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Harmonic Minimization in a MPPT based MJSC Photovoltaic Microgrid using Modified Cascaded H Bridge Multilevel Inverter

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Abstract

The renewable energy sources penetration has increased nowadays. Numerous techniques are developed for grid connected photovoltaic system for intensive penetration of photovoltaic (PV) production into the grid from various research papers. Several researches have been carried out in the field of PV design, but few work for grid connected multi-junction solar cell. Cascaded multilevel inverter provides many advantages over conventional inverters to improve the overall efficiency and reduce harmonics with the grid integration of renewable energy sources. The paper proposes a design of multi-junction photovoltaic solar cell with maximum power point tracking and a novel topology of cascaded multilevel inverters to improve power quality delivered to grid in terms of harmonics, by minimizing total harmonic distortion of microgrid (MJSC) interface. A model was developed and the system was tested for performance. The results found were encouraging as compared to the traditional methods. MATLAB/Simulink platform is used to model and simulate the entire system.

Keywords*: PV System, MPPT, Photovoltaic array, Cascaded multilevel inverters, RES interfacing, Harmonic distortion*

1. Introduction

There is an increase in the demand of renewable energy sources like wind and solar, to be used as stand-alone as well as grid connected generating units as per the availability of nearby grids. To fulfill the present energy crises an efficient manner to extract the power from the incoming solar radiation is required. Micro grids are key elements to integrate and penetrate renewable energy systems, to grid. The effective utilization of renewable energy resources is carried out using maximum power point tracking techniques [1] [2]. The solar provides the clean and pollution free impact on environment [6]. Today, the grid integration of renewable energy sources (RES) such as photovoltaic systems based applications are becoming more popular. Multilevel inverters/converters are introduced for higher power and medium voltage applications [6]. Cascaded multilevel inverters (MLI) are widely applied in PV systems grid interface. Multi junction solar cell has become a break through over conventional silicon PV, for solar electricity production. In this paper, MJSC with maximum power point tracking is used to extract maximum power and improve conversion efficiency. The power quality which is delivered to the grid in terms of harmonics of MJSC PV micro grid is reduced by the novel topology and switching control strategy of modified cascaded H bridge multilevel inverter. The sections are organized as follows: Section II presents multi junction Solar Cell. Cascaded Multilevel Inverters of grid connected photovoltaic system is presented in section III. MJSC PV array modeling, MPPT technique and proposed topology of multilevel Inverter modeling using MATLAB/Simulink with results are presented in section V, VI and VII.

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2. Multi-Junction Solar Cell

Modernization in photovoltaic systems has led to various researches in the field of solar cell which use large spectrum of solar radiation to improve the efficiency. Multi-junction solar cell (MJSC) is a combination of various types of photovoltaic junctions stacked over each other via homo-junctions, intrinsic materials or tunnel junctions. Solar cells are made up of various band gap energies as well as physical properties. Combining several of these solar cells allows it to effectively capture and convert into electrical power from a huge range of photon wavelengths. Nowadays, MJSCs are able to generate approximately twice the power compared to normal or regular solar cells [3, 7-9]. Theoretical efficiency of around 30% was obtained by Boeing Spectrolab Inc. triple junction GaInP/GaInAs/Ge solar cell. This involves an innovative method in which the Photovoltaic cells are concentrated. The concentration level is separated into four regions. Due to increase in the level, MJSC face tracking and overcomes the issues of thermal management, and improves the tunnel junction stability due to increase in current densities [4].

3. Cascaded H-Bridge Multilevel Inverter/Converter

Multilevel inverters are used to interface renewable energy sources to the grid. The output voltages are obtained with minimum distortion and reduced dv/dt stresses with multilevel inverters. The stress in the bearings of motor can also be reduced using multilevel inverter. Different range of switching frequencies, input current with low distortions, are added advantages. There are different types of multilevel inverters/converters such as Cascaded H Bridge, diode clamped and capacitor clamped inverters/converters. Depending upon the number of voltage levels required, separate DC sources in series are connected in cascaded H Bridge inverters. The number of voltage levels is equal to 2s+1 where s is the number of DC sources. For fundamental switching frequency, efficiency is high of multilevel inverters. PV system using cascaded H bridge converter requires separate DC sources. Sun darkening, reduces the power drops, which leads to the increase in the efficiency and improving reliability of the PV system using cascaded multilevel inverter. The increase in switches, complexity in designing gate driver circuit, switching losses and cost are certain drawbacks of multilevel inverters, but the number of switches for the same voltage levels can be reduced effectively [12]. Cascaded multilevel inverters are best suited for renewable energy sources grid integration where separate need of DC sources is required for PV or fuels cells applications.

