IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 19, Issue 3 Ser. I (May. – June. 2024), PP 48-56
www.iosrjournals.org

Grid Integration of Solar Generation using 5-Level Neutral Point Inverter for Three Phase System

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Abstract:
The development of the conventional power system into a green grid has led to the massive deployment of solar generation. To facilitate the stand-alone operation numerous modular inverter topologies are available. But for large grid integration robust efficient inverter topologies are required. This work presents the 5-level three phase neutral point clamped inverter topology for solar generation in grid connected operation. For gate pulse generation sinusoidal PWM with in-phase carrier wave is used. The control is designed using sine wave as carrier signal. This control is robust and simple to implement and is not vulnerable to the system dynamics. The model has been designed in MATLAB simulation and the results are obtained for constant as well as variable irradiations. The efficiency of the topology designed is justified by the harmonic analysis for PV-side inverter output and grid side voltage and current as per the IEEE standard.
***Key Word**: Neutral point clamped, multi-level inverter, solar system, sinusoidal PWM, DC-DC converter, MPPT.*

I. Introduction

Enormous researches are going on for inverter topologies for easy and efficient grid integration of Solar Generation System (SGS). In a way to transform the Conventional Utility Grid (CUG) into a green grid with minimum carbon traces, solar based renewable source is the popular choice across the world. Since it is available in abundance as well as the technology for converting solar irradiance into electricity is become matured enough to deploy bulk generation. In the process of installation of solar generation, inverters play a very important role, since it converts the raw solar power obtained from solar irradiations into the useable applications for the loads. During the development of the solar inverters, conventional two-level full-bridge Voltage Source Inverters (VSI) were employed whether it is for single-phase or three phase applications. The VSI has limited application when connected for the sensitive and specific load applications. Slowly Multi-Level Inverters (MLI) were developed for SGS. The MLIs were highly used in many recent applications because of its nature of high voltage handling capacity. MLI has the capability of producing typical output voltage levels by interchanging the inverter groups. In the case of MLI, as the level of voltage increases, the output delivered by the converter will also have moderately diminished output waveform. In general, MLI have broad three types as neutral point clamped, flying capacitor and the cascaded type connected. These MLIs have been utilized in many applications as discussed in [1]. The purpose and special implementation of the MLIs are examined by the re-enactment after-effects. As the utilization and applications increases, there topologies also evolved as per the applications and need for the higher voltage levels. Though solar is popularly adopted as roof top or stand-alone operations with numerous applications. But, bulk power generation through it cannot be ignored. Huge installation of solar is facilitated with grid connected operation and for grid-tied solar generation VSI is typically installed. The performance of the Grid Connected Solar Generation (GCSG) can be enhanced by utilizing MLI topology. Though single-phase grid connected operation of solar has widely researched by scholars [4-10], but three phase grid connected is not much addressed in literature [11, 12]. This paper presents a sinusoidal carrier wave PWM generation based 5-level Neutral Point Clamped (NPC) MLI for three phase grid integration of GCSG. The GCSG forms the PV-array, MPPT (Incremental N' Conductance), DC-DC converter. NPC MLI for three phase integration has three sets for gate pulse generation. The system has been modeled in matlab and the results are obtained for both constant and variable irradiance.

II. Multi-Level Inverter (MLI)

In industrial power systems and power distribution, the UPQC can improve PQ at the PCC [9]. A UPQC The Multi-Level Inverter (MLI) has replaced conventional VSI in last few decades due to its ease of generating AC output near to the sinusoidal wave in form of small-steps of lower Dc-level [11]. These small-steps of lower DC-level combines to form high AC output voltage due to this wastage is reduced to a great extent as compared to conventional VSI which generates AC with rectangular waveform [12, 13].

The MLI are more advantages over conventional VSI which can be summarized below;

- Staircase waveform quality is one of the main highlights. Multilevel inverters generate the output voltages with very low distortion hence problems of electromagnetic compatibility can also be reduced.
- Multilevel inverters can operate on both fundamental switching frequency and high switching frequency Pulse width modulation. The lower switching frequency usually means lower switching loss and higher efficiency.
- Multilevel inverters can usually draw input current with low distortion.
- Multilevel inverters generate smaller common voltage. By using the advanced mode technology, the Common mode voltage can be reduced.

