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Harmonic Analysis in PV Connected Power System

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***Abstract*— In recent years it is shown in many researches that power quality problems in existing energy system are to be minimized for fulfillment of today's need of energy sector. In developing countries, per capita energy consumption is going to increase for upliftment of their living standards, and this increased per capita energy consumption can be met with incorporation of renewable energies in larger amount. Many of researchers have found their ways to incorporate renewable energies in existing energy sector worldwide, most of the renewable energy is utilized in energy sector as solar and wind. However, with incorporation of these renewable energy sources many power quality problems have also been introduced like as harmonic distortion, voltage sag and swell, interruption in current and voltages etc., and this affect the reliability of system. For better implementation of renewable energy sources in existing system, power quality problems are also to be reduced in the system. In this paper A PV system of 250kW has been modeled and connected to existing grid system. Further the harmonic analysis with PV system connected grid has been carried out and harmonic filters has been designed which are connected in parallel with PV system and existing system. The modeling is done in MATLAB simulink.**

Keywords*— *PV Array; IGBT Convertor; MPPT; Inverter control; filter

I. Introduction

Energy system is a primitive source which gives energy services to the customers. The energy system contains a consolidated arrangement of economical and technical systems that fulfill the energy demands. An energy demand is not a fixed amount; it varies accordance integrated set to price, consumption and regulation. Energy system is defined as production, conversion, delivery and use of energy into service such as establishment of grids, use of energy demand management including day lighting, solar building designing, respectively. For the most part, energy systems are adapted; to cut down the idea of non-inexhaustible assets, leak of hazardous substances and to minimize momentary cost of appropriate energy sources. The power generation from combined renewable source of energy makes power system more reliable and environment friendly. The demand of energy is increasing over last many years. Recently, diesel oil have highest cost or rate of pollution in environment due to fossil fuels behavior with exponentially decline in the cost of solar module become all the more encouraging source of electricity generation. Generally, photo voltaic system (PV) is considered as the components of energy generation systems [4].

The objective of this paper aims to analyze the impact of harmonic on 250kW photovoltaic (PV) array with existing grid system. The PV system modelling and simulation is conducted using MATLAB Simulink software. In this results show that the proposed system gives AC power output by using solar PV system. Analyses are then carried out to investigate the impact of the PV system on AC current output. Based on the study, it is found that PV array installed at higher value of irradiance system produces more harmonic distortion in AC output current.

II. PV System

PV system is basically a power system unit which it converts light energy into electrical energy by using semiconductor materials. A solar photovoltaic cell is an energy technology in which solar energy is convert into form of useful electricity by the process is called photovoltaic effect that generates voltage and current in PV cell when it is exposed in solar light. It is made of highly purified silicon material because silicon energy band gap (1.12eV) is approximately equal to photons energy band gap (1.6eV) [4]. The equivalent circuit of solar PV cell with one diode is depicted in fig 1.

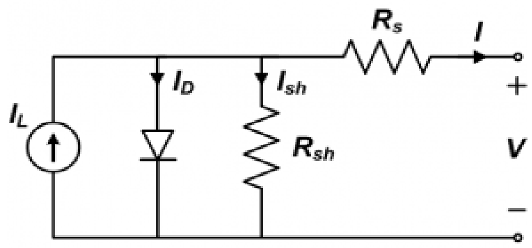

Fig.1 Equivalent circuit of one-diode model of PV cell

The load current I can be expressed in terms of output voltage V is given as:

$$I = I_L - I_O * \left\{ \exp\left(\frac{q}{nkT_C}(V + IR_S) \right) - 1 \right\} - \frac{V + IR_S}{R_{sh}}$$

Where, V is Diode Voltage, T_C is Cell Temperature (K), k is Boltzmann Constant ($1.382*10^{-23}$ J/K), q is Electron Charge($1.062*10^{-19}$ °C), I_L is Light Current, I_O is Saturation Current, R_S is Series Resistance, R_{sh} is Shunt Resistance, N_S is Number of PV Cells Connected in Series.

In this thesis work of PV Array, we assume that day time from morning 6 AM -evening 6 PM. For particular time interval, the value of amplitude and temperature is varied. Amplitude is just an irradiance multiplying by thousand. The values of time intervals are given as below:

