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Improved Dynamic Performance and Power Quality Issues of Grid Connected Pv-Array

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Abstract

In this work, a detailed model of grid-connected PV-array have been simulated in MATLAB/Simulink environment with a fixed step size of one microsecond and a study is conducted to analyze the dynamic performance of the system. The PV-array system of capacity 100 KW consisting of boost converter, 3-level voltage source inverter using pulse width modulation technique, is connected to a utility grid through three single-phase transformers. The boost converter using improved incremental conductance is implemented to meet the output power pattern developed by the array with the specifications of the PV-array in a faster manner. The total harmonic distortion 'THD' of the electrical supply produced by PV-array is reduced to 1.94% by using suitable passive LC filter. The THD of the supply is within the limits as specified by IEEE standard-1547. In addition to this, the power factor correction block is implemented to feed with a supply of better power quality.

Keywords: Boost converter, Grid-connected, Incremental conductance (MPPT), LC filter, PV-array, THD.
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Introduction

Global warming and increasing load demand are the two main challenges for the power industry in a country like India. Both the challenges can be handled by using renewable energy resources. Out of many renewable resources like hydro, solar and wind, solar is preferred due to its easy availability.

Solar Energy varies according to time of day, moon phase, season and random factors such as weather. So to extract maximum power from sun rays of varying intensity at every instant, a technique named 'Maximum Power Point Tracking (MPPT)' is employed.

Some of the methods of MPPT are Perturb and Observe, Incremental Conductance, Temperature Method, Constant Voltage Method, Beta Method etc. Out of these methods, incremental conductance is a preferred method as it has faster convergence.[1]

One efficient method of effectively utilizing the energy generated from the sun is by connecting the PV-array with the utility grid to eliminate the problem of storage losses in batteries.[2]

The output power obtained from the PV-array is DC in nature. The various electrical equipments connected to the grid work on AC supply. This presents a need for conversion of the DC power into AC power before feeding it to the grid. This is achieved with the help of an inverter. There are different modes of operation of inverter i.e. 120° operation, 180° operation, Pulse Width Modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM). The problem associated with inverter operation is the generation of harmonics.

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The SPWM technique is adopted for the inverter operation in this work for better performance in contrast to other techniques;[3,4] it helps in the reduction of low frequency harmonics and high frequency harmonics are reduced with the help of an appropriate economical passive LC filter. Maintaining high power factor helps to reduce system losses, improves the power quality and reduces the current required for a given power rating. Ideally, power factor is desired to be unity. Thus, there is a need of an appropriate power factor correction block to maintain a high power factor.[5]

The emerging solar technology and its connection with the grid has given the researchers a direction to explore the grid connected PV-array systems. Many studies have been conducted on the same. Modeling of the system can be done in many ways. Various models of grid connected PV-array systems viz. average model, detailed model etc.

