Reactive Power Control for Grid Tied PVG System with ANN Based Transformerless Inverter

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Abstract: The Rise in power demand with growing population across the world has led to the development of renewable energy sources. Amongst all the renewable energy sources PV power generation system proves to be more superior and efficient than other renewable sources. Recent innovations in transformerless inverters have proven to be efficient and reliable than conventional ones. The major difficulty in handling the transformerless inverter is the leakage currents, which is for the reason that parasitic capacitance is in between PV array and ground. This leakage current leads to several protection issues along with unstable CM voltages. Here the recommended transformerless inverter aimed at grid connected PV system has capability to reduce leakage currents. It also provides the required reactive power to the system to maintain constant CM voltage. To provide high quality current injection into the grid, PR controller and fuzzy controller are used. In this study the detailed analysis of the operating modes of the H6 PV transformer less inverter system, investigation of the leakage currents and outcomes obtained in MATLAB simulation are to be presented.

Key Words: Common mode (CM), parasitic capacitance, reactive power, ANN controller, Transformer less inverter.

I. INTRODUCTION

With the rapid growth in population the demand for electrical power has been increasing and there has been a limitation on usage of natural resources. In order to meet the electrical power demand there has been great interest towards renewable energy sources[1]. Among all the renewable sources solar power is measured to be the better one in order to meet the demand since it is pollution free and inexhaustible. With the rapid increase in power electronic devices and incentive beneficiary from the government, PV module price decreases, and so grid-connected PV systems plays an important role in distributed power generation. Typically galvanic isolated transformers are used in grid connected PV machine for protection reason. Galvanic isolation prevents DC current injection into the grid and the leakage currents between grid and PV module are reduced [2]. By the usage of high frequency transformers at the DC aspect and low frequency on inverter facet the overall performance of the system is decreased. In order to overcome this problem transformerless grid tied with PV system is employed.

In this paper a new scheme of grid connected PV system with full bridge topology inverters are presented under low frequency transformer. With the help of this galvanic isolation [3], it reduces the usage of inverter filter requirement and also eliminates the compliance of electromagnetic interference. Though, converters implanting frequency of the transformer with 50 Hz is huge and transformer is accounted up to 1-2% of power loss.

Aimed at the above reasons, researchers are actively in the study of results for removing line frequency transformer, with a view towards getting maximum efficiency deprived of increase in the cost of converter. The key problem that ascends when you suspend the low frequency transformer is remain at the place of parasitic capacitance amongst solar cells and metal frame of panel [4]. This suggests that leakage current to ground and it can drifted to resonant circuit is collected the line conductors, grounding of MV/LV distribution transformer plus the parasitic capacitance of the PV field. Uncertainty, modest full bridge is used deprived of coupling transformer or else defined variety strategy, high frequency common mode voltage differences at converter output cause abnormal stages of earth leak current, which makes EMI, reduces the security of the arrangement and reason the interruption of device remain to residual current device (RCD).

By removal of galvanic isolated transformer, the leakage currents between grid and PV module are increases, the parasitic capacitance effect occurs and it leads to common mode voltage fluctuation at grid side [5]. This common mode voltage fluctuation be contingent on the switching scheme and topology structure, hence which leads to capacitive leakage currents. These leakage currents increases the grid harmonic currents and system losses. To inject reactive power into system, this PV inverter is interfaced with grid. In recent international regulations certain rules have been imposed regarding minimum reactive power handling by grid-tied PV inverter system.

Previously transformerless H-Bridge inverter is utilized for PV System. The basic simple H-Bridge PV transformer less inverter is shown in figure 1. The principle benefit of this topology is potential to generate reactive to the grid. The main disadvantage of this device is the bipolar pulse width modulation to avoid common mode voltage and excessive switching losses in IGBTs [7].

A High Efficient Reliable Inverter Circuit (HERIC) topology has been utilized to overcome these problems. High Efficient Reliable Inverter Circuit (HERIC) topology in figure 2. For better reduction of core and switching losses, the H6 topology is implemented with unipolar. When HERIC topology operated under Reactive Power Generation, the MOSFET switches cause the reverse recovery voltage issues [8].
Another H5 transformer less topology show in figure 3 which is make from fig1 through addion an second switch at the at DC side of the full bridge inverter. For example when this system preform with input voltage 345V dc and switching frequency 16-kHz then system efficiency has 98%. But, this topology consumes great transmission losses due to that the current necessity conduct over 3 switches in series throughout active segment [9]. Every other drawback of the H5 is line frequency switches i.e., S1, S2 can’t make the use of MOSFET gadgets due to fact that the MOSFET frame diode is gradual reverse recovery.