MLIs are designed by the array combination of semiconductors switches, the output of which generate voltages with stepped waveforms. The commutation of the switches permits the addition of the voltages developed across the switches, which reach high voltage at the output [14, 15]. The combination has many variants and named as per the combinations. In their early stage of development, the MLIs are designed using basic three structures Nabae, Takahashi and Akagi proposedin1980 [16] namely; Diode Clamped, Flying Capacitor, Cascaded H-bridge topologies. These when become popular are further developed to numerous different topologies. Each topology has its unique characteristics which is featured as per the application and concept of the inventor to meet a particular requirement. Though all topologies have their specific design, component requirement and applications, but NPC is widely adopted as the conventional MLI topology since its design is simple, easy to implement and is not atall vulnerable to the system dynamics.

It also can be employed for various high-power applications by connecting with Renewable Energy Resources. MLI now a days have become a suitable method for reducing switching losses in high power application. The appropriate developments and advancement on MLIs make them a capable technology for high power drives. As the output wave form of MLI is stepped wave form which is nearly equal to fundamental waveform, the power quality as well as harmonic profile is improved which reduces the size of the filter and if total harmonic distortion is less than recommended limit of IEEE then the filter may even be removed. This will remarkably reduce the cost of the circuit and even saves the energy loss in the filter circuit. With the conventional topologies, higher voltage level design needs more component which can make the system bulky and accordingly for higher no. of switches, driver circuit also become complex.

This paper presents the three-phase topology for NPC. The NPC is designed by a series combination of power switches whose connecting point is clamped by the combination of two diodes between consecutive pairs and the neutral point is clamped with the combination of capacitors as shown in figure 1 [13]-[15]. The negative point of the upper inverter and the positive point of the lower one are assembled together to constitute the new phase output, while to make the neutral point N, the initial phase outputs are connected via two clamping diodes. These are efficient in applications operating at fundamental frequency switching [16]. A common DC-source which is PV generated is used across all the phases and to produce 5-level voltage output. It consist of total 8 switches per phase which are triggered using sinusoidal PWM. Four for positive half cycle and 4 for negative half. Capacitors are used to divert the voltage across positive and negative switch combinations.

