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A Novel Approach for Grid Integration of Cascaded H-bridge Multilevel Inverter Under Partial Shading Condition

Swetapadma Panigrahi, Amarnath Thakur
Departement of Electrical and Electronics Engineering, NIT Jamshedpur, India

Article Info	ABSTRACT
	A modular cascaded H-bridge PV inverter based system is presented in this paper. It helps in obtaining the maximum output power of PV system along with increase the overall efficiency of the whole system. Moreover to utilize the system up to the best a distributed MPPT controller is attached with each PV panel. As partial shading causes power imbalance at the converter output that leads to imbalance grid current, a control technique called the modulation compensation is adopted in such a way that if three phase unbalanced voltage varies directly according to unbalanced power, the injected zero sequence voltage components make the grid current balanced.

Corresponding Author:

Swetapadma Panigrahi,
Departement of Electrical and Electronics Engineering,
National Institute of Technology,
Jamshedpur, Jharkhand, India, 831014
Email: dipa.tat@gmail.com

1. INTRODUCTION

From the last couple of years renewable energy sources are growing extensively to fulfill the energy demand of consumers. Among the different energy sources, solar energy is the most reliable and sustainable one [1]-[3].With the wide development of power electronics technology it becomes easier to integrate various PV inverters with the utility grid. A PV-inverter is the main component for integration in a grid-connected application. It converts the DC power available from solar panel into AC power that is fed into an utility grid. PV panels are connected either in series or parallel or both to obtain the required voltage and power. This arrangement is called as centralized PV inverter. But the requirement of high voltage DC cable between PV panel and inverter limits its usage.

Till now different types of PV inverters are developed based on PV module connected method, utilization of transformer and number of power stages [4]. Among the various inverter toplogies the multilevel inverter configuration is paying the attention of the researchers worldwide for large scale applications. Because of its multilevel structure the output waveform obtained in the grid side must be sinusoidal with less harmonics content [5]. It does not require any bulky low frequency transformer for its integration with the grid. Moreover,because of the requirement of individual DC source for each H-bridge configuration,the voltage control can be done individually. A single phase seven level CHB comprises of three H-bridges each fed by multiple strings of PV panels through their own individual H-bridge is presented in Figure 1. In such arrangement, the individual MPPT , called distributed MPPT technique is applied to track the extreme power of each PV panel [6].

2. SYSTEM DESCRIPTION

2.1. Modular cascaded H-bridge multilevel inverter

A seven level CHB inverter produces the output voltage values (levels) with respect to negative terminal of the capacitors. If n represents the number of step of phase voltage with respect to the negative terminal of the inverter , then the number of stages k between two phases across load is represented as,
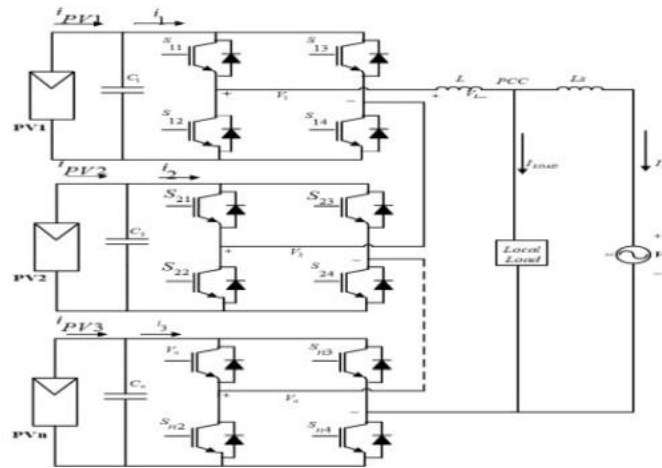

