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Effect of Load Variation on a Voltage-Source Grid-Connected Inverter for a Solar Photovoltaic System

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ABSTRACT

Voltage source grid connected inverter (VSI) of 250 kW has been designed and simulated to be synchronized with a grid of 33 kV using a new designed control unit capable of controlling a photovoltaic (PV) system on both DC and AC sides. The control unit is capable of performing maximum power point tracking technique (MPPT) and DC voltage regulation at the DC side. On the AC side, it controls the pulse width modulation (PWM), current regulation and the phase lock loop (PLL). The design has been performed by preparing the inputs, forming the mathematical equations and simulating them via MATLAB/Simulink package. Results showed that the controller is capable of managing load variation effects on DC side of the PV system. Several changes have occurred on the AC side due to the load variation. A detailed analysis of the results is presented and discussed.

1. INTRODUCTION

Renewable energy has become widely used in electrical power generation, especially solar PV energy that generates electricity directly from the sun’s irradiance. Solar energy could be used to produce electricity, heat and for lightning. It is used directly to generate electricity via photovoltaic (PV) cells which has become one of the most important renewable energy sources. Photovoltaic cost is decreasing and it is expected to decrease more as demand and production increases [1] [2].

Solar energy can be classified into two types: passive and active. Passive solar energy is making direct and indirect use of thermal energies from the sun. Indirect use of solar energy is possible mainly in buildings or structures [3].

PV cells produce DC current, thus inverters are used to convert this DC into AC. The inverter is the heart of photovoltaic grid connected systems. It is connected between the PV cells and the power grid, playing an essential role in the energy development and utilization, affecting the economics and reliability of the PV grid generation systems [4].

PV cells have several topologies of grid connection; voltage source grid connected inverter (VSI) topology is used in this paper. The VSI inverter converts fixed DC voltage into a variable AC voltage. It also performs controlling mechanism on both frequency and amplitude. The essential use of VSI inverters is transforming a unidirectional DC voltage into a bidirectional AC voltage. In paper [7], the reliability of the MPPT controller with changing irradiations, the robustness of the MPPT controller against load variations and the reliability of the MPPT controller with simultaneous change of irradiation and load has been discussed using Artificial Intelligence. Paper [8] aims to investigate the influence of load coordination with solar energy availability on the size and cost of standalone PV renewable energy systems. An investigation on the effects of photovoltaic (PV) solar power variability and forecast uncertainty on electric power grid operation in the Arizona Public Service system has been discussed in [9].

2. VOLTAGE SOURCE GRID CONNECTED INVERTER (VSI)

There are several topologies used in connecting the inverter to the grid. These topologies differ according to the characteristics of the DC-side power supply. Voltage source inverter uses a diode rectifier to convert the direct current (DC) to AC voltage [5].

VSI is not controlled through electronic firing as in current source inverter (CSI) drive. Parallel capacitors are used as DC link for regulating the DC bus voltage ripple and storing energy.

The inverter consists of insulated-gate bipolar transistor (IGBT) semiconductor switches. Sometimes there are other alternatives to the IGBT; insulated gate commutated thyristors (IGCTs) and injection enhanced gate transistors (IEGTs).

The main function of the IGBT switches is to generate a PWM voltage output that regulates the grid voltage and frequency [5].

VSI topology cannot operate with a low PV voltage since it requires the PV voltage to be higher than the peak line-to line grid voltage in order to enable power transformation to the grid. Therefore, in practice a DC-to-DC boost converter is usually added resulting a two-stage VSI to step up the low PV voltage to the required level [6].

3. OBJECTIVES

Grid-connected PV systems are affected by the non-linear characteristics of the PV cells and the surrounding atmospheric conditions.

The objectives of this paper are:

- To design a VSI inverter and a control unit capable of operating the PV system on different load conditions.
- To investigate the effect of load variation (both increase and decrease) on the PV system's performance (current, voltage and power).

4. METHODOLOGY

The methodology followed in this paper involved preparing the inputs and calculating the required values for the simulation process. The simulation inputs were the technical specifications of the PV panel, the inverter and the inverter control unit. Perturb and observe algorithm was used for implementing MPPT with DC-DC boost converter. The output was fed to the three-phase voltage source inverter controlled through PWM signal. The input voltage of the inverter was regulated through a regulating circuit to match the output voltage of the inverter with the utility grid voltage. An RCL filter is used to eliminate harmonics. Phase matching was implemented using a PLL circuit. Power flow from the grid to the load and from the solar system was controlled by detecting the voltage of the grid side and the solar irradiance.

The whole system was simulated using MATLAB/ SIMULINK software.

5. TECHNOLOGY DESCRIPTION

The designed PV system aims to transfer electrical power from PV panels to the grid. The model is simulated at constant irradiance of 1000 W/ m^2 and constant temperature of 45 °C.

