CASCADED MODULAR MULTI-LEVEL INVERTERS WITH ACTIVE & REACTIVE POWER CONTROL OF LARGE SCALE GRID CONNECTED PV SYSTEM WITH FUZZY LOGIC CONTROL APPROACH

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ABSTRACT
Due to its advantages like clean energy production and more abundance availability solar energy is the most concentrated topic from last 20 years. Grid connected PV system gaining its importance due to high demand of power across the globe. Now a days different topologies of Multilevel Inverters are developing. By using this multilevel inverters we can interface the PV systems with Grid easily and effectively. But PV system facing so many problems like power flow control and output voltage disturbances because PV systems produce irregular output voltages. This paper demonstrates the Cascade Multilevel inverter with Active and Reactive power control using Fuzzy logic control approach of for Grid Connected PV System. With the help of this model we can improve the performance of the total PV system. In this paper we proposed a 3-MW, 12-kV PV system with the Fuzzy Logic control strategy is modelled and simulated in MATLAB.

KEYWORDS: Fuzzy Logic Control, PV System, Multilevel Inverter.

INTRODUCTION
Due to over population and industrialization the demand for electrical power is increasing more and more. Fossil sources also depleting day by day. In order to achieve the power demand renewable energy sources are the best alternative. Among all renewable sources Solar energy is most popular and having more abundance all over the globe and as well as pollution concern also PV system is the best alternative in renewable sources. After development of new power electronic devices it is becoming easy to establish large scale PV generating systems. There are mainly two types of generating systems in PV. One is small scale PV system and another one is large scale PV system. Small scale PV systems are mainly used in Distributed Generating systems (DG).The problem with PV DG system is for designing this system high voltage gain need to be required [1-4]. In order to achieve this high gain we are choosing Grid connected PV system that is Large scale Grid connected PV system.
In Grid connected PV system Power Electronic devices such as converters and inverters are main parts along with PV panels. Converters are used for stepping up the voltage which is produced by PV panels. Voltage source inverters are needed for conversion of DC-AC supply and for getting MPPT or stabilizing the DC voltage. Cascaded Modular Multilevel Inverters having so many advantages like improved Waveform quality and less THD etc. For interfacing Large scale PV system with Grid the main medium we requires is this Cascaded Modular Multilevel Inverters [5]. Thus Large scale PV systems with Cascaded Modular Multilevel Inverters are facing some severe problems like mismatch of MPPT power values of each Module, Thermal gradient, dirt etc. In this entire system the input for grid is given by Cascaded Multilevel inverter which converts DC output from DC-DC converter to AC supply for each phase of grid. If the output of Inverter is mismatch to the grid requirements then active power flow will get disturbs [6, 7]. For example if a converter module having high active power generation then automatically that module will supply more AC supply to the grid this may cause degrade of power quality due to over modulation. In Order to overcome this problems proper control strategies are developing for this large scale cascaded PV systems. There are different control techniques for cascaded PV system. For DC-DC converter we will use MPPT control technique for stabilizing DC [8] voltage and for Multilevel inverter we will use any of the PWM control techniques along with PI controller etc. By using this methods we can’t achieve Reactive power compensation and design of PV system wise also some problems are there like leakage current etc [9-12].

In this paper we proposed a large scale PV system interfaced with grid by means of a Current fed dual active Bridge DC-DC converters and Cascaded Modular Multilevel Inverter which is controlled by fuzzy logic controller along with PI controller. By using this topology we can get symmetrical active power in all modules and thus we can get reactive power compensation easily.

This paper consists of two stage large grid connected PV system circuit in section II. And in section III control techniques used for both DC-DC converters and Multilevel Inverters are described briefly. In section IV simulation done by using Matlab-Simulink with 12 Cascaded PV Inverter modules with proposed decoupled active and reactive power control by using fuzzy logic controller and finally ended with conclusion in Section V.

CIRCUIT TOPOLOGY AND DESIGN PARAMETERS

A. Circuit Topology

Block Diagram for large scale Cascaded PV system is shown in Figure-1. Only single phase circuit is shown in the figure. And the proposed large scale cascaded PV system is showed in Fig (2), which gives the three phase large scale Cascaded PV system in which two stages of power conversion takes place. In 1st stage power harvested from solar panel is given to DC-DC converter for Boost or Buck action i.e for voltage stabilization we are using Current Fed Dual Active Bridge DC-DC converters. The end of this CF-DAB DC-DC converters are connected with cascaded Modular Multilevel Inverters with High Voltage Insulation.
In this configuration no need of line frequency transformers, Inverter module is directly connected to grid without any line Frequency Transformers. This is the one of the main advantage of this model compared to conventional methods. In DC-DC converter module each of the individual section is connected to one PV panel this is nothing but we are achieving MPPT for each section independently so we can harvest more solar energy. This paper is focused on applying of Fuzzy Logic Control to Modular Multilevel Inverter with active and reactive power control of Grid connected Cascaded PV system.