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TABLE 1 Time Intervals

Time Range	6 AM	8 AM	10 AM	12 PM	2 PM	4 PM	6 PM
Time (sec)	0	1.5	3	4.5	6	7.5	10

solar radiation which is form to solar resource, is a general term for the electromagnetic radiation emitted by sun and these radiations can be captured and used in the form of energy i.e. heat and electricity. The amount of irradiance is responsible for hourly variation in sunlight. According to this table, in early morning 6AM, in all seasons relative to irradiance of the sun is low (0) in the sky and the lowest temperature is often recorded just after sunrise. Consequently, with each passing seconds, the sun emits more energy than early morning. Its ray travel further through the atmosphere than at Noon (12PM), sunlight is at its highest point of irradiance (1). The maximum temperature is recorded at noon. On a clear day, the maximum amount of solar energy is recorded around solar noon. At morning (6AM) and evening (6PM) solar radiation is passing through more of the atmosphere, which reduces its irradiance. Here, Irradiance= Amplitude (W/m2)*1000; the values of time, amplitude and temperature are given as below:

TABLE 2 Values of Time, Amplitude and Temperature

Time (sec)	Amplitude	Irradiance (W/m2)	Temperature (ºC)
0	0	0	20
1.5	0.3	300	25
3	0.6	600	30
4.5	1	1000	35
6	0.8	800	32
7.5	0.6	600	28
10	0	0	25

III. HARMONICS AND FILTER

Power quality (PQ) problems of renewable energy sources are not new one; recently these problems have great impact on residential, commercial and industrial clients. Now a day, there is an increasing attention on power quality in electric power system. There are finite numbers of issues which influence the power quality of power system. Due to these, voltage and frequency are deviate from the rated values, which distort sinusoidal waveform and degrade the power quality. Harmonics distortion plays important role in power quality issues of power system. There are various issues like transients, voltage sag ,voltage swell, power frequency variations, current interruption in power system in which harmonics distortion is one of them Harmonics are defined as in term of the voltage and current having frequency which is integral multiple of fundamental frequency. These positive integer multiple of fundamental frequency generate distortion in output waveform i.e. not pure sinusoidal. Harmonics are termed as unwanted signals that present in the system because of non-linear load and causes voltage and current harmonics in the system.

Odd harmonics =multiples of odd integer in fundamental frequency such as 3, 5, 7, 9, 11 etc.

Even harmonics =multiples of even integer in fundamental frequency such as 2, 4, 6, 8 etc. Mostly, power system elements produce only odd harmonics. In solar PV system inverters are used to render and take power from grid and these are the sources of harmonics in PV plant. So, harmonics analyses in the power system are necessary to maintain system reliable and efficient [3].

Total harmonics distortion is measurement of harmonic distortion present in the waveform. Normally, there are two types of harmonic filters are used in the power system to mitigate harmonic distortion i.e. active harmonic filter (AHF) and passive harmonics filter (APF). To achieve acceptable distortion, reduce harmonics and improve power quality use shunt harmonic filter and connected in parallel which mitigate harmonics but practical passive filters are installed because of easy availability. In this work, to extract fundamental and harmonic distortions in current signals use FFT analysis. In many research works has done by using pulse width modulation (PWM) techniques for mitigate of harmonics [8].

IV. SIMULATION RESULT

This system consists of 250 kW PV Array is connected to one power switching devices IGBT and Inverter control which consists of MPPT, PLL, PWM modulator, current regulator, DC voltage regulator etc. and converter is modeled using PWM controlled-IGBT bridge. A 250/25kV three phase transformer is used to connect inverter control to the utility distribution system. Simulation model for 250 kW PV array with filter disconnected is shown in fig. 2.

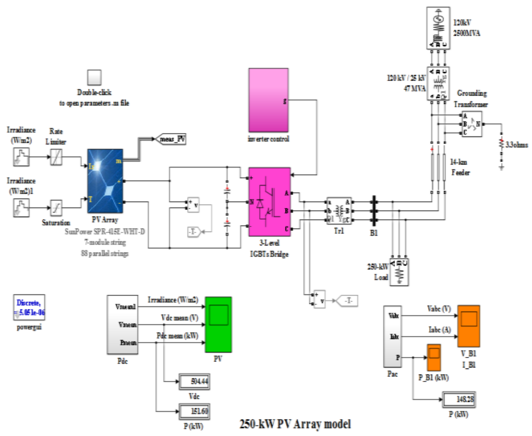

Fig. 2 Simulation model of 250kW PV System without filter

We assume that in last case at morning 6 AM – evening 6 PM, Time = [0 1.5 3 4.5 6 7.5 10] sec; Irradiance = [0 0.3 0.6 1 0.8 0.6 0]*1000 W/m2; Temperature = [20 25 30 35 32 28 25] ºC; harmonic distortion is around 23.74%. At Y-Axis in waveform, tick value for voltage $2.5*10^4$is assume as 2.5 and so on. Output voltages, current and power waveform and harmonic analysis for all cases shown below in fig 3, 4, 5 and 6.

