Study of Technical Parameters in Grid-Connected PV System

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Abstract - *With the rise of the power electronics technology and the decline in the price of photovoltaic (PV) panels, the use of the PV system as distributed generation has been increasing. During the grid connection of the PV system, parameters like voltage magnitude and frequency should be maintained within tolerable limits so that the power reliability and quality are assured. These parameters obtained from the PV source should be matched with grid parameters before synchronism and shouldn't be disturbed during the operation as well. However, there are several conditions that affect these parameters, one being an islanding condition. During this situation, the voltage and frequency show unhealthy nature and hence the operation of the PV system in the islanded condition under this scenario is forbidden. In this paper, the overall modelling of the grid-connected PV system is done first and the output nature of voltage and frequency waveforms from the inverter are studied. Later, the islanding scenario of the overall system is modelled and hence the nature of voltage and frequency waveforms are simulated and studied at different load conditions. All the modelling and simulations are done in MATLAB/Simulink environment.*

Key Words: Mathematical modelling, Inverter controller, Grid-connected PV system, Maximum Power Point Tracking (MPPT), Islanding, MATLAB/Simulink.

1. INTRODUCTION

Due to the advantages of environment friendly energy source with free availability, cheap operation and maintenance cost, PV energy has become the promising source of distributed generation [1]. To sum up the simulation of overall grid connected three phase PV system, several modelling stages have to be preceded, which are modelling of PV array, maximum power point tracking (MPPT), DC-DC converter, DC-AC converter and inverter controller. Several works regarding the modelling of such various stages have been presented in numerous research papers. [2]-[4] are some collection of papers which presented the modelling of PV modules with the use of MATLAB/Simulink. The literature [5]-[7] reports several techniques for implementing MPPT. Similarly, the modelling of DC-DC converter which performs regulation of the DC voltage as required is referred from [8],[9]. For grid integration, DC should thus be converted to three phase AC which is equivalent to grid alternating parameters. So, the proper design of DC-AC inverter and its control unit is thus required. The collection of literature [10]-[12] presents the design of inverter along with the inverter controller which ensures the parallel operation of the PV system and power grid. Based on the study of this referred literature, the former section of this research paper performs the modelling of the aforementioned stages in MATLAB/Simulink.

During the grid connection, it is required to ensure that the parameters of the PV system should match the grid parameters. These parameters include three phase voltages, its phase sequence and the frequency. Before the grid connection, these parameters are studied in this paper so that the reliability and quality of the power are ensured. Also, an algorithm is modelled in this paper where the inverter output parameters are compared with that of grid parameters which decides the time of PV system and power grid synchronization. There are several conditions that might affect the nature of the aforementioned parameter. One of those conditions is known as islanding. Islanding is the state where the distribution generation (DG) like PV energy source carries on with supplying local loads despite the disconnection of grid [13]. The frequency and voltage waveforms at point of common coupling (PCC) during the islanding conditions show different nature according to the availability of the local load capacity [14]. This research has restricted its scope to studying and analysing the voltage and frequency waveforms under several local loads condition. Moreover, several research papers present islanding detection and its mitigation techniques, some of them are [15]-[17].

2. MODELLING

2.1 PV Array with Maximum Power Point Tracking (MPPT) technique

The model representing the practical single diode PV module is presented in figure 1. For many applications of power system planning, such a model is preferred since it has a smaller number of computation and yields less computational error in comparison with double diode model [18]. Based on the following equations [19], the PV module's mathematical modelling is illustrated in the

MATLAB/Simulink environment, which is shown in figure 2. The desired power output can be achieved with the introduction of the number of PV modules in series and parallel configuration.

$$I_{ph} = [I_{sc} + Ki*(T_c - T_{ref})] * (G/G_{ref}) \quad (1)$$

$$I_o = \frac{Isc+Ki(Tc-Tref)}{e^{\left[\frac{q(Voc+Kv(Tc-Tref))}{NsAkTc}\right]}-1} \quad (2)$$

$$I = I_{ph} - I_o\left(e^{\left[\frac{q(V+Rs*I)}{NsAkTc}\right]} - 1\right) - \frac{V+Rs*I}{Rp} \quad (3)$$

