A Novel Approach for Solar Photovoltaic Power Conversion Using Modular Multilevel Converter

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Abstract

This project presents an attempt to develop grid connected solar photovoltaic array power conversion using modular multilevel converter. The proposed system makes use of single stage power conversion with maximum power point tracking and modular multilevel converter (MMC) as interfacing unit into the grid. Here 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.

I. INTRODUCTION

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. Conventional inverter topologies such as voltage source inverter (VSI) and the current source inverter (CSI) are being utilized to convert solar power generated electrical power into the utility grid. Whereas these topologies require additional DC/DC converter stage resulting in a two stage power conversion and also require interfacing transformer to inject power into the grid. These topologies not only increase the circuit complexity but also increase the cost and space requirements. 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.

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. They offer lower total harmonic distortion (THD), low dv/dt device switch voltage stress, lowering the switch voltage and power rating etc. The multilevel inverter is well suited for high power medium voltage applications and in particular dominated by cascaded multilevel inverter and neutral point clamped multilevel inverter. In these medium voltage applications cascaded multilevel inverter and neutral point clamped multilevel inverter requires transformer to obtain electrical isolation between active DC sources of the H-bridge or NPC converter cells. This condition introduces losses, increases converter footprint, making converter costly, bulky and complex. The main drawback of the cascaded multilevel converter coupled with the transformer makes circulation 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.

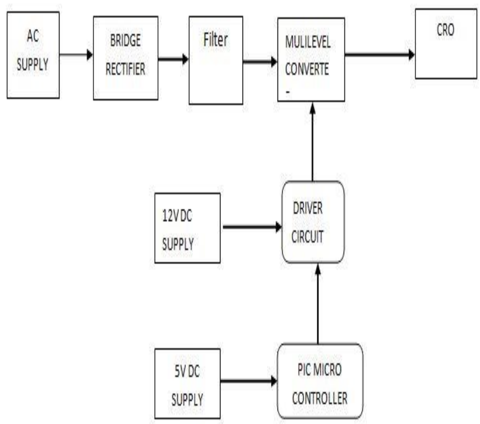
EXISTING SYSTEM LIMITS:-

- 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.

PROPOSED SYSTEM MERITS:-

- In order to overcome the above mentioned problems, multilevel inverter came into picture and attracted more attention because of their significant properties. They offer lower total harmonic distortion (THD),
- Low dv/dt device switch voltage stress, lowering the switch voltage and power rating etc.
- The multilevel inverter is well suited for high power medium voltage applications and in particular dominated by cascaded multilevel inverter and neutral point clamped multilevel inverter.
- This project proposed 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.

BLOCK DIAGRAM:



II. OVERVIEW OF A PHOTOVOLTAIC (PV) MODULE

To understand the PV module characteristics it is necessary to study about PV cell at first. 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. 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.

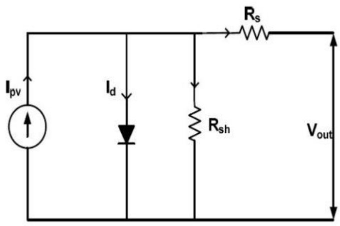


Fig.1.Electrical equivalent circuit of PV cell.

The main characteristics equation of the PV module is given by

$$I = I_{pv} - I_o\left[\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right)-1\right]-\frac{V+IR_S}{R_{sh}}$$

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{\alpha K}\right]\left(\frac{1}{T_n}-\frac{1}{T}\right)$$

$$I_{pv} = [I_{sc} + K_i(T-T_n)]\frac{G}{G_n}$$

Where,
I and *V* cell output current and voltage;
Io cell reverse saturation current;
T cell temperature in Celsius;
K Boltzmann's constant;
q electronic charge;
Ki short circuit current/temperature coefficient;
G solar radiation in W/m2;
Gn nominal solar radiation in W/m2;
Eg energy gap of silicon;
Io,n nominal saturation current;
Tn nominal temperature in Celsius;
Rs series resistance;
Rsh shunt resistance;
α ideality factor between 1.0 to 1.5;
Ipv light generated current;

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 I-V characteristics of the PV module under varying solar radiations at constant cell temperature (T = 25 ºC).

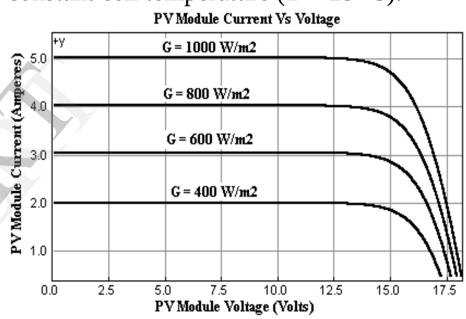


Fig.2. Current versus voltage at constant cell temperature T = 25 ºC.

