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Design and analysis of Multilevel Boost Converter and Line Commutated Inverter for Universal System

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Abstract- The photovoltaic system capable of operating in both grid-connected and stand-alone modes. The multilevel boost converter and line commutated inverter has been extracting the maximum power. The duty ratio of the multilevel boost converter is extracting maximum power from PV array. A fixed firing angle of line commutated inverter is able to track the maximum power with duty ratio which remains the same for all irradiations. The advantage of the proposed system is to eliminate the use of a separate maximum power point tracking controller. Here 70% of power may connected to the grid with the help of line commutated inverter and remaining power may fed to stand alone mode for DC motor.

Index Terms- Photovoltaic (PV), Multilevel Boost Converter, Line Commutated Inverter, Grid-Connected, Sand-alone mode**.**

1. INTRODUCTION

Renewable energy systems, such as Photovoltaic (PV) is playing a more and more important role in energy production [1]. The stand-alone systems, grid-connected PV systems have gained more importance because of reduce the energy demand [3-4]. In this paper, separate MPPT controller has been eliminate for extracting the maximum power from the renewable energy source.

The firing angle of LCI is adjusted continuously to obtain the maximum power. The PV system is proposed to feed the power to both grid and stand-alone load continuously, eliminating the hardware equipment such as transformers, synchronisation circuits and sensors. This mode of operation is achieved with the help of dc–dc Multilevel Boost Converter (MBC) and a LCI.

The advantages of MBC are: (i). High switching device and (ii). Continuous input current. An SCR bridge in LCI mode is used for connecting the PV energy available at the output of MBC to the grid. As one of the popular applications of stand-alone system is water pumping, a dc motor has been used in the present of salient feature of this
configuration for any irradiation, the required duty cycle of MBC is same for extracting the maximum power from PV array, the firing angle of LCI being fixed. This feature of the proposed scheme eliminates the need for separate MPPT controller which will require the voltage and current sensors for sensing the feedback or feed forward voltage and current signals[2]. Further the flexibility to vary the ac power fed to the grid as well as the dc power fed to the stand alone load is an added advantage.

Renewable energy generation has increase the energy utility, MPPT or constant output voltage algorithms have also been employed which in turn requires sensors for providing the feed forward or feedback signals. Apart from the stand-alone systems, grid-connected PV systems have gained more importance because of the rising energy demand. Various configurations of grid-connected system are reported in recent papers. Most of them use insulated gate bipolar transistor IGBT-based force commutated inverters with or without dc–dc converter and transformer[8].These systems, they need separate synchronisation circuit for interfacing with the grid in addition to MPPT controllers. Very few have reported the silicon controlled rectifier SCR based line commutated inverter LCI which reduces the complexity of the control circuits of IGBT inverter. In these papers, one or more number of transformers are also used apart from the power converters, and separate MPPT controller has been employed for extracting the maximum power from the renewable energy source. More importantly, the firing angle of LCI is adjusted continuously to obtain the maximum power.

2. DESCRIPTION OF THE PROPOSED SYSTEM

The Block diagram of the proposed scheme is shown in Fig. 1. This scheme of renewable power generation consists of a PV array, a multi output boost converter, a line-commutated SCR inverter and controllers for generating gate pulse to IGBT and firing pulses to SCRs. As the dc–dc multilevel converter is used as multi output boost converter in the proposed configuration[8]. To obtain a steady direct voltage from the PV panels, the capacitance C_i between the PV array and MBC is used. The total output voltage of the converter is divided into equal voltages across four capacitors. The output across C_1 is connected to a single phase LCI through the dc link inductance L_{dc} which smoothens the dc current from the MBC. The maximum power is extracted from PV array out of which 70% of power is fed LCI and remaining power is fed to DC motor. From the analysis of the proposed system presented in Section 3, the duty ratio is found to be constant for fixed firing angle of LCI for various irradiations. Thus, there is no need for a separate closed loop MPPT controller.

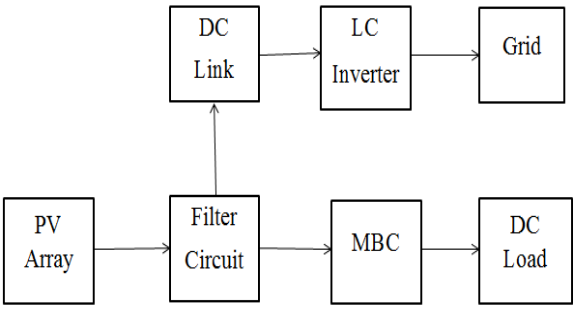

Fig.1 Block Diagram for proposed system.

