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Modelling and Performance Analysis of Grid Connected Photovoltaic Power Systems

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Abstract: Grid connected PV system is considered as one of the promising technologies to meet the growing demand of energy in present scenarios. This paper studies the impact of increased penetration of PV generation on power quality parameters in a power network. The performance analysis of grid connected photovoltaic power systems is carried out under different levels of solar irradiance and also under varying load conditions. For this simulations are carried out on a 100 kW grid connected PV system which is designed and modelled in MATLAB/ Simulink software. The simulations results are presented considering Power Quality (PQ) issues such as voltage variations at the Point of Common Coupling (PCC) and current and voltage Total Harmonic Distortion (THD) at different load demand/types conditions.

Key words: Distributed generation, photovoltaic systems, power quality, MATLAB/Simulink.

Introduction

Recent trend in the power industry is towards the integration of Renewable Energy Sources (RES) like photovoltaic (PV), wind, biomass etc. with the conventional grid system (Li et al., 2014). This is not only to meet the growing demand of energy throughout the world but also to reduce the adverse effects of fossil fuels on earth environment (Akella et al., 2009). Renewable energy sources provide clean energy to the consumers at reasonable cost and also present an opportunity for the consumers to generate energy at their ends. This factor reduces the dependence of consumers on the energy distributors and also allow them to reduce the burden of tariffs. One viable option in current scenario is the integration of Photo-voltaic (PV) in conventional grid system. However, it has been revealed from the detailed literature survey that grid connected PV system has many power quality issues associated with it due to the intermittent nature of PV (Eltawil et al., 2010; Eftekharnejad et al., 2013; Gupta et al., 2015).

Some of the power quality issues encountered in grid connected PV system are overvoltage, THD (Total Harmonic Distortion), power factor, and voltage fluctuations (Gonzalez et al., 2011; Kumary et al., 2014; Vinayagam et al., 2016). Power generated by the PV should be properly accommodated by the grid to avoid the overvoltage problem. The introduction of a PV system in a network leads to increased interference in a distribution system due to an increase in harmonics especially in the case of non-linear loads. It is important to maintain the balanced flow of real and reactive power in a power network to maintain power factor at optimum value. The output of a PV system is dependent on the irradiance level; thus a variation in irradiance

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directly leads to a variation in the PV output. As the irradiance level cannot be constant throughout the day, a standard PV system is prone to voltage fluctuations (Kumar, 2015; Farhoodnea et al., 2013; Ayub et al., 2014; Meshram et al., 2013).

The paper aims to analyze the performance of grid connected photovoltaic system in distribution network. For this, utility grid integrated with 100 kW PV system power system is modelled and simulated using MATLAB/Simulink (Matlab/Simulink software, 2016). The study is then carried out to analyze the impact of PV on power quality parameters like THD (Third Harmonic Distortion), voltage stability etc. The performance is tested under different load scenarios like variable load conditions or load types (linear/non-linear/dynamic). The study also demonstrates the working of PV under different irradiance level scenarios. Simulation results are of load voltage, THD, grid power, and load bus power for different loads.

Modelling of Grid Connected Photovoltaic System

Figure 1 shows the MATLAB simulink model of 25 kV, 2500 MVA utility grid connected to 100 kW PV system. The grid model consists of 25 kV distribution transformers and 120 kV transmission system. The PV model consists of 66 strings of five series-connected PV modules connected in parallel. Number of series-connected cells in each PV module is 96. The open circuit voltage (Voc) and short-circuit current (Isc) of PV module is 64.2 V and 5.96 A, respectively. The voltage (Vmp) and current (Imp) of PV module at maximum power is 54.7 V and 5.58 A, respectively. The PV array delivers a maximum power of 100 kW at 1000 W/m^2 sun irradiance. 5 kHz DC-DC boost converter increases the PV natural voltage from 273 V DC to 500 V DC. MPPT controller automatically varies the duty cycle in order to generate the required voltage to extract maximum power. 1980 Hz 3-level 3-phase VSC converts the 500 V DC link voltage to 260 V AC and keeps unity power factor. 10-kvar capacitor bank is used for filtering harmonics produced by VSC. A 100 kVA 260 V/25 kV three-phase coupling transformer is used to connect the converter to the grid.

