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HARMONIC ANALYSIS OF HIGH PENETRATION PV SYSTEM ON GRID

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Abstract—Installations of Solar Photovoltaic systems in distribution networks are increasing in very swift manner. These PV systems have both pros and cons associated with it. In terms of cons, it has power electronic devices which provides harmonics and thus affects the power quality of the grid by causing harmonic distortion. The aim of this study is the harmonic analysis of PV systems on grid. To emulate a realistic scenario a certain level of harmonics is also injected in the considered network through a dynamic load. Number of PV sources has increased and then the THD is analyzed for these cases. The scheme involves photovoltaic generation (PV) modules which are basically act as a DC current Source, which is connected to the grid through DC-DC converter and DC-AC Converter. Instead of current source inverter a voltage source inverter is utilized and the controlling technique is applied owing to control the voltage source inverter. MATLAB/SIMULINK tool has been used to simulate the considered grid connected PV system and to analyze it for the varying environmental conditions. Maximum power point tracking based on perturb & observe algorithm has been considered to analyze the system for maximum utilization under different irradiation and panel temperatures. These PV system provides harmonic distortion in the grid which affects the power quality of the grid as it is large in number. And with the no. of PV systems increasing rapidly it may become a bigger problem.

Keywords—Photovoltaic Generation Model; Maximum Power Point Tracker; Boost Converter; Inverter; Dynamic Load; Grid;

I. INTRODUCTION

Nowadays, because of the rapidly increasing world's power demand, it is required to have an energy source which is clean, impregnable and economic. And this need of energy can be solved by solar power as it is available in abundance and thus it can become an alternative substitute for conventional energy and this energy shortage problem can be solved by it. Because of the advancement in solar photovoltaic (PV) technology and the benefits from government subsidies, the installation of solar PV technologies has increased manifolds in both residential and commercial sectors. But there is a big concern of poor power quality of the grid which is due to harmonic distortion caused by these PV's [1]. Harmonic problems are common in distribution networks, mainly coming from non-linear loads, transformers and increased use of power electronics equipment [3]. Standalone generation meets the local load demand and if there is an excess generation then it can give it to the grid to meet the other loads. Tremendous work has been done in standalone and grid-tied (GT) operation of PV system such as meeting the residential loads, water pumping system [2]. In the present work, the attempt is made to represent the performance of GTPV. In order to draw the maximum efficiency out of GTPV system, the simplest of all MPPT algorithms P&O algorithm has been utilized.

In this paper, a scheme is employed wherein a PV Array is providing power to a grid through power electronic converters such as DC-DC converter and an inverter. Grid has a dynamic load and static load. Utility companies are familiar in estimating the harmonic levels and their potential effects on the network. However, with the penetration of PV systems on the customer side, it is becoming difficult to estimate the exact harmonic contributions from PV systems and there is a lack of study found in the literature [1]. This research has focused on the harmonic impact of PV system installations in a typical Grid Environment. Multiple installations of PV systems in various locations together with the proliferation of non-linear loads can introduce an issue of increased harmonics in the distribution system [5].

A. Modeling

The PV Array is used as a direct current source and interfaced with the DC/DC boost converter with the help of controlled current source. The dc side inductor Lboost is employed to eliminate the ripples in the dc current and the dc side capacitor Cboost is used to filter the ripples in the dc-link voltage. For simplicity, the discrete average model of the inverter is being utilized as an interface between the DC/DC converter and the ac load and plays the crucial part of the power conditioning circuit. The maximum power point tracker (MPPT) is ensuring the maximum utilization of the incident solar energy. The block diagram of a grid-connected solar PV system is shown in Fig.1. The circuit consists of solar PV arrays, maximum power point tracking (MPPT) controller, a DC/DC converter and an inverter operated with the control system block. The solar PV panels are arranged in series and parallel to form a PV array and to obtain the preferred voltage and current appropriate with the power network. A mathematical model has been considered and developed in MATLAB/SIMULINK software which has all the dynamic characteristics identical to a real PV system. The relationship between output voltage and current of PV array is expressed as follows

$$I_{pv} = N_p I_{sc} - N_p I_{rs} \left\{ \exp\left[\frac{q}{nkT_c} \left(\frac{V_{pv}}{N_s} + \frac{I_{pv} R_s}{N_p} \right) \right] - 1 \right\} - \frac{N_p}{R_p} \left(\frac{V_{pv}}{N_s} + \frac{I_{pv} R_s}{N_p} \right) \quad (1)$$

where PV cell short-circuit current Isc(T) = [Isc(T ref) + KI(T − Tref)]S/Sref; cell's reverse saturation current Irs = Isc(Tref) + KI(T−Tref)/exp[(q(Voc,(Tref) + Kv(T−Tref)/nkTref)]−1; Ns and Np denote the number of series and parallel panels. T, Tref and S, Sref are the actual and nominal temperatures and solar irradiances, respectively. The PV arrays produce a DC output, which is connected to a boost converter to obtain a high DC-link voltage. The DC/DC converter is operated with an MPPT system, which generates a duty cycle for the gate switch. A P&O algorithm based MPPT has been utilized in this work. This MPPT controller extracts the maximum power from solar PV arrays and is essential for increasing the efficiency of PV system. The output of DC converter is connected to a DC/AC inverter.