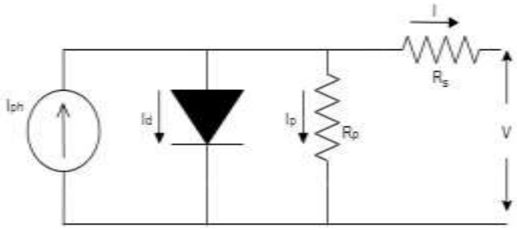

Figure 1: Single diode PV module

I_{ph} : Photocurrent
I_{sc} : Current during short-circuit
K_i : Coefficient of the temperature of current during short-circuit condition
T_c : Temperature of the module (K)
T_{ref} : Module temperature at STC
G : Irradiance (W/m2)
G_{ref} : Irradiance at STC (W/m2)
V_{OC} : Open circuit voltage
K_v : Coefficient of the temperature of voltage during the open-circuit condition
k : Boltzmann's constant
N_s : No. of cells
Q : Charge of electron
I_o : Saturation photocurrent
A : Ideality factor
R_s : Series Resistance
R_p : Parallel resistance
I : PV current
V : PV voltage

MPPT technique plays a significant part in maximizing the efficiency of the PV model. Several techniques of MPPT like perturb, and observation (P&O), fractional open-circuit voltage, fuzzy logic control, incremental conductance, and so on have been researched [20]. Among which, the P&O technique is widely used because of its effortless implementation. In this research, we use perturb and observe method with a variable current parameter which is referred to from [21]. Figure 3 represents the flowchart of the implemented P&O algorithm.

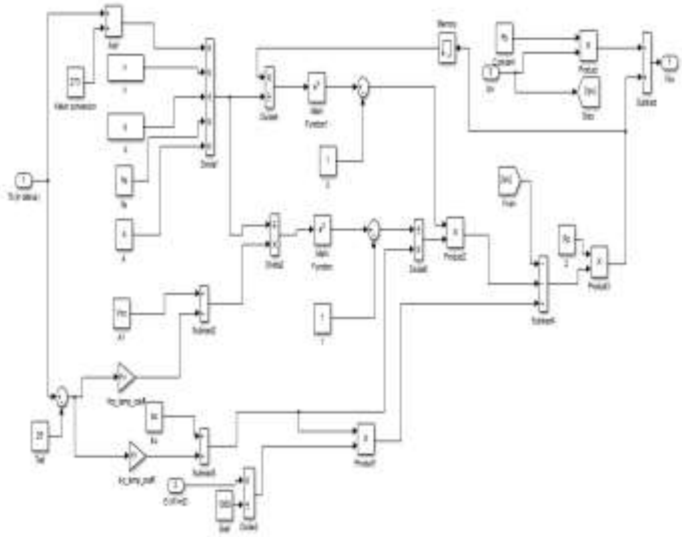

Figure 2: PV module mathematical model

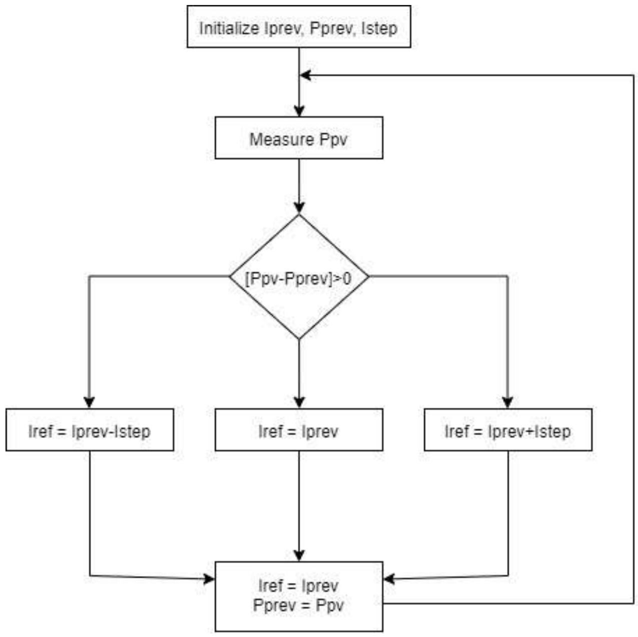

Figure 3: P&O algorithm

2.2 DC-DC converter

The DC-DC converter is such designed that the required utilization voltage output can be achieved either through increasing or decreasing the DC voltage obtained from the PV array system. Several converters like a buck, boost or buck-boost converter are employed to achieve the regulation of voltage through the modes of switching [22]. In this research, the modelling of boost converter based on the circuit diagram is shown in figure 4 and the related equations [23]. Based on the following equations, the mathematical model of the system is represented in figure 5.

