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SIMULATION AND COMPARISON OF TOTAL HARMONIC REDUCTION TECHNIQUES OF 80 KW SOLAR PHOTOVOLTAIC SYSTEM AT SHIVAJI UNIVERSITY, KOLHAPUR USING MATLAB SIMULINK

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ABSTRACT

This paper presents the simulation and modeling of 80 kW grid connected Solar PV system at Shivaji University, Kolhapur by using various harmonic reduction techniques Using MATLAB Simulink. The overall modeling of Solar PV system consisting of design of PV array, MPP tracking, PLL modeling, inverter control model and LC filter. The harmonic mitigation is achieved byselecting the best suitable reduction technique for the proposed system. In this paper, the simulation of series passive filters and combinations of shunt passive filters technique is done to reduce the total harmonic distortion in the system. This paper investigates the effect of THD reduction in the performance of solar PV system using harmonic reduction techniques in MATLAB Simulink.

KEYWORDS: Series passive filter, shunt passive filters, solar PV model, harmonic reduction, THD.

INTRODUCTION

Renewable energy are sources of clean, inexhaustible in nature and also increasingly competitive energy. Solar Photovoltaic energy is one of the important source as it contains less noise, maintenance and pollution free.[1]

In grid connected solar system, the energy generated and distributed to the grid as per load demand. The electricity generation can be achieved without battery backup that reduces the storage losses in the system. The solar PV systems consist of solar panels, inverter parameters and other electrical and mechanical hardware which generates electricity using the energy available from sunlight.[2]

The function of inverter is to convert dc to ac output voltage at desired magnitude. Generally, during conversion the output waveforms obtained are non sinusoidal i.e. it contains harmonics due to power electronic devices in the inverter.

This affects the power quality of the existing system. The harmonics present in the system can be reduced by using various types of filters in the system.[3]

In this paper, 80 kW of grid connected solar photovoltaic system at Shivaji University Kolhapur is considered for study and modeling using MATLAB Simulink. The harmonics present in the system is studied and reduced by suitable harmonic reduction techniques using MATLAB Simulink. The techniques are studied on the basis of implementation feasibiligy, opeartional methods and performance of the existing system. The methodology of this paper is divided in three sections: I. Model of solar PV system II. Harmonic reduction using series passive filter III Hamonic reduction using various combinations of series and shunt Passive filters with and without capacitive filter.

I. METHODOLOGY

Site Description

The Shivaji University has installed total 180 kW of Solar PV System. Out of 80 kW system supplies power to Chemistry department of Shivaji University and remaining 100 kW of power supplied to main building of shivaji university, Kolhapur. The study is consults with only 80 kW system used for Chemistry department of Shivaji university kolhapur.

There are three inverters of capacity of 27 kWp each connected in parallel combination to each other. One inverter is connected to 84 modules of 315 Wp each having capacity 27 kWp. To each inverter, there are four set of 21 series connected modules are connected in parallel combination. Inverter having charge controller, incoming supply power goes to charge controller and then it gives to battery charging unit.

A. Model of Solar PV system

i. PV array

The PV panel specifications are given below Solar PV panel has capacity of 315Wp of Waree company. Maximum power (Pmax) = 315 W, Open circuit voltage (Voc) = 45.25 V, Short circuit voltage (Isc) = 9.29 A, Maximum power voltage (Vmp) = 36.75 V, Maximum power current (Imp) = 8.58 A, Maximum system voltage = 1000 V DC, Temperature coefficient of Voc = -0.3253 %/ deg C, Temperature coefficient of Isc = 0.0718 % /deg.

The solar module contains solar cell arranging in series pattern. The many solar modules arranging in series and parallel connections forms a solar PV array.[4]

The equivalent circuit of the PV cell is given below

But the photon current of PV array is mainly depends on the two factors.

1. Irradiance

Irradiance is a process by which an object is exposed to radiation. It is measured in W/m^2 .The variation of solar irrandiance can be studied by the I-V and P-V curves. The irradiance is always directly proportional to the photocurrent i.e. as the solar irradiation increases the output current also increases.

2. Temperature

The increase in temperature of cell increases the reverse saturation current and reduces the band gap. Therefore, temperature adversely affects the voltage of the cell. It acts like negative factor affecting performance on a solar cell. The temperature of the cell linearly varies with the photon generation.[6]

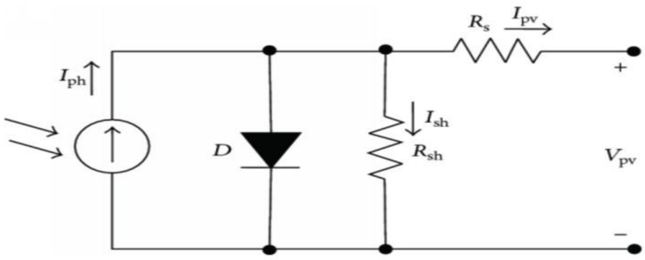

Figure 1: Equivalent circuit of solar cell.

