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A FUZZY CONTROLLED TRANSFORMER LESS SINGLE PHASE INVERTER FOR REACTIVE POWER COMPENSATION IN GRID TIED PVG SYSTEM WITH WATTLES POWER CONTROL

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ABSTRACT

The Wide growth in the world population demands the development of renewable energy sources. Among all there has a great demand for photovoltaic (PV) power generation system as it proves to be more efficient than other sources. In present generation the transformerless inverter topologies have proved to be more efficient, less cost and maintains less leakage current by removing the conventional frequency transformer. The flow of leakage current between the PV module and the grounded grid is very damaging due to the unstable voltage and lack of galvanic isolation. Which is reduced with the transformerless inverter for grid connected photovoltaic system. It also have the ability to manage the good amount of reactive power which will helps to maintain constant common mode(CM) voltage. A fuzzy logic controller(FLC) and PR controller is used in this topologies to maintain high quality current injected to the grid.

Keywords: Common mode voltage (CM), parasitic capacitance, reactive power, Fuzzy logic controller, Transformer less inverter.

1. INTRODUCTION

The Electrical power is playing a crucial role for the needs of human growth and development. But as there is a shortage of natural resources for generation of power the world is switching for renewable energy sources such as sunlight based solar, wind, tidal and so on are few of such choices that can solve the issue of energy shortage. Among them solar power is consider as a better option to meet the demand of today's generation as it is pollution free. The usage of power electronic devices and photovoltaic modules were increased rapidly. They were used in grid connected pv system which plays main role in distribution of power. For the safe usage of the system galvanic isolation transformers are used in grid connected photovoltaic system. The galvanic isolation protects the grid from injection of dc current and reduces the leakage current. By using high frequency transformers on the DC side and low frequency on inverter side the overall efficiency of the system is reduced. In order to overcome this problem transformer less grid tied PV system is employed.

When the galvanic isolation transformer is neglected then the leakage current is increased, the coomom mode (CM) voltage change at grid side is occurs with the effect of parasitic capacitance. This common mode voltage fluctuation depends on the switching scheme and topology structure hence which leads to capacitive leakage currents. The grid harmonic currents increases and also the system losses due to these leakage currents. Grid-tied transformer less PV inverter has the ability to inject reactive power into the utility grid. Certain rules have been urged to maintain minimum reactive power handling by the grid connected photovoltaic inverter system.

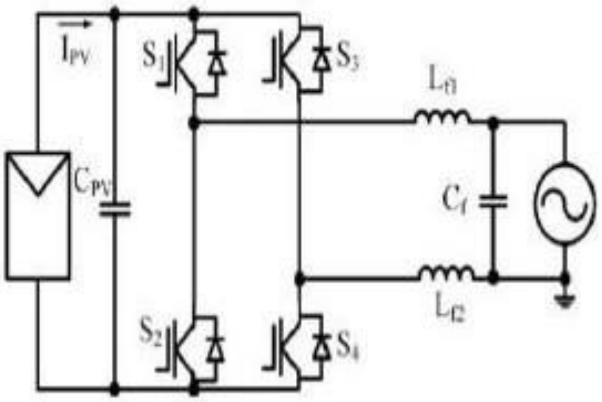

Figure 1: The single phase H-bridge inverter

The basic structure of H- Bride photovoltaic transformerless inverter is shown in figure 1 which is used in PV system in previous days.

This topology have advantage and also disadvantage with it, as it has the ability to generate reactive power to the grid and as high switching losses in IGBTs. To overcome these disadvantages High efficient Reliable Inverter circuit (HERIC) is used which is shown in figure 2. Unipolar topology is implemented to reduce the core and switching losses. The reverse recovery voltage is occurred in the MOSFET switches when High efficient Reliable Inverter circuit (HERIC) is used in reactive power.

H6 Single phase transformerless inverter topology shown in figure 3 whichmade from single phase H-bridge inverter by adding extra switches in the DC side of the full bridge inverter. If we see an example of this system with an input oltage of 345V dc and switching frequency 1Khz then it have an efficiency of 98%. However, this topology has high conduction losses due to the fact that the current must conduct through three switches in series during the active phase. Another disadvantage of the H5 is that the line frequency switches S1 and S2 cannot utilize MOSFET devices because of the MOSFET body diode's slow reverse recovery.

