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Research Article

Implementation and Analysis of Standalone and Grid Connected Solar Photovoltaic System

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Abstract: This paper proposes the Implementation of standalone and grid connected PV system. Voltage, current and power profile are analyzed at different stage of system. The topology of a String of PV module with a two level inverter is developed. Photovoltaic array is modeled with N_S series cells and N_P parallel cells. Boost converter is used to get regulated voltage for inverter. However the output of solar array varies due to change of solar irradiation and weather conditions. Perturb and observe MPPT algorithm is employed to control the boost converter for variable solar irradiation. Inverter is developed using six IGBT switches with PWM controller. More and more use of static power converter and switched mode power supplies injects harmonic current into the system. L and LC filters are designed for inverter rating and used in the system for harmonic compensation. Comparison for L and LC filters has been done in terms of Total harmonic distortion of line voltage and line current. The complete model is simulated in MATLAB, version 7.1. Developed standalone PV system and grid connected PV system are simple and easy to understand. These systems are more suitable for medium power applications.

Key words: PV system, P&O MPPT, Duty cycle, Simulation model, MATLAB/ Simulation, Harmonics, PWM controller, FFT analysis.

INTRODUCTION

Over the past few decades, the photovoltaic (PV) market has grown radically and the price for PV systems has decreased rapidly due to technology development in solar cell manufacture and performance improvement on efficiency conversion. An attempt is made to develop standalone and grid connected Photovoltaic system. Analysis of voltage, current and power profile at different stages in the system can be done. Many topologies are available for standalone and grid connect PV system like String, multi string topologies etc. Those are considering either battery for storing the PV power from solar array or transformer for step up voltage before connecting to grid. Large size batteries and its control are required for large PV system. And large rating transformers are also required, due to which the system can become more complicated. Battery and transformer require more maintenance.

Among various types of renewable energy sources (RES), solar energy and wind energy have become the most promising and attractive because of advancement in power electronic technique. Photovoltaic (PV) sources are used nowadays in many applications. As they have advantage of being maintenance and pollution free. In the past few years, solar energy sources demand has grown consistently due to the following factors:

1) Increasing efficiency of solar cells.
2) Manufacturing technology improvement.
3) Economies of scale.

Meanwhile, more and more PV modules have been connected to utility grid in many countries. Now the largest PV power plant is more than 100MW all over the world. Furthermore, the output of PV arrays is influenced by solar irradiation and weather conditions. More importantly, high initial cost and limited life span of PV panels make it more critical to extract as much power from them as possible. Therefore, Maximum power point tracking (MPPT) technique should be implemented in DC/DC converter to achieve maximum efficiency of PV arrays. Several algorithms have been developed to achieve MPPT technique[1, 2].

As the capacity of PV system growing significantly, the impact of PV modules on power grid can't be ignored. They can cause problems like flicker on the grid; harmonics may get increase, and aggravated stability of the power system[3]. To both increase the capacity of PV arrays and maintain power quality, it's necessary to comply with the technique requirements of the PV system, such as fault-ride-through capability and harmonic current regulation. Especially when a large scale PV module is connected to the grid, the effects on the grid may be quite severe. Therefore, the system operation and system stability under fault conditions should be examined, when PV modules are interface with power grid.

Increasing use of static power converters like rectifiers and switched mode power supplies causes injection of harmonic currents into the distribution system. Current harmonics produce voltage distortions, current distortions, and unsatisfactory operation of power systems. Harmonic mitigation plays an essential role in grid connected PV system. IEEE Std. 519 was first introduced in 1981 and most recently revised in 1992 to provide direction on dealing with harmonics produced by static power converters and nonlinear loads[3]. This standard helps to prevent harmonics from negatively affecting the utility grid.

The main technical requirements in developing a practical PV system include a) an optimal control that can extract the maximum output power from the PV arrays under all operating and weather conditions and b) a high performance-to-cost ratio to facilitate commercialization of developed PV technologies[2]. Since the solar energy is highly nonlinear characteristic, and its performance changes with operating conditions such as irradiation and ambient temperature, it is technically challenging to develop a PV system that can meet these technical requirements.

METHODOLOGY

Circuit diagram of standalone and grid connected PV system is as shown in **Fig.1.** String type single stage PV system and boost converter with P and O MPPT technique is employed. A two level inverter with PWM controller is used for inversion. Harmonics are generated by switching device. L and LC filters are designed and used for harmonic compensation.