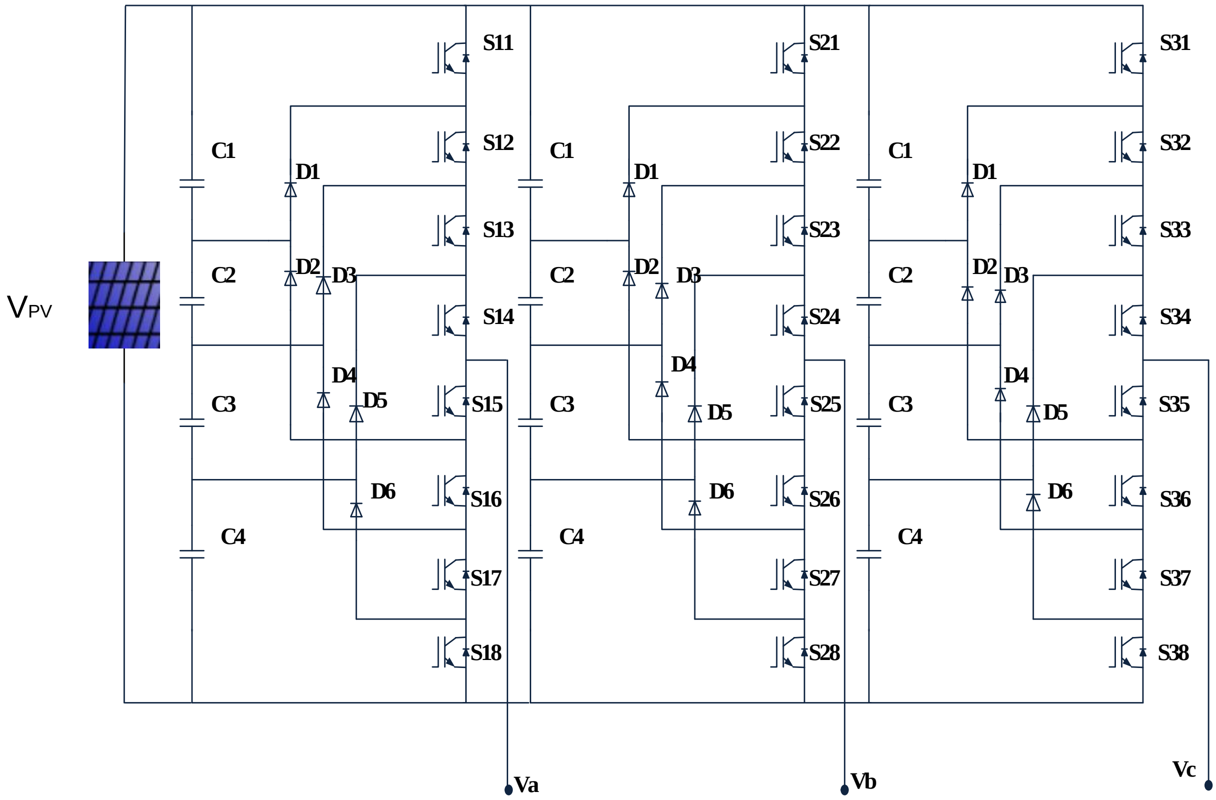

Fig. 1. Schematic of three phase NPC-MLI topology

III. MATLAB Simulation

Solar systems generally employed as standalone system or grid connected inverters [17]. The standalone system generally supplies the local load like, rooftop system of remotely installed system where grid can't be reached. The grid connected system needs a proper synchronization to interact with the grid [18]. The profitability of such system is worthy when the communication and power flow is two way. Which means power can either be supplied or can be consumed when needed. The available grid interactive PV system can be as shown in. Various architecture and control topologies have been proposed in literature on integration of wind and solar energy systems and their hybrid combinations for power quality improvement when operated in a stand-alone as well as grid connected mode [6]-[8]. In this work a 5-level NPC-MLI is designed in SRF to integrate the solar system with the utility grid. For simulation of GCSG, solar module is used which is already available in MATLAB library having design parameters as shown in table 1. The simulation model of the Solar is shown in figure 2. The output of PV-array is regulated for the maximum value using incremental N' conductance maximum power point tracking algorithm and DC-DC converter boost that output as per the required three phase AC system as shown in figure 3. In the proposed work the Dc-output obtained from solar when regulated with the help of DC_DC converter is fed as the DC-source to the proposed NPC-MLI. The foremost complication is to design a controller to synchronize the MLI with the grid [19]. For this the switching of 5-level NPC is designed using sinusoidal PWM technique in which sine pulse is obtained by referencing the grid signals as shown in figure 4. Hence the three-phase output generated from 5-level NPC is completely synchronized with the grid. The switching pulses are generated using variable frequency based PWM. The synchronization process is carried out using synchronous frame signals which is obtained using grid voltage reference signals to generate control for PI and PLL. The designed system s tested using MATLAB software for three phase distribution system with constant and variable irradiance. The matlab simulation for the proposed system is shown in figure 5.