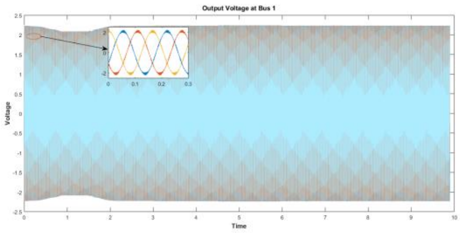

Fig. 3 Output Voltage Waveform of system with filter disconnected

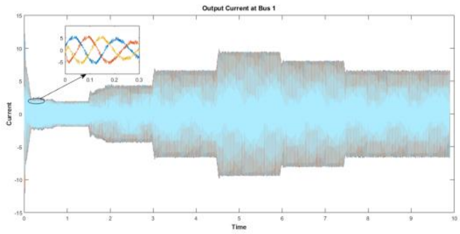

Fig. 4 Output Current Waveform of system with filter disconnected

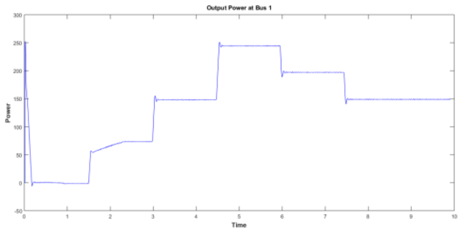

Fig. 5 Output Power Waveform of system with filter disconnected

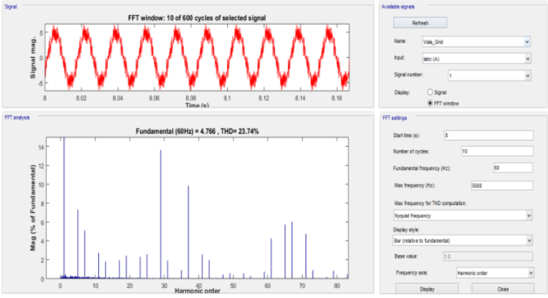

Fig. 6 FFT analysis of current waveform with filter disconnected

Harmonics distortion at bus current in PV array with filter disconnected in this case is 23.74%. For all case studies of irradiance and temperature, output power, harmonic distortions at bus 1 are shown in table 3.

TABLE 3 irradiance and temperature, output power, harmonic distortions without filter

Irradiance (W/m2)	Temp (ºC)	Bus Voltage (Volts)	Bus Current (Amp)	P Out (watt)	Harmonics at Bus Current (%)
0	20	2.085	2	0	1882.46
300	25	2.227	4.3	73	48.72
600	30	2.235	6.5	148	24.31
1000	35	2.241	9	244	14.15
800	32	2.235	8	197	18.90
600	28	2.234	6.5	149	23.82
0	25	2.088	1.8	0	1867.03

In this 250 kW PV array with inverter choke RL and small filter C is used to diminish harmonics generated by IGBT inverter. Simulation model for 250 kW PV array filter connected is shown in fig. 7.

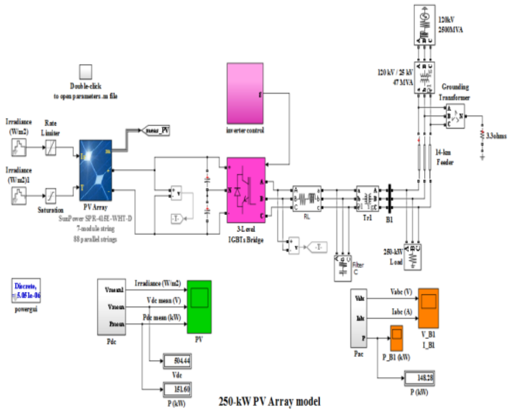

Fig. 7 Simulation model of 250kW PV System with filter

In these output waveforms, in all case voltage waveforms with filter connected are same but current is varied. For first case at 6 AM, for time range = [0 10] sec, Irradiance = 0 W/m2, Temperature is 20ºC current is 0.3 amp, power output is near about 0 kW and because of low value of irradiance harmonic distortion is maximum around 191.06%. In similar way, for second case at 8 AM, time range = [0 10] sec, Irradiance = 300 W/m2, Temperature is 25ºC for this current is 2.5 amp, power output is near about 73 kW and harmonic distortion is around 5.76%. Similarly, for third case at 10 AM, time range = [0 10] sec, Irradiance = 600 W/m2, Temperature is 30ºC for this current is 4.8 amp, power output is near about 148 kW and harmonic distortion is around 2.14%. Similarly, in forth case at noon 12 PM, time range = [0 10] sec, Irradiance = 1000 W/m2, Temperature is 35ºC for this current is 8 amp, power output is near about 245 kW and because of maximum value of irradiance harmonic distortion is minimum around 1.52%. Similarly, for fifth case at 2 PM, time range = [0 10] sec, Irradiance = 800 W/m2, Temperature is 32ºC for this current is 6.4 amp, power output is near about 197 kW and harmonic distortion is around 1.90%. Similarly, for sixth case at 10 AM, time range = [0 10] sec, Irradiance = 600 W/m2, Temperature is 28ºC for this current is 4.9 amp, power output is near about 149 kW and harmonic distortion is around 2.30%. Similarly, for seventh case at 6 PM, time range = [0 10] sec, Irradiance = 0 W/m2, Temperature is 25ºC for this current is 0.3 amp, power output is nearly 0 kW and harmonic distortion is around 191.31%. Output voltages, current and power waveforms of all cases shown below in fig. 8, 9, 10, and 11.