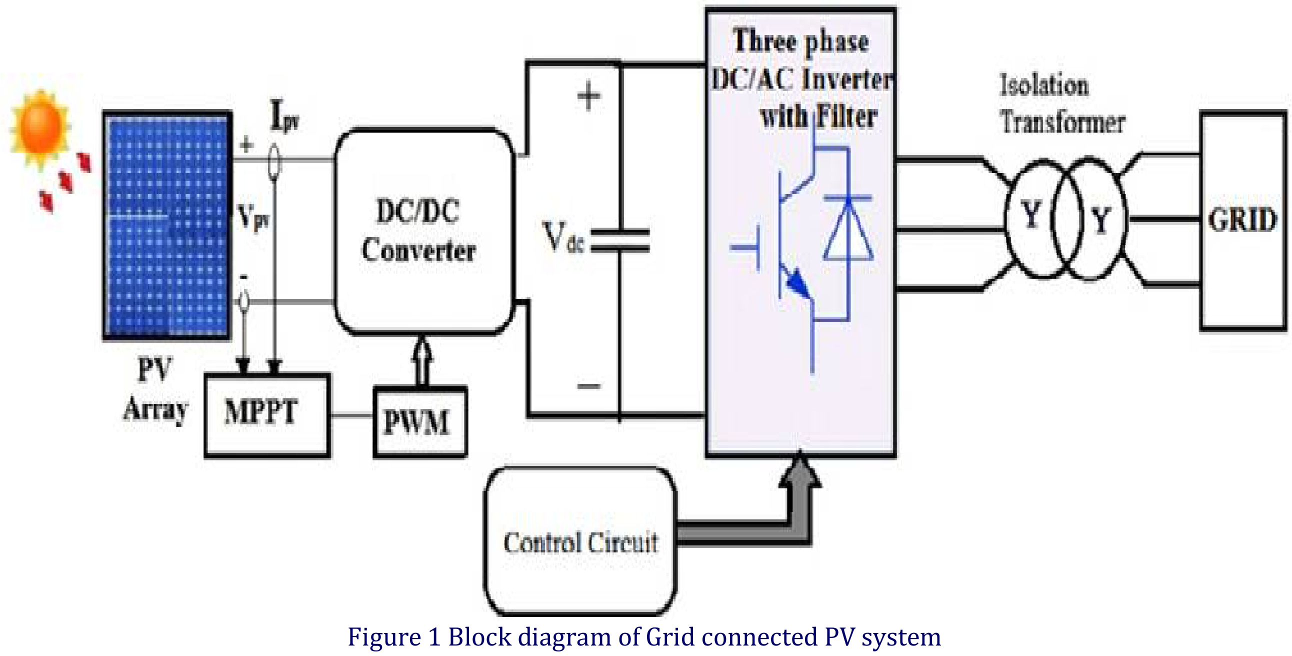


Figure 1 Block diagram of Grid connected PV system

B. PV Model

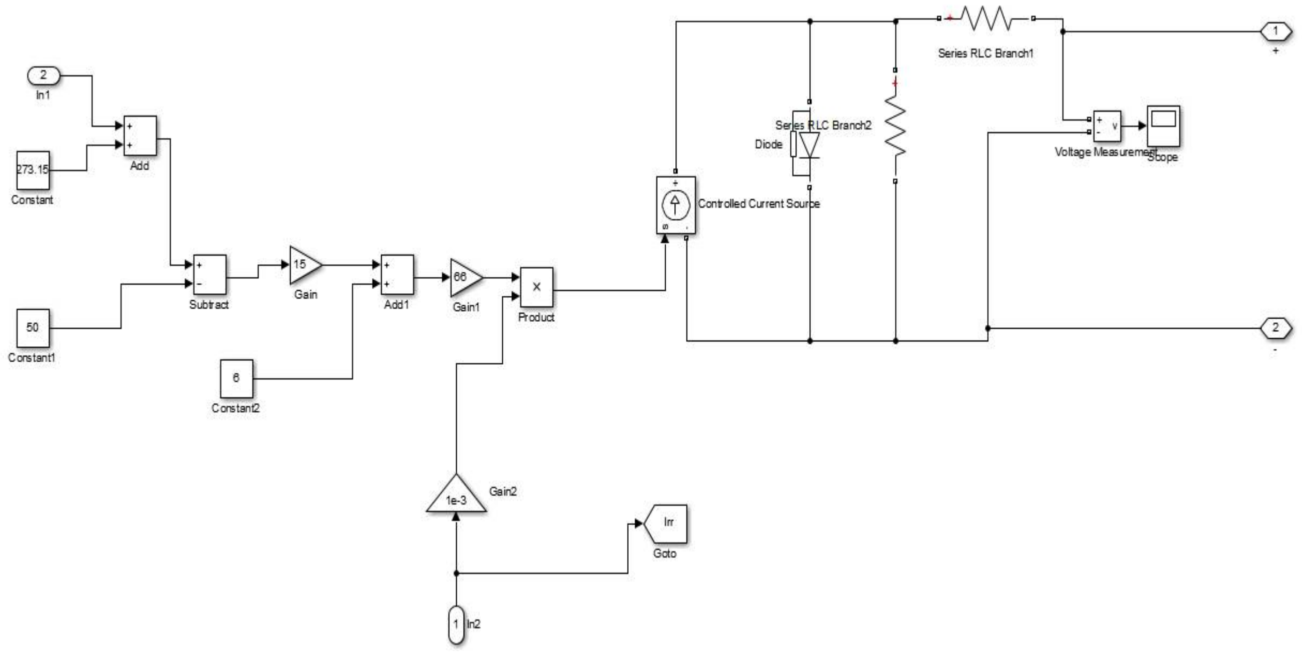


Figure 2 PV Array

IL=S/Sref*(IL_ref+alpha_isc*(Tcell_K-Tref_K))……………………………..(2)

IL (light-generated current) is a current source, diode (Io and nI parameters), series resistance Rs, and shunt resistance Rsh to represent the irradiance- and temperature-dependent I-V characteristics of the modules, these are the five parameters which is used to build a PV Array model. An array of photovoltaic (PV) modules are implemented in the PV Array block. The array has strings of modules connected in parallel and each string has modules connected in series. Figure 2 represents simulink model of PV Array and Eq. 2 has been used for it.

C. Inverter control

The term SPWM stands for "Sinusoidal pulse width modulation" is a technique of pulse width modulation used in inverters. With the help of switching circuits an inverter generates an output of AC voltage from an input of DC to reproduce a sine wave by generating one or more square pulses of voltage per half cycle. The output is said to be pulse width modulated, if the size of the pulses is adjusted. Some pulses are produced per half cycle by this modulation technique. The widths of all pulses are amplified or reduced while keeping the sinusoidal proportionality to change the efficient output voltage. only the on-time of the pulses are changed during the amplitudes with PWM (pulse width modulation) .

D. DC-DC Converter

In order to have, maximum power transferred from PV system to the load, the DC/DC boost converter is employed with an aim to achieve load matching. in order to have effective load matching, MPPT based P&O algorithm produces duty cycle, which in turn, controls the switching of boost converter.

E. MPPT Purturb and Observe

For maximum power transfer, MPPT tracking mechanism which is based on principal of impedance matching between load and pv module is necessary. By changing the duty cycle of the switch of a DC-DC converter the impedance is matched. The power from solar module is calculated by measuring the voltage and current[4]. Figure 3 represents the Flow chart for P & O algorithm which is utilized for simulink model of MPPT.

