GRID CONNECTED SINGLE PHASE FIVE LEVEL MODULAR MULTILEVEL CONVERTER

Sanjyot S. Patil

[1]*M-Tech Student, Department of Electrical Engineering,*

Dr. Babasaheb Ambedkar Technological University, Lonere, Raigad, Maharashtra, (India)

ABSTRACT

Single phase grid connected ModularMultilevel Converter (MMC) for power conversion is presented in this paper.Designing efficient Power conversion emphasizes to track the maximum power operating point makes use of maximum power point tracking (MPPT) technique with MMC as interfacing unit into the grid is used in Photovoltaic System.Perturb &Observe (P&O) technique algorithm is implemented toregulate the DC link voltage of MMC and to synchronize the grid utility voltage with the current to attain unity power factor operation. Operation of proposed MMC topology is verified by the simulation results presented in this paper. The AC output is free from the higher order harmonics and grid voltage and current are in phase. The validity of recommended system is verified by MATLAB simulation.

Keywords:Modularmultilevel converter(MMC), Photovoltaic(PV)array,MPPT, Grid, Total harmonic distortion(THD).

I. INTRODUCTION

The endlessly increasing demand of energy and environmental issueslike global warming and pollution, the growth of renewable energy sources are recommended. Among various renewable energy resources such as solar, wind, tidal, geothermal, biomass etc., the solar photovoltaic system is more attractive and promising green resource because of present in great quantity, safe, free of costand eco-friendly.PV(photovoltaic) systems are considered to be one of theefficient and well accepted renewable energysources for small tolarge scale power generation, because of its suitability in distributed generation, mobile applications, and transportation and satellite systems

[1].The PV module directly converts the light energy in to the electrical energy at low voltage DC and has relatively low conversion efficiency. To improve the efficiency and convert low voltage DC source into suitable AC source, the power electronics converters are used to convert DC into AC.

The single stage solar power conversion using MMC 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 [2].

Existing System Limits:

- In case of two-level inverter,it injects maximum PV power into grid with a unity power factor, however the system contains higher order harmonics. [6]
- High*dv/dt*&*di/dt* stress across the semiconductor power switch and high power losses due to high switching frequency.

Suggested System Merits:

- In order to overcome the above mentioned problems,multilevel inverter come into picture and attracted more attention because of their significant properties. They offer lower total harmonic distortion [THD].
- Low *dv/dt* 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.
- Generate low harmonic output voltage, this eliminates filtering requirements.
- For medium voltage application, it allows to avoid interfacing transformer.
- Modular structure allows to extend higher number of levels easily.
- Capacitor voltage balancing is attainable independent of the load.

This paper gives the effective operation of the five-level MMC for grid interface which satisfy the control objectives, synchronizing grid utility voltage with output current for unity power factor operation and low total harmonic distortion [13-17].Section 2 gives introduction about basic characteristics of the PV module which is followed by Section 3 shows MMC operation with the proposed single stage power conversion of solar energy. Section 4 discusses proposed system & its control method using per turb & observe maximum power transfer algorithm, PI & PLL control as interfacing unit. Section 5 and 6 explains about simulation results and effectiveness of the proposed topologies over conventional inverter topologies for medium & large power conversion [1-8].

II. OVERVIEWOF A PHOTOVOLTAIC (PV) MODULE

A PV cell is the basic structural unit of the PV module that generates voltage when sunlight fallsonit. The power generated by a PV cell is very small. To increase the output power, the numbers of 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.

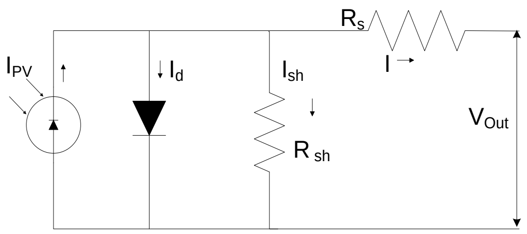

Fig.1: Ideal PV cell with single-diode

The characteristics equation of PV module is given by,

$I=I_{pv}-I_d-I_{sh}$(1)