Results and Discussion

Figure 2 shows the characterization study of PV array used in the simulated system. It is shown that simulation

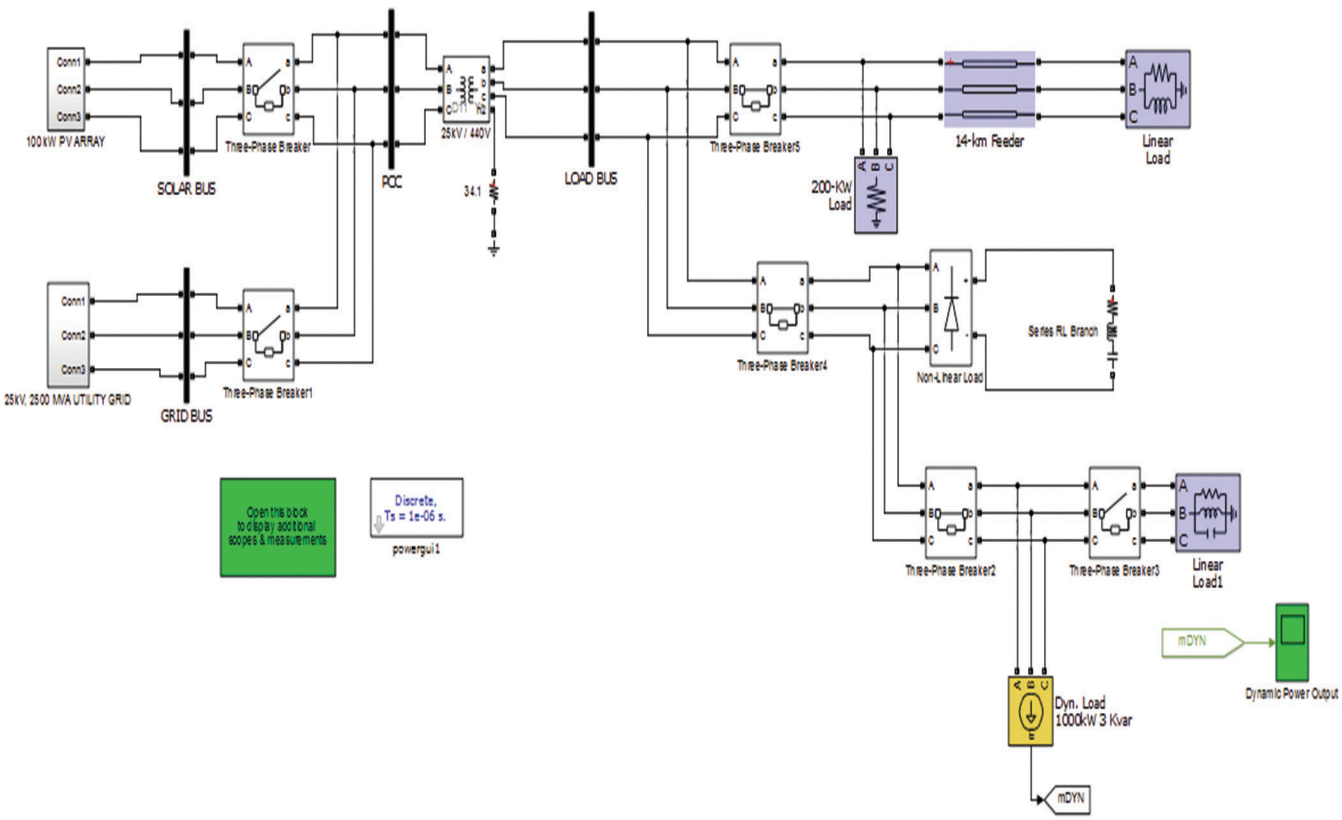

Figure 1: Grid connected photovoltaic system simulated in Matlab/Simulink.