F. P & O Algorithm

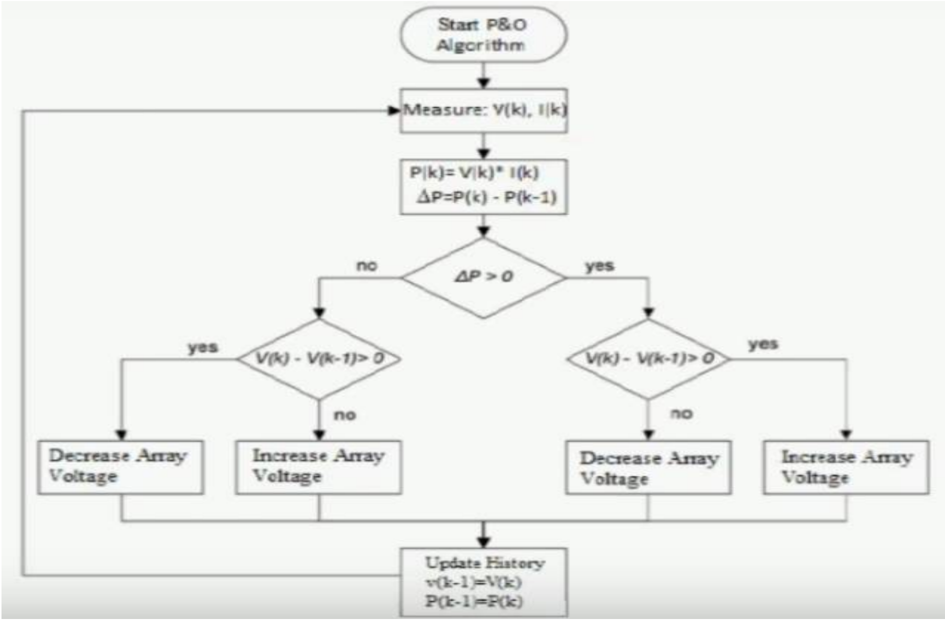


Figure 3 P & O Algorithm