$I=I_{pv}-I_0\{\exp[\frac{q(V+RsI)}{nkTk}]-1\}-\frac{V+RsI}{Rsh}$(2)

where V and I represent the output voltage and current of the PV, respectively

R_s and R_{sh} are the series and shunt resistance of the cell;

*q*is the electronic charge (1.602x 10^{-9} C);

$I_{pv}$is the light-generated current;

I_o is the reverse saturation current;

n is a dimensionless factor;

k is the Boltzmann constant (1.381 x 10^{-23}), and

T_k is the temperature in ^{o}K;

The PV module characteristic depends on the solar irradiance and the temperature of the photovoltaic module. As the solar irradiance increases, the photocurrent increases while the PV voltage increases slightly, hence, the power produced by the PV module increase.The open circuitvoltage of the PV module decreases with a rise of the PVmodule temperature.The effects of solar irradiance and temperature on the I-V & P-V characteristics of PV module are illustrated in fig.2 &fig.3.fig.2 shows the standard V-Icharacteristics of the PV module under varying solarradiations at constant cell temperature (T = 25 ºC).

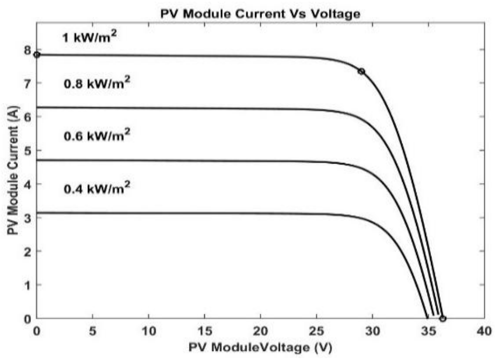

Fig.2: Current versus voltage at constant cell temperature T = 25 ºC

fig.3 shows the standard V-I characteristics of the PV module undervarying cell temperature at constant solar radiation (1000W/m2).

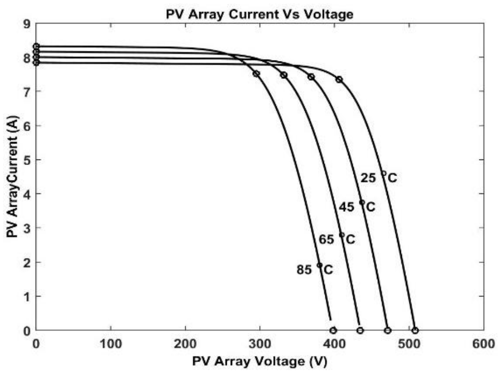

Fig.3:Current versus voltage at constant solar radiation G = 1000 W/m^2

III. MODULAR MULTILEVEL CONVERTER

Modular multilevel converter is a new topology suitable for medium& high voltage applications. The modular multilevel converter usage hasincreased widely in the electrical power industry.Modularmultilevelinverter is capable of minimizing the total

harmonicdistortion on both AC and DC side, generating lowvoltage stress on switching devises for high voltagelevel, generating low *dv/dt*, operating with lowswitching frequency and operating with any number ofvoltage level.

Thebasic component of the MMC is called a submodule.It is ahalf bridge inverterwith capacitor as shown in Fig.6. Each submoduleconsists of two insulated-gate bipolar transistor (IGBT)/diodeswitches (S_c, S_m, D_c and D_m).The sub-module consistsof two switches: the main switch Sm and auxiliaryswitch S_c. When the S_m is on and S_c is off, the outputvoltage V_o is equal to ½V_{dc} and nothing is happening tothe capacitor; when the S_m is off and S_c is on, the outputvoltage V_o is equals to zero and the capacitor ischarging.Table.1 gives the switching states of the submodule.