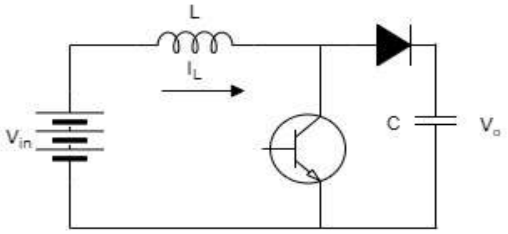

Figure 4: Boost converter

When the switch is in 'ON' state,

$$\frac{dVo}{dt} = \frac{-Vo}{C*R} \quad (4)$$

$$Vin - L\frac{di_L}{dt} = 0 \quad (5)$$

When the switch is in 'OFF' state,

$$Vin - L\frac{di_L}{dt} - Vo = 0 \quad (6)$$

$$\frac{dVo}{dt} = \frac{1}{C}(i_L - \frac{Vo}{R}) \quad (7)$$

And, $D=1-\frac{Vo}{Vin}$ (8)

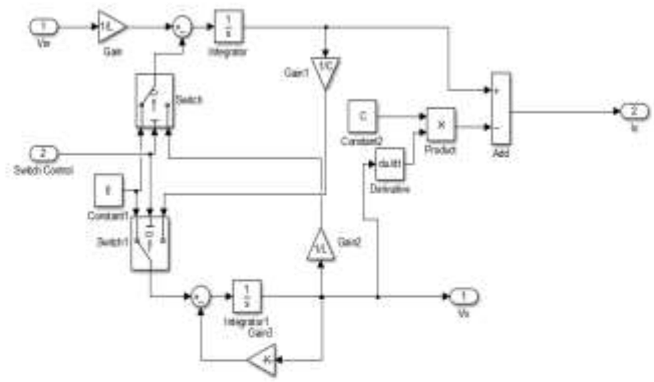

Figure 5: Mathematical model of the boost converter

2.3 Three Phase Grid Tied Inverter

A three-phase distortion-free, alternating current (AC) is required during the grid connection of the PV system. Fig 6 shows a circuit diagram of the two-level inverter with a three-phase voltage source (VSI) and with six switches, and a dc source 'V'. The mathematical expression from the above circuit is referred from [24] and is given below. The mathematical model based on these expressions is figured in figure 7.

$V_{rn} = V_{ro} - V_n$ (9)

$V_{bn} = V_{bo} - V_n$ (10)

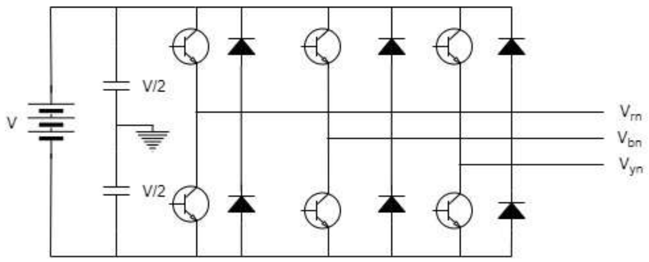

Figure 6: Circuit diagram of inverter

$V_{yn} = V_{yo} - V_n$ (11)

So, $V_{rn} + V_{bn} + V_{yn} = V_{ro} + V_{bo} + V_{yo} - 3V_n$ (12)

And, at balanced condition, $V_{rn} + V_{bn} + V_{yn} = 0$

$V_n = (V_{ro} + V_{bo} + V_{yo})/3$ (13)

$V_{rn} = (2V_{ro} - V_{bo} - V_{yo})/3$ (14)

$V_{bn} = (2V_{bo} - V_{ro} - V_{yo})/3$ (15)

$V_{yn} = (2V_{yo} - V_{ro} - V_{bo})/3$ (16)