G. Irradiance and Temperature

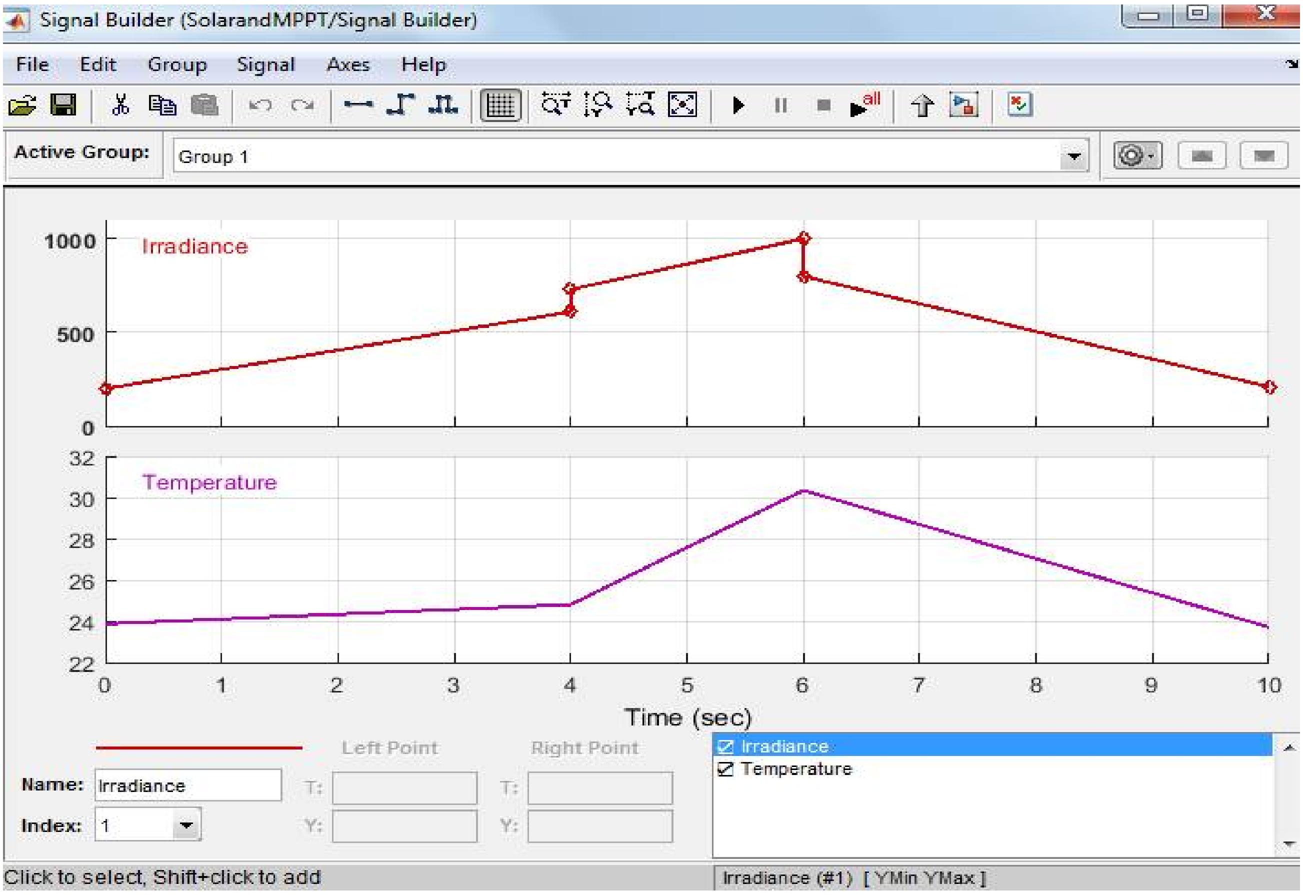
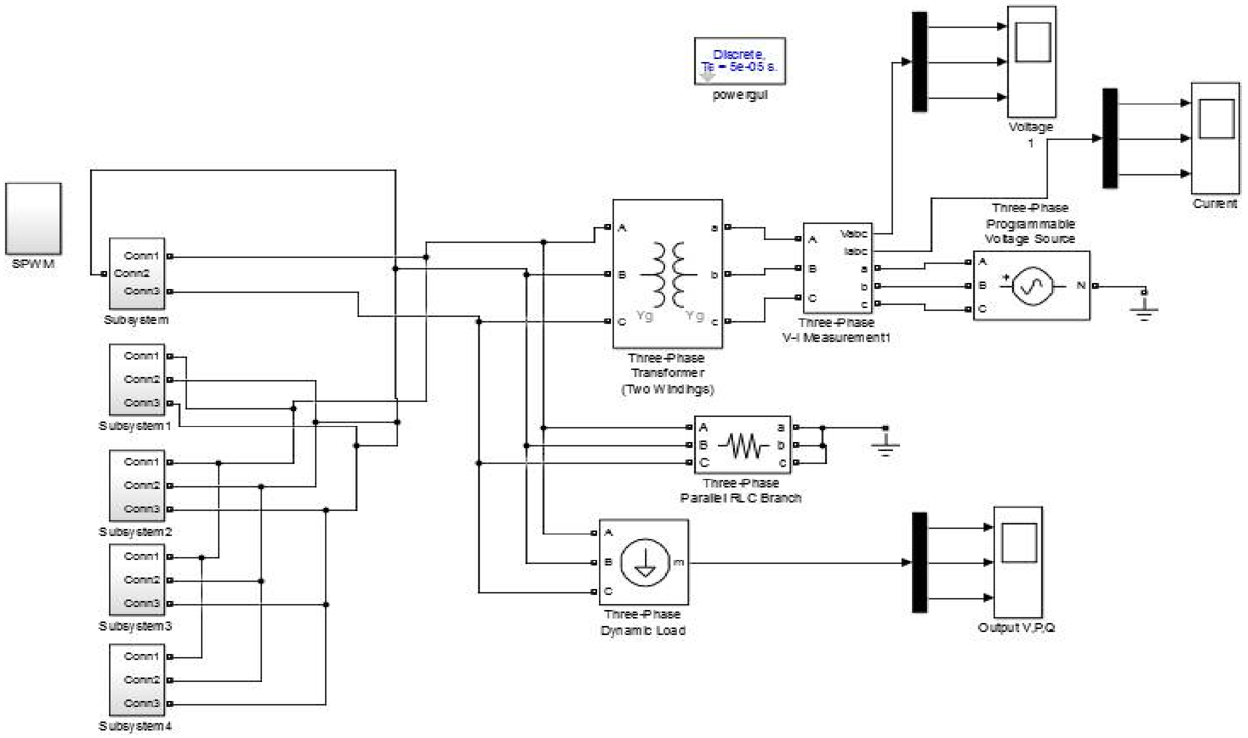