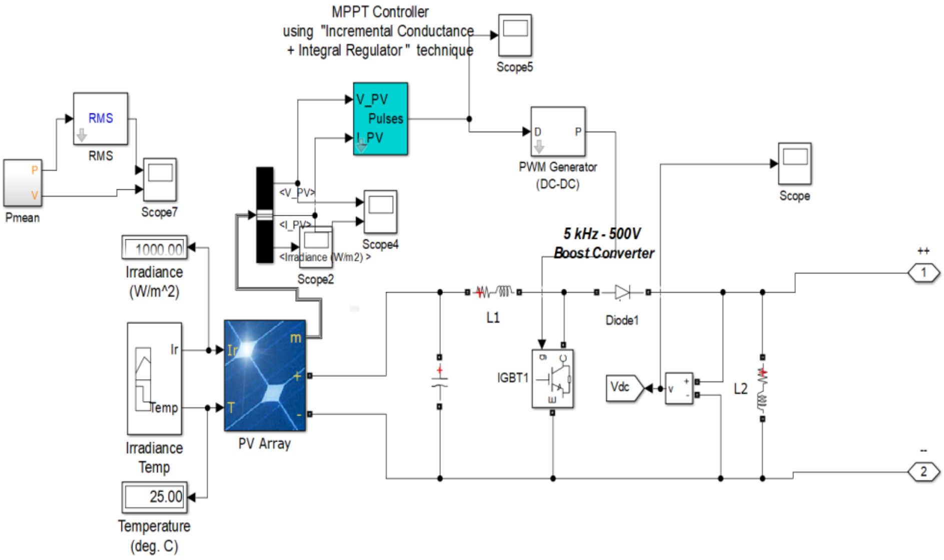

Fig. 2. Simulation model of PV-boost converter

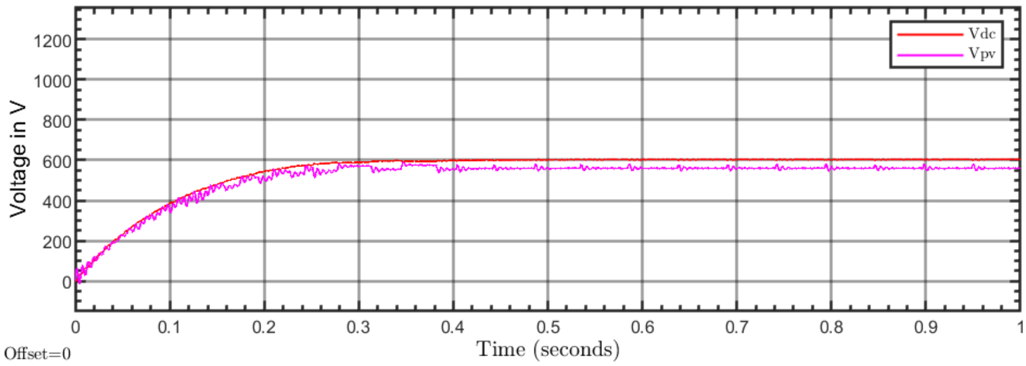

Fig. 3. DC-out put of PV and boost converter for constant irradiance

Table no 1 Design Parameter for PV

Parameter	**Value**
V_{PV}	500 V
I_{PV}	60 A
Irradiance (Standard)	1000 W/m^2
Operating Irradiance G_r	1000, 1000-500 W/m^2
Quality factor, N	0.94
Series resistance, R_s	0.374 Ω
No of cell connected in series, Ns	10
No of cell connected in parallel, Ns	10
Cell reference Temp, T_{r0}	25^{0}C
Cell operating Temp, T_r	25^{0}C
V_{oc} for module	64.2 V
I_{sc} for module	5.96 A