2.1. *Solar cell*

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. A photovoltaic module is a packaged, connected assembly of solar cells. The solar module can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel and array of solar modules, an inverter, and sometimes a battery and solar tracker and interconnection wiring[4].
Fig.2 The output current *I* and the output voltage V of a solar cell are given by

$$I = I_{ph} - I_{do} - \frac{V_{do}}{R_{sh}} \quad (1)$$

$$V = V_{do} - R_s I \quad (2)$$

Where,

I_{ph} is the photocurrent
I_{do} is the average current in diode
I_g is the phase current

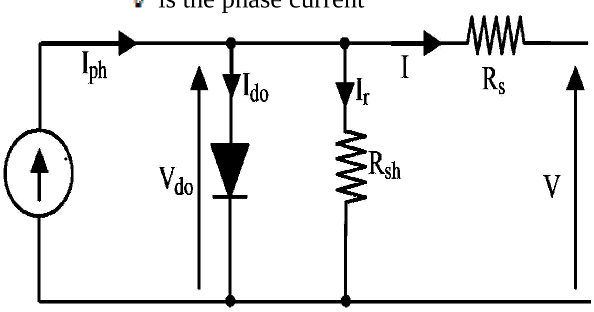

Fig.2 The electrical equivalent circuit of a solar cell

The output of the current source is directly proportional to the light falling on the cell (photocurrent). During darkness, the solar cell is not an active device; it works as a diode, i.e., a p-n junction. It produces neither a current nor a voltage. Thus, the diode determines the *I–V* characteristics of the cell.
A PV generator is a combination of solar cells. In the Solar cells consist of a p-n junction diodes of various modelling of solar cells have been proposed. Thus, the simplest equivalent circuit of a solar cell is a current source in parallel with a diode.

2.2. *PV Generator Model*

A faster Look-up–based model was developed to simulate the PV generation as shown in Fig.3. Here, the measured I-V curves were scaled to 25c cell temperature to utilizing the temperature coefficients of the PV module and used to consume a Look-up table.

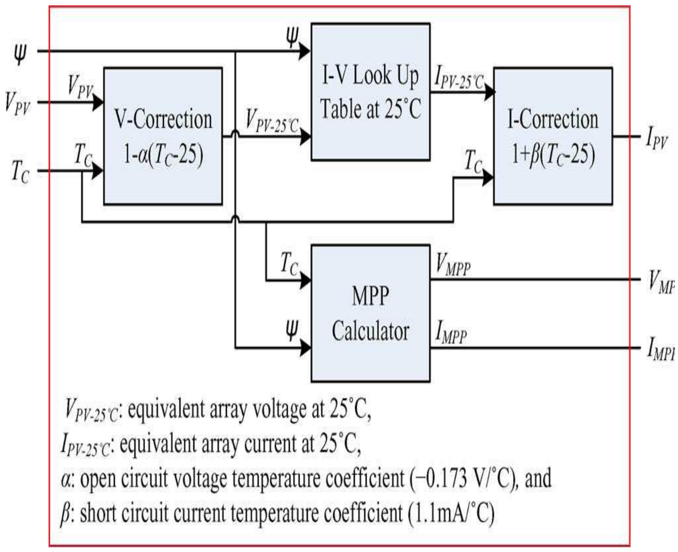

Fig.3 Look-up table-based model for PV generator

The influence of cell temperature was accounted for using the temperature coefficients of the array short circuit current and open circuit voltage. These were also used to calculate the MPP voltage and current from look-up table respectively, at 25c cell temperature. The effect of temperature on the fill factor of the PV array was neglected. This is a reasonable assumption for the proposed system to be better characteristics of the Hetero junction with intrinsic.

2.3. *DC link model*

The line commutated inverter is a conventional phase-controlled converter operating with fixed maximum possible firing angle**.** Since the utility line voltage is fixed, the voltage at the dc terminals of the phase controlled bridge is also fixed[1]. The equation for the average current in the dc link can be written as

$$I_d = (V_o + V_{cd})/r_s \quad (3)$$

where

***r*,** is the circuit resistance,

Vo and Vcd are the average voltages of rectified.