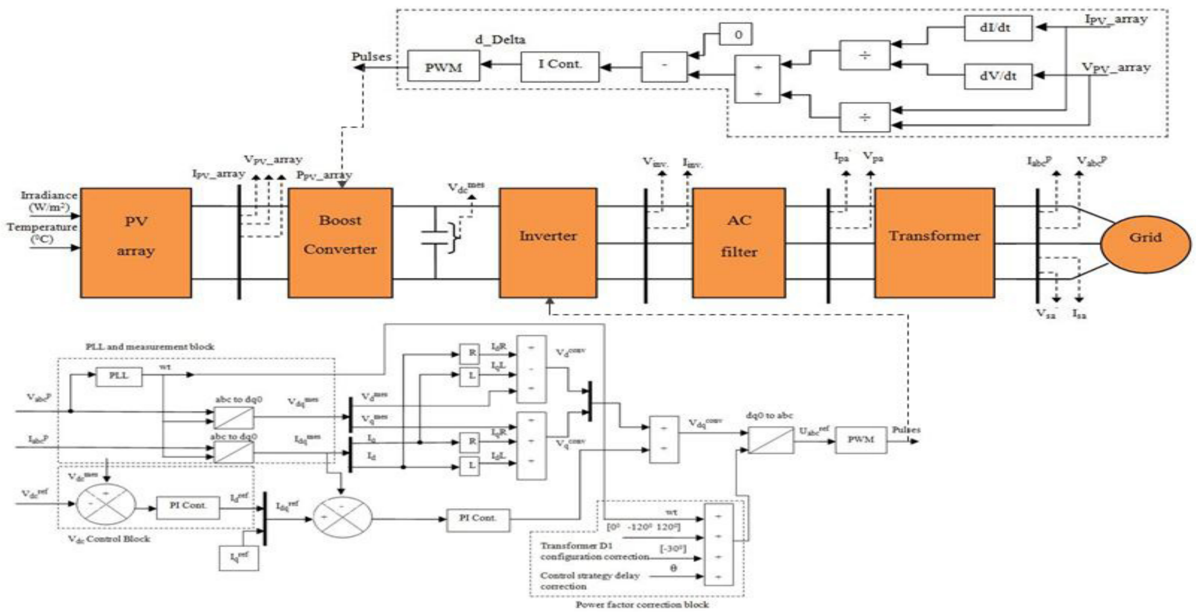

Figure 1: Block diagram representation of a grid-connected PV-array system with its control strategies

have been proposed by the researchers to understand their performance.

While designing an average model of a system, certain approximations and assumptions are considered. They are based on average value of electrical parameters. They are specifically developed for the designing of controllers, which is out of scope of our research work.

In this work, the detailed model of grid connected PV-array has been studied to analyze its performance. To improve the power quality and to implement a passive filter for harmonic reduction, the detailed model is chosen.

As per the above discussion, the objectives of this work are:

- To develop a detailed model of grid-connected PV-array for studying its dynamic behavior by implementing a strategy to follow the dynamic characteristics in a fast manner and extraction of maximum solar energy as per the specifications of PV-array.
- To implement a suitable economical passive LC filter for reducing the harmonics.
- To implement a power factor correction block, incorporating a system which nullifies the effect of transformer and inverter with its associated control circuitry.

Mathematical Modeling of Pv-Array System

The model studied in this research work is implemented in MATLAB/Simulink environment. The model shown in Figure 1 can be divided into two parts i.e. Power circuit and Control circuit. The components of the model are PV-array, DC-DC boost converter, Three-phase 3-pulse inverter (VSC), AC filter, transformer and utility grid. These components with their appropriate control strategies make the complete grid-connected PV-array model. The block diagram with the internal control circuitry is given along with the description and mathematical modeling of these components.

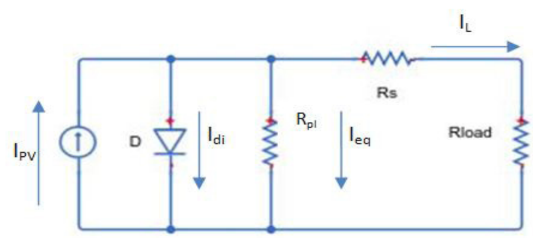

Figure 2: Equivalent circuit of a PV-array

PV-array

The PV-array constitutes of the solar cells as the elementary component. A solar cell is a p-n junction made up of silicon. Number of cells combines to form a PV panel (or solar module) and hence form large photovoltaic arrays. To obtain the required power, the cells are connected in series (to form solar panels) and these solar panels are connected in a parallel group.[5] The studied model PV-array consists of 66 parallel strings and there are 5 series connected modules per string.[6] The equivalent circuit of a PV cell (ideal) can be shown as a current source in parallel with a diode. For the practical circuit a series and shunt resistance are also added to it. The series resistance (R_s) is of small value and equivalent shunt resistance (R_{pl}) is a high value resistance.[7]

Applying KCL, I_{PV} is given as:

$$I_{PV} = I_{di} + I_{eq} \quad (1)$$

$$I_L = I_{PV} - I_{di} - I_{eq} \quad (2)$$

$$I_L = I_{PV} - I_s\left[e^{q\left(V+I_L.R_s/n.K.T\right)} - 1\right] - \left(\frac{V+I_L.R_s}{R_{pl}}\right) \quad (3)$$

where I_s is reverse saturation current, I_{PV} is insulation current, I_L is the cell current, I_{eq} is equivalent branch current, V is cell voltage, I_{di} is diode current, n is p-n junction quality factor, K is Boltzmann constant, T is temperature (in Kelvin), q is electron charge (in C).[1]

DC-DC converter with modified MPPT controller

The DC-DC converter used is a 5 KHz boost converter. Its role is to increase PV natural voltage (273 V DC at maximum power) to 500 V DC. The switching duty cycle of DC-DC boost converter is optimized by a MPPT (Maximum Power Point Tracking) controller which is using the 'Incremental Conductance with Integral Regulator' technique.[9] This MPPT controller automatically varies the duty cycle in order to generate the required voltage to extract maximum power from PV-array. The power at the MPP (P_{mpp}) is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}). The controller maintains this voltage (MPP) until the irradiation changes and the process is repeated.

