Asymmetric Control of DC-Link Voltages for Separate MPPTs in Five-Level Inverter

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Abstract—It is important to improve the overall efficiency of a photovoltaic (PV) inverter when it is connected to the induction motor .Fundamentally, the conversion efficiency from dc to ac power of an inverter is important. However, in the presence of partial shading, maximum power point tracking (MPPT) on PV modules is more important than the conversion efficiency. In this paper, a new control method for a five-level inverter is proposed. With the proposed method, each dc-link voltage of the five-level inverter can be asymmetrically regulated. When PV modules are split into two and each split module is connected to the respective dc-link capacitors of the inverter, the asymmetric control can be helpful because separate MPPTs are possible. The effectiveness of the proposed method was examined through simulation using MATLAB/SIMULINK.

Index Terms—Asymmetric voltage control, grid-connected inverter, maximum power point tracking (MPPT), photovoltaic (PV),motor drive.

I. INTRODUCTION

The conventional energy sources are fast depleting these days. So the demand for renewable energy sources has been increased. Among the renewable energy sources photovoltaic systems can be considered as a very good source of energy because of its consistency and cleanliness. The power developed by photovoltaic system is DC. To convert this DC power a photovoltaic inverter is used. Stand alone systems were the first cost effective application of photovoltaic's. Stand alone systems are used in those cases were it is not possible to install an electricity supply from an existing utility grid. Stand alone PV systems requires an energy storage system. Rechargeable batteries are used for this and it requires a separate charge controller.

Now a days grid connected photovoltaic systems are gaining importance. In grid connected systems, power generated by the solar cells are supplied directly to an existing electrical grid. Such systems are becoming popular these days because of the elimination of battery subsystem. In grid connected systems, improving the output waveform of the inverter helps to reduce the harmonic content, thereby reducing the filter size and electromagnetic interference. Multilevel inverters are suitable for such applications.

For better MPPT, additional dc–dc converters can be used to connect split PVmodules to the centralized inverter. However, although this structure may be helpful to deal with partial shade, the conversion efficiency may be degraded due to multiple conversions. Moreover, the installation and maintenance costs increase. Therefore, it is worth augmenting the degree of freedom for MPPT while the number of conversion stages does not increase. Recently, five-level inverters have been discussed for implementing a centralized PV inverter, as the conversion efficiency can be increased by reducing switching losses and the output harmonic property can be improved. In particular, the five-level inverter shown in Fig. 1 is preferred because conduction losses are further minimized by reducing the average number of switch modules on the current paths .

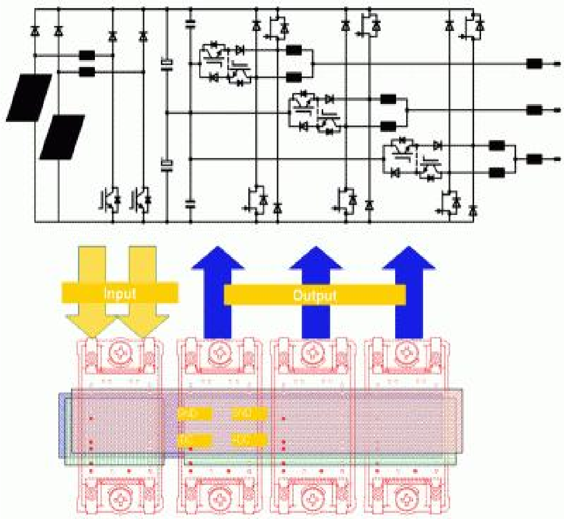

Fig. 1. PV modules and the multi-level PV inverter.

Inherently, the five-level inverter has a split dc-link, whose voltages can be controlled by manipulating the zero-sequence voltage added to the voltage references. Although the voltages of the split dc-link are supposed to be symmetric in general they can be regulated asymmetrically. At the same time, as shown in Fig. 1, the current path of *i*np pv can be intentionally established. Then, if the asymmetric regulation applies to the split PV connection in Fig. 1, separate MPPTs on the PV modules become possible without an increment in the conversion stage.

