Design and Implementation of Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC)

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Abstract: ***In this paper Proposes, makes an attempt to develop grid connected modeling of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC). The proposed system makes use of single stage power conversion with maximum power point tracking and modeling of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) as interfacing unit into the grid. In this paper, perturb & observe method of maximum power point algorithm is used to regulate the DC link voltage of the MMC and to synchronize the grid utility voltage with the current for attaining near unity power factor operation under varying environmental conditions. Recently renewable energy power supplied into the utility grid has been paid much attention due to increase in fossil fuel prices, environmental pollution and energy demand boom. Among various renewable energy resources such as solar, wind, tidal, geothermal, biomass etc., the solar photovoltaic system being more attractive and promising green resource because of its abundant availability, safe resource, cost free and eco-friendly. The solar photovoltaic (PV) modules directly converts the light energy into the electrical energy, but energy obtained from the PV module acts as low voltage DC source and has relatively low conversion efficiency. In order to improve the efficiency and convert low voltage DC source into usable AC source, the power electronics converters are used to transform DC into AC. The simulation results presented in this paper verifies the operation of proposed MMC topology such that the AC output is free from the higher order harmonics and grid voltage and current are in phase. Mathematical modeling of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) and the results of simulations in MATLAB/SIMULINK software are presented to investigate the correctness of the results.***

Keywords: Solar module, Batteries, PMDC motor, Charge Controller.

1. Introduction

The single stage solar power conversion will satisfy all the control objectives like maximum power point tracking (MPPT), synchronization with grid voltage, and lower harmonic content in the output current. At present scenarios several solutions for a grid connected PV system with conventional two-level and multilevel inverter has been reported in the literature [1]. In case of two-level inverter, it inject maximum PV power into the grid with a unity power factor, however the system fails to be free from higher order harmonics, high voltage stress across the semiconductor power switch and high power losses due to high switching frequency. In order to overcome the above mentioned problems, multilevel inverter came into picture and attracted more attention because of their significant properties [2]. Current between phase during unbalanced network conditions and it may cause asymmetrical phase voltages. The modular multilevel inverter has strong potential to replace cascaded multilevel converter in medium voltage applications [3]. Current between phase during unbalanced network conditions and it may cause asymmetrical phase voltages. The modular multilevel inverter has strong potential to replace cascaded multilevel converter in medium voltage applications. This project, presents the design of a solar photovoltaic power conversion system with single stage modular multilevel converter. Currently intensive research is going on in MMC and it has high potential for medium power applications. Modular multilevel converters have several advantages over conventional multilevel topologies. Those significant are as follows. Generate low harmonic output voltage, this eliminates filtering requirements. For medium voltage application, it allows to avoid interfacing transformer. This Paper presents the design of a solar photovoltaic power conversion system with single stage modular multilevel converter. Currently intensive research is going on in MMC and it has high potential for medium power applications. Modular multilevel converters have several advantages over conventional multilevel topologies. Those significant are as follows. Generate low harmonic output voltage, this eliminates filtering requirements. For medium voltage application, it allows to avoid interfacing transformer. Modular structure allows extending higher number of levels easily. Capacitor voltage balancing is attainable independent of the load. Although MMC are investigated with many applications, but it has not been reported in the literature with single stage solar PV power conversion system. This paper demonstrates the effective implementation of the photovoltaic supported MMC for grid interface which satisfy all the control.