Fig.3.shows the I-V characteristics of the PV module under varying cell temperature at constant solar radiation (1000 W/m2).

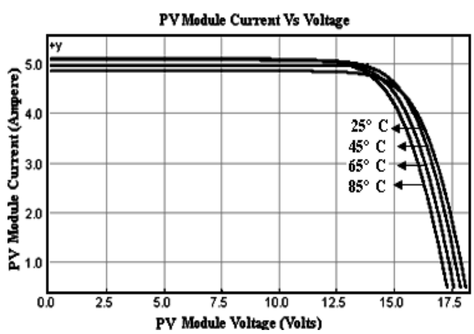


Fig. 3. Current versus voltage at constant solar radiation G = 1000 W/m2.

III. MODULAR MULTILEVEL CONVERTER

Modular multilevel converter is new topology suitable for medium voltage applications. Marquardt and Lesnicar designed modular multilevel converter (MMC) in 2002. The basic component of the MMC is called a submodule. It is a half bridge with capacitor as shown in Fig.4. Each submodule consists of two insulated-gate bipolar transistor (IGBT)/diode switches (S1, S2, D1 and D2). The switches within the submodule are switched in complementary fashion. The submodule has two switches, the main switch S1 and auxiliary switch S2. When S1 is on and S2 is off, the output voltage Vo is equal to ½ Vdc and no charging take place at the capacitor. When S1 is off and S2 is on, the output voltage Vo is equal to zero and capacitor is charging.

Main Switch(S1)	Auxiliary Switch(S2)	Output Voltage(V_o)	Capacitor State
ON	OFF	1/2 Vdc	Not Charging
OFF	ON	0	Charging

Table.1 gives the switching states of the submodule.

Fig.5 shows 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. Inductance Ula and Lla are used to take over the difference between the current of the upper and lower arm.

Whereas RL and LL are load resistance and load inductance of the MMC converter. Depending upon the voltage requirement the sub modules are inserted on the upper and lower arm.

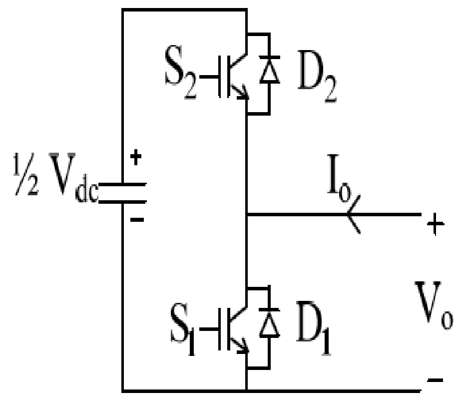


Fig. 4. Structure of one sub-module.

The number of voltage levels for the MMC can be identified using the formula
NV = n/2 +1 (4).

Where, NV – number of voltage levels
n – Total number of sub-modules.
In this paper three level output voltage is obtained using ramp comparison current control technique with the modular multilevel converter. The control function verror is compared with the carrier vtri of switching frequency fsw and amplitude Vtri. The three level output voltage is obtained by following unipolar PWM of the control function.
verror– vtri > 0, then S1 is on and Vo= ½ Vdc
verror– vtri < 0, then S2 is on and Vo= - ½ Vdc

ADVANTAGES:-

- 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.
- High efficiency

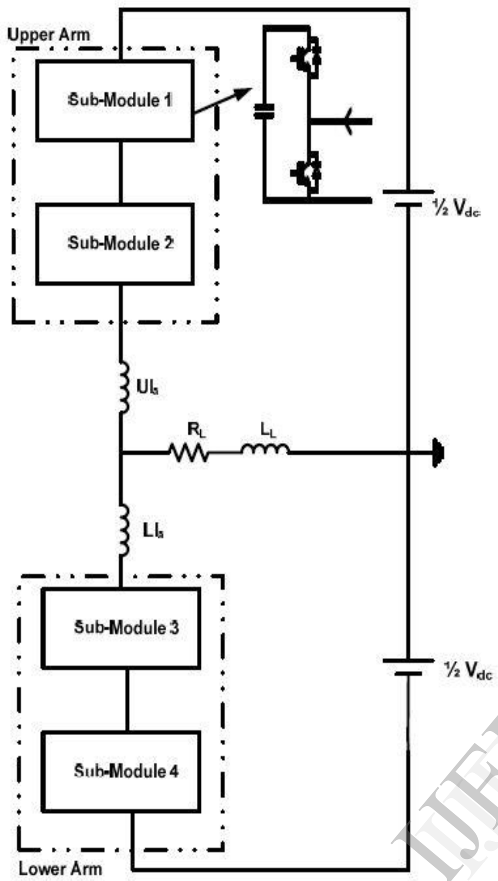


Fig. 5. Single phase of three level modular multilevel converters.