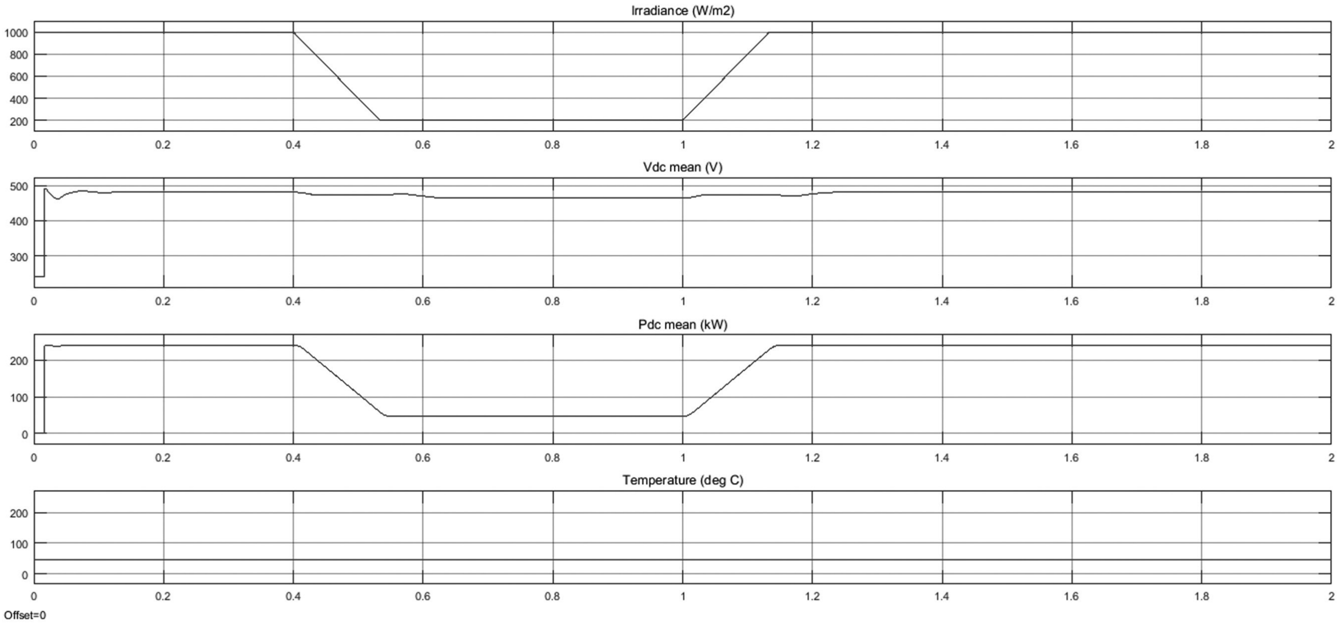

Figure 2: PV voltage and power characteristics at standard irradiance and temperature levels.

study is carried out under standard temperature and irradiance test conditions (25°C, 1000 W/m^2). Under these conditions, PV array generates 100 kW power.

Load Variations in the Distribution Network

The main objective of the system is to analyse the power, voltage and THD variations in a distribution network with the integration of PV. Initially the system operates under different load conditions and power distribution between the utility grid and PV system is analyzed. For this, a load of 500 kW is connected to the system. Simulation results, as shown in Figure 3, shows that the grid is supplying 423.9 kW power and the power supplied to the load by PV system is 76.10 kW. Thus, it is shown that the excess of power requirements by the load other than the PV capacity is fulfilled by the grid.

When the value of load connected in the distribution network is less than the maximum power output capacity i.e. 100 kW of PV generation, the extra amount of PV power will be supplied to the grid. The value of irradiance and temperature is maintained constant as in previous case. Consider a case of 50 kW load connected in the system. The maximum power that PV system generates comes out to be 88.2 kW. Thus the grid power comes out to be negative which is as shown in Figure 4.