Several attempts to control dc-link voltages asymmetrically in multilevel inverters have been reported . They can be differentiated according to their pulse width modulation (PWM) schemes. The asymmetric control of the split dc-link based on direct power control (DPC) has been reported. Because the DPC method is based on variable switching frequency, the filter design cannot easily meet the harmonic and EMI regulations. Moreover, as described in, the switching frequency of an inverter based on DPC should be high enough to achieve a tolerable quality of the grid currents, thus resulting in higher switching losses .Other method based on space vector modulation (SVM) has been reported for the asymmetric control. Intrinsically, the SVM method is

complicated to implement because the dwell time of each vector should be geometrically computed. In addition, the sector in which the voltage vector is included should be identified and an extra table is required to optimize the switching patterns . Moreover, additional compensation should be considered to handle asymmetric dc-link voltage. Even with this compensation, the switching frequency can be intermittently increased depending on the operating condition. This is not desirable for both the filter design and the loss minimization.
Compared to the SVM method, the carrier-based PWM method is simple to implement

II. CONTROLLERS FOR ASYMMETRIC DC-LINK VOLTAGES

A. Voltage Control of a Split DC-Link
The voltages of a split dc-link in a three-level inverter can be described as

$V_{dcH} + V_{dcL} = V_{dc}$
$V_{dcH} - V_{dcL} = \delta V_{dc}$ (A)

where V_{dcH} and V_{dcL} are defined in Fig. 1.
Initially, the regulation of V_{dc} is conceptually equivalent to modulating the total energy stored in the capacitor bank of the inverter. That is, V_{dc} can be changed by regulating the active power supplied to the grid. For instance, if the output power to the grid is less than the input power from the PV modules, V_{dc} increases and vice versa. Therefore, regulating V_{dc} is easily achieved by the conventional method shown in Fig. 2. Each PI gain can be determined according to the method presented in earlier work . On the other hand, the regulation of δV_{dc}, which is the difference between the high- and low-side dc-link voltages, is related to modulating the ratio between the output power from each capacitor. This can be described as
$P_o = \frac{d}{dt} \times \frac{C_{dc}}{2}(V^2_{dcH} + V^2_{dcL})$ (B)

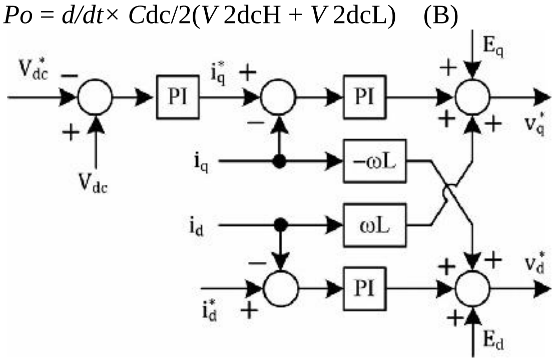

Fig. 2. Voltage controller for V_{dc} .

where P_o is the output power from the capacitor bank and C_{dc} is the high- or low-side capacitance of the split dc-link. Given that the power from each dc-link is proportional to the corresponding voltage, the voltage difference can be adjusted by modulating the output power ratio between each dc-link. In addition, this modulation may be essential if asymmetric powers are supplied to the split dc-link from the PV modules, which are connected as shown in Fig. 1. According to (1), the simultaneous regulation of V_{dc} and δV_{dc} is equivalent to that of V_{dcH} and V_{dcL}. That is, when the references to V_{dcH} and V_{dcL} are given by separate MPPTs, these references can be achieved through the simultaneous regulation of V_{dc} and δV_{dc}. Particularly, how to regulate δV_{dc} is proposed in this paper.

III. MODELING OF PV MODULE

The basic unit of a PV module is the solar cell, which consists of a p-n junction that converts light energy directly into electrical energy. The equivalent circuit of a solar cell is shown in Fig. 3.