2. Overview of a Photovoltaic (PV) Module

A PV cell is the basic structural unit of the PV module that generates current carriers when sunlight falls on it. The power generated by these PV cell is very small [4]. There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1. Perturb and observe (hill climbing method)
2. Incremental Conductance method
3. Fractional short circuit current
4. Fractional open circuit voltage

Perturb & Observe (P&O) is the simplest method. In this algorithm use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method. To increase the output power the PV cells are connected in series or parallel to form PV module. The electrical equivalent circuit of the PV cell is shown in Fig. 1

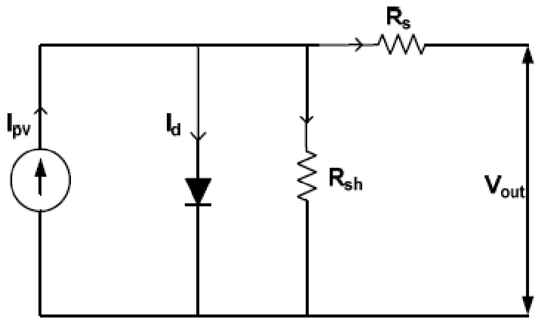

Figure 1: Equivalent circuit of PV module

The I-V characteristic of a PV module is highly non-linear in nature. This characteristics drastically changes with respect to changes in the solar radiation and cell temperature. Whereas the solar radiation mainly affects the output current, the temperature affects the terminal voltage. Fig 2 shows the PV module voltage vs PV module current characteristics of the PV module under varying solar radiations at constant C. A substantial increase of photovoltaic (PV) power generators installations has taken place in recent years, due to the increasing efficiency of solar cells as well as the improvements of manufacturing technology of solar panels. These generators are both grid-connected and stand-alone applications. We present an overview of the essential research results. The paper concentrates on the operation and modeling of stand-alone power systems with PV power generators. Systems with PV array-inverter assemblies, operating in the slave-and-master modes, are discussed, and the simulation results obtained using a renewable energy power system modular simulator are presented. These results demonstrate that simulation is an essential step in the system development process and that PV power generators constitute a valuable energy source. They have the ability to balance the energy and supply good power quality. It is demonstrated that when PV array- inverters are operating in the master mode in stand-alone applications, they well perform the task of controlling the voltage and frequency of the power system. The mechanism of switching the master function between the diesel generator and the PV array-inverter assembly in a stand-alone power system is also proposed and analyzed. Finally, some experimental results on a practical system are compared to the simulation results and confirm the usefulness of the proposed approach to the development of renewable energy systems

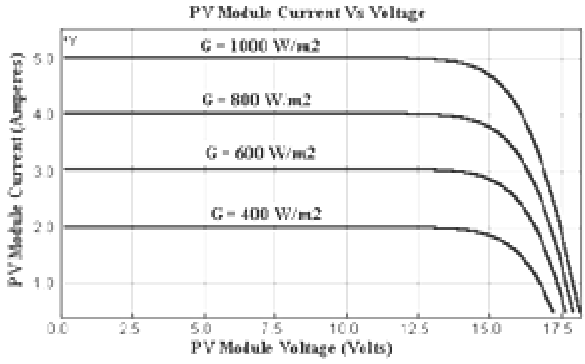

Figure 2: PV Module Voltage VS PV Module Current Characteristics

Traditional controllers connect the solar module directly to the battery when recharging. This requires that the solar module operate in a voltage range that is below the module's Vmp. solar energy gathering will benefit if your solar array consists of identical panels wired in either series or parallel, with higher voltages being of greater benefit. If you are using multiple panels paralleled with varying output values [wattage] you will not likely benefit from MPPT, a PWM controller will do the job and cost less.

A maximum power point tracker (or MPPT) is a high efficiency DC to DC converter which functions as an optimal electrical load for a photovoltaic (PV) cell, most commonly for a solar panel or array, and converts the power to a voltage or current level which is more suitable to whatever load the system is designed to drive. The most basic solar charge controller simply monitors the battery voltage and opens the circuit, stopping the charging, when the battery voltage rises to a certain level. Older charge controllers used a mechanical relay to open or close the circuit, stopping or starting power going to the batteries. More modern charge controllers use pulse width modulation (PWM) to slowly lower the amount of power applied to the batteries as the batteries get closer and closer to fully charged.