Figure 1. Configuration of single phase grid-connected PV system [7]

$$k = 2n+1 \tag{1}$$

If the DC-link voltages are equal, at the load side 7-level voltage can be obtained. The output voltage can be represented by the upcoming equations:

$$\left. \begin{array}{l} V_{H1}= (S_{11}- S_{13}). \, v_{C1}= P_1. \, v_{C1} \\ V_{H2}= (S_{21}- S_{23}). \, v_{C2}= P_2. \, v_{C2} \end{array} \right\} \tag{2}$$

where S_{XX} represents the switching state or it can be ON, 0 or OFF. P_1 and P_2 represent the discrete values having the values of -1,0,+1. For linearization, continuous switching functions S_1 and S_2 [-1,1] are taken in place of the functions P_1 and P_2 [8][9]. Equations (3) represent the dynamic behavior of the system that is represented as:

$$\left. \begin{array}{l} \frac{di_S}{dt} = \frac{1}{L}(S_1 v_{C1} + S_2 v_{C2} - Ri_s - v_s) \\ \frac{dv_{C1}}{dt} = \frac{1}{C1}(i_{PV1} - S_1 i_S) \\ \frac{dv_{C2}}{dt} = \frac{1}{C1}(i_{PV2} - S_2 i_S) \end{array} \right\} \tag{3}$$

Due to the presence of isolated DC source in case of CHB, independent MPPT control can be possible and utmost power can be obtained from the entire system more efficiently. Nevertheless, since the possibility of independent voltage control through each H –bridge, there is a power imbalance. This problem can be classified into two classes : 1) interphase (clustered) power imbalance, when power generated by each phase is not equal; and 2) inter bridge (individual) power imbalance, which happens when bridges connected to the same phase leg generates an unequal power. If this system cannot be considered seriously, dc-link voltage will float leading to voltage distortion at the grid side. Because of the inadequate irradiance obtained from sun, varying temperature and usage of the PV panels from long time, there is an unbalanced power supply to the CHB , causing unbalanced current at the grid side. Therefore this issue is considered seriously with the designing of suitable controller so that at the grid side balanced current is achieved [10][11].

3.   CONTROL STRATEGY

PV mismatches is very hazardous problem in case of large PV system. Henceforth, for utmost power extraction from the system a control scheme is essentially needed. Generally two control scheme is proposed in this paper (i) MPPT control (ii) Inverter control.

3.1. MPPT control

To show the requirement of MPPT , 185W PV panel is considered that is connected to each H-bridge of level multilevel inverter of a three phase system. The P-V and I-V curves for 185W panel is simulated in MATLAB/SIMULINK environment and are shown in Figure 2.The various plots at different radiations are shown. Each CHB inverter is connected to 185W solar panel and for a single phase system n-CHB inverters are connected in series. Likewise the whole three phase system is integrated with grid through inductor L that is used to minimize the switching current harmonics at the grid side. In order to resolve the PV mismatch issue distributed MPPT control technique is adopted.
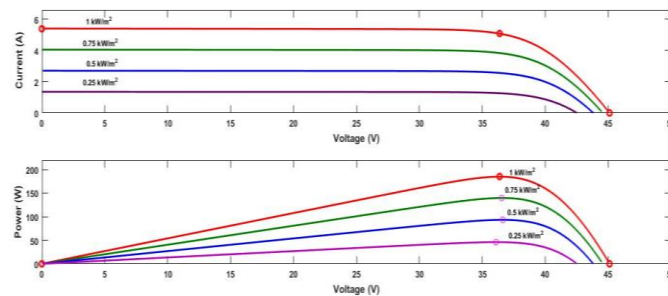

Figure 2. I-V and P-V characteristics of 185W PV panel at different solar radiations

3.1.1. Distributed MPPT control

Various MPPT techniques were developed in order to extreme power from a PV panel [12]. In this paper, Incremental conductance MPPT method is adopted to generate the dc-link voltage reference for individual PV panel. Here the MPP point goes on adjusting its position irrespective of the environment changes. In order to track MPP, Incremental Conductance (IC) method compares the ratio of incremental conductance to instantaneous conductance value of PV module. Based on this value, the slope of P-V characteristic is varied and according to the change in slope, duty cycle of converter can be generated [13-16].

For MPP tracking, applying IC algorithm the following steps are taken into consideration:

a.   When $\frac{dP}{dV} = 0$, the error is zero and V_{mp} can be found out .

b.   When $\frac{dP}{dV} > 0$ i.e $\frac{dP}{dV} > -\frac{I}{V}$,the MPP drags towards the left side of the curve (having a positive error).

c.   When $\frac{dP}{dV} < 0$ i.e $\frac{dP}{dV} < -\frac{I}{V}$,the MPP drags towards the right side of the curve (having a negative error).