When we are capable of developed a transformerless inverter predominant troubles are taken into consideration one of the trouble for an excessive effectiveness and consistency transformerless PV inverter remains as a way to gain great performance above an extensive load range is essential to use MOSFET switches for all switching devices [11]. Some other difficulty is that the inverter need to no longer ensure any shoot-via problems aimed at greater reliability. A good way towards discoursing these main issues, a different inverter topology is projected for phase transformerless PV grid-coupled systems.

The important function meant for grid coupled photovoltaic systems are generate real power and compensation of reactive power. This paper implemented with two current controllers i.e., Fuzzy controller and PR controller. These current controllers are effectively control grid current and also maintain power flows between grid and system. The PR controller can maintain the grid current in phase through the grid voltage by the inverter, therefore unity power factor is achieved. The PR+HC controllers are used to minimize lower order abnormal harmonics components existing in inverter output current, also these are gives great gain at resonant frequency. Therefore the system study state error reduce to zero. Due to 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.

II. H6 TOPOLOGY AND OPERATING PRINCIPLE

2.1 Circuit configurations

The H6 transformerless inverter topology shows in Figure 5 and its consists of 6 MOSFETs (S1-S6) along with 6 Diodes (D1-D6). The coupled inductors are L1A, L2A, L1B, L2B, L1g, L2g form the LCL filter adopted to grid and signifies the input is dc voltage in addition dc link capacitor. In H6 topology the MOSFETs body-diodes contains of low reverse-recovery problems after adding the reactive power into the grid [12]. in order to reduce issues present topology developed with high reliability and efficiency. The
suggested topology also comprises of unipolar SPWM through 3 level output voltage.

Fig. 5. (a) H6 topology [12]

Fig. 5(b). H6 Circuit with coupled inductor

2.2 Principle of Operation of H6 topology

The switching pattern of suggested topology is in Fig.6 In this MOSFETs S1, S2, S3, S4, S5, S6 signifies main switches and their operating gate signals G_s1, G_s2, G_s3, G_s4, G_s5, G_s6 are correspondingly. The principle of operation of the suggested topology is categorized into four sections as shown in Fig.5. The proportional operation of the high-quality and the -ve halve cycle of the grid contemporary are identical, consequently right here positive half of cycle has discussed. But then the -ve halve of operation is shown in Fig.7.

Region I: In region I, the voltage of a grid (V_g) and the grid current (I_g) are +ve. All through the duration inside the region I, S2 continually on, though S1 & S3 synchronously and S5 opposite commutate with great switching frequency. There are constantly states that produce the output voltages are in two states i.e +V_{PV} and zero.

State 1(T_0:T_1): At t = T_0, the switches S1 & S3 remain switched on and current via inductor rises over grid as shown in Fig.7(a). Now this time interval , the voltages V_{IN} and V_{2N} may stand define as: V_{IN} = +V_{PV} and V_{2N} = 0, consequently the output voltage of inverter V_{12} = (V_{IN} - V_{2N}) = +V_{PV}.

State 2(T_1:T_2): While the switches S3 & S1 become-off, the current passes through inductor freewheels via D5 and S2. At present this state, V_{IN} drops and V_{2N} rises till their values are identical. Hence, the voltages V_{IN} and V_{2N} become: V_{IN} = V_{PV}/2 and V_{2N} = V_{PV}/2 and inverter output voltage is V_{12} = 0.

Region II: Currently, inverter final voltage exists negative, however, current remains to be +ve. All through the period of this range, S5 is constantly on, even as S6 & S4 synchronously and S2 opposite commutate with great switching frequency. Here are also two states that provide the output voltage of -V_{PV} and zero. The negative 1/2 cycle operated in states to produce the output voltage of -V_{PV} and 0.

State 3(T_3:T_4): Going on the state 3, the MOSFETs S6 and S4 are on and clear out inductors remain demagnetized. For that inverter final voltage is -ve then the grid current rests positive; consequently, the current through the inductor is enforced to freewheel over the D1 and D2 diodes then falls unexpectedly intended forcontinuing the inverse voltage as shown in Fig. 7(c). The voltages V_{IN} and V_{2N} can be well-defined as V_{IN} = 0 and V_{2N} = +V_{PV}, thus the inverter output voltage V_{12} = (V_{IN} - V_{2N}) = -V_{PV}. 

Fig.7. Principle of operation of H6 circuit (a) state 1 (b) state 2 (c) state 3 (d) state 4
State 4(T4:T5). When \( t = T4 \), the switches S6 and S4 are switched off and S2 is turned-on. Consequently, the current allows over D5 and S2 alike as per state 2. Fig. 7(b) can be mentioned as equivalent circuit in inductor. This state is termed as energy storage mode. Then voltages \( V_{IN} \) and \( V_{2N} \) could be: \( V_{IN} = V_{PV}/2 \) and \( V_{2N} = V_{PV}/2 \), and thus the inverter output voltage, \( V_{12} = 0 \).