This type of controller allows the batteries to be more fully charged with less stress on the battery, extending battery life. It can also keep batteries in a fully charged state (called "float") indefinitely. PWM is more complex and doesn't have any mechanical connections to break. The most recent and best type of solar charge controller is called maximum power point tracking or MPPT. Solar power systems use 12 volt batteries; Solar panels can deliver far more voltage than is required to charge the batteries. By, in essence, converting the excess voltage into amps, the charge voltage can be kept at an optimal level while the time required to controller allows much higher voltages in the wires from the panels to the solar charge controller The MPPT controller then converts the excess voltage into additional amps. By running higher voltage in the wires from the solar panels to the charge controller, power loss in the wires is reduced significantly. MPPT charge controllers are more expensive than PWM charge controllers, but the advantages are worth the cost [7]. If you can afford it, and your system design allows for it, you will benefit from MPPT controller. The final function of modern solar charge controllers is preventing reverse-current flow.

3. Modular Multilevel Converter

Each sub module consists of two insulated-gate bipolar transistor (IGBT)/diode switches (S1, S2, D1 and D2). The switches within the sub module are switched in complementary fashion. The sub module has two switches, the main switch S1 and auxiliary switch S2. When S1 is on and S2 is off, the output voltage V_o is equal to ½ V_{dc} and no charging take place at the capacitor. The basic working principle as well as the static and dynamic behavior is explained in detail on a single-phase AC/AC-converter enabling four-quadrant operation. The M^2LC-family has already been introduced and examined for applications like traction converters, operating directly on the power line, and network interties. With this prototype converter system, the characteristics of various different M^2LC-topologies can be investigated, including single or three phase DC/AC converters as well as multiphase AC/AC converters. The prototype converter has been designed in such a way that its configuration can be quickly changed between wide ranges of topologies.

A flexible control system has been implemented, which is capable of controlling up to 32 IGBTs per converter arm, independently. The proposed MMC is controlled by two control loops. The inner current control loop and the outer voltage control loop. The inner current control loop is designed to control the grid current to be sinusoidal and synchronized with the grid voltage. In outer voltage control loop, the reference DC link voltage is generated by the MPPT algorithm; it sensed IPV and VPV and then generates vmax. This Vmax is DC link voltage required to be regulated across the MMC. The error resulting from the DC voltage control loop is passed through the proportional plus integral (PI) controller.

When S1 is off and S2 is on, the output voltage Vo is equal to the three level configuration of the MMC, where two sub modules are connected in series on the upper arm and two sub modules are connected on the lower arm [5]. Inductance $\mathbf{U_{la}}$ and $\mathbf{L_{la}}$ are used't' take over the difference between the current of the upper and lower arm. Whereas R_L and L_L are load resistance and load inductance of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC). Depending upon the voltage requirement sub modules are inserted on the upper and lower arm.

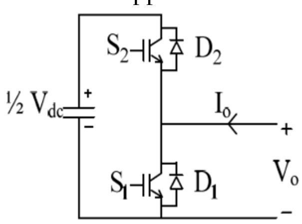

Figure 3: MMC Structure of One Sub-Module

In this paper, the proposed topology of the photovoltaic supported modular multilevel converter and its controller design with maximum power point tracking technique are described. The MMC proposed for a grid connected photovoltaic system is based on the single stage solar power conversion system. The photovoltaic supported modular multilevel converter single phase grid connected system. Fig.3 shows the MMC Structure of one sub Module Model of Photovoltaic Power Conversion Upper and lower arm meet voltgare and current waveforms. The photovoltaic module is nonlinear in nature, because it is greatly affected by its environmental condition like change in solar radiation and cell temperature.

During day time sunshine won't be constant, cloud may pass over so panel may be not be getting constant radiations. Fig.4. Shows the PV Supported three level Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC). Therefore it is necessary to track the maximum power all over the day. Capacitor voltage balancing is attainable independent of the load. Although MMC are investigated with many applications, but it has not been reported in the literature with single stage solar PV power conversion system.