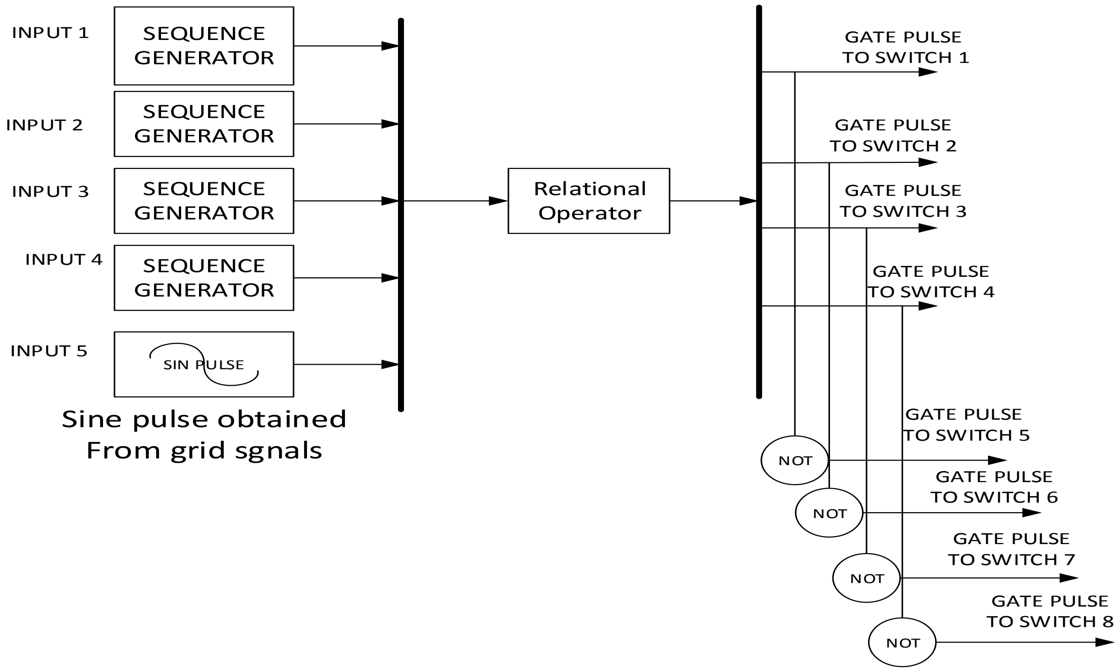

Fig. 4. PWM topology for 5-level NPC-MLI

IV. Simulation Results

The complete simulation model for the designed 5-level NPC for GCSG is shown in figure 5 with design parameter as mentioned in table -2. Simulation is performed in three parts. In the first part, NPC 5-level for three phase is designed with constant DC-source of 600 V which generates five level three-phase voltage as shown in figure 6 with distorted and unbalanced current. In the second part, a PV-boost converter is designed which generated 30 KW of power. This PV-generation is then connected across the DC-bus of the three-phase 5-level NPC, replacing DC-source as shown in figure 5. Now for grid connected solar in the third part, to synchronize the PV-connected NPC-MLI with the grid a filter unit is designed.

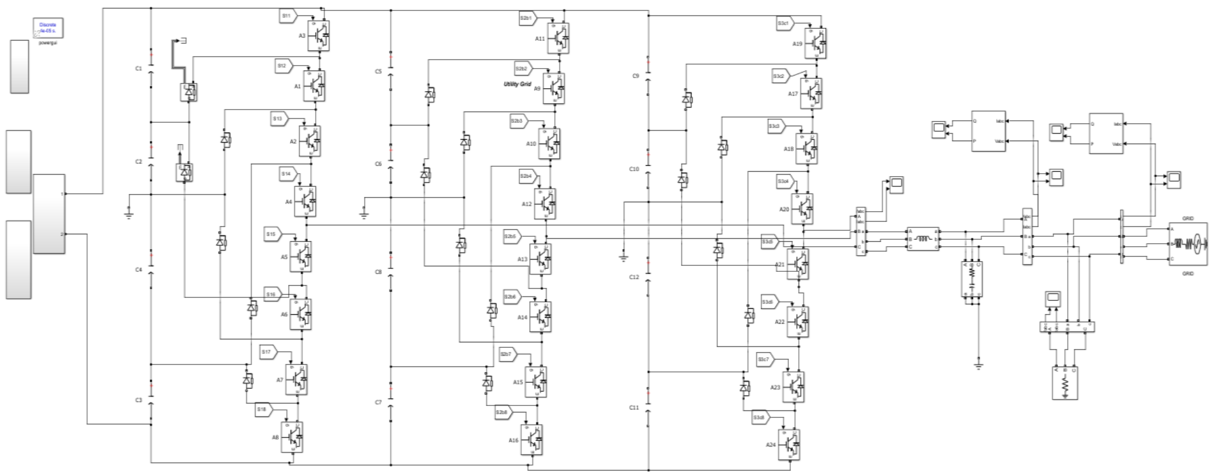

Fig. 5. Simulation results for voltage and current under linear loading.

Table no 2 Design Parameter

Parameter	**Value**
Grid voltage	415 V (RMS) phase-phase
Grid frequency	50 Hz
Switching frequency	7 KHz

Boost converter inductor	0.99 mH
Boost conductor Capacitance	1000 µF
Resistance	0.1 Ω
PV-power	30 KW
Linear load	20 KW
Capacitance of NPC	12 kF
Filter inductance	5mH
Filter capacitance	200µF

The three phase voltage and current output for NPC-MLI is shown in figure 6. The voltage phasor has 5-level output, but the current is distorted and unbalanced and approximately negligible which is the current required by the components of the NPC. This is the output of PV-generation integrated with the 5-level NPC. For grid connected operation, in between NPC and grid, a filter unit is inserted which synchronize the frequency of NPC with the grid. Performance of the designed system has been analysed for both constant and variable irradiance. For constant irradiance of 1000w/m^2, the voltage and current output at The Point Of Interfacing (POI) is shown in figure 7. The THD at the interfacing point for voltage is 0.03% as shown in figure 8 and for current is 0.17 % as shown in figure 9. Now for analysing performance of the system under variable irradiance, the solar radiation is reduced to 500w/m^{2}as shown in figure 10. The DC-output of solar and boost converter under this condition is shown in figure 11. The voltage and current at the point of interconnection is shown in figure 12.