The dc link current id is inverted by the line commutated inverter and forced to the utility line, feeding the power generated by the HF rectified source ***in*** to the utility line. For continuous current operation,

$$V_{ed}=(2\sqrt{2}\,V\cos\alpha)/\pi \quad (4)$$

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure.

For single phase line commutated inverter

$$V_{ed}=(3\sqrt{2}\,V\cos\alpha)/\pi \quad (5)$$

For three phase line commutated inverter

The line commutated inverter, where ***a*** is the firing angle of SCR's and *V* is the line to line rms voltage.

2.4. *Multilevel Boost Converter*

A four-level boost converter with the input source voltage at the medium position as developed. The detailed working of the converter is explained in . To avoid the high power dissipation in lower device than the higher one, MBC topology with central source is used [8].The converter consists of one IGBT switch, seven diodes and seven capacitors. This converter has the advantage of extending the number of levels by simply adding the capacitors and diodes. The voltage gain of the converter for a four-level output is given by

$$\frac{V_0}{V_{ph}}=\frac{4}{1-\delta} \quad (6)$$

where

V_{PV} is the PV array voltage.

V_o represents the full string output voltage.

δ is the duty ratio.

2.5. *Line commutated inverter*

The IGBT converter operates as a rectifier and both Edc and Idc values are positive Line commutated inverter is the conventional 1 - 0 or **3** - fully controlled SCR bridge working in the inverting mode *(a* > 90"). For firing angles **>90°,** the terminal voltage *Vcd* is negative and hence the rectified HF power is forced to the utility line. In the present system, the LCI is operated with fixed maximum firing angle *(a* = **180"** - y) as near to 180" as possible.

Thus the line PF is near unity. However a margin angle is to be provided for the safe operation of the inverter.

$$E_{dc}=\frac{2V_{mg}}{\pi}\cos\alpha \quad (7)$$

where

V_{mg} is the peak value of the ac grid voltage

α is the firing angle

2.6. *DC Load*

In the proposed system, a separately excited DC motor is used as stand-alone load**.** A dc motor-pump set can be connected directly to the PV generator as is the case with most commercial dc PV pumping systems. In this case, the system operates at the intersection of the current–voltage curve of the PV generator and the load-line. This operating point may be far from the maximum power point (MPP) of the PV generator wasting a significant part of the available solar power. To better match the PV generator to the motor-pump set, a pump controller is required. For dc PV pumping systems, the pump controller is basically a dc–dc converter whose duty ratio is controlled by a maximum power.

3. STEADY STATE ANALYSIS OF THE PROPOSED SYSTEM

For tracking the maximum power from solar array, the duty ratio of the dc–dc converter has to be adjusted. Conventionally, an analog or digital controller using any one of the MPPT algorithms can be used. Assuming the converters to be ideal, the duty ratio corresponding to maximum power point (MPP) can be estimated. From, it can be seen that

$$V_{dc} = E_{dc} + I_{dc}R \quad (8)$$

Where,

V_{dc} is the output voltage across the top one-fourth of the string of MBC.

E_{dc} is the dc-link voltage

I_{dc} is the dc link current

Further

$$I_{dc}=I_0-I_a \quad (9)$$

Where,

I_o is the overall output current of MBC.

I_a is the motor armature current.
Therefore using (9) in (8), we obtain

$$V_{dc}=E_{dc}+(I_o-I_a)R \quad (10)$$

$$V_{dc}=\frac{V_m}{1-\delta_m} \quad (11)$$

Where,
V_m is the PV voltage,
I_m is the PV current
δ_m is the duty ratio at MPP, then