In the incremental conductance method as shown in Figure 3, the controller measures incremental changes in PV-array current and voltage to predict the effect of a voltage change. It is based on the calculation of slope of the power v/s voltage curve of the PV panel. This slope must be zero at MPP, positive on the left and negative on the right side of the MPP. Instantaneous and Incremental conductance of PV panel can be expressed as I/V and $\Delta I/\Delta V$ respectively and their relationship at condition of MPP is given by.[8]

$$\begin{aligned} &\frac{\Delta I}{\Delta V} + \frac{I}{V} > 0 \quad \textit{left of MPP} \\ &\frac{\Delta I}{\Delta V} + \frac{I}{V} < 0 \quad \textit{right of MPP} \\ &\frac{\Delta I}{\Delta V} + \frac{I}{V} = 0 \quad \text{atMPP} \end{aligned} \quad (4)$$

The incremental conductance method is based on the observation that at the maximum power point, $\Delta P/(\Delta V{=}0)$ and $P{=}VI$. The current from the array can be expressed as a function of the voltage. Therefore,.

Setting this equal to zero yields: $\Delta I/(\Delta V{=}(-I(V))/V)$.

Therefore, the maximum power point is achieved when the incremental conductance is equal to the negative of the instantaneous conductance.[9] An additional controller is incorporated with incremental conductance method of MPPT to improve its performance i.e. to minimize the error between actual and incremental conductance.

Three-phase inverter (Voltage source converter)

SPWM inverters are employed in which the switches of inverter are controlled on the basis of comparison between a sinusoidal control signal and a triangular signal.

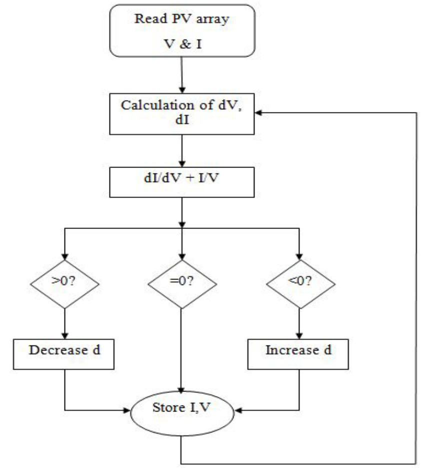

Figure 3: Flowchart showing working of Incremental Conductance (MPPT)

PWM technique is employed to convert the input dc into a controlled ac output voltage.

Under this phenomenon, the output voltage is fed back to a PWM controller. It controls the pulse width of switching pulse generated at the oscillator section. The change in the pulse width of the switching pulse cancels the changes in the output voltage and hence the inverter output remains constant irrespective of load variations.[4,10]

In a grid-connected PV-array system, the real and reactive power control has been done through a current regulator. The variables to be controlled by the inverter are the real and reactive power injected into the grid. The 3-phase variable obtained from the inverter in the 'abc' frame is represented as

$$\begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} = \begin{bmatrix} Y_m \cos w_o t \\ Y_m \cos(w_o t - 120°) \\ Y_m \cos(w_o t + 120°) \end{bmatrix} \quad (5)$$

where, Y_m is the maximum magnitude of voltage or current and w_o is the angular frequency.

The 3-phase stationary 'abc' frame can be transformed into the 'dq' rotating frame by Park's transformation.

The expressions for real and reactive powers after performing the Park's transformation can be given as

$$P_{active} = \frac{3}{2}\left[V_q I_q + V_d I_d\right] \quad (6)$$

$$Q_{reactive} = \frac{3}{2}\left[V_q I_d - V_d I_q\right] \quad (7)$$

In the current regulation scheme of power control, the d-axis and the q-axis reference current are generated by the real power control loop and the reactive power control loop respectively. The currents are described as

$$I_d^{ref} = \frac{2}{3}\left[\frac{P_{active} V_d + Q_{reactive} V_q}{V_d^2 + V_q^2}\right] \quad (8)$$

$$I_q^{ref} = \frac{2}{3}\left[\frac{P_{active} V_q - Q_{reactive} V_d}{V_d^2 + V_q^2}\right] \quad (9)$$

These reference currents are controlled by a 'PI current controller' to achieve steady state error equal to zero. PLL synchronization unit maintains synchronism between the phase and the frequency of a PV-array system and utility grid.