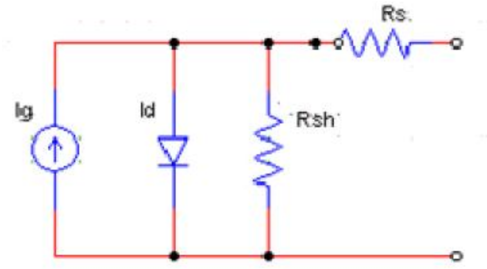

Fig.3. Equivalent circuit of solar cell

Here Ig is the light generated current, Id is the diode current, Rsh is the shunt resistance which describes the leakage current, Rs is the series resistance which describes the voltage drop as the charge carriers migrate from the p-n junction to the electrica contacts. A number of PV cells are connected together so as to form PV modules and PV arrays. The mathematical model for simulating PV modules or arrays consists of the following
equations.

$$I = n_p I_g - n_p I_{rs}\left[\exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1\right] \quad (1)$$

where I is the PV array output current; np is the number of solar cells connected in parallel; Ig is the light generated current also called Insolation current; Irs is the reverse saturation current; q is the charge of the electron; k is the Boltzman's constant; T is the cell temperature in Kelvin; A is the ideality factor; ns is the number of cells connected in
series.
The reverse saturation current Irs varies according to the following equation:

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_g}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (2)$$

Where Irr is the cell reverse saturation current at reference temperature; Tr is the reference temperature, Eg is the band gap energy of the semiconductor used in the solar cell. The light generated current Ig varies according to the
following equation:

$$I_g = [I_{scr} + K_i(T - T_r)]\frac{G}{100} \quad (3)$$

Where Iscr is the short circuit current at reference temperature; Ki is the short circuit current temperature coefficient; G is the incident solar radiation in mW/cm2.

IV. MAXIMUM POWER POINT TRACKING

The P-V curve of a solar cell is a single peak curve. It implies that there is a particular operating point at which maximum power can be extracted from the solar cell. A maximum power point tracking controller is used for this. One among the most commonly used MPPT controllers is discussed here, ie. Incremental Conductance method. The flow chart of Incremental Conductance MPPT method is shown in the Fig. 4.

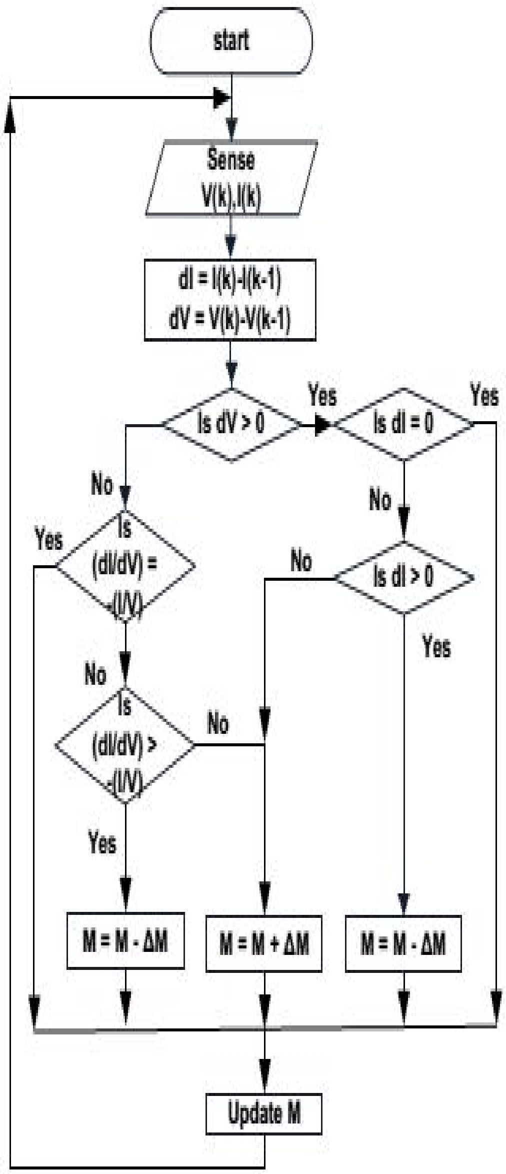

Fig. 4. Flow chart of Incremental Conductance MPPT

At maximum power point(MPP), dI/dV = - I/V. In Incremental conductance method the condition for MPP are checked and the duty ratio of the DC-DC converter coupled to the PV module is adjusted accordingly.