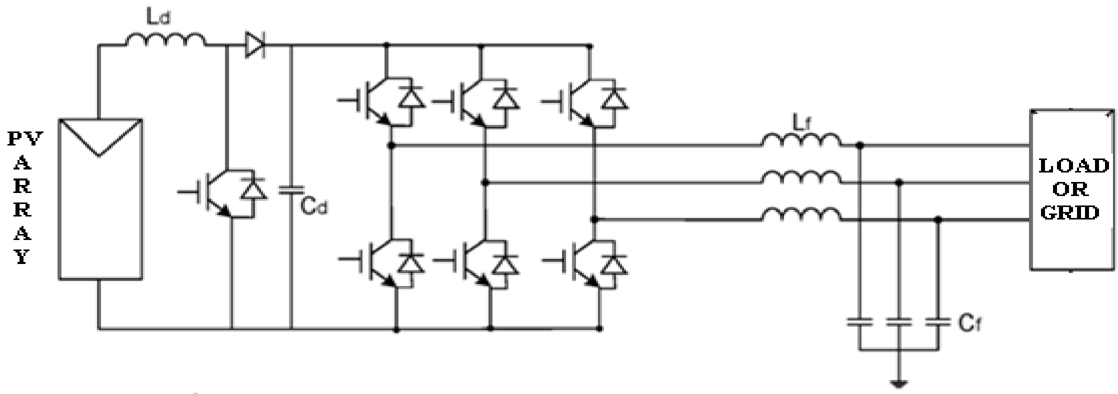

Fig.1: Stand alone or grid connected Solar PV system

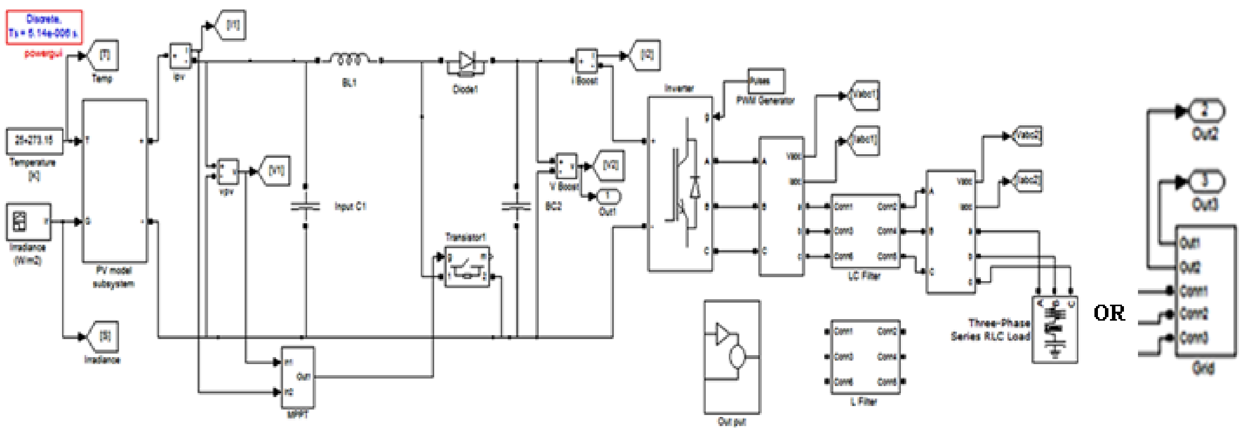

Fig.2: Simulation Model of Standalone or grid connected PV System

Fig.2 represents the complete simulation model of the stand alone or grid connected PV system. The PV arrays are connected to RLC load via boost converter and inverter. The solar PV array model is modelled using mathematical equations[4]. The simulation model of PV array with N_s=900 cells i.e. series cells and N_p=10 i.e. parallel cells is presented. Temperature of 25˚C and irradiation range from 500W/m^2 to 1000W/m^2 is considered. The parameters require for PV array model is taken from data sheet of KC85T standard solar panel. A program is written in MATLAB for calculating values of R_S and R_P. Solar panel parameters are as shown in **Table 1.** All above considerations for PV system are required to get sufficient voltage and current.

Table 1: [1]Parameters of KC85T solar array at 25^0C, AM 1.5 and 1000 watt/m^2

Imp	5.02A
Vmp	17.6V
Pmax_e	87.3W
Isc	5.34A
Voc	21.7V
Kv	-8.21e-2 V/K
Ki	2.12e-3 A/K
Ns	36
R_S	620.06
R_P	0.333

Boost converter with perturb and observe MPPT technique is used to get regulated DC voltage, which is required for inverter input. Here boost converter is used and duty cycle of switch (MOSFET) in converter is varied according to solar irradiation variation and maximum power of solar PV array. An embedded MATLAB program is written to get maximum power from solar array[1]. Two level six IGBT switched inverter is directly considered in MATLAB with 180˚ conduction, Pulses for inverter are considered with modulation index (m) of 0.85 and 10KHz switching frequency.