A DC–DC converter is used to boost the PV voltage to a level higher than the peak of grid voltage. The converter also tracks the maximum power point of PV module using perturb and observe algorithm. A PWM based DC-AC inverter (3- levels IGBT voltage source inverter) is used for enforcing sinusoidal voltage waveform with matching phase frequency with grid voltage using PLL. The output voltage wave shape of PWM inverter is square PWM wave. Therefore, an RCL filter is used for coupling the inverter to the grid by converting the PWM square wave to a pure sine wave. An inverter control mechanism has signals that drive the three-phase VSI to regulate the power conversion process from DC to AC using a voltage regulator in order to supply the desired amount of real and reactive power to the grid from the PV system. Active power is controlled by varying the angle between grid and inverter voltage. The supply of reactive power is controlled by varying the amplitude of inverter voltage using a current regulator. Three-phase decoupling transformations is used to step up the output voltage before the connection to the grid.

The block diagram of synchronous controller for the grid-connected inverter is represented in Figure 1. The inverter has two PI controllers to compensate the current vector components that are defined in synchronous reference frame (dq).

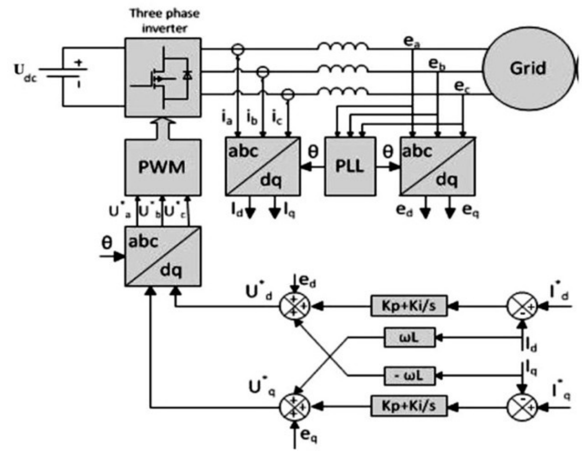

Figure1: Block diagram of synchronous controller for the grid-connected inverter.

The modeled control unit detailed structure is shown in Figure 2.

An investigation on the performance of the system has been performed when the load increases from 32.25 MW to 62.25 MW. Another investigation has been performed to study the decrement effect of the load to 17.25 MW.

Figure 3 shows the model of the designed PV system in MATLAB/ SIMULINK package. The model shows the PV array with irradiance and temperature inputs. A three level

IGBT bridge inverter, an inverter control unit and RLC filter are shown in model.

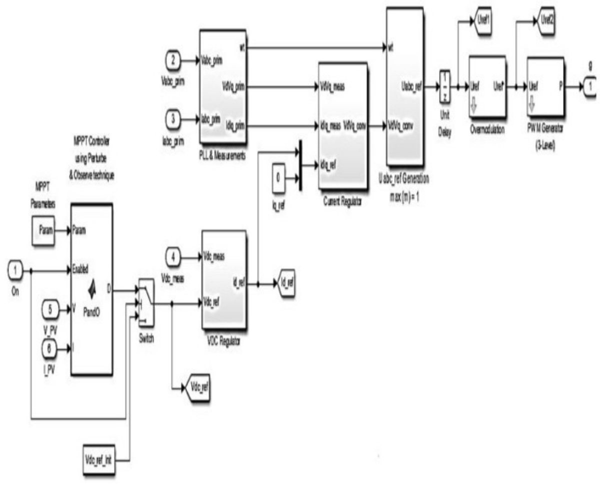

Figure 2: The modeled control unit structure.

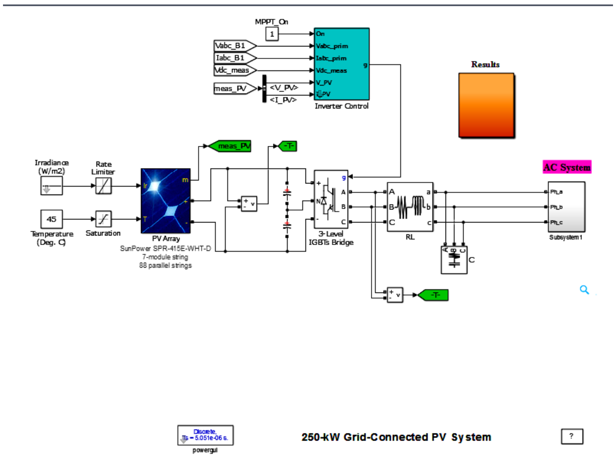

Figure 3: Model of the PV System in MATLAB/ SIMULINK.

5. RESULTS

A model of a grid connected VSI of PV module has been designed and simulated using MATLAB/ SIMULINK package. An inverter control unit was designed and simulated to be capable of delivering the maximum generated power from the PV panel despite of the different operating conditions surrounding the PV system.

Table (1) shows the results of operating the system at normal, high and low load conditions.

The power decreased to 236.7 W with a rise time 507.44 us and overshoot 2.19 % as shown in Figure 6.

When the grid's load has decreased to 17.25 MW, the generated voltage has increased to 27.04 kV with rising time equals to 5.82 ms and overshoot of 0.501 % as shown in Figure 7.