Practically solar cell is non ideal, it requires the shunt resistance and series resistance component added to model. In Hence.

$$Iph = \frac{G}{Gref}(Iph + \mu sc * \Delta T)$$

Where,
G = irradiance
Gref = Irradiance at STC
ΔT = Tcell – Tref (8)

This model, Rs is introduces the voltage drops and internal losses due to flow of current and Rsh is taken for considering the leakage current to the ground when the diode is reverse biased.[5]

The fundamental PV cell equation can be derived from the theory of Shockley diode equation and semiconductor theory. Using KCL to the above circuit diagram, we get,

$$I - Iph \quad Id \quad Ish \qquad (1)$$

Where,
I = solar cell current Iph= photon current Id = diode current
Ish =current generated in shunt resistance Rsh The diode equation of the solar cell is given as,

$$Id = Io[exp(V \quad I * Rs)/(n * Vth) \quad 1](2)$$

Tref = cell temperature at STC = 25+273 =298 K
µsc = coefficient temperature of short circuit current Iph = Photocurrent at STC
Rs and Rsh can calculated using newton raphson method at max power,
We have,

$$Imax = \frac{Pmax}{Vmax} = Iph - Io\left(exp\frac{Vmax + Imax * Rs}{a} - 1\right) \qquad (8)$$

By putting the values of Io and Iph,

$$Rp = \frac{Vmax + Imax * Rs}{Isc - Isc * expB + Isc * exp\left(\frac{Vo}{a}\right) - \left(\frac{Pmax}{Vmax}\right)}$$

Where $B = \frac{Vmax + Imax * Rs \quad Vo}{}$

$$a = \frac{Ns * A * K * Tc}{q} \qquad (9)$$

$$Rs = \frac{(Rs\ ref)*Ns}{Np}$$

$$Rsh = \frac{(Rsh\ ref)*Ns}{Np}$$

The series and shunt resistance is given as,

Where,

Io = reverse saturation current Vth = thermal voltage

$$Vth - K * T/(q)$$

Where, (3)

Where,

Ns= Number of series connected solar cells Np= Number of parallel connected solar cells

K = Boltzmann constant =1.38×10^ (-23) J/K,

T= temperature of cell q = charge of electron

The Shunt current in the circuit can given as,

$$Ish = (V \quad I * Rs)/Rsh \qquad (4)$$

Now, put equation (2) and (4) in equation (1),

$$I = Iph - Io\left\{exp\left\{\frac{q*(V - I*Rs)}{n*K*T}\right\} - 1\right\} - \frac{V - Rs*I}{Rsh} (6)$$

$$I - Iph - Io\left[exp\frac{V}{aref} - 1\right] (5)$$

The output current at standard test conditions (STC) is,

Modelling of PV array

80 kW System of PV array has been modelld using Warree 315 Wp panels. The datasheet calues and the parameters are shown in fig.

The short circuit condition Isc is, Put V=0,

$$Isc = Iph \qquad (7)$$

Electrical Characteristics*	
Nominal Maximum Power (P_m) in Watts	315
Power tolerance	0 / + 5 W
Open Circuit Voltage (V_{oc}) in Volts	45.25
Short Circuit Current (I_{sc}) in Amps	9.29
Voltage at Maximum Power (V_{mp}) in Volts	36.75
Current at Maximum Power (I_{mp}) in Amps	8.58
Maximum System Voltage in Volts	1000
Module Efficiency (%)	16.25
Maximum Series Fuse Rating (A)	15

*Under Standard Test Conditions (STC) of 1000 W/m² irradiance, AM 1.5 spectrum and 25°C cell temperature.

Figure 2: specifications of PV panel.

The PV array model consist of following subsystem models

Photon current: it is modeled as follows. The load current of PV cell is given by the equation:

$$I_L = \frac{S}{S\,ref} \times (I_L + \propto isc * (Tcell - Tref))$$

Where,

S= Signal input

S ref = Reference Signal I_L ref = reference current

Tcell = Actual cell temperature (K) Tref = Reference Temperature (K)

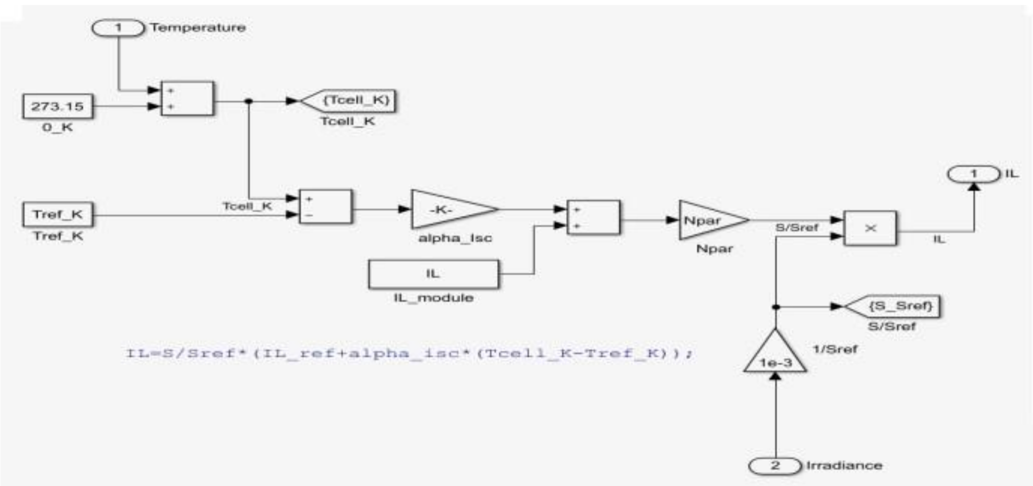

Figure 3: subsystem of photon diode

Nser= no.of series connected modules per string The modeling of diode current is shown in fig.