B. Design Parameters
This paper proposes A 3MW/12KV line to line voltage PV system. And number of cascaded inverters are 4 i.e n is 4. Each phase can produce 1MW then from this each inverter module
can produce 250Mw of power. The average Dc voltage of individual inverter is 3000V. The switching frequency of each power device is 5KHZ. We are using $ inverters per phase so each phase PV inverter can generate 9 level output. Ldc1 and Ldc2 are DC inductors used in DC-DC converters, Ls is the leakage Inductor. High frequency capacitor is used in parallel with PV panel Cpv. High frequency transformer is connected between Low Voltage side of converter and High Voltage side of converter with having turns N. CLV and CHV are capacitors corresponds to Low Voltage Side and High Voltage Side. The circuit parameters are tabulated in Table-1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Capacitor voltage</td>
<td>$V_{dc}$</td>
<td>3000 V</td>
</tr>
<tr>
<td>DC Capacitor size</td>
<td>$C_d$</td>
<td>400 uF</td>
</tr>
<tr>
<td>Filter inductor</td>
<td>$L_f$</td>
<td>0.8 mH</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$f_w, f_c$</td>
<td>5 kHz</td>
</tr>
<tr>
<td>Number</td>
<td>$j$</td>
<td>5</td>
</tr>
<tr>
<td>Capacitor voltage in low voltage capacitor</td>
<td>$V_{L, i}$</td>
<td>300V</td>
</tr>
<tr>
<td>Capacitor voltage in low voltage capacitor</td>
<td>$V_{L, f}$</td>
<td>600V</td>
</tr>
<tr>
<td>Transformer turn ratio</td>
<td>$N$</td>
<td>2</td>
</tr>
<tr>
<td>PV arrays output voltage</td>
<td>$V_{pv, i}$</td>
<td>100 V - 200 V</td>
</tr>
<tr>
<td>Leakage inductor</td>
<td>$L_e$</td>
<td>2.5 µH</td>
</tr>
<tr>
<td>DC inductor value</td>
<td>$L_{dc,1}, L_{dc,2}$</td>
<td>12.5 µH</td>
</tr>
<tr>
<td>Capacitor in high voltage side</td>
<td>$C_{HV}$</td>
<td>2 mF</td>
</tr>
<tr>
<td>Capacitor in low voltage side</td>
<td>$C_{LV}$</td>
<td>300 uF</td>
</tr>
<tr>
<td>PV arrays output capacitor</td>
<td>$C_{PV}$</td>
<td>100 uF</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$f_w, f_c$</td>
<td>50 kHz</td>
</tr>
</tbody>
</table>

DESIGNING AND CONTROL TECHNIQUE

A. Current Fed Dual Active Bridge(CF-DAB) DC-DC Converters Control

Figure-3 shows the CF-DAB DC-DC CONVERTERS control for individual Unit of DC-DC Converter module [18]. The same technique can be used for all the modules. As the name itself tells Dual Active Bridge, This control has two degrees of Control Freedom. The main parameters used in this control technique are Duty cycle (D) and Phase shift angle ($\phi$), by which PV panel voltage and Low voltage Side voltage is controlled The Duty cycle bandwidth is taken as 10 kHz. Which is must higher than 100HZ, Thus MPPT is achieved in PV panel. In this paper a simple high bandwidth PI controller is applied. Power transferred from LVS to HVS is given by the phase shift angle $\phi$.VLV is controlled by VHV/N i.e high voltage divided by number of turns.
B. Fuzzy Logic Controller for Cascaded Modular Multilevel Inverter:

Fuzzy controller is the robust control technique used for Multilevel Inverters and PMSM motors etc. The main parts in fuzzy system are Fuzzy Membership Functions and Fuzzy sets. The Block diagram for Fuzzy logic controller is shown in Fig(4).