$$I_{dc}=\frac{I_{m(1-\delta_m)}}{4} \quad (12)$$

Where,
V_m= pv voltage
δ_m=duty ratio

However, from (2), it can be found that E_{dc} is function of grid

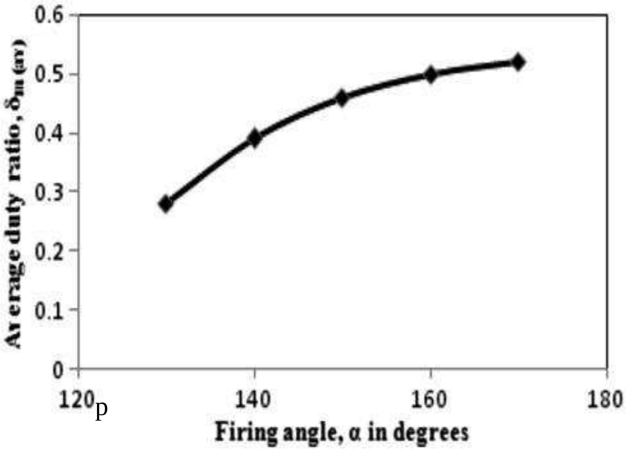

Fig.4 Variation of duty ratio of firing angle

Voltage and firing angle of LCI. Hence, δ_m is a function of grid voltage, firing angle, motor current and maximum PV array voltage and current. Using (8), we can estimate the duty ratio for which MPP operation takes place for the given irradiation and firing angle of LCI.
The average value of maximum duty ratio for fixed firing angle for various irradiations is found for the proposed configuration with constant armature current, I_a. The variation of average δ_m with respect to firing angle, α for all irradiations is shown in Fig.4

4. Relationship Between the Panel Power and Grid power

The power input from the panel is constant under a constant insolation and the power output to the grid is time varying at twice of the grid frequency.

$$V_{ac}(t)=V_m \sin\omega t \quad (13)$$

$$I_{ac}(t)=I_m \sin\omega t \quad (14)$$

$$P_{out}(t)=V_{ac}(t)i_{ac}(t) \quad (15)$$

Where,
V_m= Peak voltage
Im=Peakcurrent
ω= angular frequency

The relationships between and . At the steady state, the average value of is equal to . That is

$$P_{in}=\frac{1}{2\pi}\int_0^{2\pi} P_{out}(t)dt =\frac{P_m}{2} \quad (16)$$

The capacitor acts as a buffer for absorbing the difference between and the low-frequency profile of the capacitor voltage varying between a dc value .

5. Simulation results

Using MATLAB/Simulink, the overall simulation model of the system has been built by integrating the subsystems of PV array, MBC and LCI with a 110 V, 50 Hz single phase utility grid and 230 V DC motor. In the proposed scheme the model of pv array is obtained using pv cells.

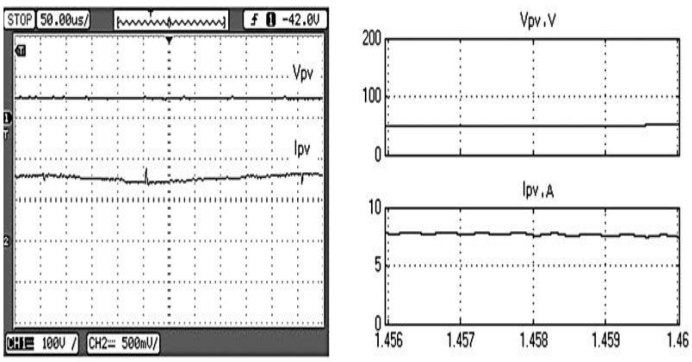

Fig.5 Simulation waveform of pv voltage vs time

A independent current source, a controlled current source, measurement blocks and arithmetic blocks, the model of PV array has been implemented. The power electronic components available in power system block set (PSB), the MBC and single phase inverter circuits have been modelled.

The DC machine available in PSB is modelled as separately excited DC motor. The pulse generators are used for providing the gate pulse to IGBT switch in MBC and firing pulses to LCI. The duty ratio of the MBC is adjusted to the output voltage which in turn is fed to the inverter and motor.

$$R_{eq} = \frac{(1-\delta)}{N^2} \quad (17)$$

where,

R_{load} is the load impedance and Req is the equivalent impedance seen from the perspective of PV array and. For the proposed configuration, both R_{eq} and R_{load} vary with irradiation and the ratio of R_{load} and R_{eq} almost constant for different irradiations at MPP, thus providing a constant noted that the maximum power occurs at same duty ratio, for the proposed configuration and it cannot be generalised that the same will be true for any grid connected PV system employing LCI.