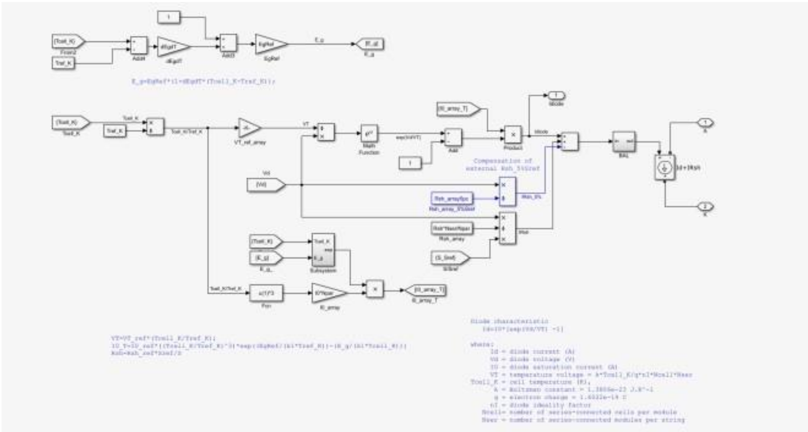

Figure 4: subsystem of diode current.

Complete model of PV array

The output of PV array depending on the irradiation and temperature is modeled as follows.

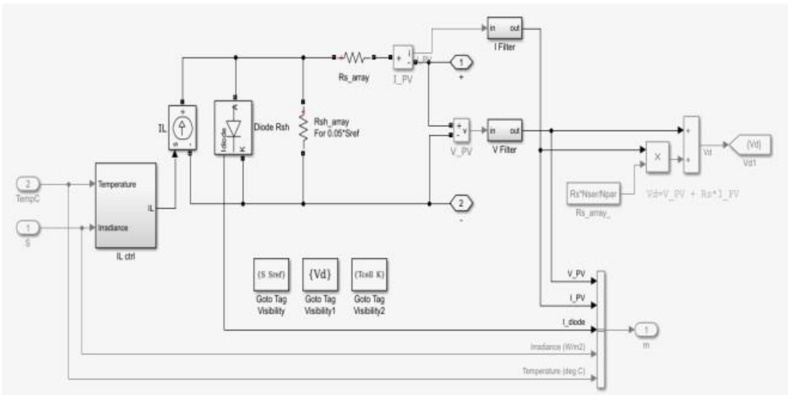

Figure 5: complete PV array

Inverter Control

The string inverter of FRONIUS is used to convert dc power to ac power. Solar Inverter is most important part of the Solar Photovoltaic System. It converts the variable direct current output of a photovoltaic panel into alternating current. Inverter regulates the active power delivered to grid and the voltage by controlling the modulation index of inverter and inverter firing angle which determines the magnitude and phase of voltage.[4]

The inverter control components as follows

Diode Current: The current through the diode is can be calculated as

$$Id = Io \times [\exp\left(\frac{V_G}{V_t}\right)^{-1}]$$

a) PLL and measurements

The phase lock loop (PLL) provides the local reference to the inverter. It synchronizes the inverter and the AC grid voltage waveforms. The block diagram of PLL and measurements are given below.

Where,

Id = diode current Vd= voltage of diode

Io =reverse saturation current Vt = temp. voltage (V)

$$\frac{K \times Tcell}{q \times nI \times Ncell \times Nser} = \times 10^{-19} \quad \times 10^{-23}$$

Where,

K= bolzman constant = 1.386 Q= electron charge = 1.602 nI= diode ideality factor

Ncell = no. of series connected cells per module

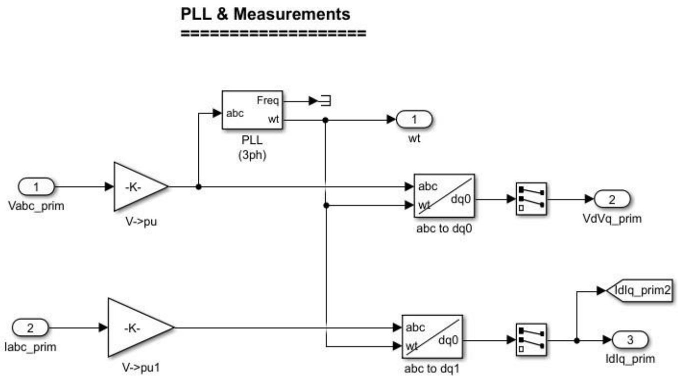

Figure 6: subsystem of PLL measurements.

b) Maximum power point tracking (MPPT)

MPPT is a technique that used in solar photovoltaic system to maximize the power extraction under all conditions. It implements different algorithm and switch between them based on operating condition of array. The purpose of the MPPT system is to sample the output of the cell and determine the resistance to obtain maximum power for any given environmental conditions. It is of 3 types: 1. Perturb and observe 2. Incremental conductance and 3. Constant voltage. The parameters of MPPT in MATLAB are as follows.

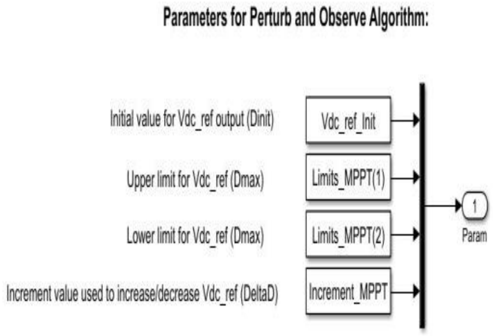

Figure 7: Parameters of mppt.

c) DC voltage regulator

It regulates the DC power output of the inverter of solar photovoltaic system. The controlling parameters of gain in DC voltage regulator is as follow.