The voltage obtained from the inverter has been expressed in the rotating d-q reference frame. The equation is described as

$$\begin{bmatrix} V_d^{meas} \\ V_q^{meas} \end{bmatrix} = \begin{bmatrix} Ls & w_o L \\ -w_o L & Ls \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (10)$$

V_d^{meas} and V_q^{meas} are the grid voltages, I_d and I_q are the inverter currents, L is the inductive filter and V_d and V_q are the voltage control signals.

It can be observed from eqn. 10 that I_d and I_q are not dependent only on V_d and V_q, but also the coupled voltage w_L. Hence, the coupled value needs to be cancelled in order to control I_d and I_q independently. The current feed forward compensation is employed to decouple the current in d-q frame. The equation is given as

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} V_d^{meas} \\ V_q^{meas} \end{bmatrix} - \left(k_p + \frac{k_i}{s}\right) \begin{bmatrix} I_d^{ref} \\ I_q^{ref} \end{bmatrix} + \begin{bmatrix} -w_o L & 0 \\ 0 & w_o L \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (11)$$

V_d and Vq are the control signals from the 'PI current control' block. From eqns. 10 & 11 the relationship between reference control current and inverter current is given as

$$\begin{bmatrix} I_d^{ref} \\ I_q^{ref} \end{bmatrix} = \left(\frac{Ls}{k_p + \frac{k_i}{s}} + 1\right) \begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (12)$$

Reference current can be decoupled into d and q axes components by employing feed forward compensation and hence, they can be controlled independently.[11,12]

DC Link Capacitor

The DC link capacitor is needed due to the fluctuating nature of renewable energy sources. To reduce the ripples of DC link voltage (to keep it nearly constant), a capacitor (which acts as a filter) is employed. Hence, it simply provides a stable dc voltage source. The DC link capacitor plays a damping role in contributing to maintain the stability of the MPPT and the grid-connected inverter during the transient behaviors. Thus, it helps in maintaining maximum output power.

AC Filter

To limit the output current ripple and to achieve an acceptable damping rate, an AC filter is used and is designed as per requirements. The inductor in the AC filter connected to DC-AC converter can be determined using values of maximum acceptable amount of ripples in current, DC link voltage and switching frequency as follows:

$$\Delta I_m = V_{dc} / 12 L_{fl} . f_{sw} \quad (13)$$

where V_{dc} is DC link capacitor voltage and f_{sw} is switching frequency to give the value of inductor (L_{fl}) to be used. The series resistance (R_d) with the C_{fl} prevents the harmonic oscillations and is a damping resistance. Another series resistance (R_{fl}) with the filter's inductance part represents its parasitic resistance losses. In the studied model of PV-array, 10-kvar capacitor bank is used for filtering the harmonic produced by the voltage source converter i.e. DC-AC converter.[13,14]

Transformer and Power factor correction block:

In this model, three single-phase transformers are connected in delta star connection [9] for stepping up the voltage levels for supplying the utility grid. Due to this connection there is shift of 30° in the output from secondary of transformer.

A power factor correction unit has been employed to nullify the phase displacement between the voltages on the primary and secondary terminals of the delta-star connected transformers and the phase difference due to the time delay associated with the inverter control circuitry. Practically, most of the loads are inductive in nature (like motors, transformers etc.), they have power factor of lagging nature. Value of power factor less than unity increases the current requirement of equipment which gives rise to more losses in the system and therefore the efficiency of the system is reduced. Hence, it is necessary to maintain a high power for reduced losses in the system.

Utility Grid

In the studied model, the utility grid consists of 25KV distribution feeder & 120 KV transmission system used for transmitting the electrical energy to the end user.[6]

Performance Analysis of Dynamic Model of Grid Connected Pv-Array

The detailed model of grid connected PV-array as shown in Figure 1 has been studied here. It is composed of a number of non-linear differential equations and these are solved using MATLAB/Simulink environment. The model has been studied in a specified manner for verifying the dynamic performance.