This paper demonstrates the effective implementation of the photovoltaic supported MMC for grid interface which satisfy all the control objectives like maximum power transferring under varying environmental conditions, synchronizing grid utility voltage with output current for unity power factor operation and low total harmonic distortion. The maximum power point tracker works on the fact that derivation of the output power with respect to the panel voltage is equal to zero at maximum power point. This technique employs simple feedback arrangement with the comparison of present and previous measured values.

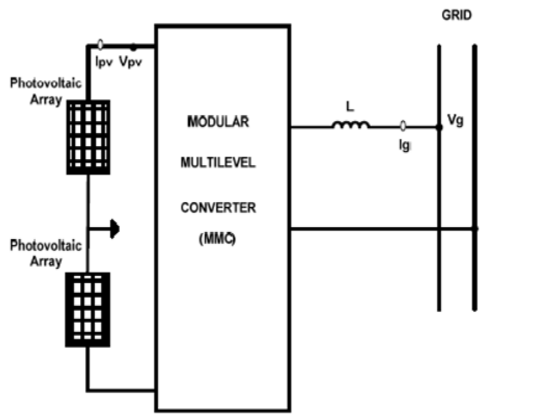

Figure 4: PV Supported Three Level Modular Multilevel converter

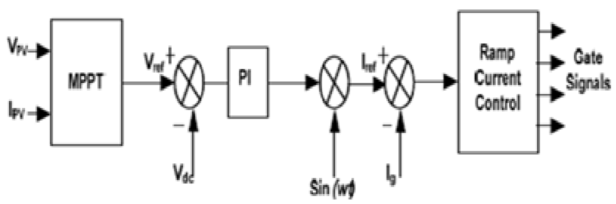

Figure 5: Block diagram of outer and inner control loop

Fig.5. Shows the block diagram of outer and inner control loop of Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC).

4. Simulation Setup

The proposed Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) with single stage power conversion is simulated with MATLAB/SIMULINK Software. The photovoltaic array for experimental setup is composed of 108 numbers of cells connected in series to form a module and 14 modules connected is series to generate voltage of 1200 V. The capacitor voltage across lower and upper arm of Modular Multilevel converter depicts, observe that converter voltage across the capacitor are balanced and maintains less voltage ripple. This increases PV lifetime, also desirable feature of MMC for grid connected PV system. The proposed MMC is controlled by two control loops. The inner current control loop and the outer voltage control loop. The inner current control loop is designed to control the grid current to be sinusoidal and synchronized with the grid voltage. In outer voltage control loop, the reference DC link voltage is generated by the MPPT algorithm; it sensed IPV and VPV and then generates vmax. This Vmax is DC link voltage required to be regulated across the MMC. For modulation index greater than one, lower order harmonics appear since for modulation index greater than one, pulse width is no longer a sinusoidal function of the angular position of the pulse. The error resulting from the DC voltage control loop is passed through the proportional plus integral (PI) controller.

A sinusoidal signal in phase with the utility grid is multiplied by the current reference to form the input reference current for the inner control loop demonstrates the effectiveness of the proposed system controller such that the injected grid current is accurately tracks the reference current.

Figure 6 shows the Simulation setup of Proposed Model of Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC). Fig.7. shows the Simulation setup of Proposed Model of Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) Upper and lower arm meet voltgare and current waveforms. Fig.8. Shows the Simulation output of converter voltage and current waveforms and Figure 9 show the Simulation output of converter voltage and current waveforms. The simulation results show that this system is able to adapt the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) for fast response and good transient performances. In addition, the result of the simulation shows the increased efficiency of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC) because of reducing the switching losses in the system. This system can provide high efficiency and low switching losses.