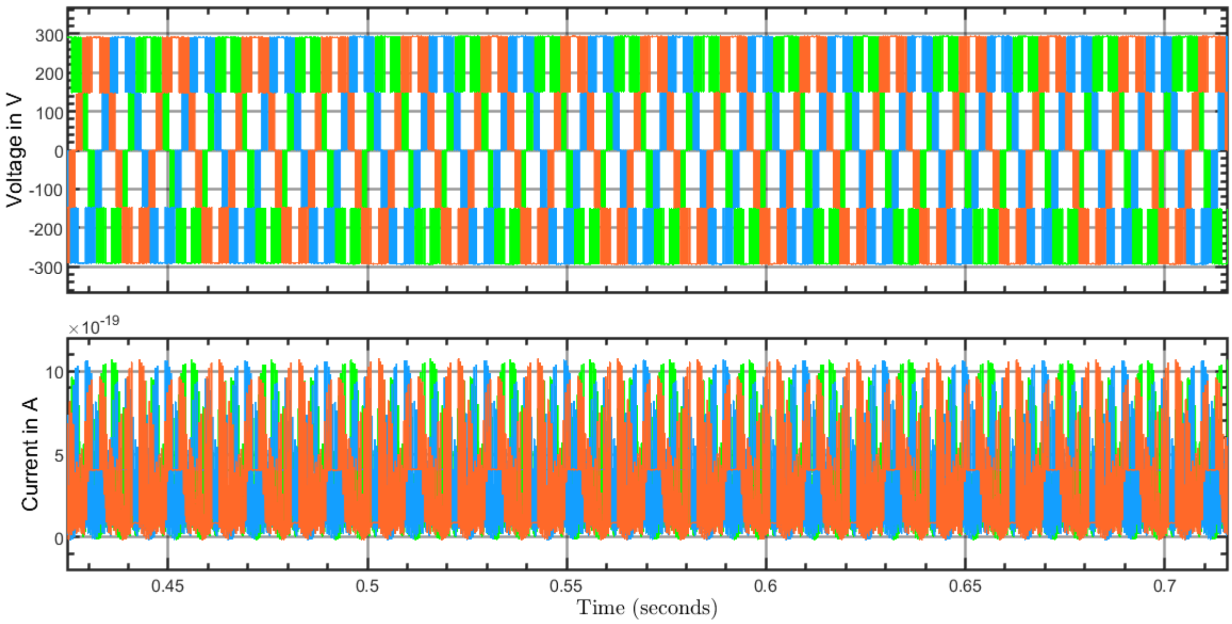

Fig. 6. Three phase voltage and current of 5-level NPC-MLI

From the results it can be seen that, for both constant and variable irradiations, the system performed stably with negligible voltage and current distortion, hence THD graphs are same as for constant irradiance output.