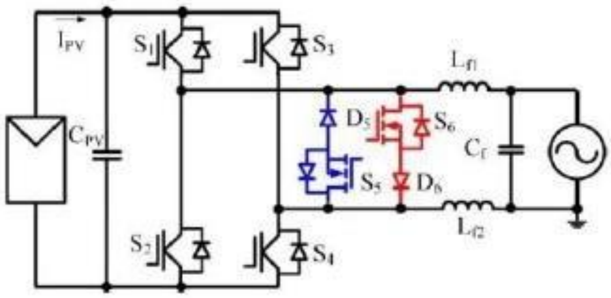

Figure 2: The HERIC inverter with paralleled auxiliary freewheeling switches

MOSFET switches were used in transformerless inverter, implementation of this topology cis shiwn in figure 4 as a dual- parallel buck inverter which is used to eliminate the high conduction losses problem in the H4 and H5 transformerless inverter topologies as there were two switches used in series with the current flow during positive half of the cycle. This arrangement is to improve the reliability of the system comes at high zero crossing distortion for the grid current output. The main drawback of using this system is the switches using here are all MOSFET diobes bodies are working when the phase difference comes between grid current and grid voltage. Which will have high impact on the decreasing of system reliability.

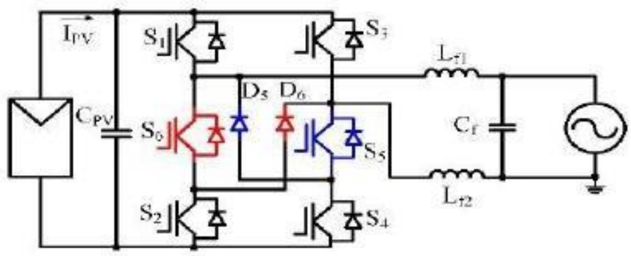

Figure 3: The H6 inverter topology

In the process of developing a transformer less inverter we have to consider two major issues in it. Firstly the issues of high efficiency and reliability. We have to use MOSFETs in all switching devices to achieve maximum efficiency at full load range of transformerless PV inverter. Secondly the transformerless inverter should not be having any shoot-through problems for maximum reliability. To eliminate these two major issues a new topology is proposed for the Single phase transformerless grid-ties SPV system.

The another important function for grid connected photovoltaic systems are generation real power and compensation of reactive power.in this paper implemented with two current controllers are Fuzzy controller and PR controller. These current controllers are effectively generate grid current and also maintain power flows between the grid and system. The PR controller can maintain the grid current in phase with the grid voltage by the inverter, so unity power factor can achieved. The PR+HC controller are minimize lower order odd harmonics components present in inverter output current, and also these are gives high gain at resonant frequency. Therefore the system study state error reduce to zero. Due this THD value of the system has been decreased. Therefore these controllers can reducing harmonic currents rejection and steady state errors as compared to the PI controllers.

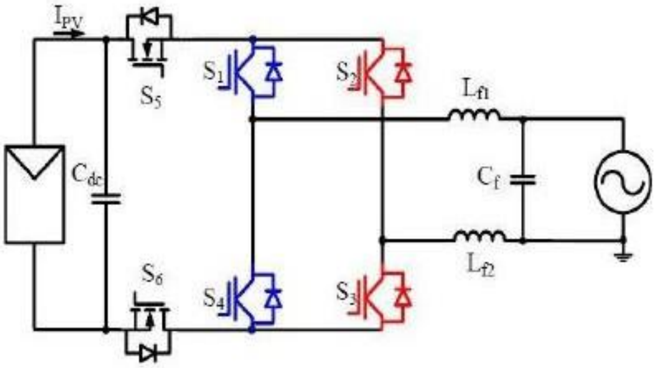

Fig .4: The symmetrical H6 inverter topology

In this Paper a new topology in single phase transformerless inverter grid-tied SPV system is developed. In Section II the circuit structure and operation principal of proposed topology is present.in section II, structure of the circuit and operating principle of proposed topology is presented. Next in section III, common mode characteristics of the system presented. Later in section IV, control methods of the system are presented. In section V, presents the simulation results of the proposed topology with real and reactive power using fuzzy controller and PR controller. that theoretical analysis is initially verified in MATLAB Simulink software environment and results are presented.