TABLE1: SWITCHING STATE OF SUB-MODULES

Main Switch (S_m)	Auxiliary Switch (S_c)	Output Voltage (V_o)	Capacitor state
ON	OFF	V_{dc}	Not Charging
OFF	ON	0	Charging

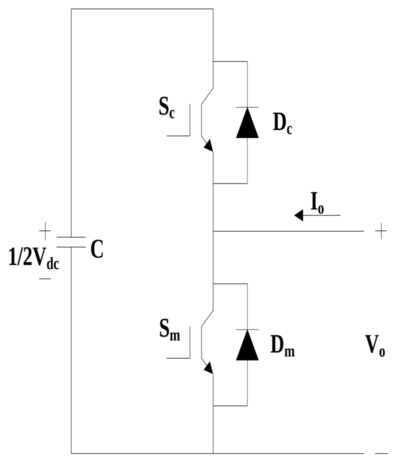

Fig.6: Structure of one sub-module

The number of voltage levels for the MMC can be identifiedusing the formula

$N_V = n/2 + 1$ (3)

where, N_V – number of voltage levels

n – Total number of sub-modules

In this paper five level output voltage is obtained using ramp comparison current control technique with modular multilevel converter. The control function $V_{error}$is compared with the carrier $V_{tri}$of switching frequency f_{sw} and amplitude V_{tri}. The five level output voltage is obtained by following unipolar PWM of control function.

$V_{error}-V_{tri} > 0$, then S_m is on and $V_0 = 1/2 V_{dc}$

$V_{error}-V_{tri} < 0$, then S_c is on and $V_0 = -1/2 V_{dc}$

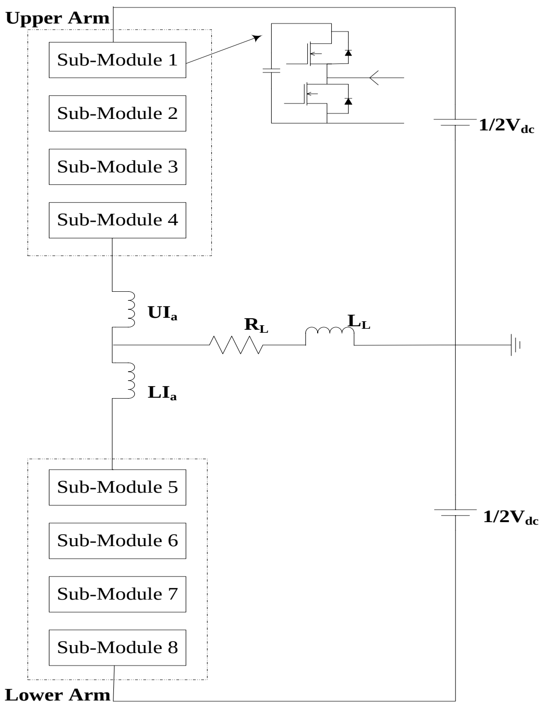

Fig.7: Single phase of five level modular multilevel Converter

IV. PROPOSED SYSTEM & ITS CONTROLLER

In this chapter, 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.9 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, cloudy atmosphereaffect the output of solar panel because of inconstant 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.8shows the P-V characteristics of the PV module.

$\frac{\partial p}{\partial v} = 0$, $V = V_{max}$

$\frac{\partial p}{\partial v} > 0$, $V < V_{max}$

$\frac{\partial p}{\partial v} < 0$, V>$V_{max}$

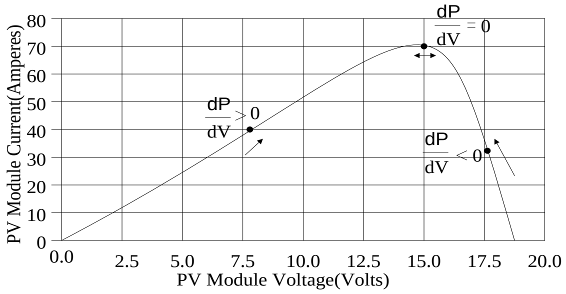

Fig.8: P-V characteristics of the module

The most popular and simple MPPT algorithm is the perturb &observe (P&O) which is also called as hill-climbing algorithm. This technique employs simple feedback arrangement with the comparison of present and previous measured values.

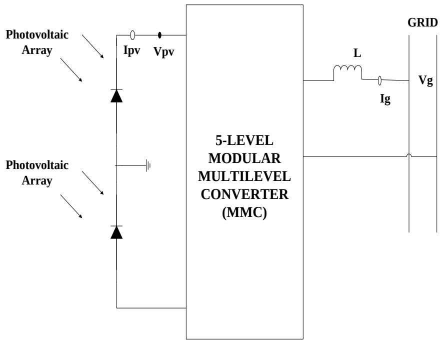

Fig.9: Photovoltaic Supported 5-level MMC

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 $I_{PV}$and $V_{PV}$and then generate V_{max}. This V_{max} 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. Effectiveness of the ramp current control technique is implemented where triangular carrier of 2 kHz is compared with the error signal in order to produce gating signal for switches of the MMC.