- The irradiance and temperature are set to 250 W/m^2 and 50°C respectively as the initial (t = 0 sec to t = 0.75sec) conditions.
- From t = 0.75 sec to t = 1.25 sec, the irradiance starts increasing and rise up to 1000 W/m^2, while temperature remains constant.
- Further after t = 1.25 sec, the irradiance remains constant, while temperature decreases from 50°C to 25°C in t=1.5 to t=1.85 sec to observe the impact of temperature decrease.
- After t = 2 sec the irradiance decreases back to 250 W/m^2 from t = 2 sec to t = 2.25 sec and the temperature remains constant at 25°C.

The model has been discretized in the steps of 1microsecond for better accuracy and model has been analyzed for 2.5 seconds. The results are given below:

Dynamic performance analysis and MPPT results

In order to extract the maximum power from the PV-array, modified MPPT controller has been used in the model. The working of this modified MPPT controller has been verified successfully as the point of maximum power is tracked under each operating condition. There are three operating points aa', bb' & cc' as per the conditions of the irradiance and temperature specified by the PV-array manufacturer.

- At t = 1.38 sec, operating point aa' for 1,000W/m^2 and 50°C gives a PV-array power and voltage of 92.88 KW and 251.79 V respectively as per the specifications of the PV-array (92.9 KW and 250.2 V) for same conditions.
- At t=1.96 sec, operating point bb' for 1000W/m^2 and 25°C gives PV-array outputs as 100.41 KW and 274.46 V matching the PV-array specification chart of 100.7 KW and 273.5 V.
- At t = 2.44 sec, operating point cc' for 250W/m^2 and 25°C gives PV-array outputs as 24.35 KW and 268 V matching the PV-array specification chart of 24.4 KW and 265.1V.

The operating point data has been shown in Table 1 and it can be seen that the point of maximum power is being tracked successfully at every instant with the use of modified MPPT controller and it matches voltage and power ratings as per PV-array specification chart.

As we can see from Figure 4 initially the irradiance and temperature remains constant till time t = 0.75 sec and the power output from the PV-array after following a transient behaviour settles to a constant value. The irradiance increases following a ramp function from t = 0.75 sec to t = 1.25 sec and temperature remaining constant, the power output tracks the variation and increases to maximum possible value. At t = 1.5 sec the temperature drops down with irradiance remaining constant, the power again follows the variation and increases slightly. Again, as the irradiance starts decreasing at t=2 sec the power outputs drops down in the same manner following the curve. So, this shows that the power output tracks the variation of irradiance and temperature at every instant of time successfully.

Implementation of passive filter for harmonic reduction

The output of the inverter is not a pure sine wave, it consists of harmonics. Effects of harmonics include increased heating losses, torque pulsations. Total harmonic distortion 'THD' is a measure of distortion produced by harmonics present in a circuit. Before injecting the PV output to grid, we need to check the THD value and ensure whether it is in the given range. For the calculation of both voltage and current THD, mathematical tool named as Fast Fourier Transform (FFT) has been used. The reduction of harmonics has been achieved by employing a suitable passive filter. One RL filter has been connected in for current harmonics reduction and another RC filter in parallel for reduction of voltage harmonics. The specifications of these filters, using equation (13) are:

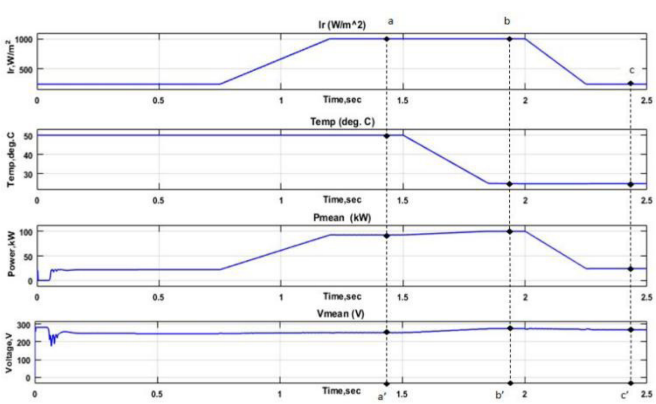

Figure 4: Waveforms obtained from PV-array with MPPT controller

Table 1: MPPT Points from given PV-array rating chart

S. No.	Operating Point	*PV-array rating*		*PV-array power (in KW)*		*PV-array voltage (in V)*	
		Irr. (W/m^2)	*Irr. Temp. (deg. C)*	*Specified*	*Observed*	*Specified*	*Observed*
1.	aa'	1000	50	92.9	92.88	250.2	251.79
2.	bb'	1000	25	100.7	100.41	273.5	274.46
3.	cc'	250	25	24.4	24.35	265.1	268