Figure 4 Input for PV Irradiance and Temperature

Figure 4 represents the irradiation and temperature as inputs to the PV Array. Whereas figure 5 represents the single line block diagram for gridtied PV system

II. SIMULATION RESULTS AND DISCUSSION



III. Figure 5 Single line block diagram of the grid-tied VSI-based photovoltaic-generation model

A. PV Power Output

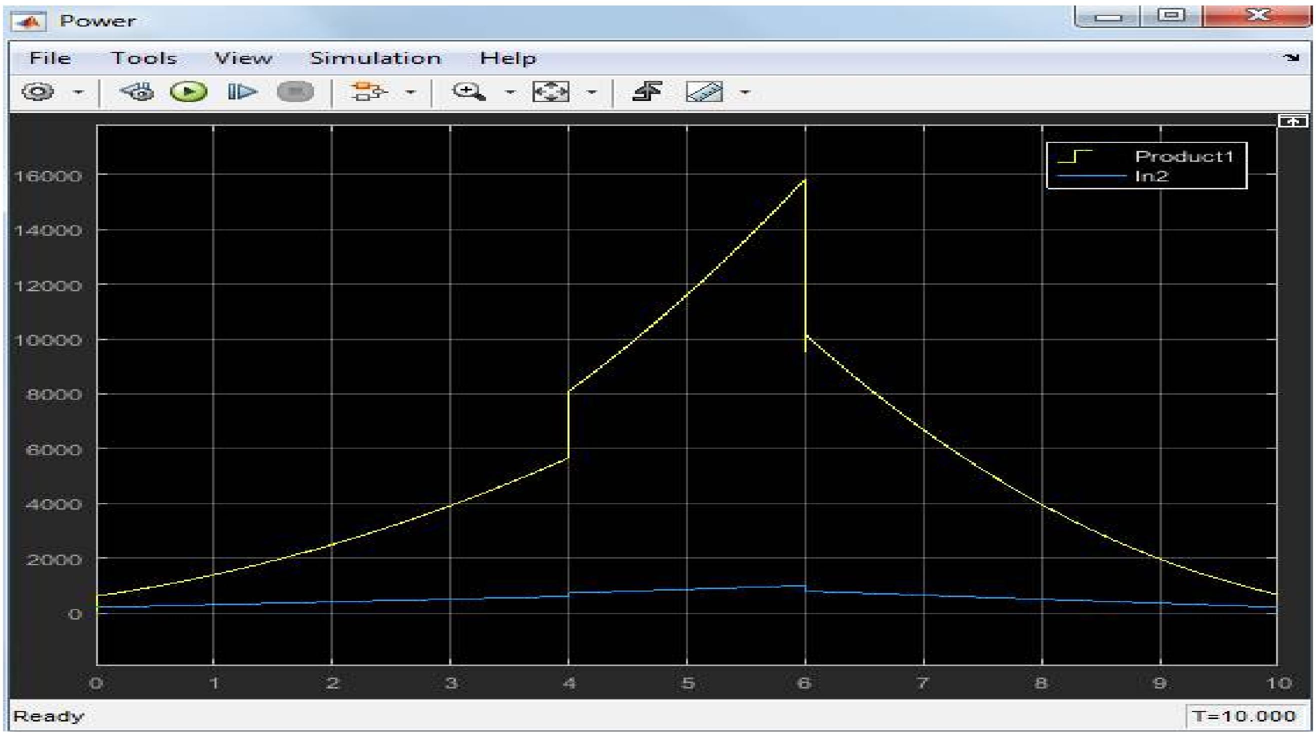


Figure 6 PV Array output

Figure 6 represents the PV array output with MPPT, Boost converter and the peak power obtained as seen from the graph is 16 KWp and it has designed for 19.2 KWp with the irradiation and temperature shown in figure 4 as an input.

B. SPWM Output

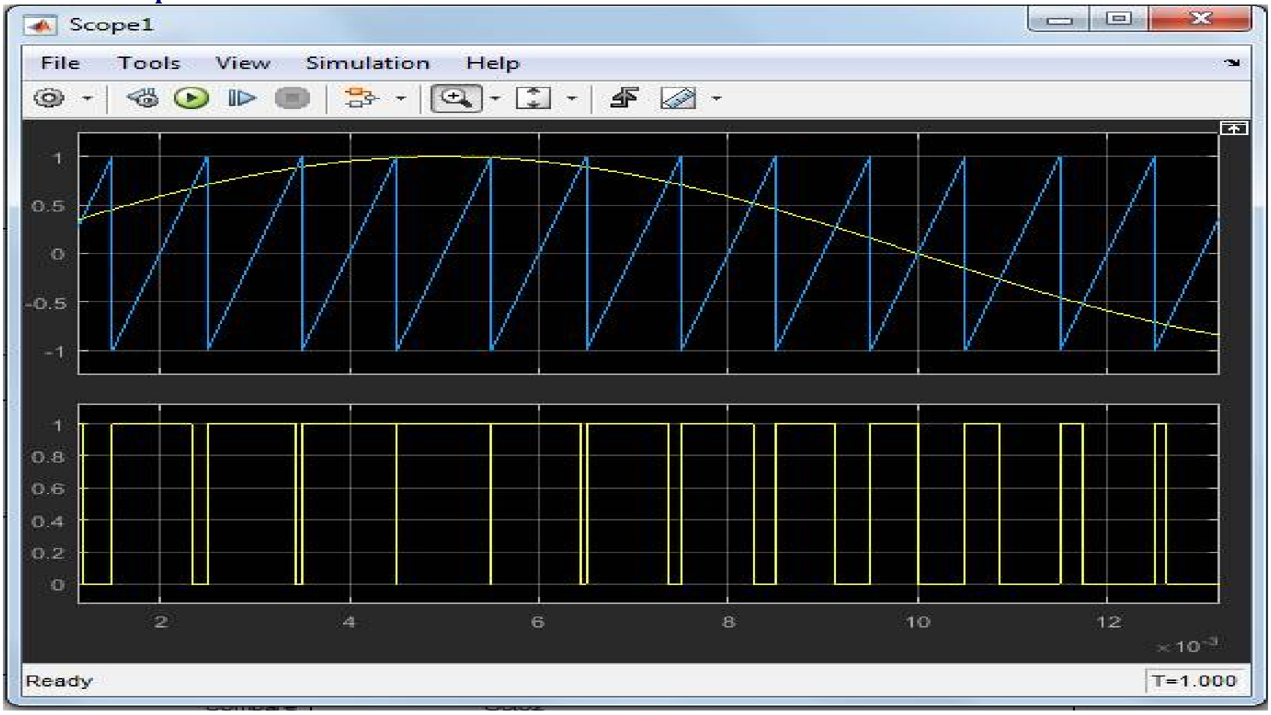


Figure 7 SPWM Output

SPWM (sinusoidal pulse width modulation) used for gate pulses for inverter and there is a scope of using different control strategy also for gate pulses of inverter. And the SPWM output has shown in the figure 7.