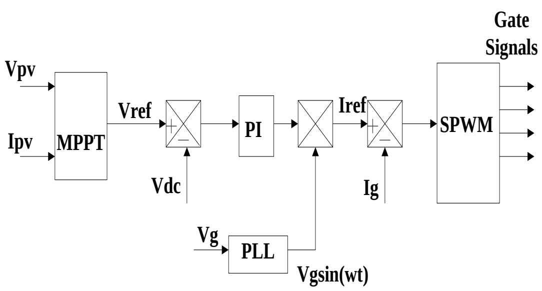

Fig.10: Block diagram of control loop

Fig.10 demonstrates the effectiveness of the proposed system controller such that the injected grid current. This tracking makes the grid current sinusoidal and free from harmonics. The photovoltaic array is composed of number of cells connected in series to form a module and modules connected in series to generate voltage of 1200 V. The circuit parameters are shown in the Table 2.

TABLE 2: SYSTEMPARAMETERS

Item	Value
PV array rated voltage	1.2kV
No. of solar cells	108
No. of solar modules	14
Standard Environmental Condition	1000 W/m2
Solar radiation, *G*	25 ^{0}C
Cell temperature, *T*	
System Frequency	50 Hz
Switching Frequency, *fsw*	2 kHz
Sub-Module capacitor, *C*	1000 µF
Ac line inductance, *L*	1 mH
Grid voltage, *Vg*	230 V
Number of cell in each arm	4
DC link Voltage	600 V
Arm inductance, *Ula*, *Lla*	0.1 mH
Load Resistance	10Ω

V. RESULTS

The proposed modular multilevel converter for grid connected PV system with single stage power conversion is simulated using MATLAB Simulink.

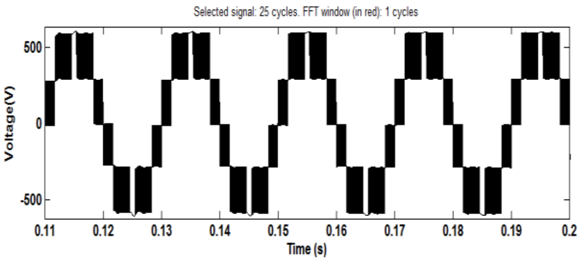

Fig.11:Output voltage of modular multilevel converter

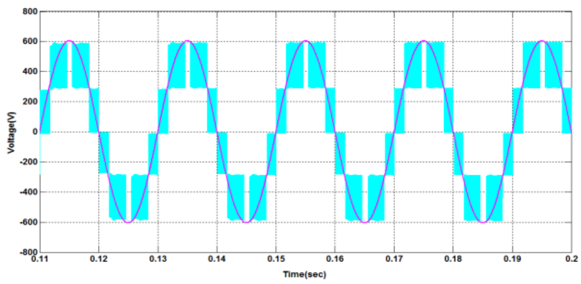

Fig.12: Output voltage of MMC & dc link reference voltage

The Five-level MMC output voltage is shown in the fig.11.The proposed controller has the better efficiency and performsalmost at unity power factor condition such that the gridvoltage. fig.12 shows synchronized output voltage of MMC with DC reference voltage. This is clearlyvisible in fig.14. fig.15. shows reference voltage waveform or error signal. fig.14. shows the ACside grid voltage with the output voltage of the proposedMMC. fig.16. shows the grid current. Fig.17. shows grid current, lower arm current & upper arm current.