Filters are considered and designed for standalone system for compensating harmonics. L and LC filters are used, and compared them in terms of THD. RLC load is connected to stand alone PV system with power of 1000W and 60Hz. Active and reactive power are considered as 100VA and 100VAR respectively.

The grid connected PV system is considered and complete model is modelled in MATLAB/Simulation. Inverter controller model is as shown in **Fig.3**. Here we are considering ideal grid i.e. 415V, 60Hz, which is connected parallel with PV system. Controller for PV system inverter is modelled by taking voltage and current feedback from grid at constant frequency i.e.60Hz. And also it is controlled the DC output voltage of boost converter. The controlled DC voltage is maintained at inverter input to get controlled AC voltage at grid terminal.

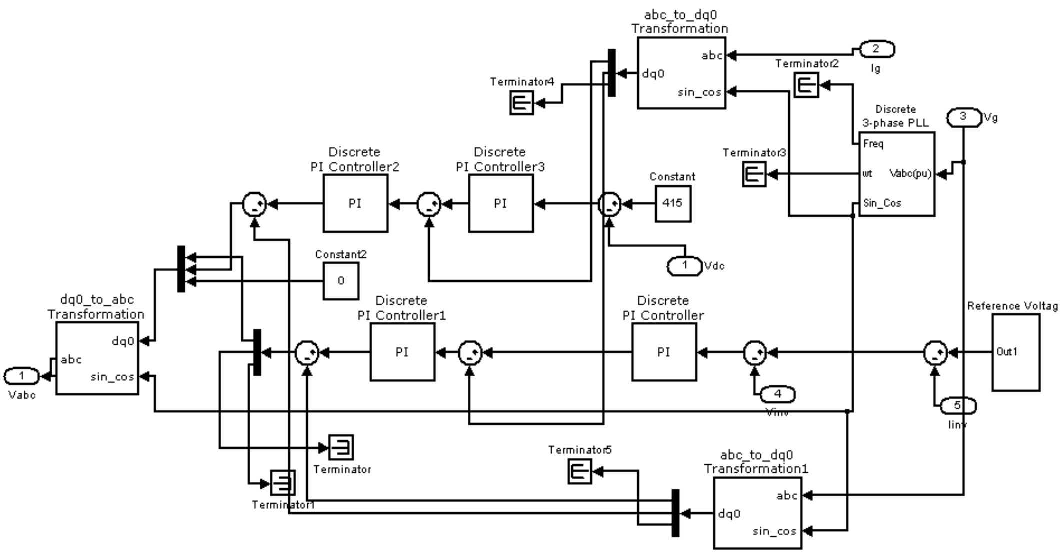

Fig.3: Simulation model of inverter controller for grid connected PV system

RESULTS AND DISCUSSION

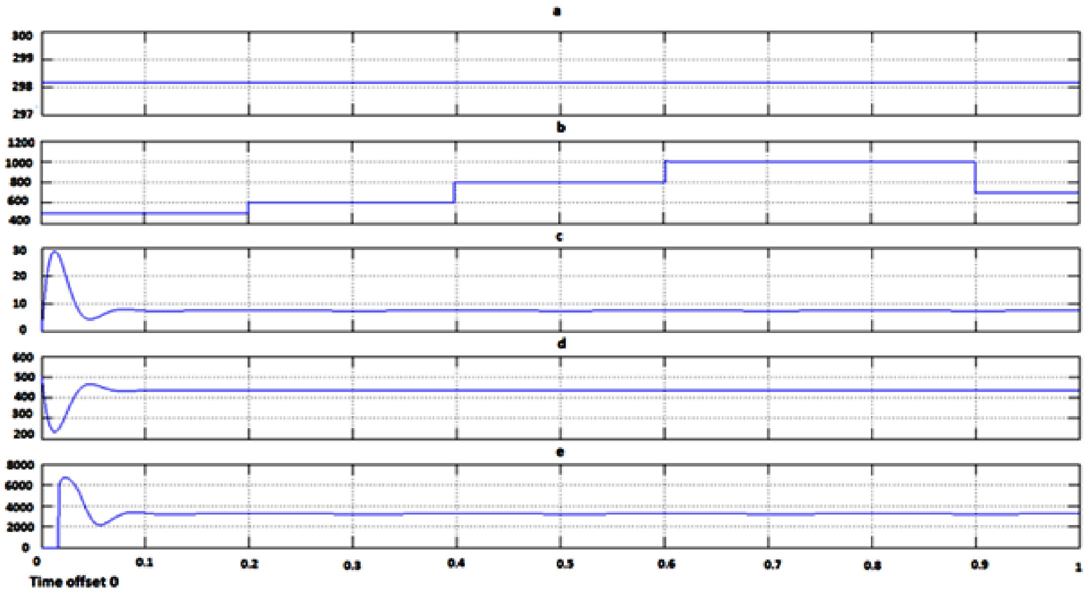

Fig.4: Boost Converter outputs connected to RLC Load through Inverter a. Temperature b. Solar Irradiation c. Current d. voltage e. power

The average variation in solar irradiations is considered from 500 W/m^2 to 1000 W/m^2. The variation of solar irradiations has been taken in between 10 AM to 4 PM. The voltage, current and power is changing according to change in solar irradiation. Simulation results are plotted for standalone system connected to RLC load. The voltage variation is in between 220V to 434V for 900 series solar cells. Boost converter supplies regulated voltage to the inverter.