KpVdc regulator =2 Ki Vdc regulator =400 It can calculated as.

$$Kp = \frac{3 * C}{20 * Ts}$$

$$Kf = \frac{Kp}{20 * Ts}$$

This regulates the sinusoidal ac output in the inverter. The calculation parameters are as follows.

Kpi regulator = 0.3= Proportional gain of PI controller Ki regulator $\times Fnom$= 20= Internal gain of PI controller Carrier freq. of PWM =fc = 33.

The modeling of current regulator is shown in fig.

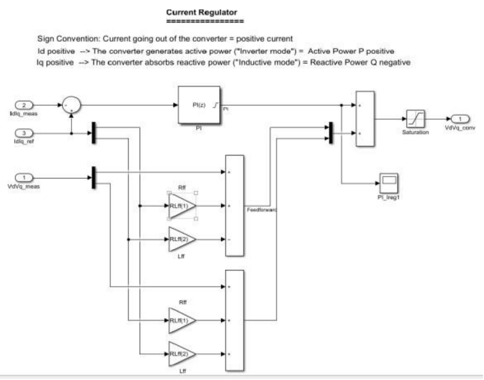

Figure 8: subsystem of current regulator

e) PWM Modulator

The PWM modulator is used to sample and convert the reference signal into triangular signals. It controls amplitude of digital signal in order to control devices and applications requiring power or electricity. He carrier frequency of PWM is Fc = 33* nominal frequency. The complete grid connected inverter model is as shown in fig.

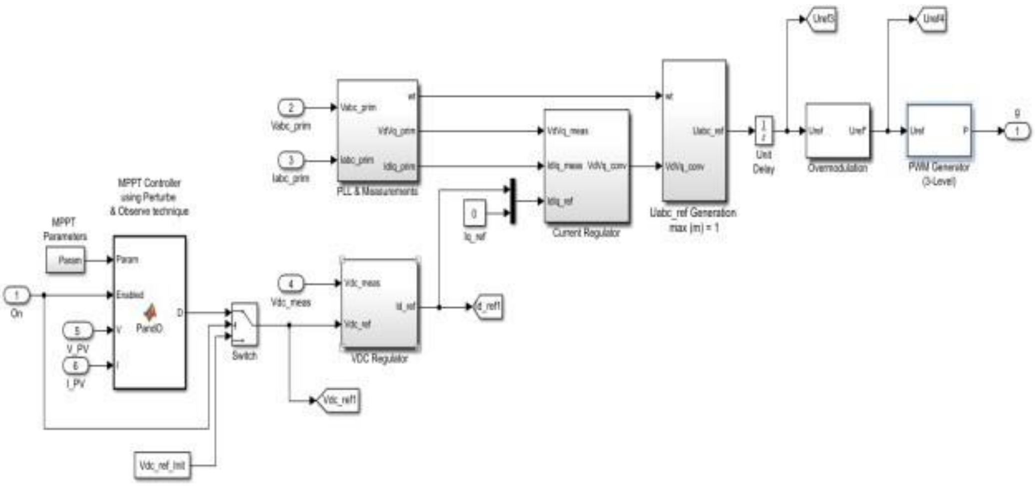

Figure 9: inverter subsystem

ii. LC filters

LC filters at the output of inverter helps to remove current harmonics. It frequency can be calculated as.

$$f = \frac{1}{2 * \pi * \sqrt{LC}}$$

Where,

L = inductance of inductor C = capacitance of capacitor

Now, the complete general grid connected solar system can be modeled as shown in fig.

Where, Kp and Kf are the Proportional and Internal gain of PI controller

C = boost converter capacitor

Ts = Switching period of inverter

d) Current regulator

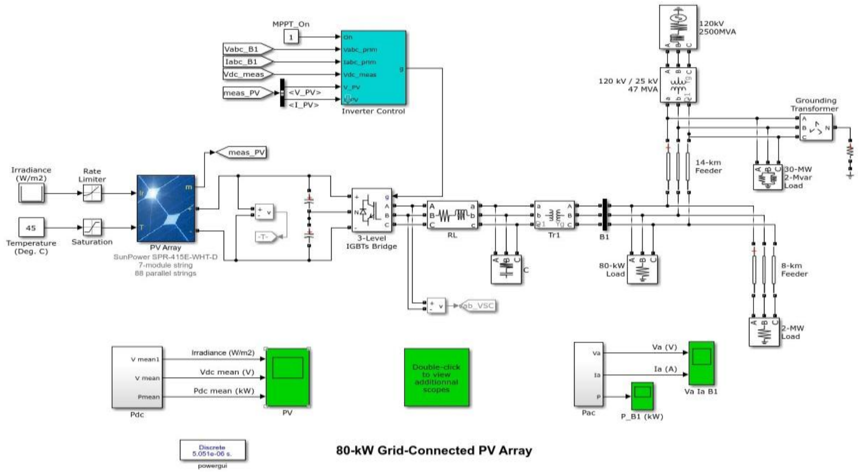

Figure 10: model of PV system The output is as follows:

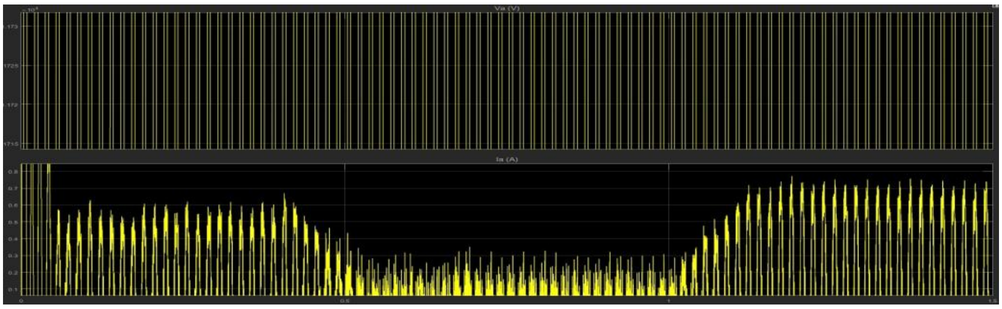

Figure 11: output voltage and current waveforms.

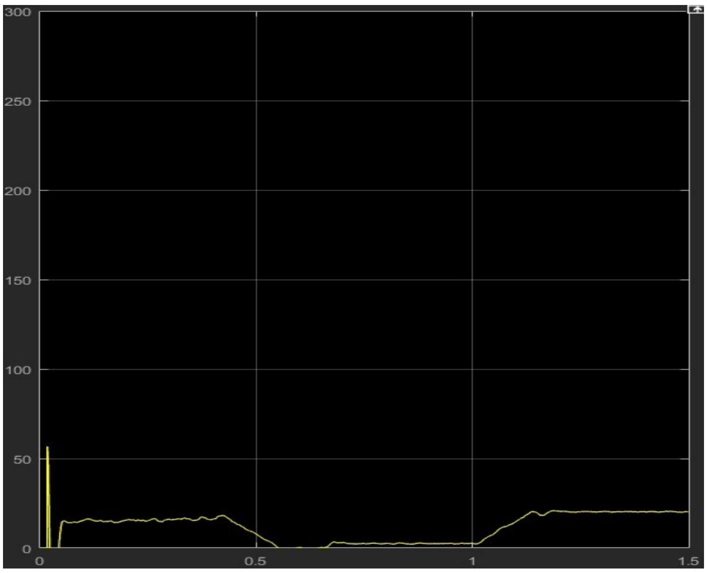

Figure 12: power output waveform.

B. Harmonic reduction using series passive filter

As the all Solar Photovoltaic System generally consist of Series passive filters for impedance matching and to obtain pure sine wave of voltage and current. Series filters consist of a parallel inductor and capacitor connected in series with the supply having large impedance. At the fundamental frequency, the filter is design to yield low impedance allowing the fundamental current to flow with only minor additional impedance losses.[3] The AC line reactor of the series passive filter improves the system magnitude of inductance in the system that alters the path of current drawn in the rectifier circuit. The series filters are used to block a single harmonic current. Each harmonic current requires the series filter tuned to that harmonic. This arrangement can create significant losses at the fundamental frequency.[7]

The modeling of the system using series passive filter is given as follows

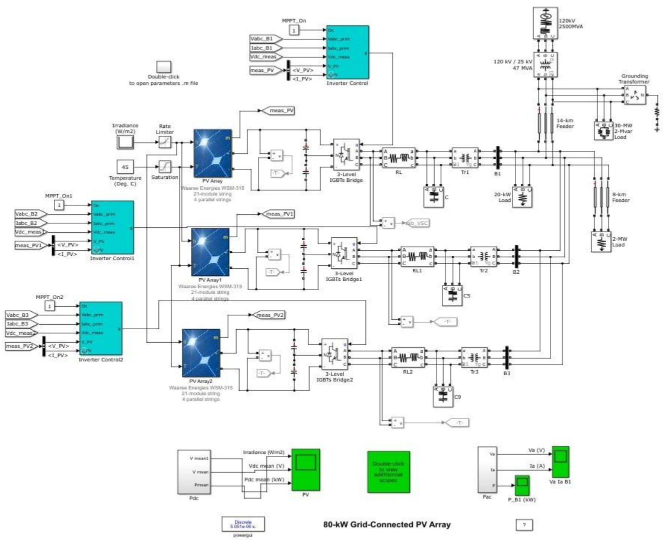

Figure 13: Simulation of system using series passive filter

C. Hamonic reduction using various combinations of series and shunt Passive filters with and without capacitive filter.

Shunt passive filters are connected in system parallel with load with low impedance in the networks at tuned frequency. The shunt passive filters are designed for filtering purpose and to provide reactive compensation of the correcting power factor in the circuit at desired level. The ac power losses are less compared to series filters. They are capable of filtering specific tuned harmonic frequencies such as 5^{th},7^{th},11^{th} etc.[7]

Here, we use the combinations of shunt passive filters for effective harmonics reduction from the existing system.

The filters used are as given as follows:

1. Double tuned filter (Y grounded): This filter is used to eliminate 11th and 13th harmonics from the system.
2. C type High pass filter (Y grounded): This filter is used to eliminate 3rd harmonics from the system.
3. High pass filter (Y grounded): This filter is used to eliminate the 5th harmonics from the system.
4. Single tuned filter (Y grounded): This filter removes 7th harmonics from the system.