2. PROPOSED TOPOLOGY ANDOPERATING PRINCIPLE

A. System Configurations

The proposed topology of Single phase transformerless inverter is shown in figure 5 with 6 MOSFETs switches in it from S1 to S6 along with 6 diodes in anti parellel from D1 to D6. It consistes of LCL type filtered inductors coupled L_{1A}, L_{2A}, L_{1B}, L_{2B}, L_{1g}, L_{2g} to the grid. The input dc voltage and dc link capacitor are named as Vpv and Cdc respectively. It contains low reverse recovery issues in the proposed topology when reactive power is injected into the grid. In order to over come that problem the proposed topology is developed with high efficiency and maximum reliability. It can be considered as unipolar SPWM with 3 level output voltage.

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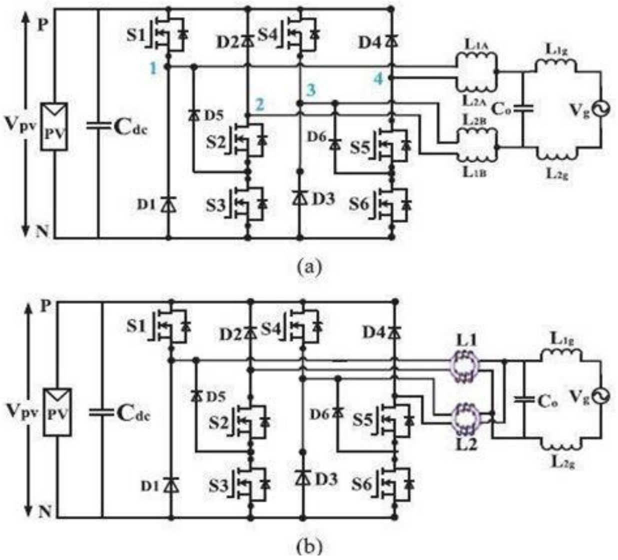

Figure.5 :(a) Circuit of the proposed transformerless topology for grid tied PV system
(b) Circuit with coupled inductor.

B. Control approach of proposed topology.

The switching pattern of the proposed topology as shown in fig.6 where the switches S1,S2,S3,S4,S5,S6 signifies main switches and their operating Gate signals are G1,G2,G3,G4,G5,G6 respectively. The principle of operation of the proposed topology is classified in to four regions as shown in Fig5. The proportional operation of the positive and negative half cycle of the grid current are same, therefore here positive half cycle has discussed .however the negative half cycle operation is shown in Fig.7.

Region I: In this region, both the grid voltage and grid current are positive. During the period within this region S2 is always on, while S1 & S3 synchronously and S5 complementary commutate with switching frequency. There are always two states that generate the output voltage of + VPV and 0.

State 1 (t0:t1): At t = t0, the switches S3& S1 are switched on and the current through inductor rises through grid as shown in Fig.7 (a). In this state, the voltages V1N and V2N can be defined as: V1N = + VPN and V2N = 0, thus the output voltage of inverter V12 = (V1N -V2N) = + VPV.

State 2 (t1:t2): When the switches S1 and S3 are turned-off, the current through inductor freewheels through D5 and S2 .In this state,V1N falls and V2N rises until their values are equal.

Therefore, the voltages V1N and V2N becomes: V1N = VPV /2 and V2N = VPV /2 and the inverter output voltage V12 = 0

Region II: In this region, the inverter output voltage is negative, but the current remains positive. During the period of this region, S5 is always on, while S6 & S4 synchronously and S2 complementary commutate with switching frequency. There are also two states that give the output voltage of – VPV and 0.The negative half cycle operated in two states that produce the output voltage of – VPV and 0.

State 3 (t_3:t_4):In this state, the switches S_6 and S_4 are turned-on and the filter inductors are demagnetized. Since the inverter output voltage is negative and the current remains positive; therefore, the inductor current is forced to freewheel through the D_1 and D_2 diodes and decreases rapidly for enduring the reverse voltage as shown in Fig. 7(c). The voltages V_{1N} and V_{2N}can be defined as: V_{1N}= 0 and V_{2N} = + V_{PV}, thus the inverter output voltage V_{12} = (V_{1N}– V_{2N}) = – V_{PV}