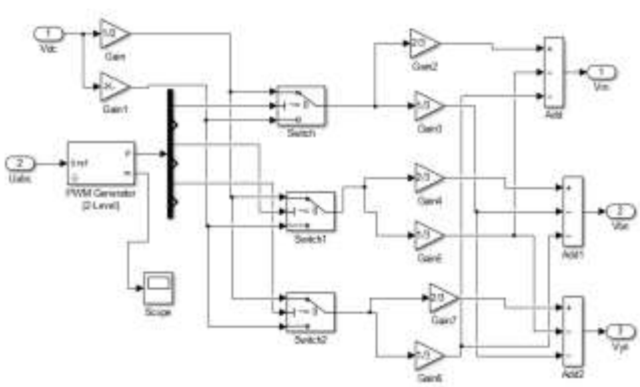

Figure 7: Mathematical model of inverter

The inverter must be able to synchronize parameters like voltage, phase and frequency between the PV system and grid. Moreover, a unity power factor must also be maintained on the grid side [23]. To maintain such condition, the current controller is modelled in this research which is shown in figure 9. In the model, the current obtained from the MPPT technique is compared to the dq component of the grid current. Discrete PID controller is used to obtaining the reference dq voltage which is fed to a pulse generator to obtain the necessary switching pulses to the inverter. Further, the LCL filter is designed to obtain the ripple-free three phase waveform. In order to damp the switching harmonics, small rated inductors can be employed for LCL filter which is advantageous in term of cost and dynamic operation [25].

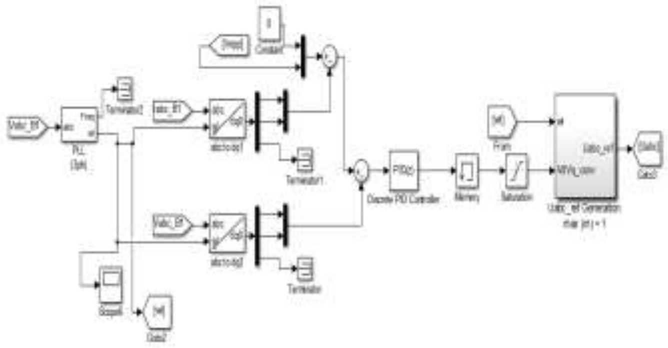

Figure 8: Inverter Controller model

2.4 Islanding Scenario

Figure 9 shows the layout of the PV system integrated with the grid according to the model that is done in MATLAB/Simulink. The arrangement of two breakers is made where breaker 1 is supposed to imitate the condition of islanding and the breaker 2 is supposed to isolate the PV system with the grid which can be termed as islanding scenario. According to the scope of the work, the study of the parameters like voltage, and frequency is done in this research during the islanding condition. During the islanding situation, the nature of the mentioned parameters according to the power demand of the local load [26]. So, the waveforms at the following different situations are studied in this paper.

- When PV generation is less than load power
- When PV generation is greater than load power
- When PV generation is equal to load power.

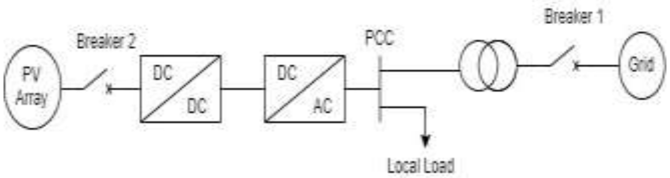

Figure 9: PV grid integration layout

3. SIMULATION RESULTS

After the completion of overall modelling, the model is simulated and analyzed in several situations. Before synchronizing the PV source with the grid, it is necessary to observe the voltage magnitude, its phase sequence and the frequency. So, the waveform of the inverter's output is simulated first. During the analysis, a scenario is created where the reference parameters for the inverter controller is provided through the grid. The grid provides reference parameters of line voltage and line current. According to this maintained scenario, the voltage and frequency waveforms are obtained which are shown in figure 10 and figure 11 respectively. In these figures, it is observed that the magnitude and phase sequence of voltage and the frequency from the inverter becomes equivalent to that of the reference grid parameters after a certain period of time. So, the synchronization breakers are programmed to be operated after the achievement of tolerable limits of the voltage and frequency. The flowchart representing such algorithm is shown in figure 12 below.