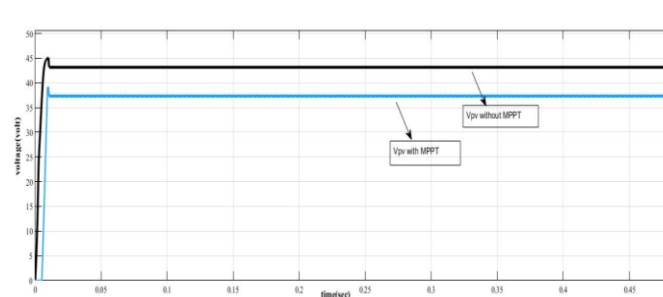After the MPPT tracking the dc link voltage reference is found to be 36.4V as shown in Figure 3.

Figure 3. MPPT voltage of 185W PV panel through incremental conductance method

3.2. Inverter control

It comprises of control of both active and reactive power. It has two different control loops : one is called the voltage control loop that is used to set the capacitor voltage across each dc link and other one is called the current control loop that is required for the generation of the sinusoidalgrid current. Figure 4. shows the control scheme for the entire system. The sum of dc link voltage V_{dc1} to V_{dcn} are compared with respective voltage reference to produce the sum of error that is passed through the total voltage controller loop to generate the reference current i_{dref} . As reactive power compensation is not taken into account in this paper, hence i_{qref} is adjusted to be zero. The phase angle of grid voltage θ is determined by a three phase locked loop (PLL). The grid currents i_a, i_b and i_c are passed through *abc* to *dq* converter circuit to generate the i_d, i_q current coordinates. These current coordinates are again feed to a PI controller to generate the modulation index in *dq* coordinates and with the help of *dq* to *abc* controller modulation indices in *abc* coordinates are generated.
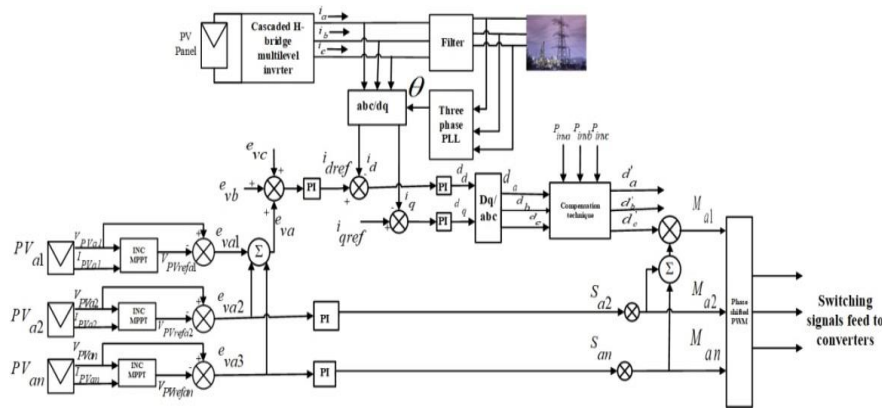

Figure 4. Control scheme for modular cascaded H-bridge multilevel PV inverter for three-phase system

For simplicity, take phase *a* into consideration. Due to individual MPPT control, the generated voltages v_{dca2} to v_{dcan} are controlled through *n-1* loop. Each voltage controller gives the modulation index proportion of one H-bridge module in phase *a*. After multiplied by the modulation index of phase *a, n-1* modulation indices can be generated. The calculation for phase *b* and *c* are also approachable in the same way to determine the modulation indices. A phase shifted modulation scheme is used for switching each H-bridge inverter.

3.2.1. Phase shifted modulation scheme

There are different modulations techniques proposed for switching of multilevel inverters [17]-[21]. Among which PS-PWM is most popularly used to produce PWM control signals for switching of the inverters [22][23] . As partial shading phenomenon causes a serious issue in case of switching of cascaded inverter, hence the modulation index of each cell must be properly updated to consider unbalanced conditions at dc side by producing different modulating signals. In order to achieve a balanced condition at grid side, cell with high power is assigned with high modulation index and with low power is assigned with low modulation index and hence each cell is modulated individually using the PWM, in order to provide an even power sharing among the cells. In PS-PWM all the triangular carriers are have the same frequency and peak-peak amplitude and a phase shift is made among any two immediate carrier waves. For *m* Voltage levels, there is need of (*m-1*) carrier signals and they are phase shifted with an angle of θ = (360°/*m-1*).