IV. PROPOSED SYSTEM

In this section, 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. Fig.6 shows the photovoltaic supported modular multilevel converter single phase grid connected system. 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. Therefore it is necessary to track the maximum power all over the day. 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.

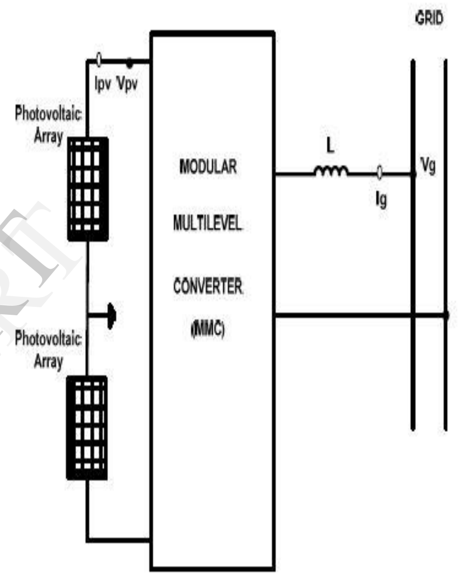


Fig. 6. Photovoltaic Supported Three Level Modular Multilevel Converter.

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. 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.

Simulation Results:

System Parameters

Item	Value
K Boltzmann's constant	k=78;
q electronic charge	q=3;
Ki short circuit current/temperature coefficient	Ki=8;
G solar radiation in W/m2	G=300;
Gn nominal solar radiation in W/m2	Gn=8.5;
Tn nominal temperature in Celsius	Tn=200;
Rs series resistance	Rs=1;
α ideality factor between	1.0 to 1.5
Ipv light generated current	Ipvn=120;

The three-level MMC output voltage is shown in the Fig.1. The proposed controller has the better efficiency and performs almost at unity power factor condition such that the grid voltage and injected current are in-phase. This is clearly visible in Fig.2. Fig.3 shows the AC side grid voltage with the output voltage of the proposed MMC. Fig.4 shows the grid current, lower arm current and upper arm current.

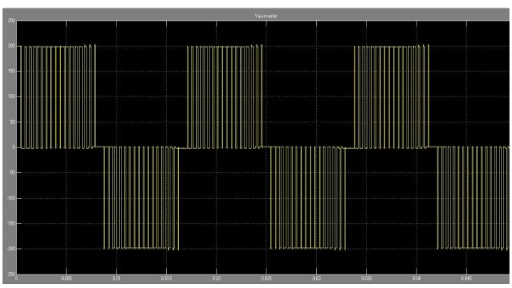


Fig.1 Output voltage of modular multilevel converter.

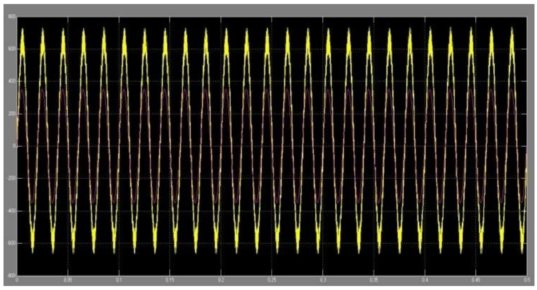


Fig.2 Grid voltage and Current.

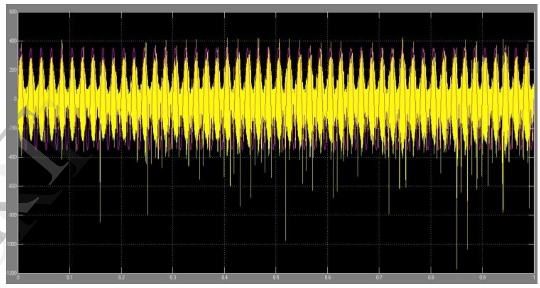


Fig.3 Grid voltage and MMC output voltage.

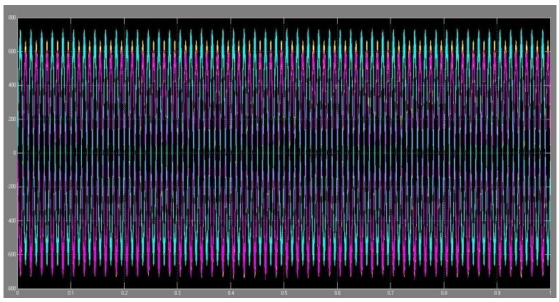


Fig.4 Grid current, lower arm current and upper arm current..

CONCLUSION

In this project, a single stage MMC based grid connected photovoltaic system is proposed. The modular concept allows the application to be extended for wide power range. This study makes an attempt and verifies that the MMC system 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. This project can have the further extension in the following possible ways.

1) Combination of solar and wind.
2) Increasing the level of the converter.
3) Changing the ctrl technique (Fuzzy).
4) Connected to the grid.

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