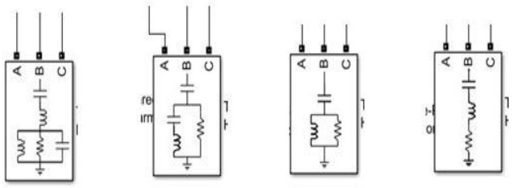

Figure 14: double tuned filter, c type filter, high pass filter and single tuned filter.

The capacitive reactance in the series passive filter plays important role in harmonic reduction. The capacitor in the series passive filter provides reactive power compensation to improve power factor.[3] Hence, the simulation model is done in two ways:

1. Simulation with series capacitive reactance
2. Simulation without series capacitive reactance

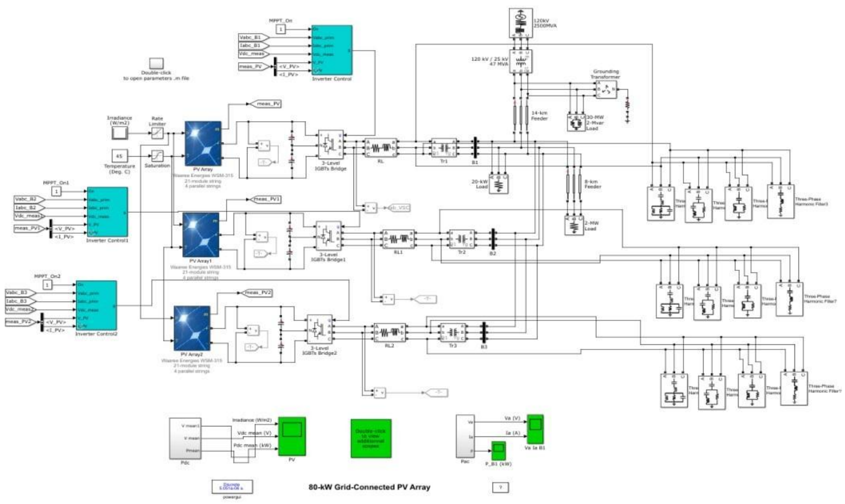

Figure 15: simulation of system using series and shunt passive combination with series capacitive reactance.

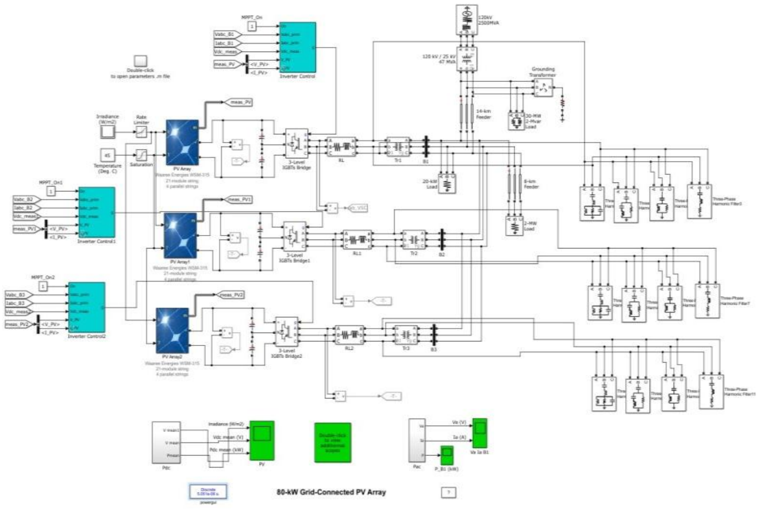

Figure 16: simulation of system using series and shunt passive filter combination without series capacitive reactance.

II. SIMULATION RESULTS

The simulation is performed using various combinations of shunt and series passive filters in the previous chapter. The total harmonic reduction is calculated by using FFT analysis technique of the above simulations in MATLAB Simulink. As we know, passive filters are used to remove only current harmonics in the system. The results obtained from the above reduction techniques on the proposed system is represented as follows:

1. Results of harmonic reduction technique using series passive filter

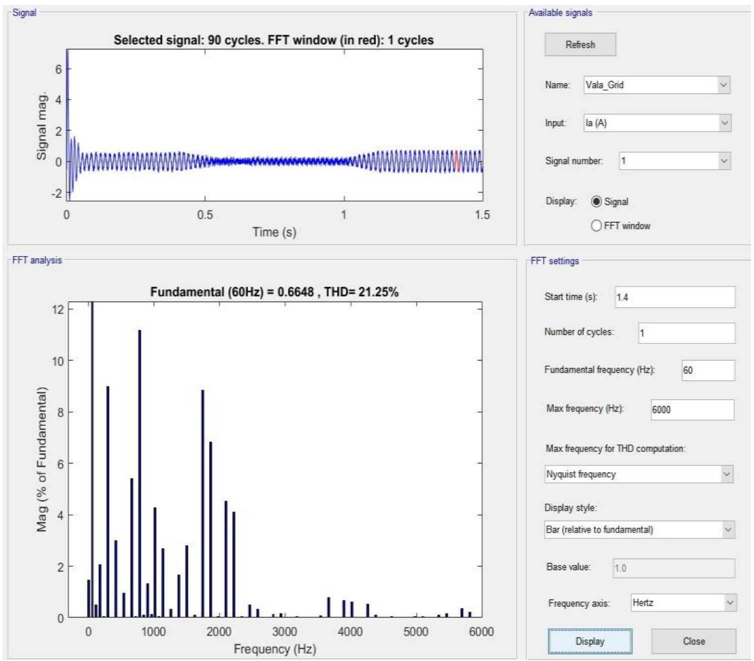

Figure 17: FFT analysis graph of Frequency Vs Mag (% of fundamental).