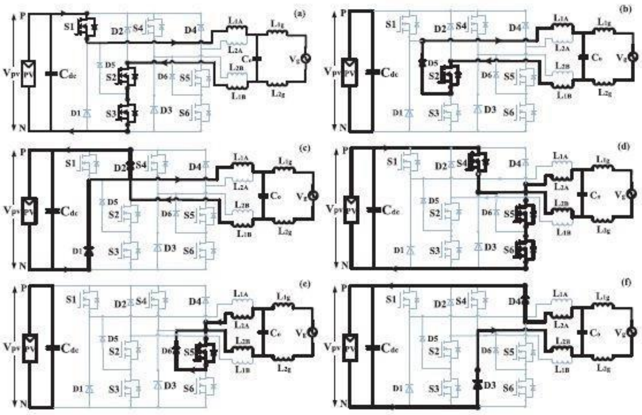

Fig.6: Switching sequence of this proposed topology.

State 4 (t_4:t_5):At t = t_4, the switches S_6 and S_4 are switched off and S_2 is turned-on. Therefore, the current allows through D_5 and S_2 like as state 2 (Fig. 7(b) can be referred as equivalent circuit) in inductor. This state is called as energy storage mode**.**

The voltages V1Nand V2Ncould be: V1N= VPV /2 and V2N= VPV /2, and thus the inverter output voltage, V12 = 0.
According to the principle of operation of this topology presented, the total CM voltages can be calculated for each state of positive half cycle operation as follows:

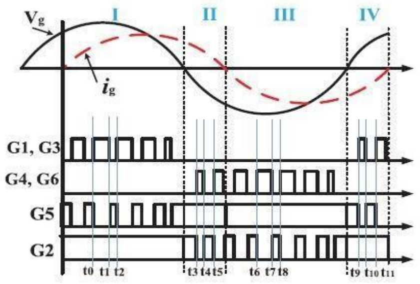

Figure 7: The operating principle of the proposed topology: ***(a) state 1 (b) state 2 (c) state 3 (d) state 4***

It is clear from equations (7)-(10) that the total CM voltage for this topology is kept same at $V_{pv}/2$ during positive half cycle operation. Likewise, the total CM voltage for the negative half cycle operation can be calculated and found to be constant at $V_{pv}/2$ due to the symmetry of operation for the negative and positive half cycle of grid current. The only variation is the activation of different power devices. Hence, it can be summarized that the total CM voltage during the entire grid cycle is kept same, decreasing ground leakage current**.**

3 .CONTROLLER DESIGN FOR SINGLE PHASE GRID TIED TRANSFORMERLESS INVERTER

The controlling structure of the proposed topology has shown in figure 8, this contains orthogonal signal generator (OSG) system for calculations of active and reactive power of the system, Two fuzzy logic controller for grid current controlling, and SPWM generation block In single phase grid connected transformerless inverter, two controllers are developed. One is the Fuzzy Logic controller (FLC) and PR Current controller.

The current controller takes care of the quality of current injected into the grid and the power interchange between the system and grid.$I_{g\alpha}$ reference which is in phase with the grid voltage controls the real power of the system and the orthogonal component $I_{g\beta}$ reference controls the reactive power exchange of the system with the grid. Hence a decoupled control of reactive and real power can be achieved.

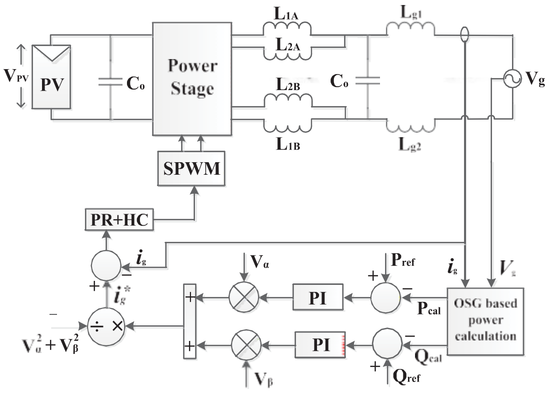

Figure 8 : Block diagram of control of proposed system with Fuzzy Logic controller

A. Fuzzy Logic controller

The fuzzy logic controller (FLC) mainly consists of two inputs in it namely error and change in error, the error is obtained by comparing the reference input signal with an output signal which is checked with respect to time that is called as a change in error. The functioning of FLC consists of four chief essentials in the structure as fuzzification, inference mechanism, rule base, and defuzzification. When these inputs are given to the fuzzy logic controller then fuzzy logic controller decided what would be the output of this controller using fuzzy rules which are settled by fuzzy controller designer. Similarly, the fuzzy logic controller output is given to the output of VSC.