4. Problem Formulation

This paper tries to develop a model of grid connected renewable energy sources. The aim is to develop the model for multi-junction photovoltaic cell and connect it with a grid using dc-ac conversion via multilevel inverter. The objective is to design a micro grid consisting of MSJC PV with maximum power point tracking, cascaded multilevel H bridge inverter and connect the overall system to the grid, test the performance of the system power quality delivered to the grid in terms of harmonics, and calculate the total harmonic distortion.

5. Proposed Methodology

This section presents our approach in developing the proposed model to achieve the problem discussed in the previous section. The modeling of the MJSC - Double-junction solar cell is carried out followed by a boost type DC/DC converter which is fired using an MPPT technique of "P&O” algorithm for charge control to achieve maximum power from the MJSC PV array. A 21–level multilevel inverter is designed and modeled; pulses are generated by switching technique, fed to multilevel inverter and simulated. A 14V DC, from MJSC PV array is fed to the MLI and an output voltage of 200V AC is obtained. The entire micro grid system is then connected to the Grid, and also load voltage and current is measured. The total harmonic distortion is calculated as shown in the figure below.

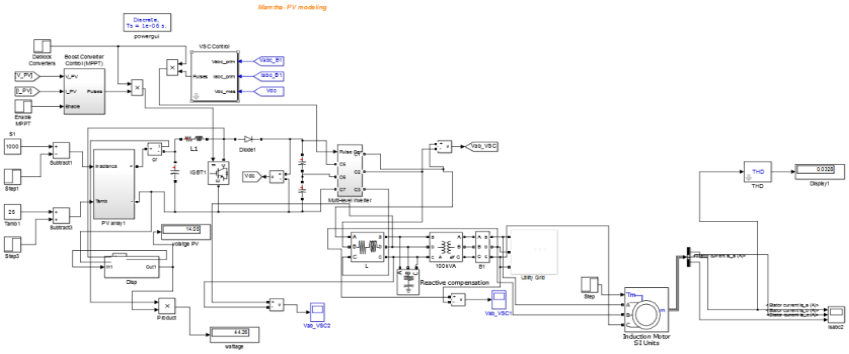

Figure 1. Grid Connected MJSC PV Modeled In MATLAB/Simulink

5.1. Multi-Junction Solar Cell Model

The MJSC circuit model is a combination of various types of cells with other materials in series, which are able to connect many cells as per requirement. The model is simulated in MATLAB/Simulink to obtain the MJSC characteristics as shown in [14].

5.2. Double-Junction Solar Cell

The InGaP (Indium Gallium Phosphide) and GaAs (Gallium Arsenide) cells are combined as tandem cell; both are from IIIeV group alloy. As seen from the materials, the band-gap energy coefficient never varies significantly instead receives more energy sources, as shown in Table 1. [14].Indium Gallium Phosphide is lattice matched with the Gallium Arsenide, to form the tandem cell [5, 9]. Copper Indium Gallium Selenide (CIGS) can be arranged with other cells which is made up of material of small crystallite and it is polycrystalline in nature. Few advantages of this CIGS are; relatively high absorption coefficient, reduced thickness; high amount of output current can be used by current density of CIGS. Copper Indium Gallium Selenide is connected with Gallium Arsenide in second tandem cell, which is carried out using IIeV cross section by creating the combination of IIeIV intrinsic semiconductor. In the periodic table Aluminum Arsenide is identical with Gallium Arsenide from IIeV alloy.

Table 1. On Solar Cell Energy Band-Gap

Group Combinations	[1] Top layer	[2] Bottom layer
InGaP/GaAs	1.86 eV	1.42 eV
CIGS/GaAs	1.70 eV	1.39 eV
ZnSe/AlAs	2.7 eV	2.12 eV

5.3. Mathematical Formulation of Single Cell

The performance of each tandem cell can be checked as follows. Each cell generated voltage (V) is [11].

$$V = V_{sh} + I R_s \qquad \text{-- --------} (1)$$

Where, V_{sh} is shunt resistance voltage drop, I is load current, and R_s is resistance in series. Current flow to grid can be represented as follows:

$$I = [Isc + Ki(TC - Tref)]\frac{G}{Gref} - Is(e^{VD}_{NVT} - 1) - \frac{Vsh}{Rsh} \quad \text{-- -------- (2)}$$