- For RL filter: R_{fl} = 0.001885 Ω, L_{fl} = 0.225 mH
- For RC filter: R_d = 576 Ω , C_{fl} = 460.51 μF

The results of total harmonic reduction 'THD' in voltage and current outputs of the inverter are shown below and functioning of filters has been discussed:

Harmonic reduction in output voltage

- Without filter
- After filtration

Harmonic reduction in output current

- Without filter

After filtration

As it can be seen from Figures 5-8, implementation of an appropriate passive filter has reduced the THD of the output voltage from 41.71% to 1.94% and for the output current, it has reduced from 5.54% to 2.80%.

Implementation of Passive filter for harmonic reduction

The PV-array is connected to utility grid via three single-phase transformers of delta/star configuration. Therefore, there is a shift in voltage and current being supplied to utility grid. To keep the power factor equal to unity, there is a need to provide a shift of 30°, which is being accomplished with the help of power factor improvement block.

Main hindrances for achieving the unity power factor are:

- Delta/star configuration of three single-phase transformers.
- Time delay due to control circuitry associated with the inverter.

In order to achieve unity power factor, it can be observed from Figure 9, a pre-shift of $(30+\theta)^0$ has been given to the output of the inverter (input at primary of the transformer). So, it can be seen from Figure 10, that the shift due to the transformer connections and delay due to inverter control circuitry is compensated. Hence, voltage and current are in same phase to provide unity power factor.

Conclusions And Future Scopes

After simulating the detailed model of grid connected PV-array, consisting of large number of differential equations in MATLAB/Simulink environment with a fixed step size of one microsecond, following conclusions have been drawn:

It is found that when boost converter with MPPT controller using incremental conductance in conjunction with integral regulator strategy is applied on to the PV-array, the power supplied by the array is following the same pattern as specified by the manufacturer of the PV-array, verifying the validity of the work done [Table-1]. Hence, the dynamic performance of the system is analyzed.

It is observed that the harmonics generated by the inverter system has been reduced by applying a suitable passive filter with parameters as for RL filter R_{fl}=0.001885 Ω, L_{fl}= 0.225 mH and for RC filter R_d=576 Ω, C_{fl}=460.51 μF. The total harmonic distortion 'THD' of the electrical supply produced by PV-array is found to be 1.94% and 2.80% in voltage and current respectively, which is within the limits specified by IEEE standard-1547.

In addition to above improvements, the power factor is kept to unity, by employing the power factor improvement block. This block nullifies the effect of 30^0 phase shift due to three single-phase transformers as well as the effect of time delay of control circuit associated with inverter.

Overall, it can be concluded that the 'dynamic performance' of the system as well as 'power quality' of the supply in terms of 'THD and power factor' have been enhanced.

The detailed model, switching function and average function modeling of the inverter can be studied in detail and implemented as per specific application.

Appendix

The 100 KW PV-array uses 330 Sun Power modules (SPR-305E-WHT-D). The array consists of 66 strings of 5 series-connected modules connected in parallel (66×5×305.2 W= 100.7 kW). The 'Module' parameter of the PV-array block allows you to choose among various array types of the NREL system advisor model (https://sam.nrel.gov/). The manufacturer specifications for one module are:

- Number of series-connected cells : 96
- Open-circuit voltage: Voc= 64.2 V
- Short-circuit current: Isc = 5.96 A

Voltage and current at maximum power: Vmp = 54.7 V, Imp = 5.58 A.