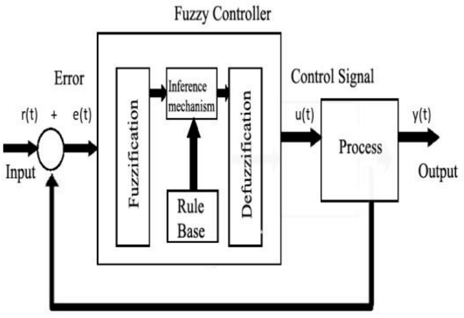

Figure 9: Structure of the Fuzzy Logic Controller.

The fuzzification component consists of two supplementary components that are called membership function and labels. The fuzzy logic controller converts input data or variable data into fuzzy membership functions according to user-defined chart. The Membership functions differ as Triangular, Gaussian, Trapezoidal, and Generalized Bell in addition to Sigmoid.

The inference mechanism component of the fuzzy logic control system consists of fuzzy rules which are settled by the controller designer shown in figure 6. Based on these fuzzy rules, the controller decided the output of the fuzzy logic controller. This is the main perceptive control of this system. The rule base is used to govern the output variable. The rule base is based on the IF-THEN rule with an exact condition and conclusion, characterized by the matrix table. Error and change in error are the two variables filled along the axes. An extreme operation is defined by the output of the membership function in the rule base. The fuzzy rule base is typically changed by the change in input

TABLE.I. FUZZY RULE BASE TABLE

E/ ΔE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	PL
NM	PL	PL	PM	PL	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

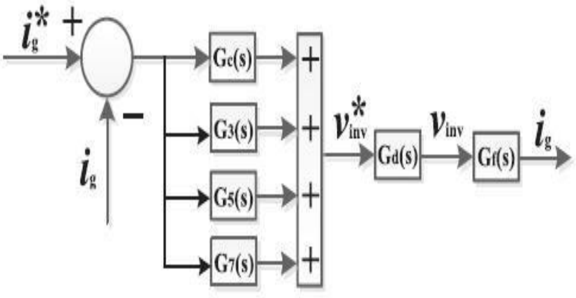

Figure 10: Block diagram of PR controller with harmonic compensator

The defuzzification component of fuzzy logic converts which controls the non-fuzzy value by defuzzification of the fuzzy set as the fuzzy data values into real life data values after examining the fuzzy rules but these real-life data values depend upon the Defuzzification method. The duty cycle is obtained as the output of FLC, which is used to control the boost converter operation. Different methods are used for the Defuzzification process such center of gravity (SOG), smallest of maxima (SOM), mean of maxima (MOM) and weighted average method. Each method has different advantages and disadvantages. These methods are set by the controller designer. FLC has more benefits as Low-cost executions founded on cheap sensors, low- resolution analog-to-digital converter. the I/O variables are expressed in seven grammatical labels such as negative large (NL), positive large (PL), negative medium (NM), positive medium (PM), zero (Z), negative small (NL) and positive small (PL). If the E is NL and 6E is NL, the duty cycle is PL, such that the duty cycle is largely increased and a similar manner for all the membership functions.

B.Proportional Resonant Current Controller

The PR current controller is utilized in the stationary frame which is different from the traditional PI controller. Due to no transformation from stationary frame to synchronous frame, the computation pattern of this controller is simple. For these cases, processor which is less in cost can be used. Besides, when grid imbalances or a sensing error occurs, this controller is more robust than the PI controller. Especially, the PR controller is suitable for constant frequency operation in the grid-connected system.

Generally, the PI controller has disadvantages such as issue in eliminating the steady-state error in a stationary reference frame. This controller structure has obtained familiarity due to its ability of removing steady- state error when regulating sinusoidal signals. Moreover, the simple execution of a harmonic compensator without any counter cause on the controller results prepares this controller well befit for grid-linked systems.

The block diagram of the PR controller with harmonic current compensator is shown in Fig.13 where Gc(s), Gh(s), and Gd(s) are the transfer function of fundamental current controller, harmonic compensator, and inverter respectively.