(I_{SC}) is the short circuit current at ambient (T_{ref}) temperature and reference (G_{ref}) irradiation. The working cell temperature (T_c) and G irradiation are respectively considered. K_i is set at 0.065 ± 0.015%/℃, which is the cell's temperature coefficient. $I_s$is the diode saturation current, V_D and V_T represents voltage across diode, thermal voltage diode and ideality factor (N) is considered as one for diode. The current (I_s) of diode is as follows, $I_S I_{RS}\left(\frac{TC}{Tref}\right)^3 e^{Eg}_{NVT}\left(\frac{TC}{Tref} - 1\right)$ ----------- (3)

I_{RS} characterizes diode reverse saturation current. For single layer the above derived formulas are carried, which specifies that the number of combinations are developed as per the model requirements and adjustments.

6. Matlab/Simulink Model

6.1. PV Model

6. 1. 1. PV array Parameters [13] and MJSC-Double Junction Solar Cell

Irradiance –1000W/$m^{2,}$ Temp-25℃, Isc-2.02A, Im-1.93A, Tref-55℃, Voc-86.8V, Vm-70.4V.

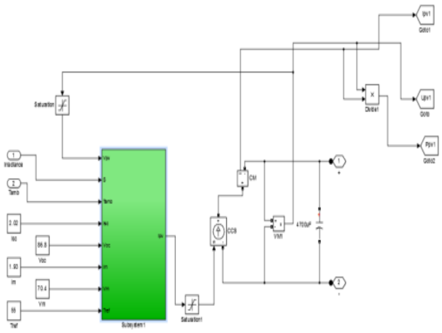

Figure 2. PV Array Using MATLAB/Simulink

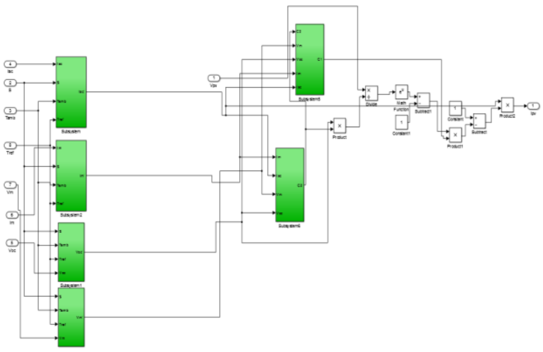

Figure 3. PV Array of MJSC-Double Junction Solar Cell

6.2. DC/DC-Converter Parameter Values

- Inductance(L) = 5mH
- Inductor Resistance(RLC) = 0.005Ω
- Capacitance(C) = 100µF
- Switching Frequency (f_s) = 50 Hz
- Initial Duty Ratio (D)= 0.5
- Load Capacitors =12000µF
- Output Voltage(V_o) =14V

6.3. MPPT P&O Algorithm for MJSC PV

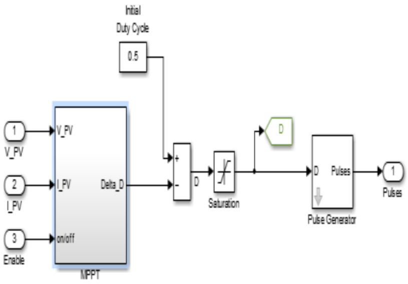

Figure 4a. MPPT P& O Algorithm

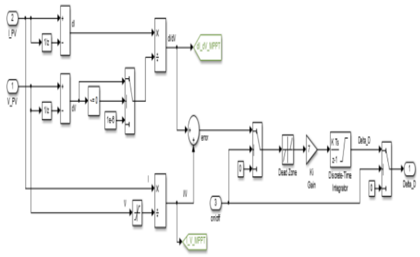

Figure 4b. MJSC PV MPPT P&O Algorithm (Subsystem)

6.4. Cascaded H Bridge Multilevel Inverter Topology

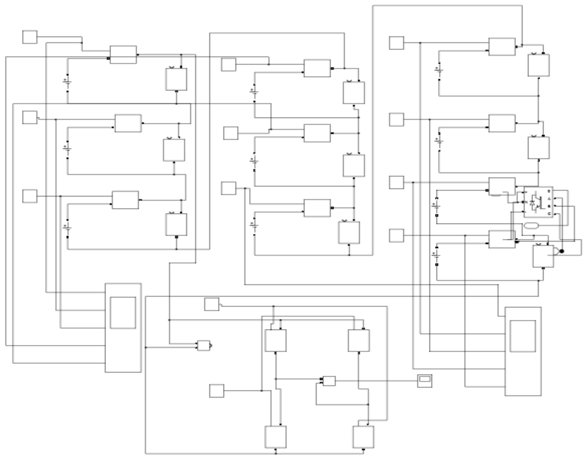

Figure 5. 21 Level Cascaded Multilevel Inverter using MATLAB / Simulink

6.4.1. Parameter Values

- Frequency = 50Hz.
- T=1/f = 0.02secs = 20msecs
- Largest Pulse width = 99.9999 (% of period)
- Phase delay =0.0005secs
- 21 level – Approximation of Sine wave
- M = 2n + 1
- n = 10, number of DC sources
- Number of switches =24
- M = 21, number of voltage levels.