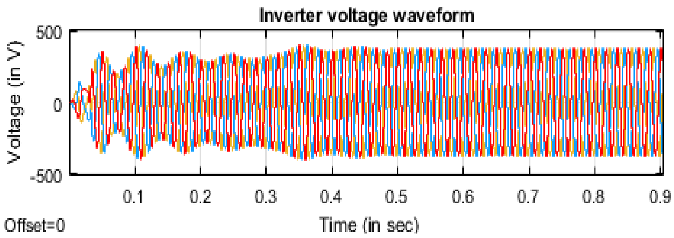

Figure 10: Voltage waveform from an inverter

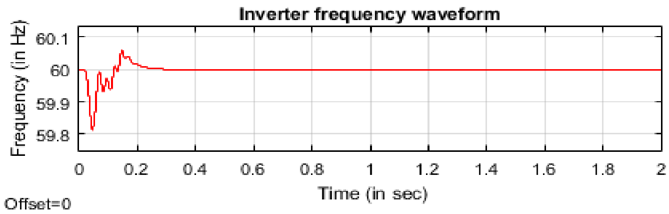

Figure 11: Frequency waveform of the inverter

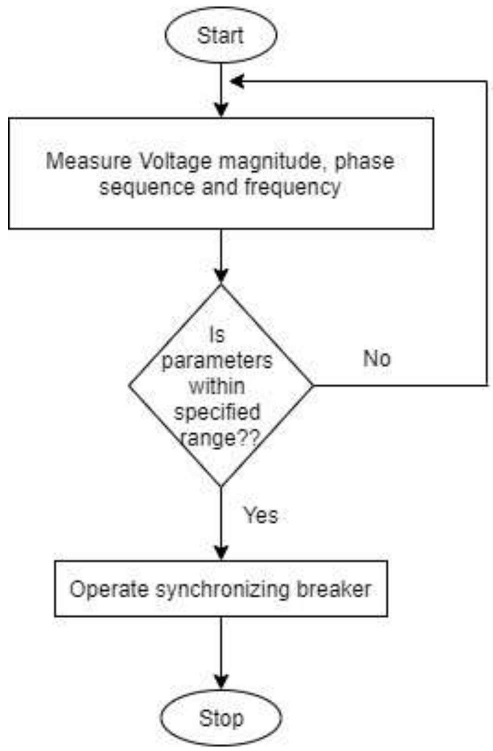

Figure 12: Flowchart to program synchronizing breaker

The modelling of 100 kW of the PV system and the power grid of 1 MVA of power with 5 km of distribution feeder line is done in our research. After the successful synchronization of the PV system with a power grid, the scenario of islanding is imitated according to the layout presented in figure 9. During the islanding scenario, the voltage and frequency show distinct characteristics according to the connection of load power. In the model, a disconnecting breaker is used in the grid side which is programmed to disconnect grid from PV system at t = 1 sec. A single-phase voltage and the frequency are simulated and analyzed in several scenarios which are described below.

• When PV generation is less than load power

Figures 13 and 14 show the nature of voltage and frequency waveform under the condition of higher PV generation. In the figure, we can observe that the phase voltage is sagging along with the increasing frequency after the encounter of islanding condition. The frequency after islanding is found to increase in linear nature.