III. HIGH FREQUENCY CM MODEL OF THE H6 TOPOLOGY FOR LEAKAGE CURRENT ANALYSIS

The Photovoltaic Panel, a Common Mode resonant circuit is to be formed [13]. An alternating Common mode voltage to be predicated in this topology construction plus control layout, due to this resonant circuit formed. And it causes the high ground leakage current flows through the circuit. So as to research the CM features, the equivalent circuit of suggested topology as shown in Fig. 8 may shown, where \( V_{IN} \), \( V_{2N} \), \( V_{DM} \) exist the managed source voltage is to be coupled to the -ve terminal N, \( L_{CM} \) and \( C_{CM} \) exist the Common mode inductor and capacitor, \( C_{PVG} \) is parasitic capacitance, and \( Z_{G} \) is grid impedance. At the period of +ve cycle, the switches S4 and S6 stay continually switched off. An end outcome, the controlled voltage assets \( V_{SN} \) and \( V_{IN} \) are zero and can be removed. As stated by the definition of common mode (CM) and differential-mode (DM) voltage:

\[
V_{CM} = \frac{1}{2}(V_{IN} + V_{2N}) \tag{1}
\]

\[
V_{DM} = V_{IN} - V_{2N} \tag{2}
\]

Solve (1) and (2) equations, \( V_{IN} \) and \( V_{2N} \) can be stated as follow:

\[
V_{IN} = V_{CM} + \frac{1}{2} V_{DM} \tag{3}
\]

\[
V_{2N} = V_{CM} - \frac{1}{2} V_{DM} \tag{4}
\]

Now to explain the Common mode model at switching frequency, equations (3) and (4) are changed intended for bridge-leg in Fig. 7. In this the grid has frequency of supply voltage, therefore the effect of grid happening on the leakage current may not noted. The Differential Mode capacitor \( C_0 \) is eliminated because it indicates not at all impact happening the leakage current [2],[14]. Therefore, reformed structure of this topology used for+ve half cycle drawn as Fig. 9. At last, model of this topology for +ve half cycle is derived in Fig 10. In Fig. 10, the resulting equation of whole CM voltage can easily result as:

\[
V_{CM} = \frac{V_{DM}}{2} \left( \frac{l_2-l_1}{l_2+l_1} \right) \tag{5}
\]

Where \( V_{CM} \) represent total CM voltage, and \( l_1 = L_{1A} \) and \( l_2 = L_{1B} + L_{2G} \). In this inverter when \( L_{1A} = L_{2A} \) and \( L_{1G} = L_{2G} \), aimed nicely planned circuit through symmetrically dependent magnetics, equation (5) may be modified as follows:

\[
V_{CM} = \frac{1}{2} (V_{IN} - V_{2N}) \tag{6}
\]
It’s perfect from equations (7) to (10) that whole (total) Common mode voltage for present topology is retained same at V_{PV}/2 for the duration of +ve half cycle operation. Similarly, full CM voltage intended for -ve half cycle operation is calculated also discovered to be regular at V_{PV}/2 because of the regularity of the operation for the corrupt & advantageous half cycle of grid present day. The most effective difference is the initiation of various energy devices. For this reason, it could be précised to be whole CM voltage throughout the complete grid cycle is stored equal, lowering ground leakage current.

IV. CONTROLLER DESIGN

The controlling structure of the suggested topology has shown in fig.11. This contains orthogonal signal generator (OSG) gadget for calculations of lively and reactive power of the gadget, fuzzy logic controller [14] for grid current controlling, and SPWM technology block [6].

In single phase grid related transformerless inverter, two controllers may evolved. One of the controller is fuzzy logic controller (FLC) and second one is proportional resonant current controller (PRC). These current controllers plays an important role in current injected into the grid with less harmonic content when the power interchange among the system and grid.\( I_g\) reference can control actual power, as well the orthogonal component of \( I_g\) reference control the reactive power \( Q\) of device by grid. Consequently the decoupled governor of real and reactive powers be performed [12],[15],[16].

4.1. Artificial Neural Networks

Figure 12 denotes the elementary design of ANN, in this an unseen layer is indicated by circle, adaptive node is denoted by square. In this construction unseen layers are existing among input and output layer, these nodes are operational as membership functions and rules are obtained depends on if-then statements are excluded. For minimalism, we are allowing for studying ANN have 2 inputs and 1 output. In present network, each neuron and element of input vector \( p \) are coupled with weight matrix \( W \).