Irradiance Variation in the PV System

In this case the value of load connected is kept constant but the value of irradiance is changed continuously.

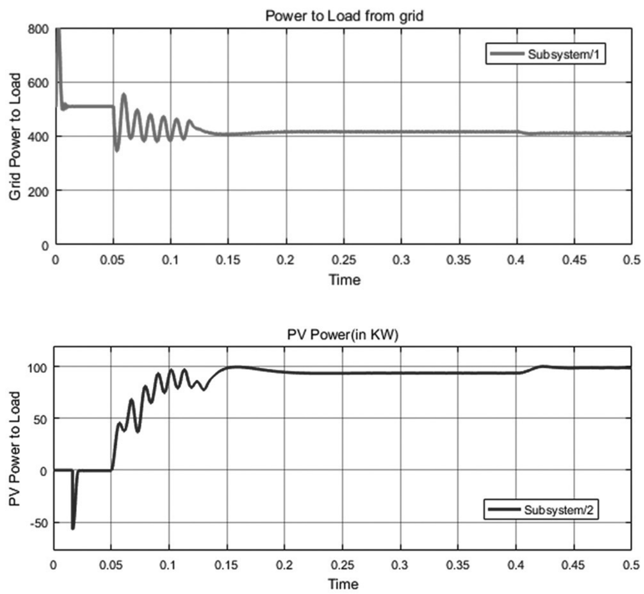

Figure 3: Power level of grid and PV under 500 kW load.

Changing the value of irradiance will have an impact on the power generation of PV system. For low value of irradiance the power output of PV will be lower than its maximum power output capacity. The simulink output and the results are as shown in Figure 5. The simulation results show that variations in the PV system power output graph goes down whereas the power curve of the grid system moves upwards as the level of irradiance goes down. The calculations show that PV system is supplying 67.77 kW of power.

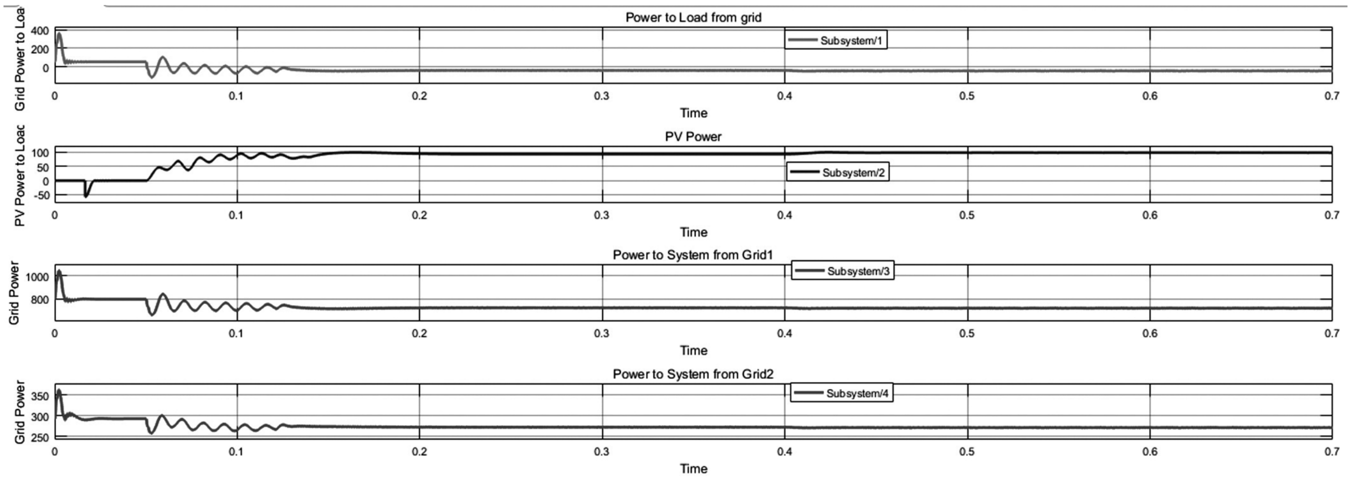

Figure 4: Power level of grid and PV under 50 kW load.