![Figure-4 Fuzzy Logic Controller Block Diagram](image)

Inputs for this fuzzification process are called crisp inputs. In this method reference signal is compared with Pulse width Modulation output and then error signal will produce. In this paper we used the double-loop dq control based on discrete Fourier transform PLL method is applied to achieve the active and reactive power distribution. If we use Fuzzy logic with this method we can get less distortion in output and improved THD. Simulink Model of Multilevel inverter control technique along with Fuzzy logic controller is shown in Figure-5. In the proposed control, individual voltage outer loop controls dc voltage of each inverter module to track the reference \( V = \text{dc} \) by the fuzzy controller.

![Figure-5 Rule Base](image)

Using the above rules we need to interface the fuzzy logic with input in Fuzzy Interface System.
Therefore, the harvested maximum power from PV arrays with CF-DAB dc–dc converters control can be effectively delivered to grid. Then after the maximum power is fed back to decrease the innerloop action. This allows the closed-loop compensators to have smaller gains and hence increased robustness. The $d$-axis component command of grid current $I_{gd}$ is synthesized \cite{15-18} by the multiple outputs from the $n$ individual voltage loops. The $q$-axis component command of grid current $I_{gq}$ is obtained based on the desired reactive power $Q_a$. The decoupled current loop controls the $dq$-components of grid current $I_{gd}$ and $I_{gq}$ to track the references $I_{gd}$ and $I_{gq}$, and then generates the total output voltage regulation $\Delta v_{sa \ d}$ and $\Delta v_{sa \ q}$, respectively. The $dq$ components of grid voltage, $v_{gd}$ and $v_{gq}$, are feedback to the output voltage to improve the system dynamic performance, respectively \cite{36}. The output voltage signal $v_{sd}$ is synthesized by $\Delta v_{sa \ d}$, $v_{gd}$ and decoupled variable $\omega L \tau_{fig q}$. The output voltage signal $v_{sq}$ is composed of $\Delta v_{sqrt q}$ and $v_{gd}$ and decoupled variable $\omega L \tau_{fig d}$. Subsequently, $v_{sd}$ and $v_{sq}$ are sent to the “active and reactive components extraction” module, which produces the decisive active and reactive components, $v_{sad}$ and $v_{saq}$ by synchronizing with $I_{ga}$. And then the “voltage distribution and synthesisization” module divides the $v_{sa \ d}$ and $v_{sa \ q}$ into the $n$ cascaded PV inverter modules according to their respective active and reactive power contribution \cite{13-14}.
SIMULATION RESULTS
The large-scale grid-connected cascaded PV system with the Fuzzy Logic control strategy is simulated in MATLAB/Simulink. Simulation Results of Grid power that is both active and reactive power and Grid Current, Grid Voltage in phase-\(a\) is shown in Figure-6. The same results will come in phases \(b\) and \(c\). The three phase output of Grid power and grid current, Voltage is shown in Figure-7. In this paper, the reactive power injection into grid (inductive reactive power) is defined as negative and reactive power absorption from grid (capacitive reactive power) is defined as positive. The active power injection into grid is defined as positive and active power absorption from grid is defined as negative. And THD values of the system for both tradition control techniques and Fuzzy logic Control system is compared in Table-3.

![Figure-6 (a). Grid power](image)

![Figure-6 (b). Grid current](image)
Figure-6 (c). Reactive Power of PV Modules

Figure-6 (d). Active Power of PV modules

Figure-6 (e). Dc Voltage

Figure-6 Simulation results of proposed PV system with decoupled active and reactive power control in phase $a$. 
Figure-7 (a) 3-Phase Grid Voltage

Figure-7 (b) 3-Phase Grid Current

Figure-7 (c) Active Power To Grid
Figure 7 (d) Reactive power To Grid

Figure 7 (e) DC Voltage in Phase a

Figure-7 Simulation results of PV system with the Fuzzy Logic control in three phase

<table>
<thead>
<tr>
<th>Topology</th>
<th>THD Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV System with PI Control techniques</td>
<td>3.98%</td>
</tr>
<tr>
<td>PV system with Fuzzy Logic Control technique</td>
<td>0.45%</td>
</tr>
</tbody>
</table>

Table-3 THD comparison

CONCLUSION

This Paper Addresses the Reactive and active power flow in Large Scale PV system and compare the traditional control techniques with Fuzzy Logic Control system. Finally we proposed a Fuzzy logic control technique for large scale grid connected PV system which gives better THD values compared to other techniques.
REFERENCES