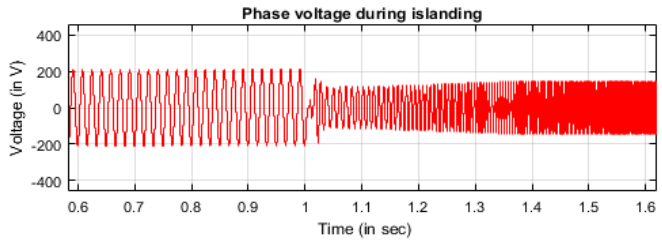

Figure 13: Phase voltage waveform when $P_{pv} > P_{load}$

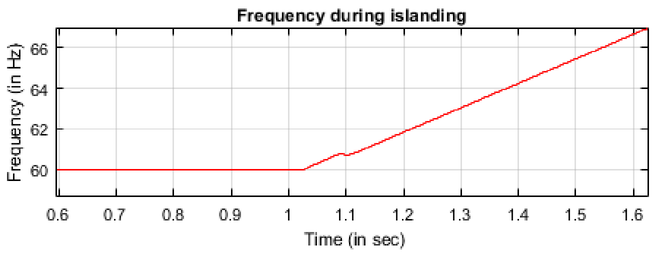

Figure 14: Frequency waveform when $P_{pv} > P_{load}$

• When PV generation is greater than load power

Figures 15 and 16 show the nature of voltage and frequency waveform under the condition of higher load power. In the figure, we can observe that the phase voltage is swelling along with the increasing frequency after the encounter of islanding condition. Similar to the above-mentioned condition, the rate of increase in frequency after islanding is linear in nature.

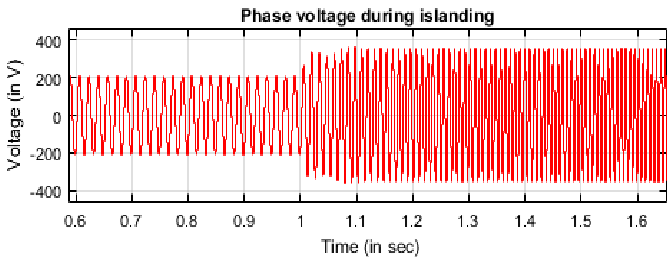

Figure 15: Phase voltage waveform when $P_{pv} < P_{load}$

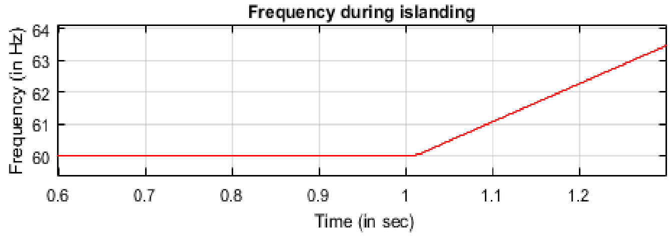

Figure 16: Frequency waveform when $P_{pv} < P_{load}$

• When PV generation is equal to load power

Figures 17 and 18 show the nature of voltage and frequency waveform under the condition of equivalent PV power and load power. In the figure, we can observe that the phase voltage and frequency are almost equivalent to the original values after the encounter of islanding condition.

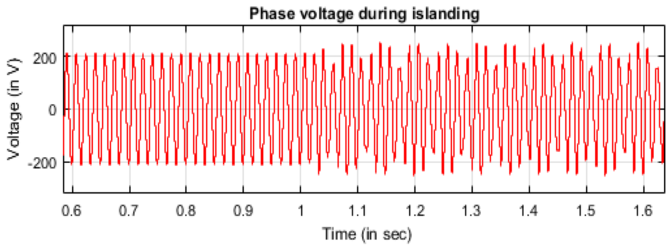

Figure 17: Phase voltage waveform when $P_{pv} = P_{load}$

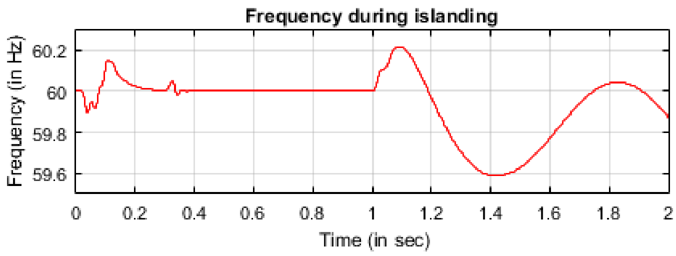

Figure 18: Frequency waveform when $P_{pv} = P_{load}$

4. CONCLUSIONS AND RECOMMENDATION

During the study, it is found that the characteristics of several technical parameters at PCC change with the change in characteristics of the grid. The paper presents the modelling of the overall PV energy system with grid connection along with the study of the contributing parameters. According to the study of the output parameters from an inverter, an algorithm is also included which ensures proper synchronization of PV energy system and the power grid. Moreover, the research can be further expanded to study the stability behaviour of the system with the PV energy sources included in the conventional grid. Similarly, the behavioural study of these technical parameters due to several faults in the grid is also recommended.

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