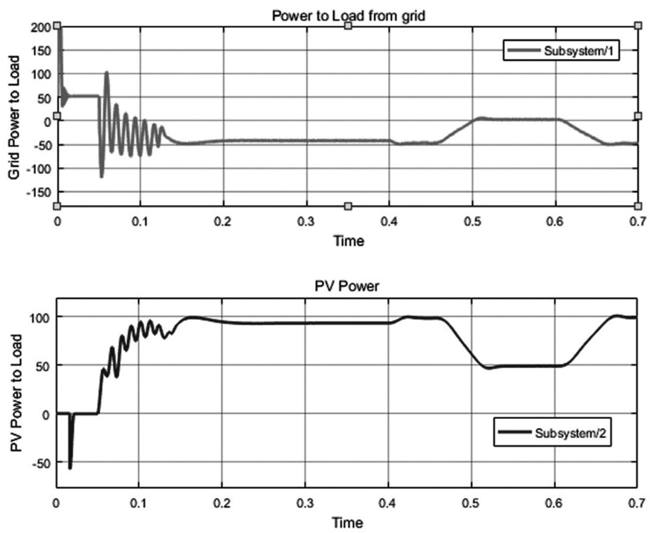

Figure 5: Power level of grid and PV under irradiance variations at 50 kW power.

Non-Linear Load Connected to the Distribution Network

In this case, the system operates under different types of loads such as linear, non-linear and dynamic loads. When the linear load is replaced by a nonlinear load, harmonics are introduced into the system. To designed non-linear load, the universal bridge block from library in MATLAB/Simulink is used. The block is set for diode mode. A parallel resistance is connected with it. The current drawn by the non-linear load will not be sinusoidal even when it is connected to a sinusoidal voltage. These non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it. Figure 6 shows the waveform distortion in load voltage waveform and Figure 7 shows that THD level of load voltage is 11.34%.

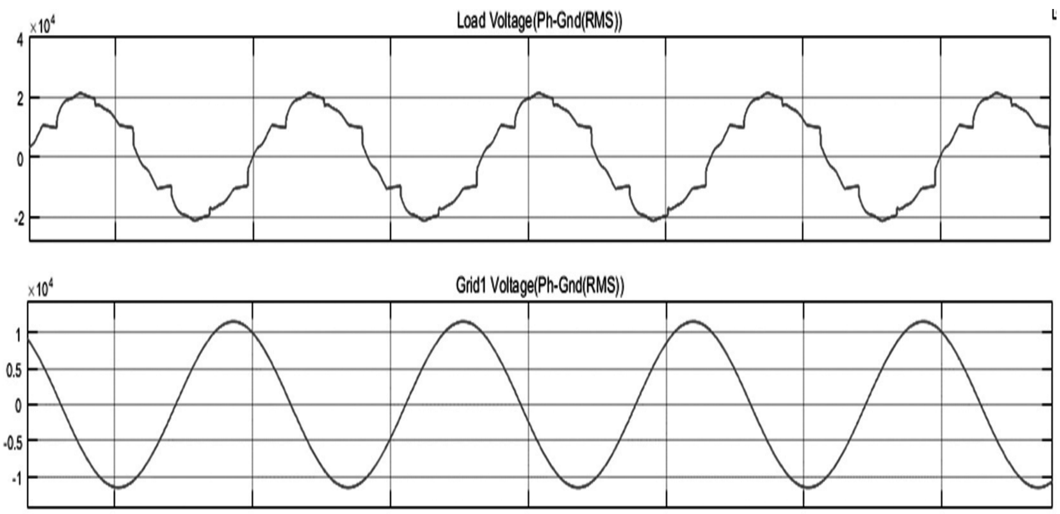

Figure 6: Waveform analysis for load voltage and grid voltage for non-linear load.