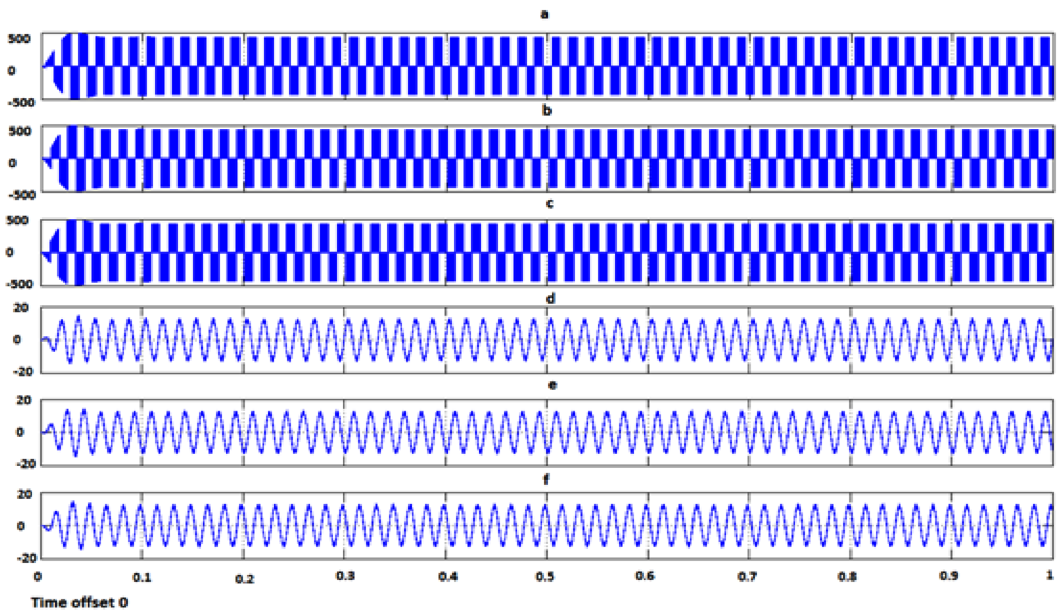

Fig.5: Line voltage and line current of Inverter without filter for standalone PV system a. V_{ab} b. V_{bc} c. V_{ca} d. I_{ab} e. I_{bc} f. I_{ca}

The regulated voltage is as shown in **Fig.4 (d)** for variable solar irradiation. This can be achieved from boost converter with duty cycle based P and O MPPT technique[1], [3]. The regulated voltage (415 V) is given to RLC load in standalone PV system as well as to grid in grid connected PV system. Inverter is made up of six IGBT switches. A frequency of 60Hz, modulation index of 0.85 and switching frequency of 10 KHz is considered. The line voltages and line currents are as shown in **Fig.5**, These are voltage and current wave forms without considering filter in system. Hence these are containing harmonics. A Two level inverter is considered here for inversion. AC output voltage is square i.e. two level wave and current is sinusoidal but contain harmonics. The harmonics are generated from switching devices like inverter. Designing and analyzing of first order filter and second order filter has been done i.e. L and LC filters. Distortions are being compensated from filters. **Fig.6** represents the line voltage and line currents with filters. All wave forms are observing as sinusoidal in shape. Harmonics are measured in percentage of distortion. Total harmonic distortion is ratio of sum of all harmonics to fundamental. Total harmonic distortion (THD) is calculated in MATLAB /SIMULINK using FFT function.