V. PROPOSED CONTROL TECHNIQUE

CONTROL SYSTEM FOR GRID CONNECTION OF PV MODULE

Fig.5 shows the block diagram of a grid connected PV system.

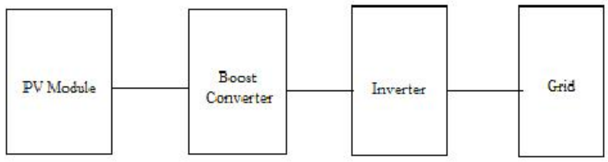

Fig.5. Block schematic of grid connected PV system

In a grid connected PV system PV module is coupled with a boost converter. The boost converter performs the Maximum power Point tracking and voltage amplification if necessary.

The inverter handles output current regulation and DC bus voltage regulation. Also while grid interfacing it should be ensured that the power flow is from the PV module to the grid. For this the DC link voltage must be kept greater than the peak value of the grid voltage. Apart from this the control system should also ensure that the current injected into the grid is sinusoidal and is in phase with the grid voltage. ie, the power must be injected into the grid at unity power factor. The block diagram for the control system is shown in the Fig. 6.

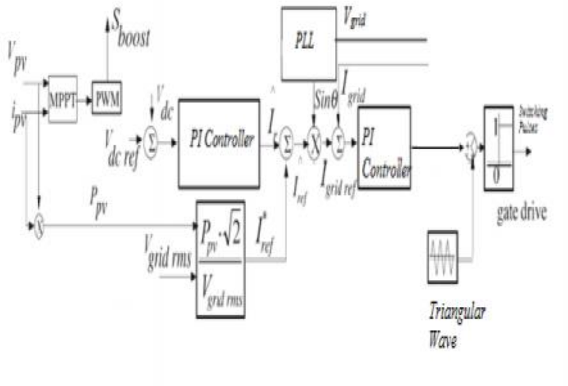

Fig.6 Control system for grid interfacing of PV system

The control system comprises an MPPT algorithm, a DC bus voltage controller, reference current generation and current controller. The two main tasks of control system are to maximize the energy transferred from PV modules to the grid
and also to generate a sinusoidal current with minimum harmonic distortion.

VI. SIMULATION AND EXPERIMENTAL RESULTS

A. Simulation Results

In order to verify whether the five level inverter can be practically used in a grid connected system simulations are performed using MATLAB/SIMULINK. The PV module is then coupled with a boost converter. The Incremental conductance MPPT was implemented using SIMULINK blocks in the boost converter. The control to the inverter is given according to the control system shown in Fig6.The speed torque characteristics of inverter fed induction motor drive are simulated and observed and are plotted below