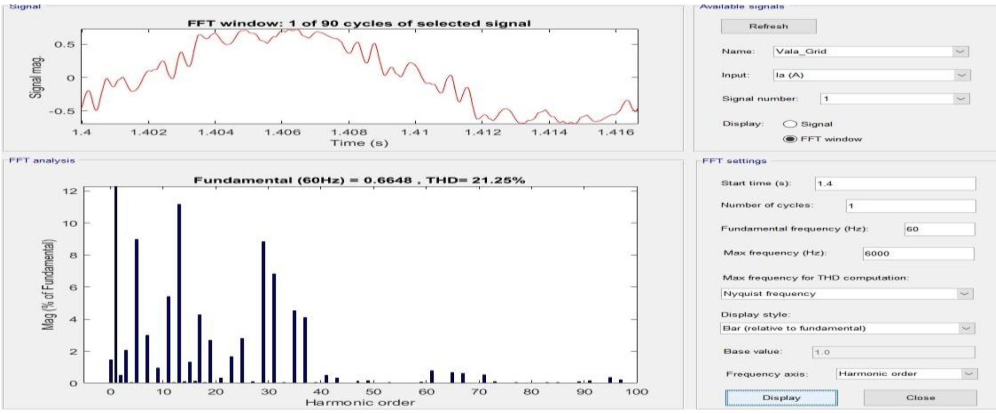

Figure 18: FFT window of signal and graph of Harmonic order Vs Mag (% of fundamental).

2. Result of harmonic reduction technique using combination of series and shunt passive filter with series capacitive reactance.

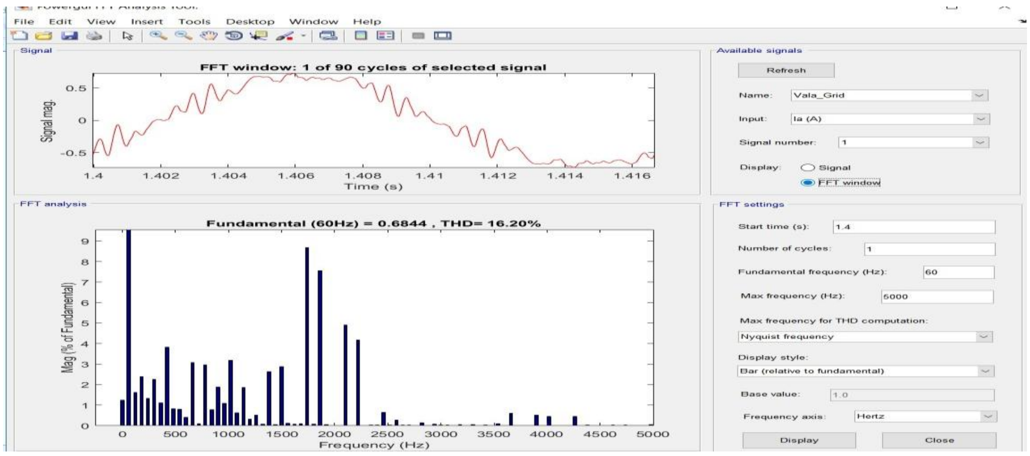

Figure 19: FFT analysis graph of Frequency Vs Mag (% of fundamental).

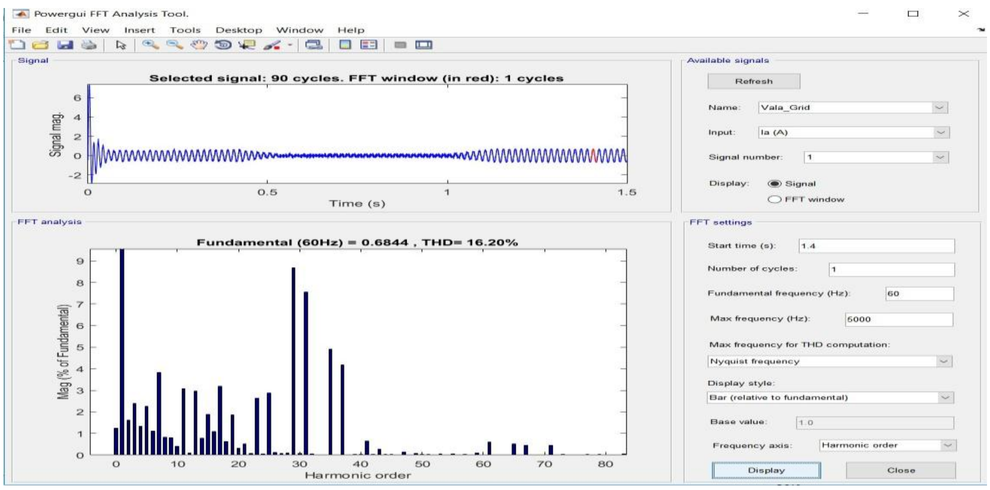

Figure 20: FFT window of signal and graph of Harmonic order Vs Mag (% of fundamental).

3. Result of harmonic reduction technique using combination of series and shunt passive filter without series capacitive reactance.