7. Results

7.1. MJSC Photovoltaic /MLI/ Grid Output Voltages

- Output Voltage - 14.05V DC
- Output Voltage of MLI – 200V AC

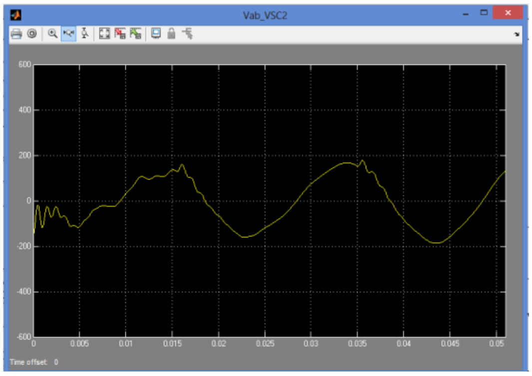

Figure 6. Output Voltage of MLI - 200 V AC

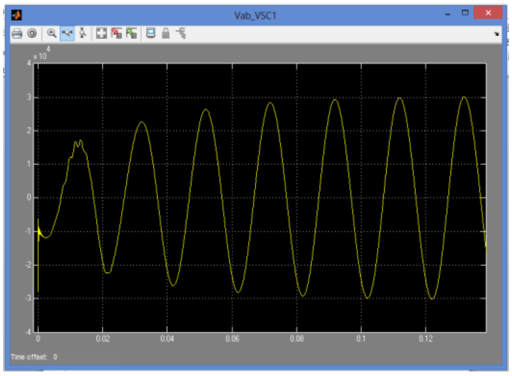

Figure 7. Grid Line voltage, V_{ab} – 20 to 30 kV AC. Phase Voltage – 16.47KV AC, Connecting 100 kVA Transformer

7.2. Induction Motor Output Voltage

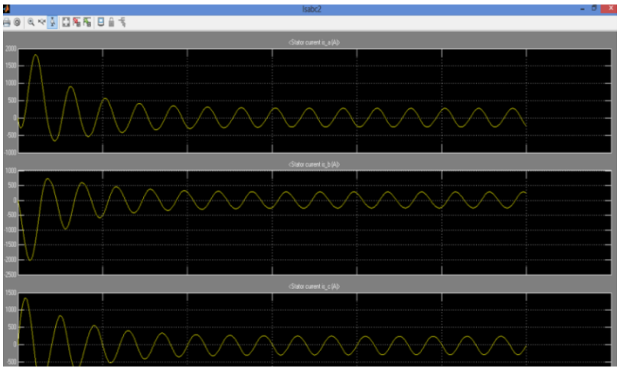

Figure 8. Induction Motor stator Currents of Phases a, b, c

3 –Phase Stator Output Voltages

Phase a, b, c = 200Volts

7.3. Power and Total Harmonic Distortion (THD):

- The power efficiency of the Multi-junction Solar cell / Output Power of MJSC PV: 44.26 W
- Total Harmonic Distortion: 3.974%

8. Conclusion

A novel approach to utilize the multi-junction solar cell photovoltaic for grid connected renewable energy sources is contributed in this paper and a suitable model is developed. The single MJSC generate more wattage, as compared with normal or regular silicon PV cells. The InGaP/GaAs/Ge combinations offer a very good performance in tandem cell. It is shown that P&O technique offered to MJSC PV is able to achieve maximum power point tracking. Multilevel inverters are currently used for integration of renewable energy sources for both higher voltages and higher power applications because of its ability to minimize the harmonic distortion by synthesizing the waveforms. The switching strategy used for cascaded H bridge multilevel inverter grid connected is able to reduce the total harmonic distortions. Simulations and tests confirm the results of theoretical analysis, and show good performance in terms of load voltage, current and reduced harmonic distortion.

Future Work

The paper has limited the work to solar renewable energy sources but other renewable energy sources are required to be implemented in future as hybrid micro grid. New topologies will be designed to reduce the switches and DC sources for cascaded multilevel inverters with minimum voltage levels.

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