Where 2 crisp inputs are \( x \) and \( y \), the linguistic variables related with node functions i.e., \( A_i \) and \( B_i \). The system is having total of 5 layers is in Figure 12.

procedure for executing ANN:

1. Recognize the number of input and outputs in normalize manner in the range of 0-1.
2. Assume number of input stages.
3. Recognize number of unseen (hidden) layers.
4. Using transig and poslin commands make a feed forward network.
5. Assume learning rate would be 0.02.
6. Take the number of iterations.
7. Take goal and train the system.
8. Create the simulation block, using ‘genism’ command.

4.2. Proportional Resonant Current Controller

The block representation of Proportional Resonant controller by way of harmonic current compensator depicts in Fig.13 the transfer function of essential contemporary controller are \( G_c(s) \), \( G_h(s) \) and \( G_d(s) \), harmonic compensator, and inverter respectively.

The Proportional resonant controller is employed in fixed frame that is not identical from the normal PI controller. Due to no transformation from fixed frame to synchronous frame, the addition pattern of present controller stands simple. Designed forall these cases, processor which is less in cost that is used. Moreover, when grid imbalances or a sensing error happens, this present controller is more robust than PI controller. Particularly, the PR controller is appropriate for constant frequency operation inside the grid-tied system. Commonly, the PI controller had drawbacks to decreases steady state error in fixed reference frame [13],[14]. This controller structure has gotten knowledge due to ability of eliminating steady-state error when regulating sinusoidal signals. Furthermore, the modest execution of a harmonic compensator devoid of any counter cause on the controller results prepare the controller as well become for grid linked systems. The transfer function of the PR controller is defined below:

\[
G_c(s) = K_{pi} + K_{ii} \ast \frac{n}{s^2 + w^2}
\]
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\[ G_h(s) = \sum_{n=1,3,5,...} \frac{K_{ih}}{s^2 + (nh_n)^2} \]

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

Fig.13. The PR controller with harmonic compensator

In the sense, \( K_{pi} \) and \( K_{ij} \) are P and R gains, \( W_0 \) is fundamental frequency, \( K_{ih} \) R-gain at \( n^{th} \) order harmonic, \( h \) is harmonic order, and \( T_s \) is sampling period.

V. SPECIFICATIONS OF SYSTEM

Table 1: System parameters

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

VI. SIMULATION RESULTS

The Analysis of this transformerless inverter topology was performed by using MATLAB/SIMULATION SOFTWARE. Parameters are considered in simulation are given in Table 1. In this simulation PV module is replaced with 400V DC Voltage source. \( C_{PV1},C_{PV2} \) are parasitic capacitances between the PV module and ground, which is emulated using thin film capacitor of 75nF. In this phase, assessment of unlike parameters along with voltage of the inverter, CM voltage, leakage contemporary and the performance of H6 topology underneath adjustments of reactive and actual energy are mentioned.

\[ (V_{1N}+V_{2N})/2 \]

\[ (V_{3N}+V_{4N})/2 \]

The Characteristics of CM voltages for H6 converter topology with pure real and reactive powers are expressed as; for positive half cycle of CM voltage \( (V_{1N}+V_{2N})/2 \) and for negative half cycle of CM voltage \( (V_{3N}+V_{4N})/2 \).

The characteristics of CM Voltages \( (V_{1N}, V_{2N}, V_{3N} \) and \( V_{4N} \) are depicted in figure 14. Due to fluctuation in CM voltage. However, the peak and RMS value of leakage current flows through this topology depicts in figure 15.

Fig.14. Common Mode characteristics of the H6 topology

Fig 15. Simulation Result for Leakage Current
Fig.16. Performance of Grid Voltage and Current

Fig.17. Performance of Grid active and Reactive Powers

The dynamic performance of the projected system is computer-generated under changes in both Pref and Qref. The simulation results of Grid Voltage and Current and its measured active and reactive powers are shown in figure 16 and 17 respectively.

From the results, it shows that there is a change in grid current with respect to step variation in load and active and reactive powers tracks the reference powers. From the results, there is very low distortion in grid voltage and current, hence the leakage current flows over the system is also very low.

VII. CONCLUSIONS

This paper Suggests the system to govern the direction of current from Photo voltaic system to grid be governed by ANN controller. Photo Voltaic system combines with inverter structure and the regulation is developing by using MATLAB / Simulink setting. By appropriate strategy of ANN with Proportional Resonant controller, the H6 PV inverter had do well in producing asextinction comeback, where, final current of inverter is sinusoidal and harmonic value is to be encountered with international standards. Finally, Simulated Results are analyzed. Additionally, this topology has the following advantage:

1. The simulated H6 topology has abilitofinjecting reactive power to the grid with low harmonic distortion.

2. CM voltage is retained same during the whole grid period. Consequently, the leakage current is well intimidated.

3. Higher performance can be found by presenting super junction MOSFETs for alldevice which have frequency 20,000Hz operation is permissible to decline the ripple in current of finand passive elements dimension.

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