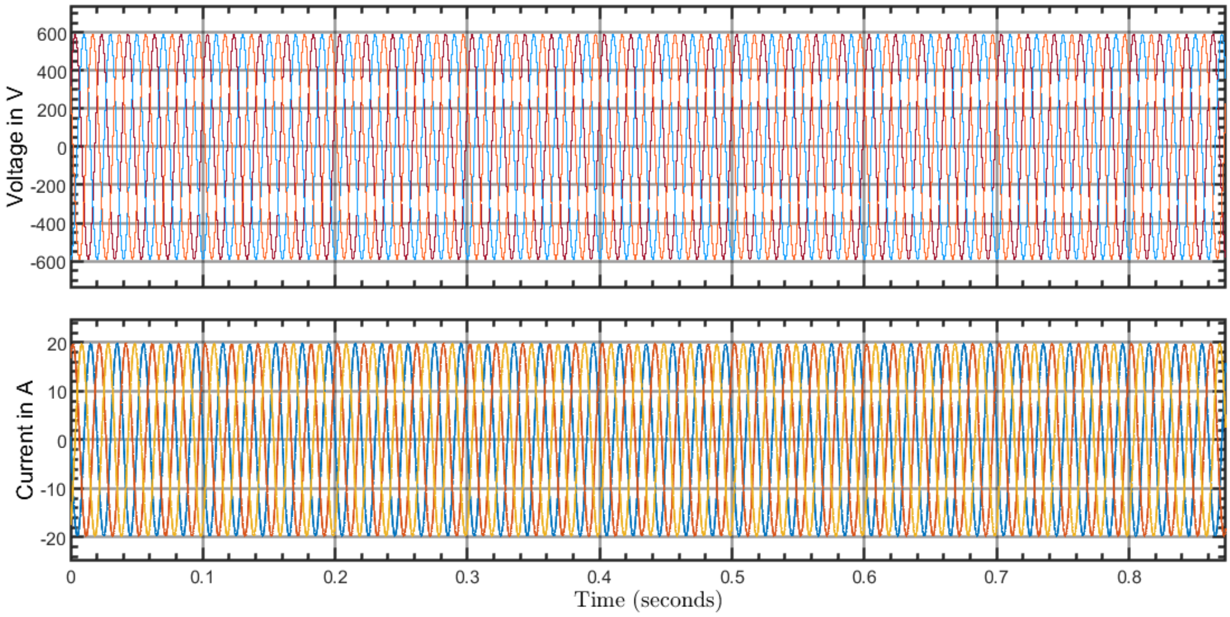

Fig. 7. Voltage and current at the point of interfacing for NPC-MLI based GCSG with constant irradiations