3.3. Power balance control

Partial shading is a common problem generally occurs in a large PV system that results in unequal power generation by the PV modules connected to each H-bridges , leading to unbalanced grid current as shown in Figure 5(a). However , the addition of zero sequence voltage v_{Nn} in each phase, manages in distribution of balanced power among the three phases so that at the grid side current is balanced as shown in Figure 5(b) [24]. If v_{ci}^* is the output voltage of the inverter during partial shading condition then with the injection of v_{Nn},the output voltage of the inverter modified as, $v_{ci}^* + v_{Nn} = v_{ci}$ (where $i= a,b,c$ for three phase voltages). It is based on the concept that if three phase unbalanced voltages at the grid side varies directly according to unbalanced power, the injected zero sequence voltage makes the grid current balanced [25]. Figure 6. shows

the modulation compensation scheme used in control block to balance the grid current. In this technique, the weighted min-max method is adopted. The weighted ratio of unbalanced power in each phase is calculated by the formula,

$$t_i = \frac{P_{inavg}}{P_{invi}} \tag{4}$$

(a)   (b)
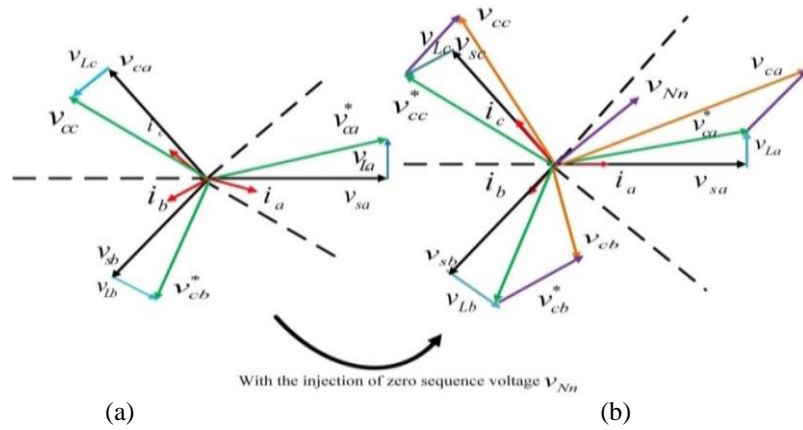
Figure 5. Vector diagrams of grid current balancing (a) without (b) with injecting zero sequence component

where P_{inavg} is the average of the injected power in three phases and P_{invi} is the inverter power in each phase.Then the zero sequence modulation index d_0 can be calculated by the formula,

$$d_0 = 0.5\{\max(t_a.d_a, t_b.d_b, t_c.d_c) + \min(t_a.d_a, t_b.d_b, t_c.d_c)\} \tag{5}$$

where d_a, d_b, d_c are the modulation indices of phase a, b and c determined by the current loop controller. After determining the modulation indices the modulation index of each phase is modified as , $d'_j = d_j - d_0$.
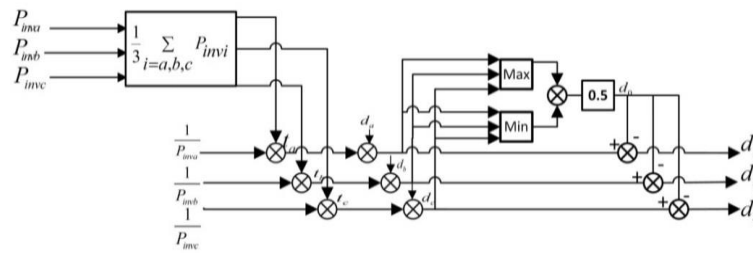

Figure 6. Scheme for modulation compensation through weighted min-max method.

