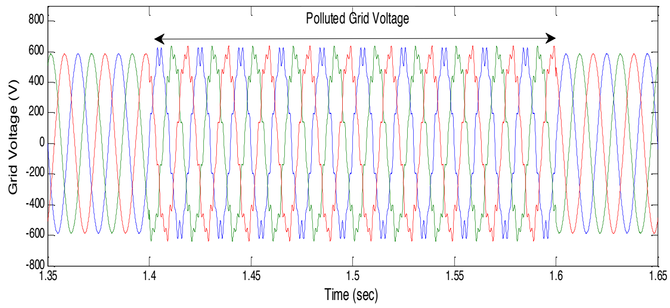

Fig. 7. Polluted three phase grid voltages

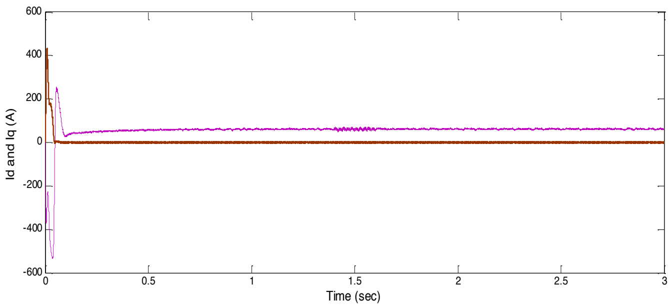

Fig. 8. *d* and *q*-axis components of current injected to the grid

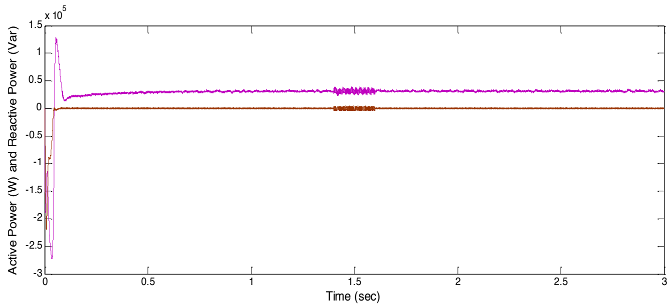

Fig. 9. Active and reactive power injected to the grid

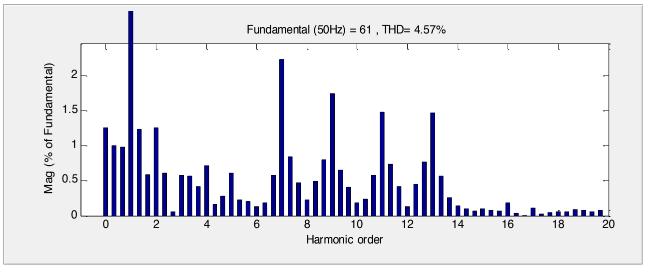

Fig. 10. THD (%) for injected grid currents

Case 3: Unbalanced Grid Voltages

The grid voltage unbalance condition may occur due to single line to ground short-circuits. To simulate unbalanced condition, the voltage of phase 'B' is varied by 15 % and maintaining other phase voltages at normal values. The voltage of phase 'B' is decreased to 15 % of its normal value from 1.4 to 1.5 sec and is increased to 15 % of its normal value from 1.5 to 1.6 sec. The simulated grid voltages are shown in Figure 11. Figure 12 shows the variation in the of i_d and i_q currents due to the unbalanced voltage effect between t=1.4 and 1.6 sec. The injected active and reactive power variation due to the unbalanced grid voltages is shown in Figure 13. It is seen that the values of injected powers into the utility grid remains the same with regards to the unbalanced grid voltages.

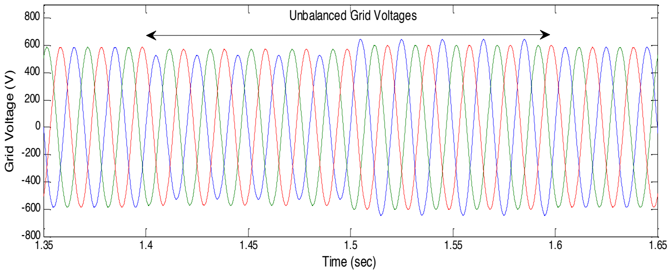

Fig. 11. Grid unbalanced three phase voltages

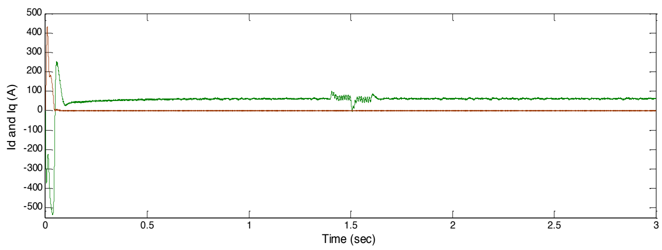

Fig. 12. *d* and *q*-axis components of current injected to the grid

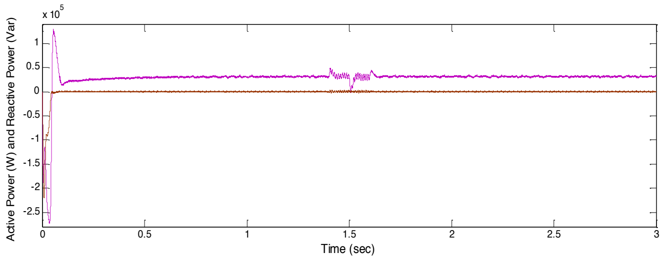

Fig. 13. Active and reactive power injected to the grid

5. Conclusion

In this paper, the performance study of grid integrated wind/PV power system has been evaluated for different grid perturbation conditions. Both wind power generator and PV panels are controlled to operate at their maximum power point. The DC and three phase AC loads are used for the study. The inverter controls the DC bus voltage and controlled to get zero reactive power injected to the utility system. It is observed that the injected powers to the utility grid remain same with regards to the perturbation. The simulation results demonstrate the capability of the current control scheme of the grid side inverter in regulating the injected active and reactive power by the hybrid system during grid perturbation conditions.

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