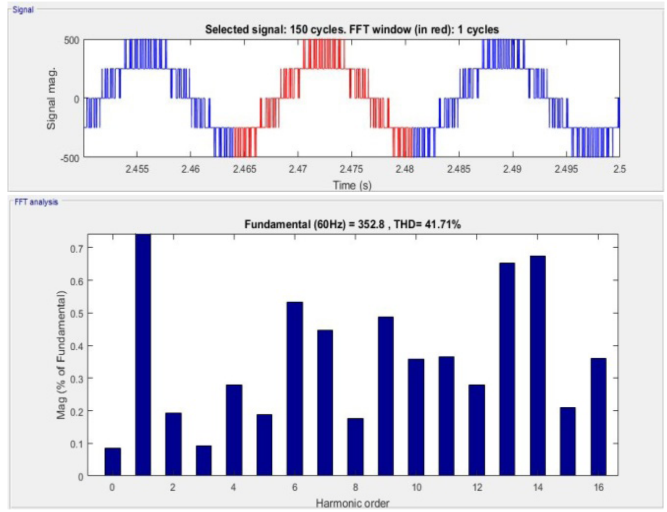

Figure 5: Unfiltered output voltage waveform and its FFT analysis

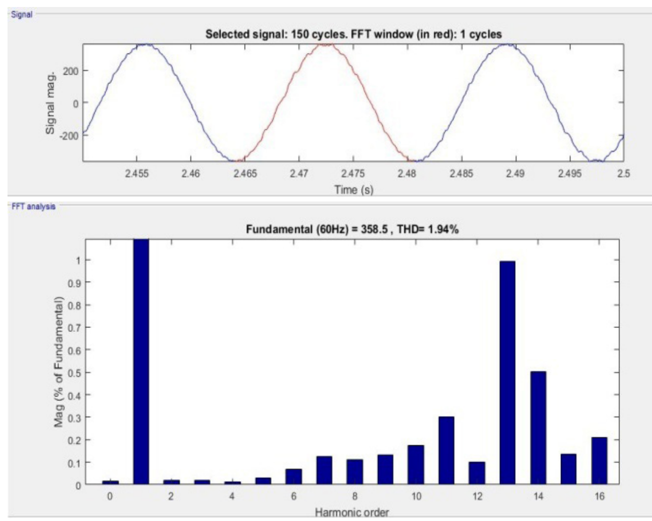

Figure 6: Filtered output voltage waveform and its FFT analysis

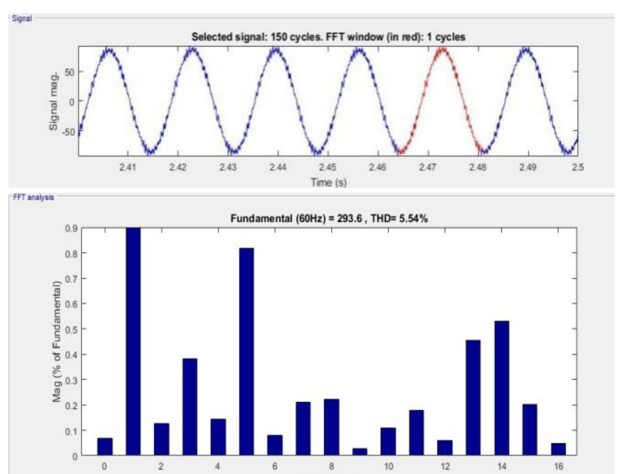

Figure 7: Unfiltered output current waveform and its FFT analysis

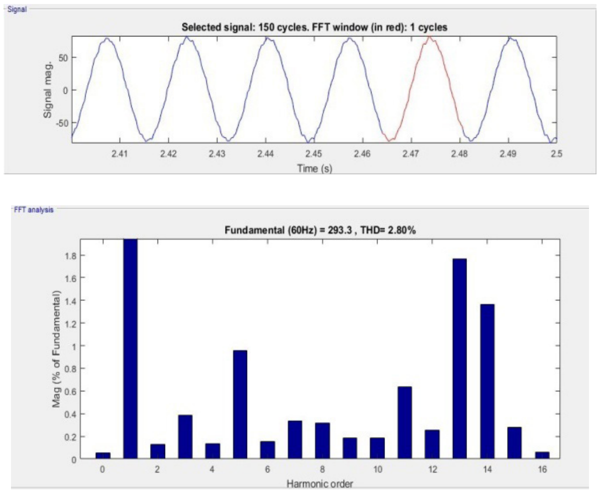

Figure 8: Filtered output current waveform and its FFT analysis

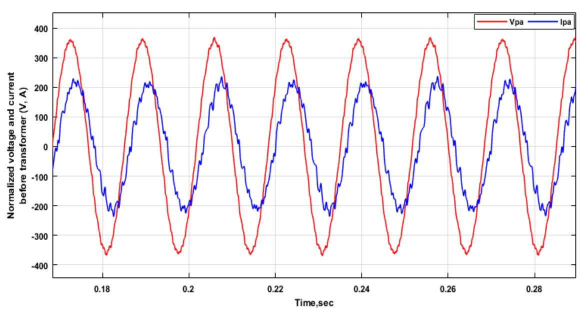

Figure 9: Pre-shifted voltage and current input waveforms at primary of delta-star transformer for maintaining power factor