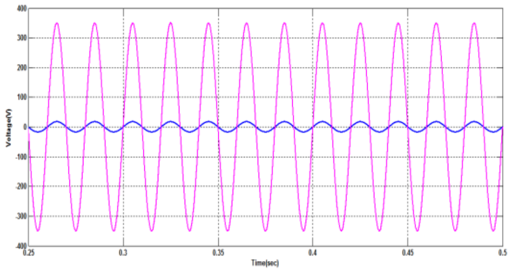

Fig.13: Grid Voltage & injected current

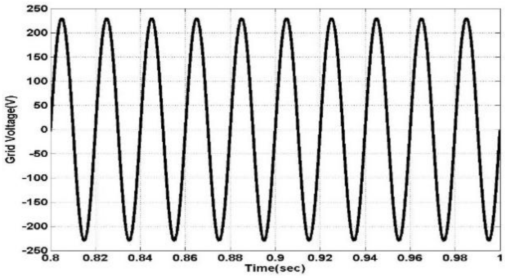

Fig.14:Proposed synchronized grid Voltage

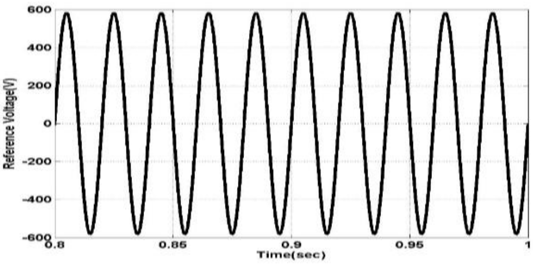

Fig.15:AC side DC link reference Voltage

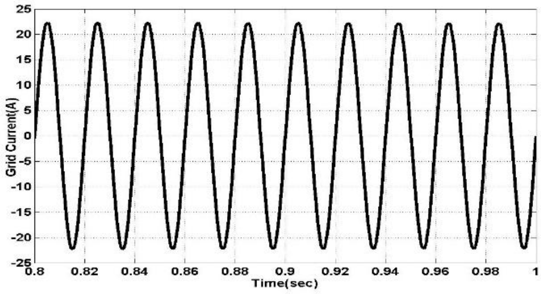

Fig.16: Grid current

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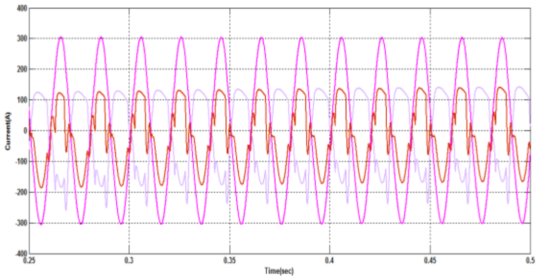

Fig. 17: Grid current, lower arm current & upper arm current

Fig.18. &Fig.19. showssignal to be analyze for FFT analysis & its FFT analysis. As FFT analysis displays THD contain in MMC output waveform which gives 23.13% THD.

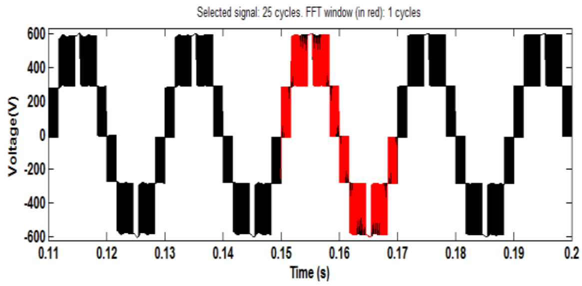

Fig.18:Signal to be analyze for FFT analysis

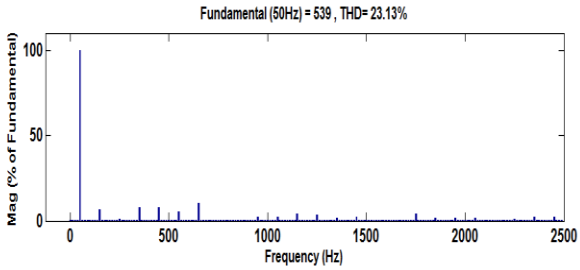

Fig.19:FFT analysis of selected signal

VI. CONCLUSION

This paper highlights the efficient use of 5-level MMC topology for single stage power conversion.By increasing or decreasing numbers of modules we can increases or decreases level of output power. This study makes an attempt and verifies that the MMC system is capable of synchronizing 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.

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