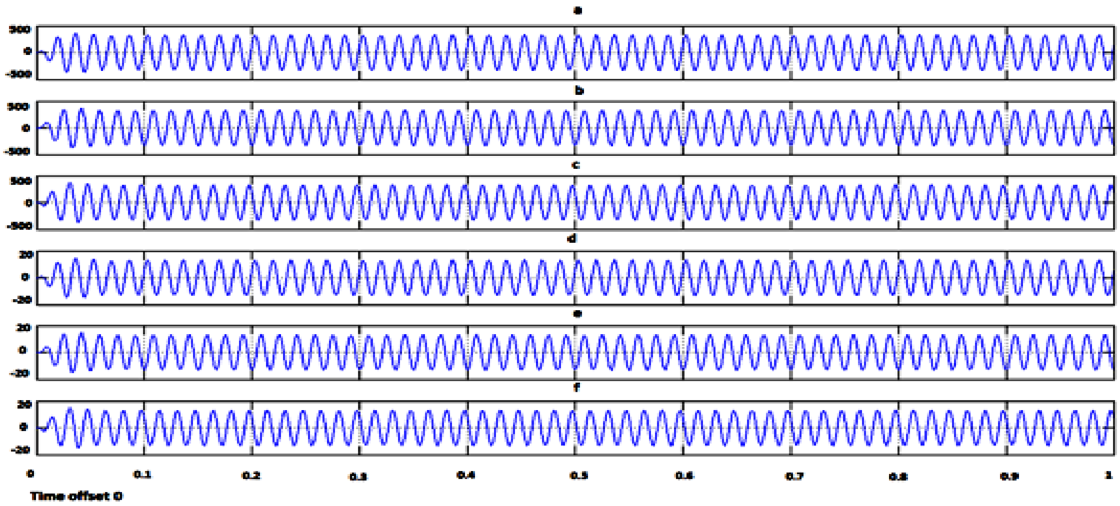

Fig.6: Line voltage and line current of Inverter with filter for PV stand alone system a. V_{ab} b. V_{bc} c. V_{ca} d. I_{ab} e. I_{bc} f. I_{ca}

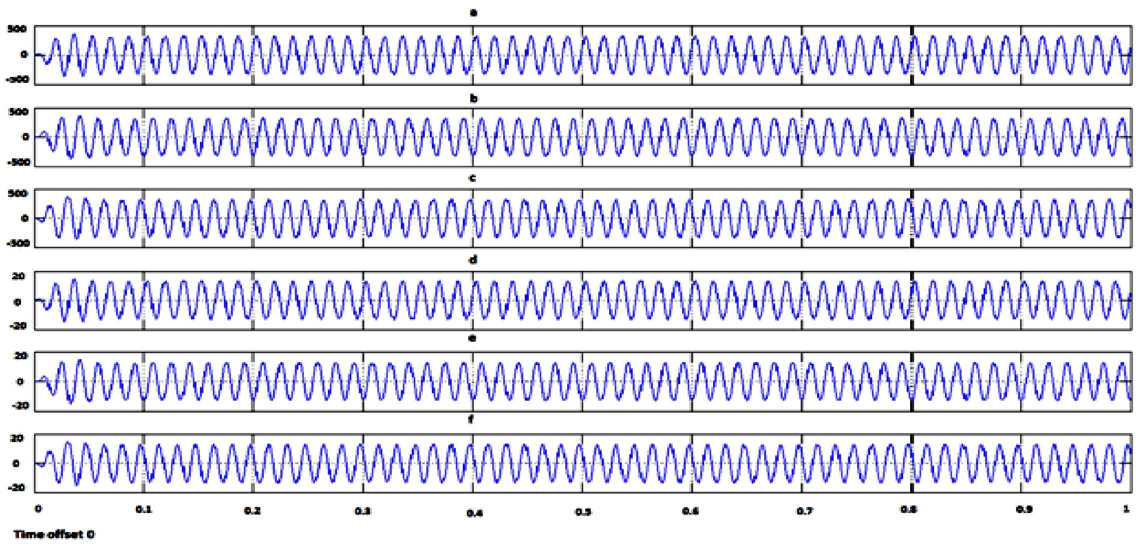

Fig.7: Line voltage and line current of Grid with filter for Grid connected PV system a. V_{ab} b. V_{bc} c. V_{ca} d. I_{ab} e. I_{bc} f. I_{ca}

Representation of FFT analysis of line voltage and line current with LC filter are as shown in **Fig.8** and **Fig.9** respectively. Here harmonic order 0 represents the content of DC component and harmonic order 1 represents fundamental and all other are 3rd, 5th and 7th harmonics.