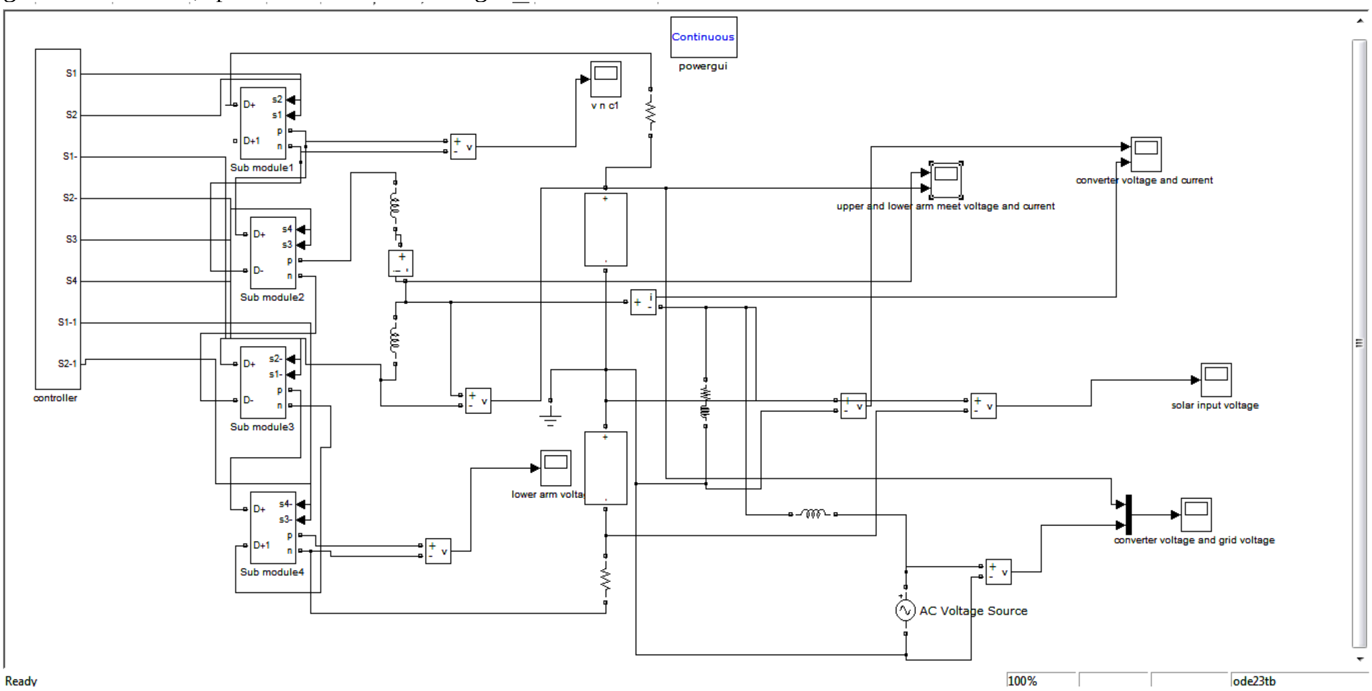

Figure 6: Simulation of proposed Model

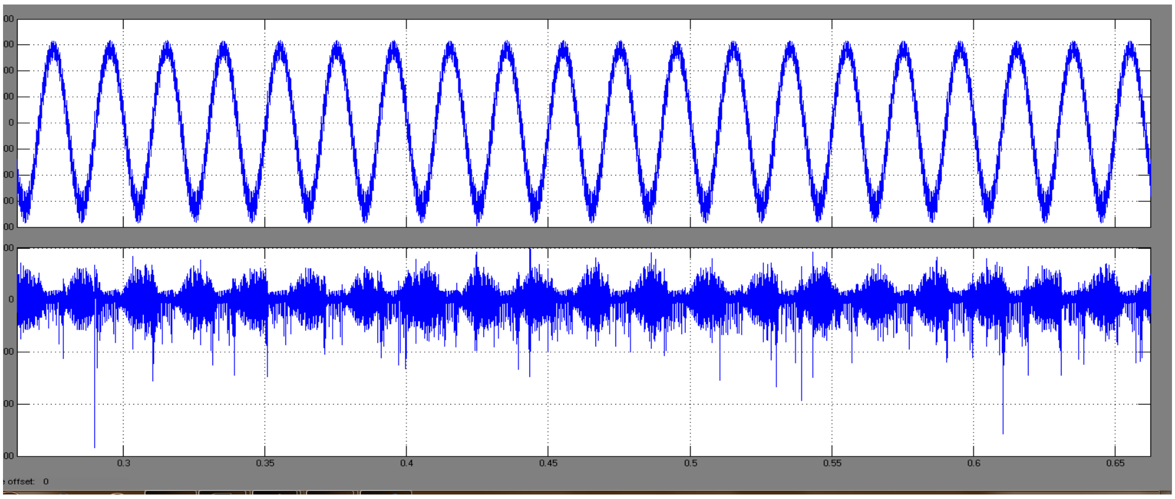

Figure 7: Upper and lower arm meet voltage and current waveform

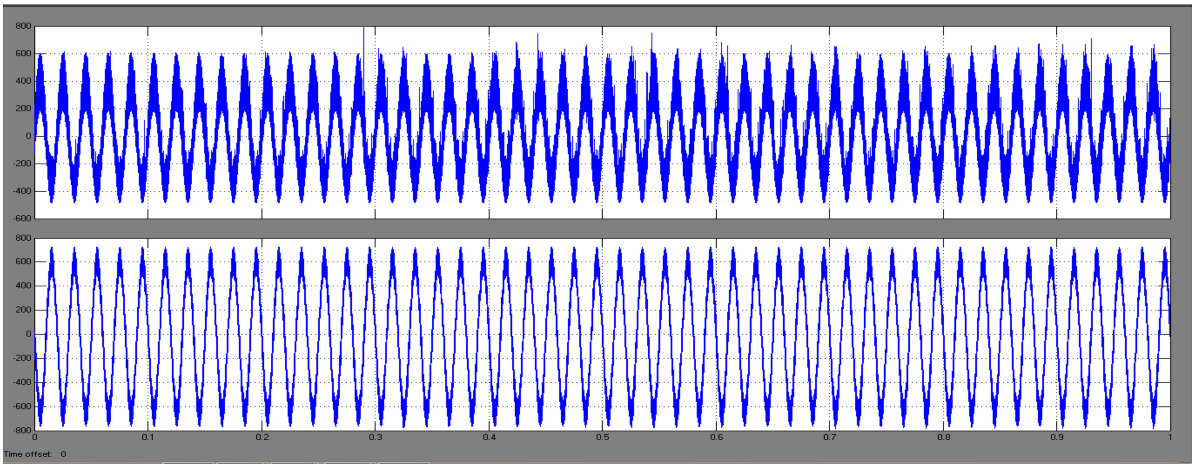

Figure 8: converter voltage and current waveform

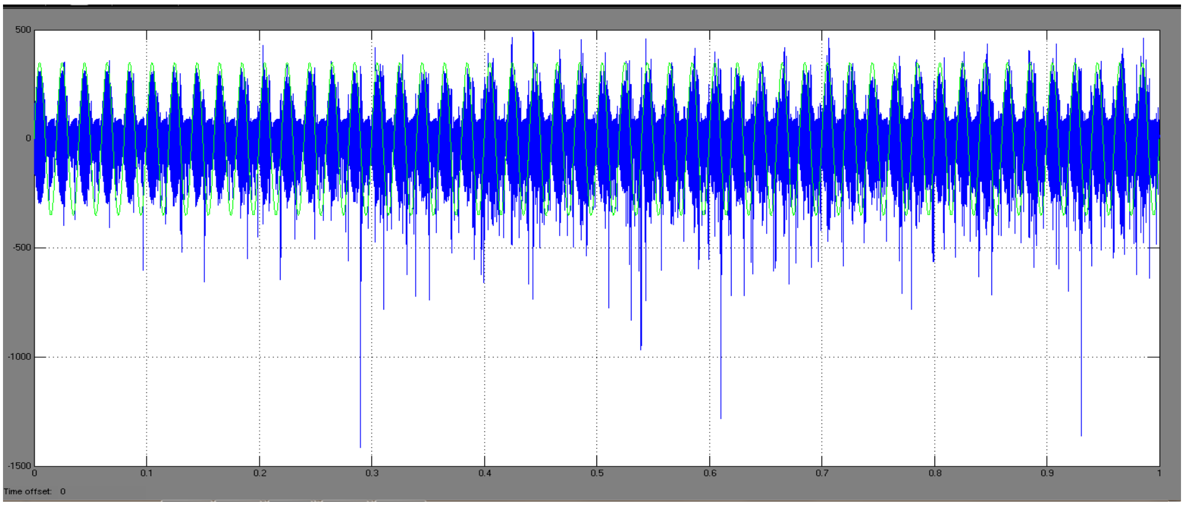

Figure 9: Converter voltage and grid voltage waveform

5. Conclusion

In this paper, a single stage modeling of the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC*)* is proposed. The modular concept allows the application to be extended for wide power range. This paper Concludes, an attempt and verifies that the Photovoltaic Power Conversion using Modular Multilevel Converter (PPCMMC*)* is capable of injecting power into the grid with low total harmonic distortion, unity power factor and high efficiency. Conventional multilevel converter requires interfacing transformer for grid connected system applications, whereas MMC topology requires filter to connect inverter into the grid. Low switching frequency of the switches in the MMC leads to low power loss. The effectiveness of the proposed grid connected MMC single stage power converter is demonstrated through simulation studies. The efficiency of the single stage Photovoltaic Power Conversion using Modular Multilevel Converter