6. Experimental investigation and results

A prototype is built to experimentally test the proposed configuration. The experimental set-up of the proposed scheme consists of a PV array of 80 V, 9.4 A (two strings of series connected four panels of 20 V, 4.7 A connected in parallel) and SCR bridge circuit with four thyristor, a separately excited DC motor rated for 230 V, 0.7 A, 1500 rpm and two PIC microcontrollers – one to generate the gate pulse for the IGBT in MBC and the other for generating firing pulses for the SCRs in LCI. The LCI is connected to a 110 V, 50 Hz single phase utility grid. This values is arrived at based on the critical value for continuous conduction as given in the following expression.

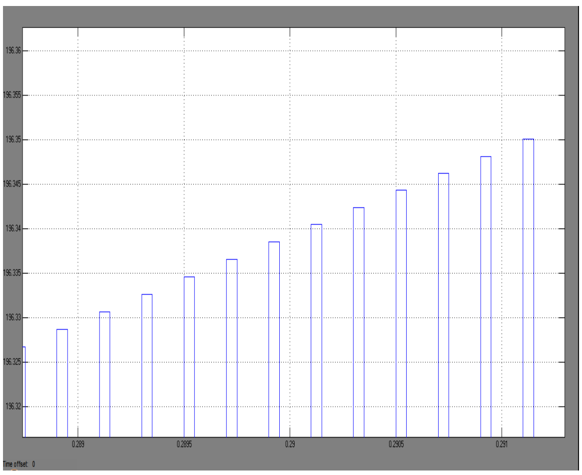

Fig.6 simulation waveform of voltage vs time for boost output

The maximum power is extracted from PV array by generating the gate pulse to MBC with the estimated duty ratio from the analysis. In the proposed system, the dc-link voltage and the armature current are made to be constant by fixing the firing angle of LCI as well as the load torque of the motor such that 70% of output power is fed to the grid and the remaining 30% power is used for driving the act for and connected across the grid terminals to reduce the 3rd and 5th order current harmonics which are predominant in grid current At nominal operating condition both simulated and experimental voltage and current waveforms of PV array, dc link, armature of the motor are obtained

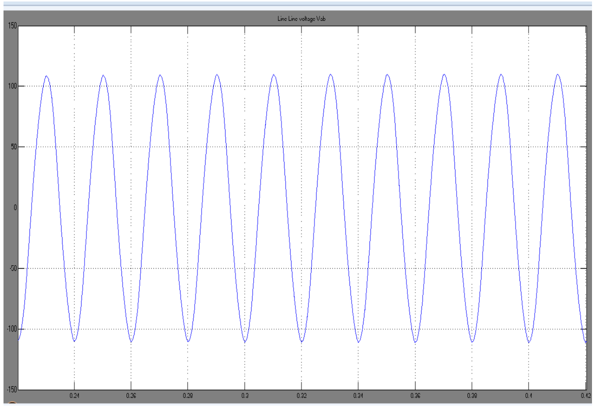

Fig.7 simulation waveform of voltage vs time for AC grid output

. At PV array supplied a maximum of 372 W out of which the system is capable of delivering an ac power of 245 W to the grid and a dc power of 93 W to the DC motor simultaneously. The grid voltage and current waveforms with and without filter. Also the harmonic spectrum of the grid current with and without filter are obtained experimentally. The efficiency of the overall system is found to be 91–92% and the effectiveness of proposed system supplying ac and dc power simultaneously is encouraging. The comparison of the results reveals that the hardware circuits built are working in tune with the theoretical analysis and simulation of the system. The system also has the flexibility to be operated in such a way that the major portion of output power can be given to the DC motor and the remaining power can be fed to the grid by adjusting the firing angle of LCI and load of the DC motor. In the proposed system is capable of operating in combined grid-connected and stand-alone modes.

7. Conclusion

In this new configuration of PV system has developed for Multilevel boost converter and Line commutated inverter so that power can be fed to both grid and stand-alone system. Here the single phase grid and separately excited DC motor is used for stand-alone load. For the analysis the extracting maximum power from PV array. Here duty ratio can be varied and extracting for all irradiation condition. The system has high priority is needed for grid.

The directly connected PV pumping system offers a low-cost implementation but has poor energy utilization depending on the distance between the load line and the MPP at different weather conditions. For this system, experimental tests produced an energy for both slow and fast changing irradiance. The complete system has been modelled using MATLAB and the close agreement between analysis, simulation and experimental results of the validity of the experimental set-up.

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