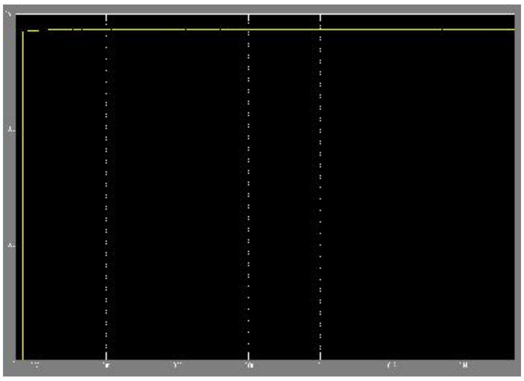

Fig.7.Induction motor speed

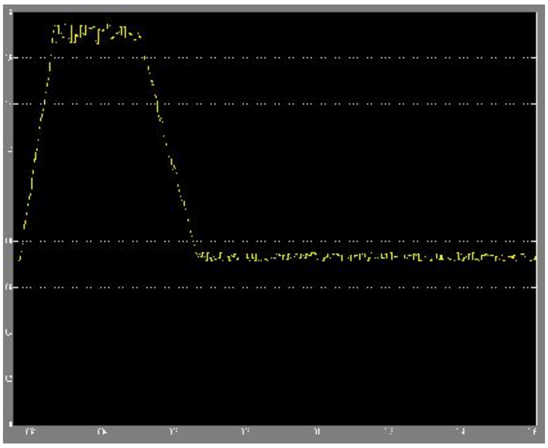

Fig.8.Induction motor torque

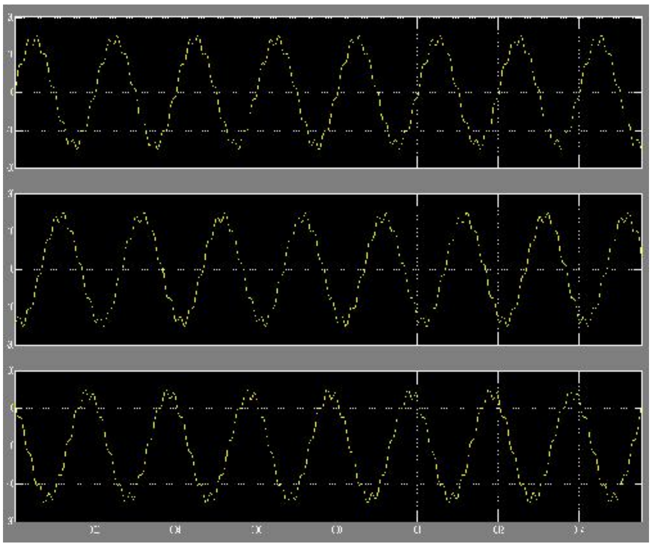

Fig.9. Stator currents of induction motor

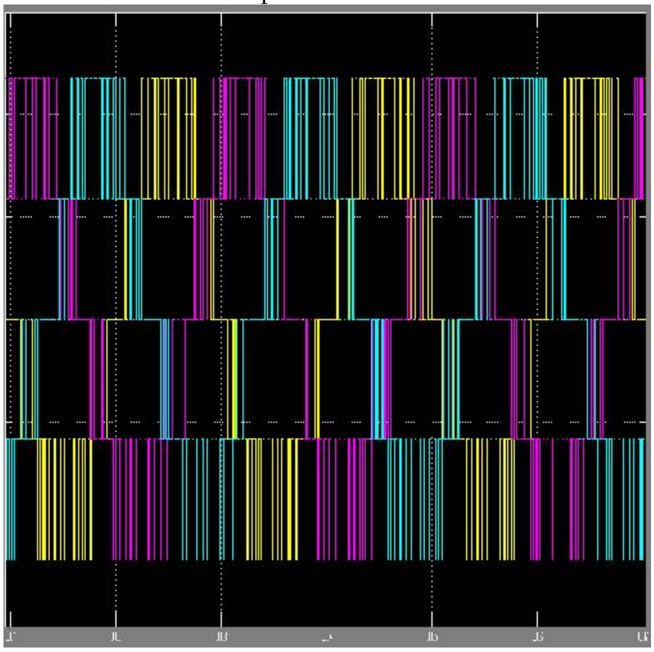

Fig.10.Five level output voltages

VII. CONCLUSION

The five-level inverter has some advantages as a grid connected PV inverter because it has one more voltage level than the two-level inverter. In combination with this advantage, the proposed control method can contribute to the enhancement
of the power generation from PV modules under given shading conditions, as separate MPPTs are possible in the proposed control system. For the separate MPPTs, the dc-link voltages of the inverter have to be asymmetrically regulated. All of the blocks pertaining to this asymmetric regulation were described in this paper. In addition, the manner of setting the gains of the control loop was explicitly suggested. The neutral point current in the five-level inverter is the important state for the asymmetric control. And inverter fed induction motor was controlled.

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