4.   RESULTS AND ANALYSIS

A seven level three phase cascaded multilevel inverter is initially simulated with 185W of PV panel as dc source in MATLAB/SIMULINK environment. All PV panels are operated at $1000W/m^2$ and at 25^0C. At time t=0.8 sec due to partial shading panel 1 and 2 of phase a get the radiation of 600 W/m^2.From Figure 7(a). it shows that the MPP voltage obtained from panel 3 of phase a is 36.4 while due to partial shading panel 1 and 2 give the MPP voltage of 36V.The MPP voltage obtained in phase b is shown in Figure 7(b). It shows that partial shading effect the MPP voltage of phase a only ,whereas the other two phases are not affected by the environmental issues. Phase current obtained of phase a under distributed MPPT is shown in Figure 7(c).
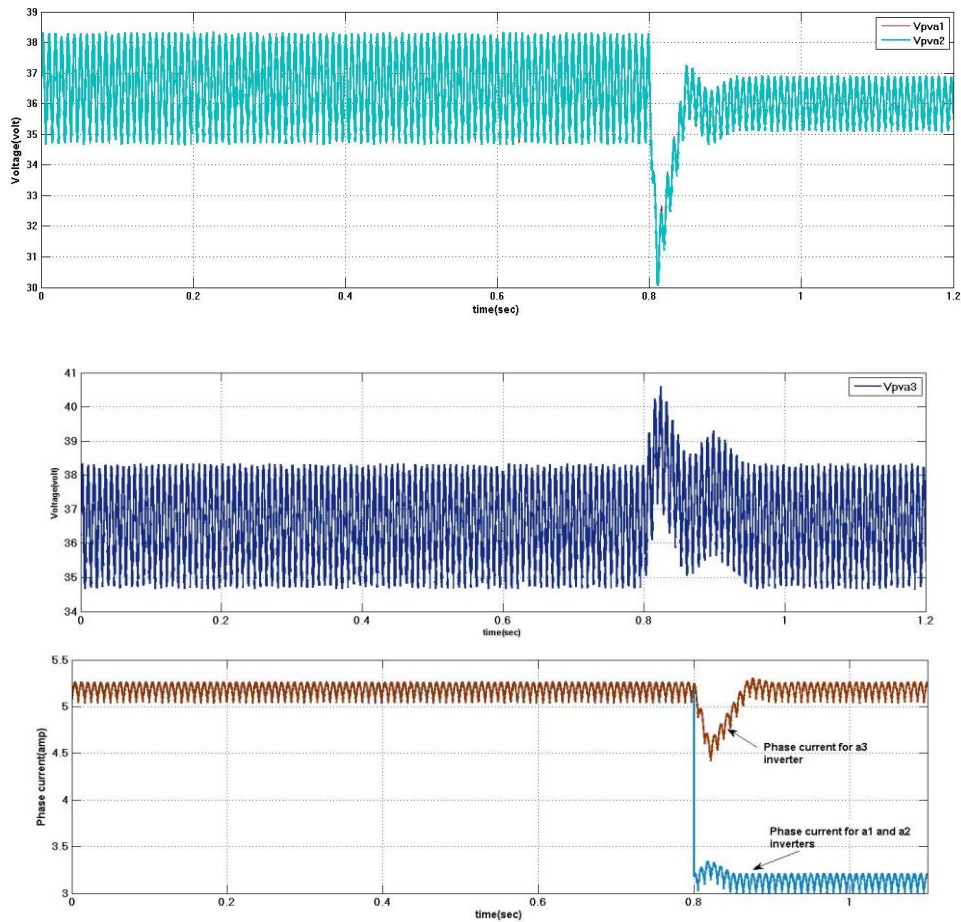
Figure 7 (a). DC link voltage obtained under distributed MPPT of panels 1 and 2 of phase *a* under partial shading condition .Figure 7 (b). DC link voltage of phase *b* obtained under distributed MPPT .Figure 7 (c). Phase current obtained of phase *a* under distributed MPPT.

Power obtained from each phase is shown in Figure 7(d). From time t=0 to t=0.8 sec, power extracted from three phase are approximately 535W and at t=0.8 sec because of change in radiation, power extracted from phase *a* is 340W causing a three phase unbalanced power. For this purpose, the modulation scheme with zero sequence voltage injection is adopted.
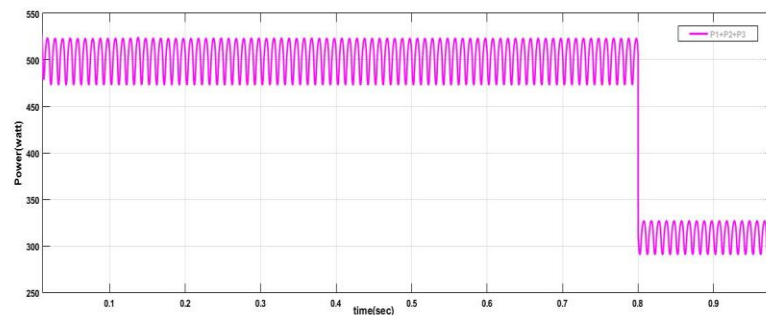

Figure 7 (d). Power extracted from three phases.