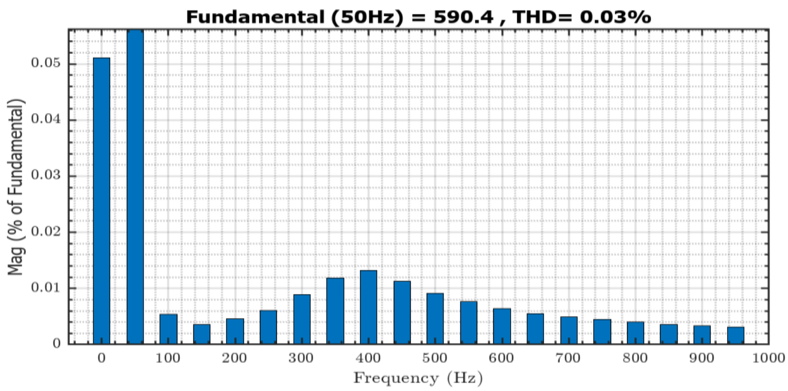

Fig. 8. Voltage harmonics with constant irradiance at POI

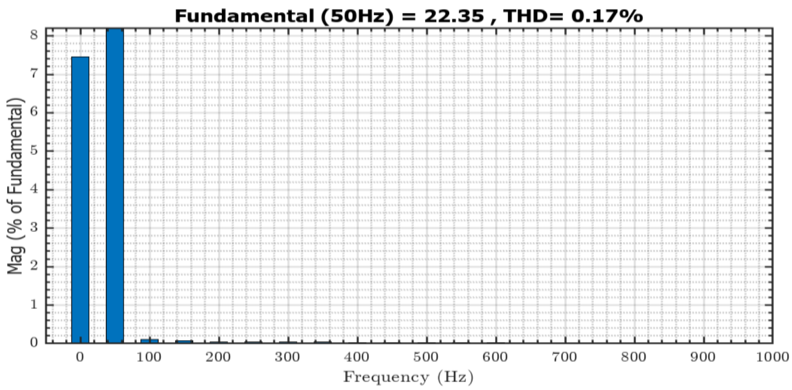

Fig. 9. Current harmonics with constant irradiance at POI

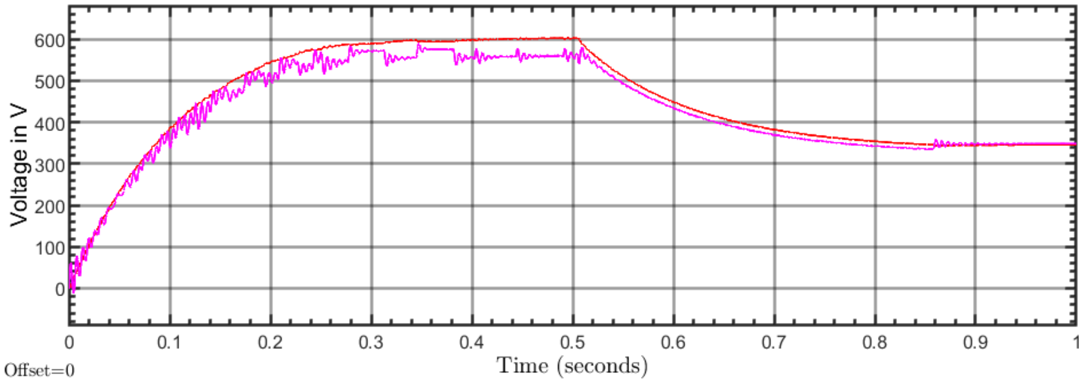

Fig. 10. DC-output of PV and boost converter for variable irradiance

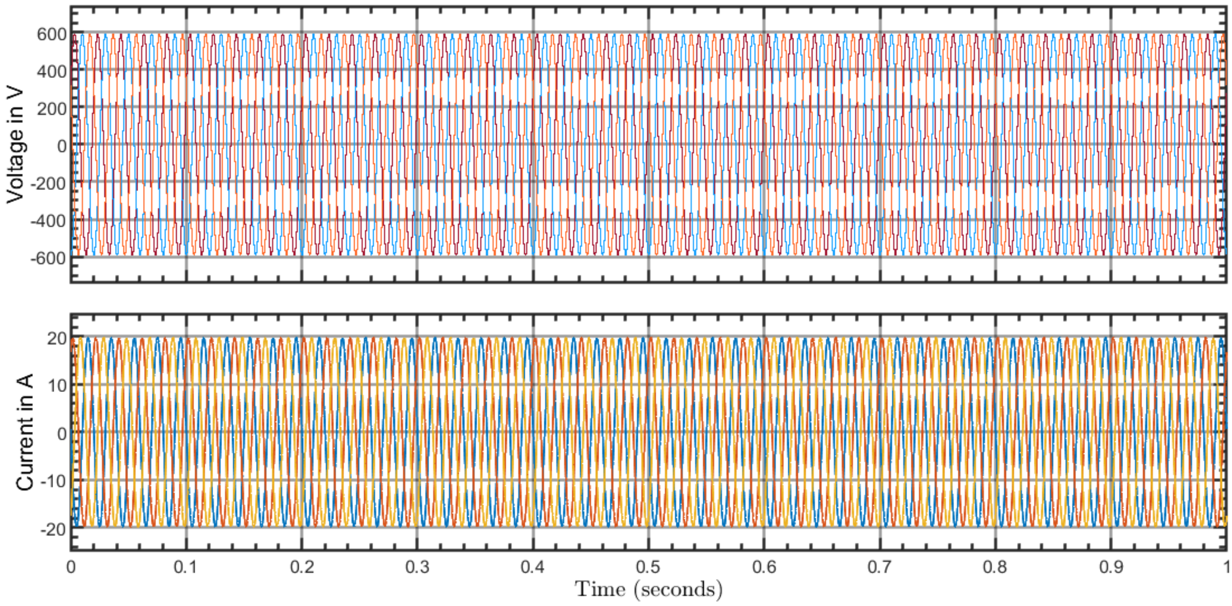

Fig. 11. Voltage and current at the POI for NPC-MLI based GCSG with constant irradiations

V. Conclusion and Discussion

This work presents a NPC-MLI topology for five level grid connected operation of PV generation. The solar generation is comprising of PV array with 30 KW output designed with incremental-conductance MPPT and DC-DC boost converter to regulate and maximize the output of GCSG. The outcomes showed how crucial the multilevel inverter is for producing a steady and pure AC voltage wave, and how successful the suggested control strategy is at resolving the problem of solar panel mismatch and cutting waste, which raises the stability and efficiency of the photovoltaic system. Results are obtained for both constant and variable irradiance and the voltage and current profile at the interfacing point remains unaffected with negligible distortion. The converter features several advantages such as the generation of high-quality currents, low harmonic content and reduced complexity. The topology proposed has the capacity to operate at a lower switching frequency than other converter, and the modularity that can reduce the cost of the solution.

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