(PPCMMC*)* based grid connected system was verified by Simulation results. In addition, the result of the simulation shows the increased efficiency of the system because of reducing the switching losses in the system. This system can provide high efficiency and low switching losses.

References

[1] J. T. Bialasiewicz, "Renewable Energy Systems with Photovoltaic Power Generators: Operation and Modeling," IEEE Tran. Ind. Electron. vol.55, pp. 2752-2758, 2008.
[2] M. G. Villalva, et al., "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," IEEE Transactions on power electronics, vol. 24, pp. 1198-1208, 2009.
[3] J.A. Gow, C. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," in proc. IEE Electric power applications, vol 146, issue 2, pp.193-200, March 1999.
[4] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, “A review of single-phasegrid-connected inverters for photovoltaic modules,” IEEE Trans. Ind.Appl., vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005
[5] L G. Leslie, “Design and analysis of a grid connected photovoltaic generation system with active filtering function” Master of Science in Electrical Engineering Blacksburg, Virginia March 14, 2003.
[6] M Malinowkski, K.Gopakumar, J Rodriguez and M A.Perez “A survey on cascaded multilevel inverters”, IEEE Trans on Indus. Electronics,Vol.57, No7, pp.2197-2205, July-2010.
[7] R. Gupta, A. Ghosh and A. Joshi, “Cascaded multilevel control of DSTATCOM using multiband hysteresis modulation”, IEEE Power Eng. Soc. General Meeting, pp.18–22, Jun. 2006
[8] G. Vachtsevanos and K. Kalaitzakis, “A hybrid photovoltaic simulator for utility interactive studies,” IEEE Trans. Energy Conv., vol. EC-2, pp.227–231, June 1987.
[9] Subiyanto, Azah Mohamed, Husasin Shareef, ”Hopfield Neural Network Optimized Power Point Tracking In a PhotoVoltaic System,”, International Journal of Photoenergy Vol. Article Id 798361, 13 pages, 2012.
[10] Nopporn Patcharaprakitia, Suttichai Premrudeepreecha charnb, Yosanai Sriuthaisiriwong.” Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system”, 2005 Published by Elsevier Ltd. Caisheng Wang, M.Hashem Nehrir, ”Power Management of a Stand- Alone Wind/ Photovoltaic/ Fuel Cell Energy System,” ,” IEEE Transaction on Energy Conversion., vol. 23, NO.3, Sep 2008.

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