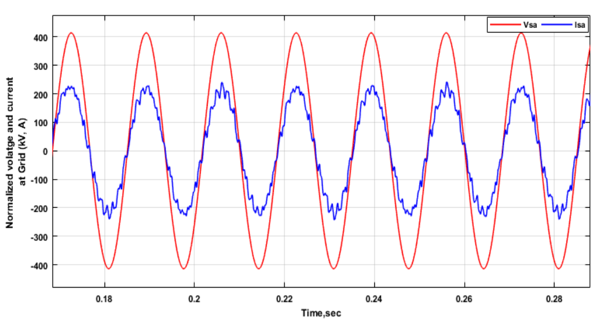

Figure 10: Voltage and current output waveforms at secondary of delta-star transformer showing unity power factor

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Conflict of Interest

Nil.

References

[1] Moacyr Aureliano Gomes de Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedo e Melo, and Carlos Alberto Canesin. (2013). Evalution of the Main MPPT Techniques for Photovoltaic Applications. *IEEE Trans. on Industrial Electrnoics*, Vol. 60, No. 3: 1156-1167.

[2] Pappu Jaiswal, S.K. Srivastava and Kishan Bhushan Sahay. (2016). Modeling & Simulation of Proposed 100 KW Solar PV-array Power Plant for MMMUT Gorakhpur. *International Conference on Emerging Trends in Electrical, Electronics and Sustainable Energy Systems (ICETEESES–16):* 261-266.

[3] Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, H. Wayne Beaty. (2012). *Electrical Power System Quality*." McGraw Hill Education, 3rd Edition.

[4] https://www.ewh.ieee.org/soc/es/Nov1998/08/PWMINV.HTM

[5] Paul C. Krause, Oleg Wasynczuk, Scott D. Sudhoff, “Analysis of Electric Machinery And Drive Systems.” IEEE Press, Wiley Publications, 2nd Edition, 2002.

[6] MATLAB Mathworks 2017 [Online].Available: https://www.mathworks.com/products/matlab.html

[7] Rafia Rawoof, R. Balasubramanian, N. Moorthy Muthukrishanan. (2015). Modeling of Simulation of 100 kWp Grid-Connected Photovoltaic Power System. *2015 Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG)*. DOI: 10.1109/PCCCTSG.2015.7503913.

[8] Dalila Beriber, Abdelaziz Talha. (2013). MPPT Techniques for PV Systems. *4th International Conference on Power Engineering, Energy and Electrical Drives*, Istanbul, Turkey.

[9] Srushti R. Chafle, Uttam B. Vaidya. (2013). Incremental Conductance MPPT Technique for PV System. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, issue 6.

[10] Sarina Adhikari, Fangxing Li and Huijuan Li. (2015). P-Q and P-V control of photovoltaic generatorsin distributed systems. *IEEE Trans. Smart Grid*, Vol. 6, no. 6: 2929-2941.

[11] S. M. Ashabani and Y. A. R. I. Mohamed. (2014). New family of microgrid control and management strategies in smart distribution grids-analysis, comparison and testing. *IEEE Trans. Power Syst.*, Vol. 29, no. 5: 2257–2269.

[12] Wenlei Bai, M. Reza Abedi, Kwang Y. Lee. (2016). Distributed generation system control strategies with PV and fuel cell in microgrid operation. *Control Engineering Practice no. 53*: 184–193.

[13] Mostafa Farrokhabadi, Sebastian Konig, Claudio A. Canizares, Kankar Bhattacharya, Thomas Leibfried. (2018). Battery Energy Storage System Models for Microgrid Stability Analysis and Dynamic Simulation. *IEEE Trans. Power Systems*, Vol. 33, No. 2: 2301-2312.

[14] M. Liserre, F. Blaabjerg, and S. Hansen. (2005). Design and control of an LC filter- based three phase active rectifier. *IEEE Trans. Ind. Appl.*, Vol. 41, no. 5: 1281–1291.