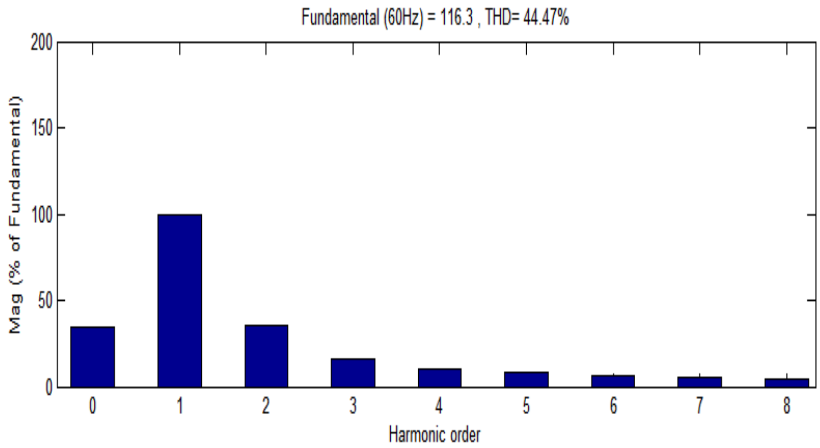

Fig.8: FFT analysis of Line Voltage with LC filter

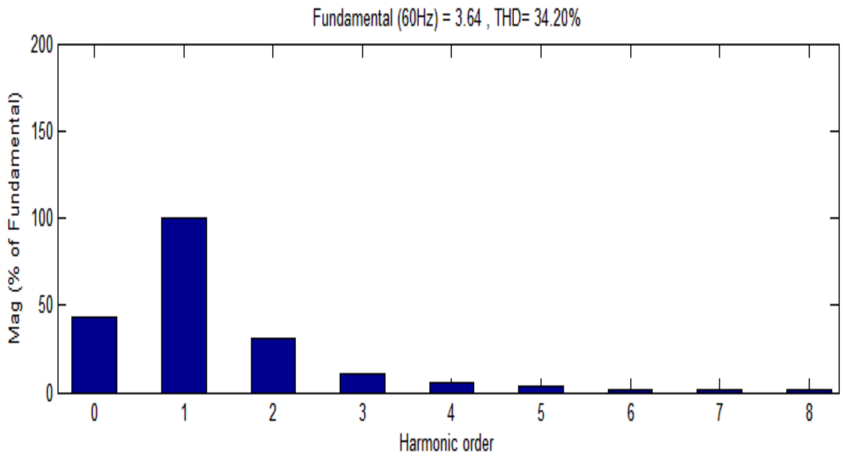

Fig.9: FFT analysis of Line Current with LC filter

Table 2: Parameters of filters and THD

	Without filter	L filter	LC filter
Inductance	-	2.6mH	2.6mH
Capacitance	-	-	15µF
THD(volt) in %	80.69	57.79	44.47
THD(curr) in%	57.79	53.60	34.20

Table 2 represents the parameters chosen for L and LC filters and THD in percentage without and with filters. The parameters are the values of filter inductor and filter capacitor. From the table 2, it is concluded that harmonics are reduced more and more by using higher order filters.

CONCLUSION

Implementation and analysis of standalone and grid connected PV system had been done. And analysis of voltage, current and power profiles at different stages in system had been done. The topology of a String of PV module with a two level inverter was developed. Photovoltaic array was modelled with N_S series cells and N_P parallel cells. Boost converter was used to get regulated voltage for inverter. Perturb and observe MPPT algorithm was employed to control the boost converter for variable solar irradiation. Inverter had been developed using six IGBT switches with PWM controller. L and LC filters were designed for inverter rating and used in the system for harmonic compensation. Comparison for L and LC filters had been done in terms of Total harmonic distortion of line voltage and line current. The complete model was simulated in MATLAB, version 7.1. This developed system can be used for hardware implementation. And also stability analysis of system can be done. These systems are more suitable for medium power applications such as Satellite applications, Off-grid applications and Grid-connected applications.

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