We assume that in last case at morning 6 AM – evening 6 PM, Time = [0 1.5 3 4.5 6 7.5 10] sec; Irradiance = [0 0.3 0.6 1 0.8 0.6 0]*1000 W/m2; Temperature = [20 25 30 35 32 28 25] ºC; harmonic distortion is around 2.33%. At Y-Axis in waveform, tick value for voltage $2.5*10^4$ is assumed as 2.5 and so on.

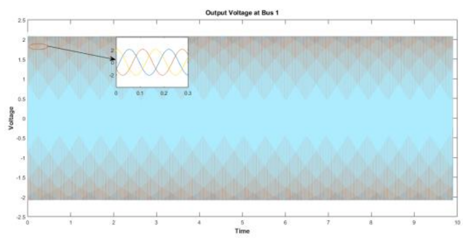

Fig.8 Output Voltage Waveform of system with filter connected

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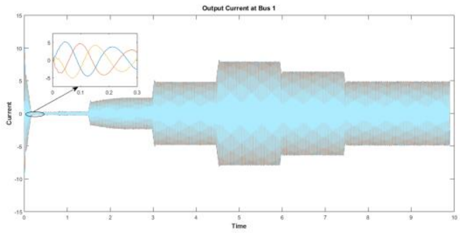

Fig. 9 Output Current Waveform of system with filter connected

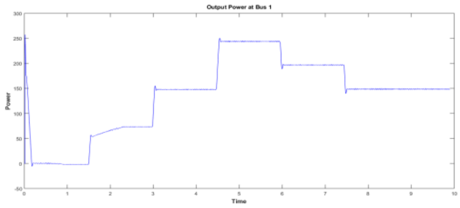

Fig. 10 Output Power Waveform of system with filter connected

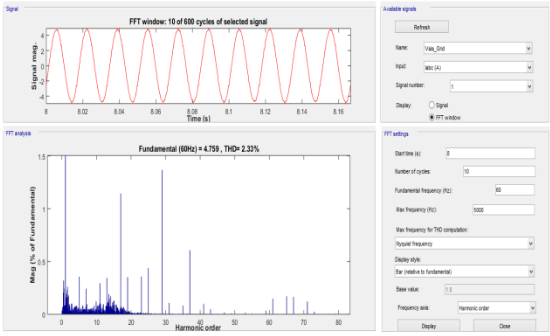

Fig. 11 FFT analysis of current waveform with filter connected.

Harmonics distortion at bus current in PV array with filter connected in this case is 2.33%. For all case studies of irradiance and temperature, output power, harmonic distortions at bus 1 are shown in table 4.

TABLE 4. Irradiance and Temperature, Output Power, Harmonic Distortions with Filter

Irradiance (W/m2)	Temp (ºC)	Bus Voltage (Volts)	Bus Current (Amp)	P Out (watt)	Harmonics at Bus Current (%)
0	20	2.079	0.3	0	191.06
300	25	2.082	2.5	73	5.76
600	30	2.0835	4.8	148	2.14
1000	35	2.085	8	245	1.52
800	32	2.084	6.4	197	1.90
600	28	2.083	4.9	149	2.30
0	25	2.079	0.3	0	191.31

Parameters of PV array used in this system are shown below in table 5.

TABLE 5 Parameters of PV Array

Different parameters	Ratings
Nominal power (P)	250e3
Open circuit voltage (V_{OC})	85.3V
Short-circuit current (I_{SC})	6.09A
Diode saturation current (I_O)	7.1712e-13 A
Shunt resistance (R_{sh})	419.78ohms
Series resistance (R_S)	0.5371 ohms

V. CONCLUSION

The modeling of 250kW PV system has been done in MATLAB simulink. The PV system is connected to existing grid and harmonic spectrum has been analyzed from FFT analysis. Further a harmonic filter is connected to the PV connected existing grid and again harmonic spectrum has been taken. From the results it has been shown that total harmonic distortion has been significantly reduced to the level of 2.3%. The study has been done for a typical day where different levels of solar radiation and temperatures have been taken.

This study can be implemented further in real power system implementation in larger scale.

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