The transfer function of the PR controller is defined below:

PARAMETERS OF SYSTEM

TABLE.II. System parameters

Inverter Parameter	Value
Input Voltage	400 V DC
Grid Voltage /Frequency	230V/50 Hz
Switching Frequency	20kHz
DC bus capacitor	470
Filter Capacitor	2.2
Filter Inductor L_{1A},L_{2A} ,L_{1B} ,L_{2B}	1 mH
Filter Inductor L_{g1}, L_{g2}	0.5 mH
PV Parasitic Capacitor C_{PV1},C_{PV2}	75 nF

4. SIMULATION RESULTS

This topology of single phase transformerless inverter grid-tied SPV system was analysed and performed with the help of MATLAB?/SIMULATION SOFTWARE. The parameters considered in the simulation are shown in table 2. In this simulation network PV modules were replaced with 400v DC Voltage source. Capacitors are used between ground and the PV modules namely Cpv1 and Cpv2 respectively. These were emulated using thin film capacitor of 75nf. In this topology common mode voltage (CMV), leakage current and the performance of proposed topology under changes of reactive and real power are discussed

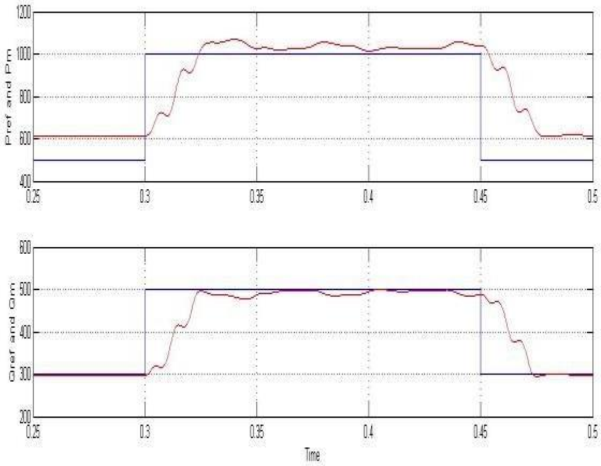

Fig.11. Performance of Grid active and Reactive Powers

$$G_h(s) = \sum_{h=3,5,\ldots\ldots} \frac{K_{ih}s}{s^2+(hw_f)^2}$$

$$G_c(s) = K_{pi} + K_{ii} * \frac{n}{s^2 + w^2}$$

$$G_d(s) = \frac{1}{1 + 1.5T_s s}$$

The common mode voltage for proposed in this system with real and reactive powers are expressed as positive half cycle and forms common mode voltage (V1N+V2N)/2. The negative half cycle of commom mode voltage (V3N+V4N)/2. The RMS value leakage current flow iw shown in figure 12. The mode of operation and simulation of commom mode (CM) voltage (V1N, V2N, V3N, and V4N) are shown in figure 13.