After zero sequence voltage injection the inverter output voltage is shown in Figure 7 (e). It shows at t=0.8 sec, due to zero voltage injection, voltage at the grid side becomes imbalance that causing a balanced grid current as shown in Figure 7 (f).
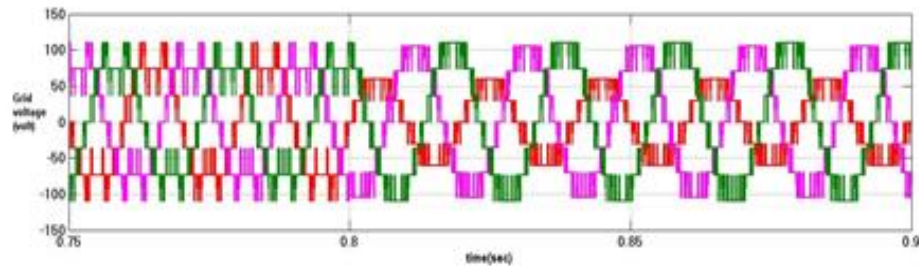

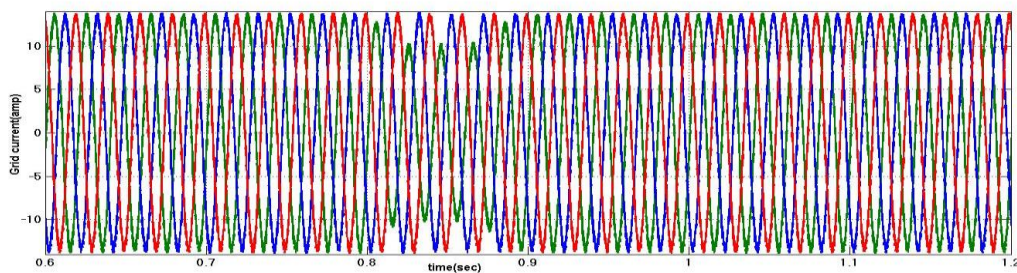Figure 7(e). Three phase inverter output voltage after proposed modulation technique

Figure 7(f). Balanced three phase grid current

5.   CONCLUSION

A three phase cascaded H-bridge multilevel PV inverter with grid integration is proposed in this paper. In order to reduce the complexity and increase the efficiency distributed MPPT is applied to each PV panel. As partial shading is an important phenomenon to be considered in a large scale PV system that has direct impact on grid current balancing, a modulation compensation scheme is proposed. It helps in balancing the grid current by injecting a zero sequence voltage in proportion to power imbalnce so that maximum power is extracted.

PARAMETERS TAKEN:
Dc link capacitor C= 3600µF , Inductor L=2.5mH, Load resistor R= 0.1Ω, Grid rated phase voltage=60 Vrms , Switching frequency= 1.5Khz

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BIOGRAPHIES OF AUTHORS

Swetapadma Panigrahi received B tech degree in Electrical and Electronics Engineering from BPUT Odisha, the M Tech degree from VSSUT,Burla, Odisha in the year 2010 and 2014 respectively. She is currently a research Scholar in the Department of Electrical and Electronics Engineering, National Institute of Technology Jamshedpur. Her area of interest include power electronics and renewable energy system.

Amarnath Thakur received the B Sc (Engg.) degree in Electrical Engineering from MIT, Muzaffarpur, the M Tech degree from IIT(BHU), Varanasi and the Ph D degree from Department of Elecrical Engineering, IIT Kharagpur in 1979, 1982 and 1997 respectively. He is currently a Professor in the Department of Electrical and Electronics Engineering, National Institute of Technology Jamshedpur. His area of interest include power electronics and renewable energy system. He is life member of the Indian Society for Technical Education New Delhi and Institution of Engineers, India.