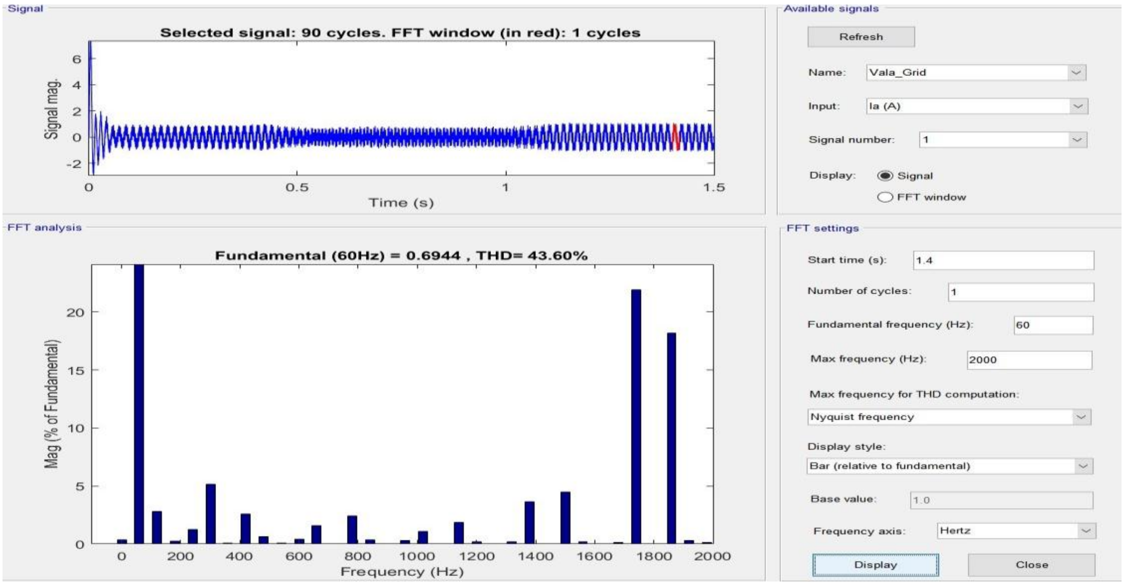

Figure 21: FFT analysis graph of Frequency Vs Mag (% of fundamental).

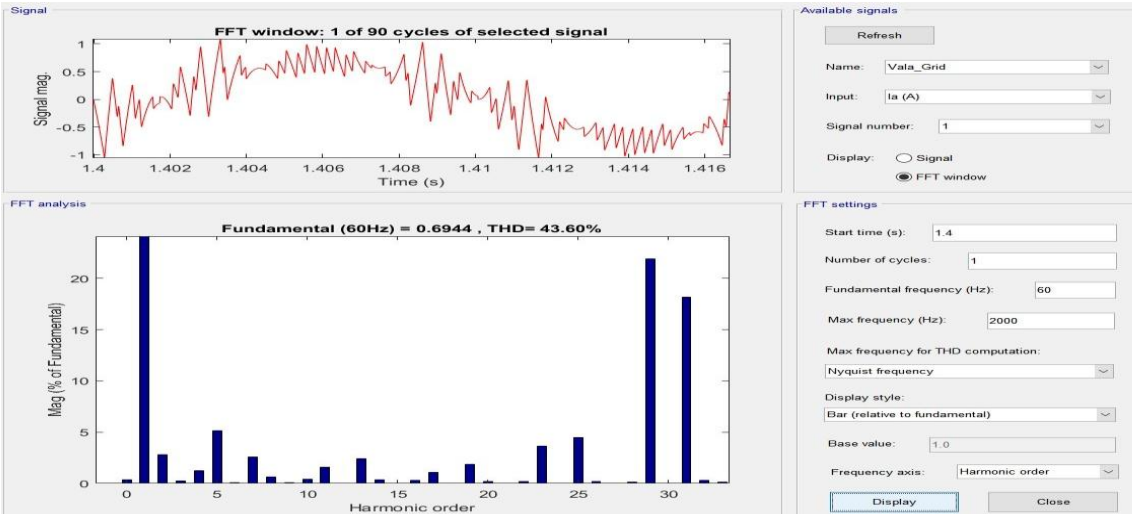

Figure 22: FFT window of signal and graph of Harmonic order Vs Mag (% of fundamental).

III. CONCLUSION AND FUTURE DEVELOPMENTS

IV. The parameter of the rooftop solar PV system of 80kW at Shivaji University, Kolhapur is studied. After simulation of model of 80 kW system we found out harmonics and various harmonic reduction techniques are implemented on the system in MATLAB Simulink. The THD calculations and conclusions of the reduction techniques used are tabulated and compared as follows:

Sr. no.	Filters used	Current THD %
1	Series passive filter	21.25 %
2	Combination of series and shunt passive filter with series capacitive reactance	16.20 %
3	Combination of series and shunt passive filter without series capacitive reactance	43.80 %

Hence, this study shows that the second method in which the combination of series and shunt passive filters with series capacitive reactance is used is more effective method for reduction of current harmonics present in the system. Because, the all the shunt passive filters arranged in parallel to system removes the respective harmonic according to individual property of the filters and both series inductance impedance and capacitance reactance helps to get pure sine wave and improves the power factor of the system.

Thus, uses of passive filters with combinations are easy, effective and economical option to minimize the total harmonics current distortion in solar photovoltaic system.

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