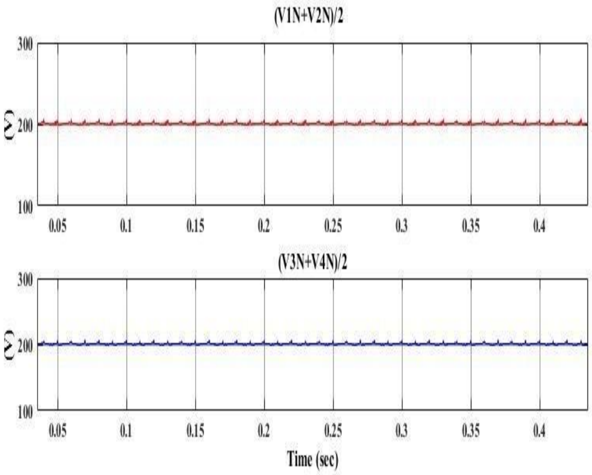

Fig.12.Common Mode voltage levels

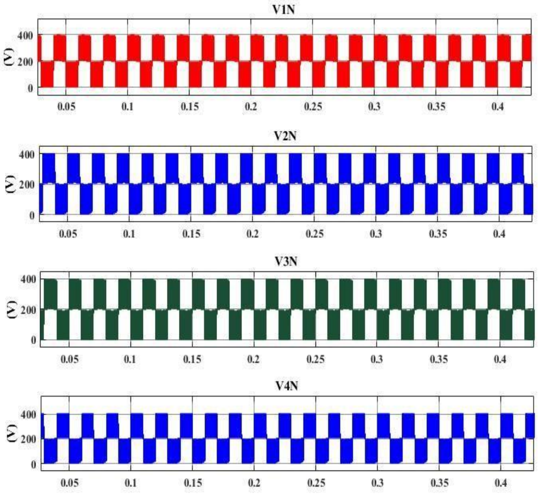

Fig.13.Common Mode characteristics of the H6topology

The performance of this proposed topology is simulated under changes of both P_{ref} and Q_{ref}. This simulation shows change in the grid current with change in the load and the reference power is tracked by active and reactive power. This topology have very low distortion voltage and current in the grid so the leakage current flow in the system will also decreased.

CONCLUSIONS

This proposed topology helps to improve the current floe fromm SPV system with the help of FLC (fuzzy logic controller). This single phase transformerless inverter system topology and its regulation model was developed with the help of MATLAB/SIMULATION. The PR controller and Fuzzy logic controller are helped to improve the system response, were the output current of the transformerless inverter was pure sinusoidal performance is Improved and the THDs of the grid currents and voltages are found less than 5% (within IEEE – 519 standard).

REFERENCES

[1] M. Pavan and V. Lughi, "Grid parity in the Italian commercial and industrial electricity market," in Proc. Int. Conf. Clean Elect. Power (ICCEP'13), 2013, pp. 332–335.

[2] M. Delfanti, V. Olivieri, B. Erkut, and G. A. Turturro, "Reaching PV grid parity: LCOE analysis for the Italian framework," in Proc. 22nd Int. Conf. Exhib. Elect. Distrib. (CIRED'13), 2013, pp. 1–4.

[3] Gu B, Dominic J, Lai JS, Zhao Z, Liu C. High boost ratio hybrid transformer DC–DC converter for photovoltaic module applications. IEEE Transactions On Power Electronics. 2013Apr;28(4):2048-58.

[4] Ribeiro E, Cardoso AJ, Boccaletti C. Fault-tolerant strategy for a photovoltaic DC--DC converter. IEEE Transactions on Power Electronics. 2013Jun;28(6):3008-18.

[5] Chen YM, Huang AQ, Yu X. A high step-up three-port dc–dc converter for stand-alone PV/battery power systems. IEEE Transactions on Power Electronics. 2013Nov;28(11):5049-62.

[6] Jain C, Singh B. A Three-Phase Grid Tied SPV System With Adaptive DC Link Voltage for CPI Voltage Imbalance. IEEE Transactions on Sustainable Energy. 2016Jan;7(1):337-44.

[7] Xiao W, Edwin FF, Spagnuolo G, Jatskevich J. Efficient approaches for modeling and simulating photovoltaic power systems. IEEE Journal of Photovoltaics. 2013Jan;3(1):500-8.

[8] Hill CA, Such MC, Chen D, Gonzalez J, Grady WM. Battery energy storage for enabling integration of distributed solar power generation. IEEE Transactions on the smart grid. 2012 Jun;3(2):850-7.

[9] Debnath D, Chatterjee K. Two-stage solar photovoltaic-based stand- alone scheme having battery as energy storage element for rural deployment. IEEE Transactions on Industrial Electronics. 2015 Jul;62(7):4148-57.

[10] Lyden S, Haque ME. A simulated annealing global maximum power point tracking approach for PV modules under partial shading conditions. IEEE Transactions on Power Electronics. 2016 Jun;31(6):4171-81

[11] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, “A variable step size INC MPPT method for PV systems,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2622–2628, Jul. 2008.

[12] S. Deo, C. Jain, and B. Singh “A PLL-Less scheme for single-phase grid interfaced load compensating solar PV generation system,” IEEE Trans. Ind. Informat., vol. 11, no. 3, pp. 692–699, Jun. 2015.

[13] B. Singh, D. T. Shahani, and A. K. Verma, “Neural network con- trolled grid interfaced solar photovoltaic power generation,” IET Power Electron., vol. 7, no. 3, pp. 614–626, Jul. 2013.

[14] C.-S. Lam, W.-H. Choi, M.-C. Wong, and Y.-D. Han, “Adaptive DC-Link voltage-controlled hybrid active power filters for reactive power compen- sation,” IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1758–1