C. 1 PV with Static Load

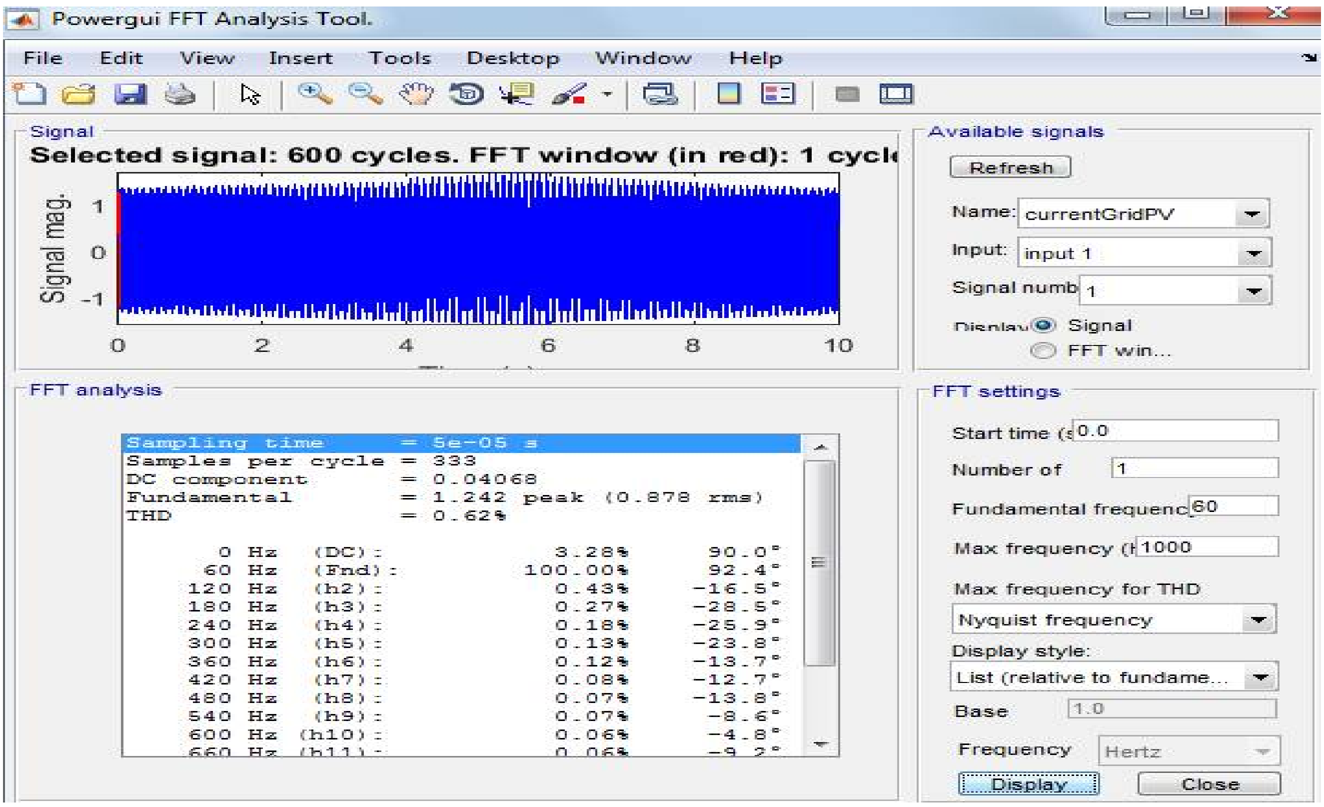


Figure 8 1 PV with Static Load

D.1 PV with Dynamic Load

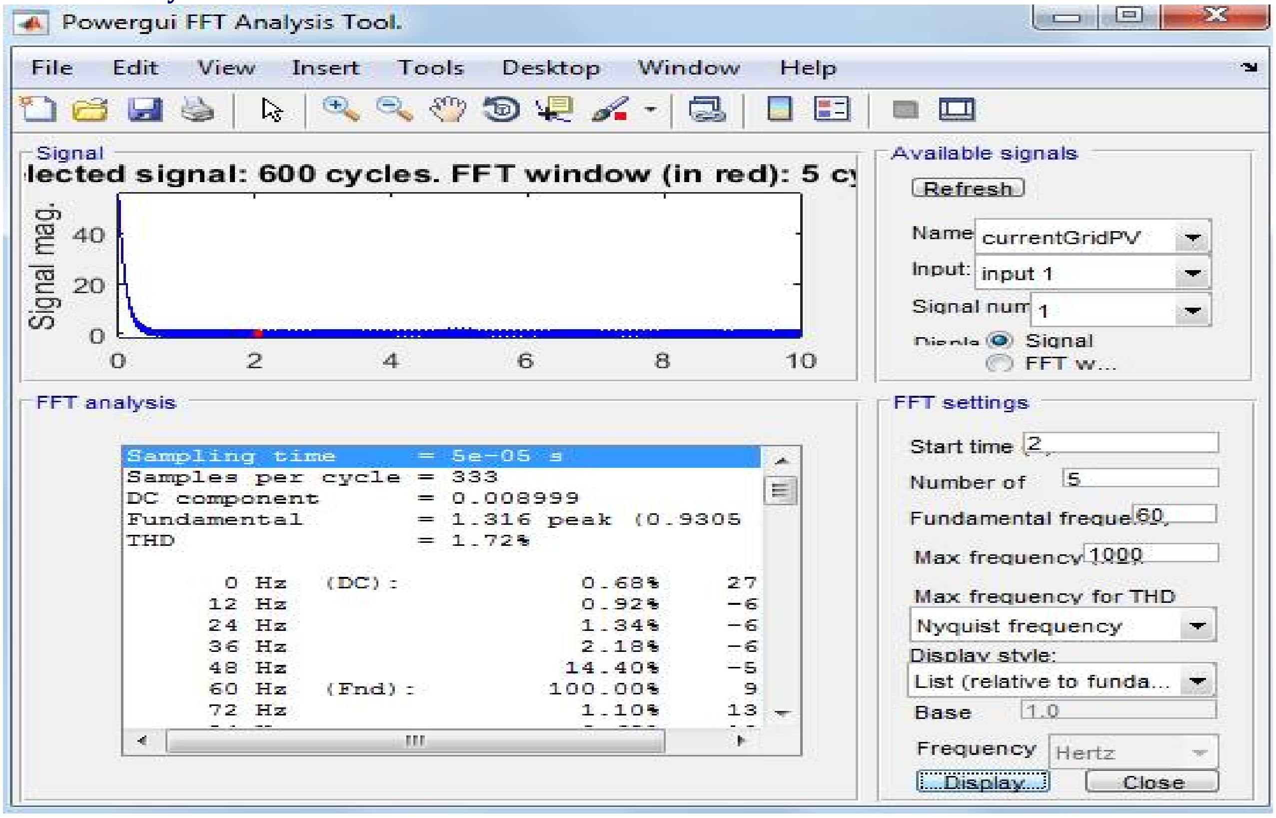


Figure 9 1 PV with Dynamic Load

Table-1 Observed THDs with Static Load

Phase Info.	No. of PV System Integration				
	1 PV	2 PV	3 PV	4 PV	5 PV
Phase A I THD%	0.62%	0.67%	1.28%	1.25%	1.23%

Table 1 shows the results of THDs for different PV penetrations and as seen from the table the THDs has increased as we go on increasing the PV penetration in some cases while there is only a little deviation in some cases.

Table-2 Observed THDs with Dynamic Load

Phase Info.	No. of PV System Integration				
	1 PV	2 PV	3 PV	4 PV	5 PV
Phase A I THD%	1.72%	1.71%	1.48%	1.38%	1.33%

With the table 2, the THD analysis o given system is done with the increased PV penetration but now with dynamic load and it can be seen that with the increase in PV penetration the THD has decreased.

IV. CONCLUSION

The harmonic impact analysis has been carried out through simulations for different case studies with the integration of PV systems in the unbalanced distribution network. High integration of PV systems and network configuration can excite harmonic resonance and it can also cancel out some harmonics as well. With static load it is found for the system under consideration with the increase in PV penetration the THD has increased in some cases while with the dynamic load the THD has found to be decreased. So, with this result with dynamic load we can say that the harmonics have cancelled out with increased PV penetration. However, The THD of the inverter output was found to be higher than the 5% limit and this may be improved by using different control strategy. The THD is in the range below 5% THD limit towards the grid with static as well as with dynamic load. Currently, the harmonic effect is shown to be under control. However, increased PV systems penetration in the distribution network can cause adverse effects. The capacity of the existing feeder lines and the transformers are not able to withstand such conditions. Therefore, the utilities are required to pay attention towards preventive measures. Further, studies are continued to understand the impact of PV systems on harmonic resonance.

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