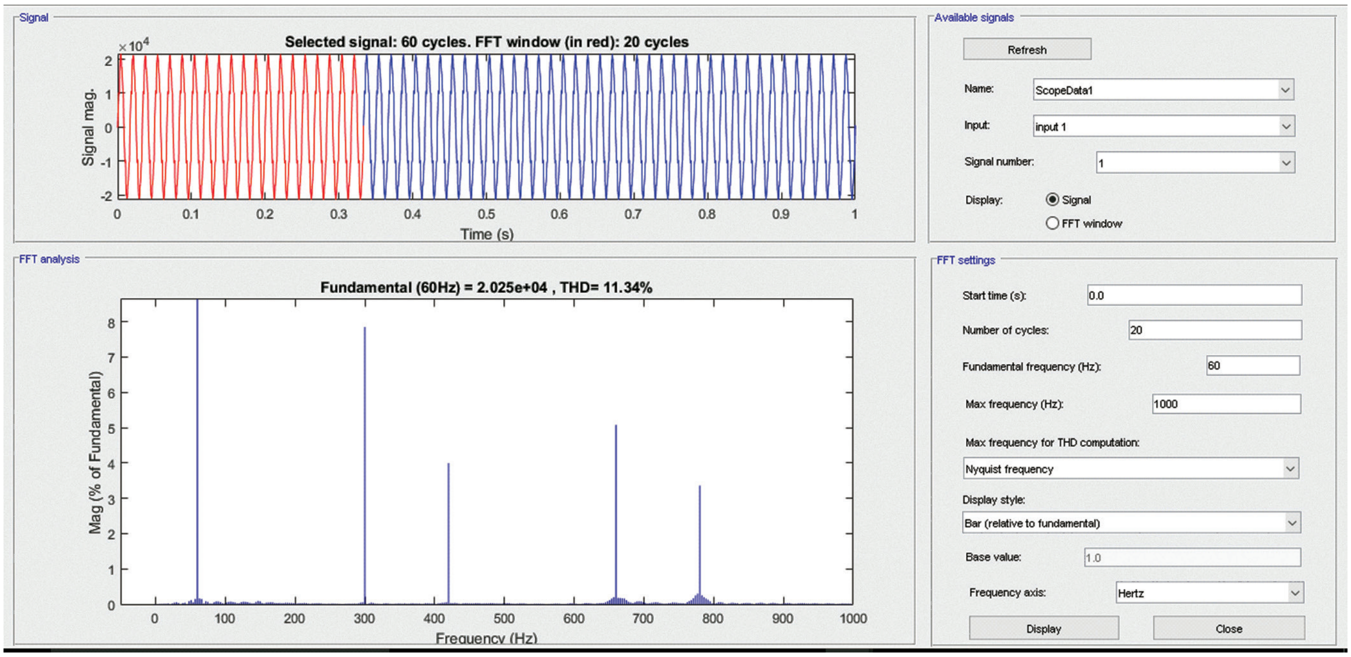

Figure 7: Harmonic analysis for load voltage for non-linear load.

Conclusion

The performance of grid connected photovoltaic (PV) system in distribution network is tested under variable loads and different load types (linear/non-linear/dynamic) scenarios. The study also demonstrates the working of PV under different irradiance level scenarios. The designed power system is modelled using MATLAB/Simulink software and simulated results analyzed the impact of PV on power quality parameters like voltage fluctuations, power variations and THD (Third Harmonic Distortion). Simulation results show that voltage at PCC is affected and harmonics are introduced in the system due to intermittent nature of PV. Therefore, this study recommends the use of more stable and efficient power electronics converters/Statcom/SVR/Harmonic Filters like devices for improved power quality in grid connected PV systems.

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