The current has decreased to 5.95 A with a rise time 5.95 ms and overshoot 0.882 % as shown in Figure 8.

Table 1: Results of Operating the System at Normal, High and Low Load.

No.	Measured Value	Normal Load (32.25 MW)	High Load (62.25 MW)	Low Load (17.25 MW)
1	Irradiance (W/m^2)	1000	1000	1000
2	Diode's Current (A)	23.88	23.00	23.00
3	PV's Current (A)	502.5	503.0	503.0
4	PV's Voltage (V)	482.1	482.0	482.0
5	Measured PV's Signal (W)	1.032	0.87	0.87
6	DC's Voltage (V)	488.7	481.0	481.0
7	DC's Power (W)	241.5	242.0	242.0
8	Reference DC's Voltage (V)	454	454	459
9	Inverter's Output Voltage	480	481	481
10	I_d (A)	0.2023	0.95	0.95
11	I_q (A)	0.1269	0.03	0.029
12	Reference AC Voltage (V)	0.88	0.87	0.87
13	AC Voltage (kV)	20.3	26.2	27.04
14	AC Current (A)	7.96	6.14	5.95
15	AC Power (W)	264	236.7	235

When the grid load changes, the control unit tries to maintain the synchronization conditions stable as possible. The DC side of the PV system maintains approximately constant. Some changes occur on the AC side. When the grid's load has increased to 62.25 MW the voltage increased to 26.2 kV with rising time 5.82 ms and overshoot 0.503 % as shown in Figure 4.

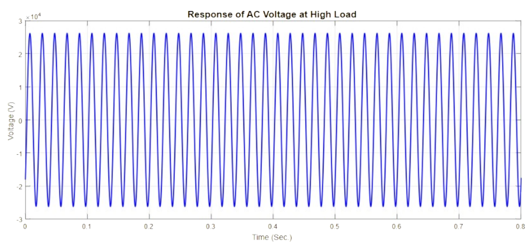

Figure 4: The Response of the Voltage at High Load.

The current decreased to 6.14 A with a rise time of 5.99 ms and overshoot 1.12 % as shown in Figure 5.

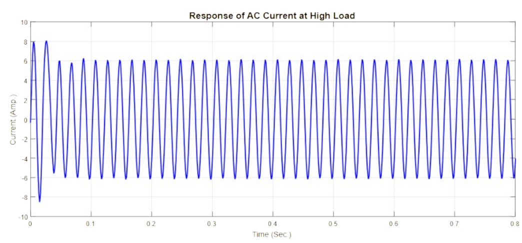

Figure 5: The Response of the Current at High Load.

The power has decreased to 235 W with a rise time 280.3 us and overshoot 5.22 % as shown in Figure 9.

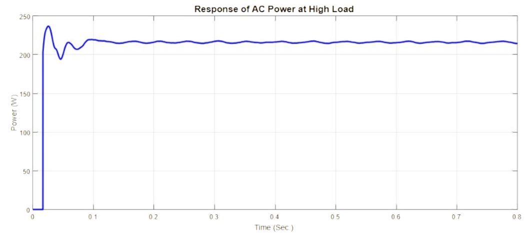

Figure 6: The Response of the Power at High Load.

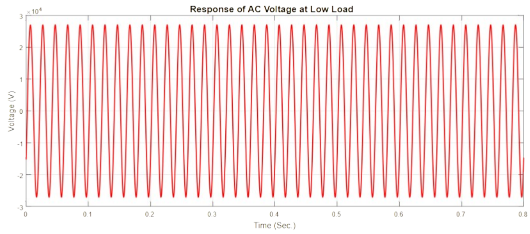

Figure 7: The Response of the Voltage at Low Load.

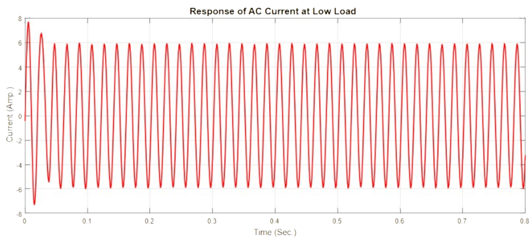

Figure 8: The Response of the Current at Low Load.

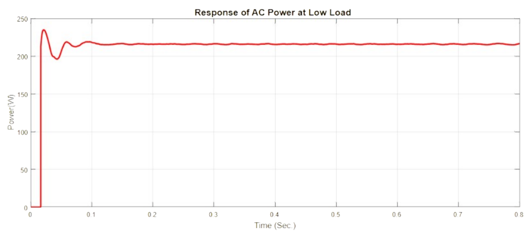

Figure 9: The Response of the Power at Low Load.

CONCLUSIONS

The results showed that the variation of the grid's load does not affect the DC side of the PV system. Although the control unit tries to maintain the synchronization conditions stable, but some change occur on the measured parameters. It is advisable to connect batteries to the PV system to charge and discharge the power when it is necessary and to maintain stable power supply to the load. The PV panel input supply could be resized to be able to operate much greater load. Further studies are recommended to investigate the system's load-balancing stability.

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