

PHOTOVOLTAIC SYSTEM BASED TRANSFORMERLESS HERIC INVERTER USING PI & SLIDING MODE CONTROLLER

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Abstract - This paper presents an efficiency analysis of transformerless HERIC inverter for photovoltaic applications implemented by IGBT switches. Transformerless photovoltaic (PV) inverter has been widely used in grid tied PV generation system due to its prominent advantages like higher efficiency, low cost, small size, minimum leakage current. In this paper, PV system based High Efficiency and Reliable Inverter Concept (HERIC) transformerless inverter topologies using pulse width modulation (PWM) with PI & sliding mode controller (SMC) has been proposed to ensure a fast and dynamic response. This paper deals with an transformerless HERIC inverter topology with low leakage currents that can be used in PV grid – tied applications. It consists of four operating modes for the proposed topology are discussed in this paper. A closed loop controller has been developed for maintaining the voltage constant at the grid side irrespective of changes in the input voltage. Finally a MATLAB/SIMULINK based model is developed and simulation results are presented.

Keywords: Transformerless HERIC Inverter, Photovoltaic Module (PV), PWM, PI controller, Sliding Mode Controller (SMC) & MATLAB/SIMULINK.

I. INTRODUCTION

Photovoltaic inverters (PV) play a vital role in the energy market. Nowadays, the invention and development of new energy sources are increasing due to the poisonous results caused by oil, gas and nuclear fuels. This has led the renewable energy sources especially the solar PV systems to the prime position in the generation of electricity [1-2]. Photovoltaic have applications ranging from small power supplies to power grids. Photovoltaic systems connected to the grid have several advantages such as simplicity in installation, high efficiency, reliability and flexibility [3]. The power-electronic technology plays an important role in distributed generation and in integration of renewable energy sources into the electrical grid. The transformer less system for Photovoltaic (PV) inverter a new emerging part in the field of power electronics. The PV inverter converts the output of PV cell to an alternating current than can be used by the utility. As the demand for the PV system is increased, our focus on the photovoltaic inverter. The application of photovoltaic (PV) grid connected system has been rapidly increasing in recent years for residential and commercial purpose. Earlier cost of the PV module was a major component in such systems. But now as the PV modules are cheaper, reduction in cost of system that includes inverter and transformer is essential. Hence transformer less system is preferred due to reduction in weight, cost, size and increase in efficiency [4]. The most attractive transformerless topology is the Highly Efficient and Reliable Inverter Concept (HERIC) topology with two switches and two diodes are added in the ac side of FB topology to decouple the PV module from the grid during the freewheeling period [5]. The most commercially famous and effective transformerless inverter, that is used as the main platform of Sunway's, is called HERIC[6,7]. Unfortunately, the power flows discontinuously through the HERIC inverter from the PV to the grid [8]. Transformerless PV inverters use different solutions to minimize the leakage ground current and improve the efficiency of the whole system [9]. Photovoltaic have applications ranging from small power supplies to power grids. Photovoltaic systems connected to the grid have several advantages such as simplicity in installation, high efficiency, reliability and flexibility [10]. The PV systems are grid-connected, produce large quantities of photovoltaic electricity in a single point. The size of PV systems ranges from several hundred kilowatts to several megawatts. Some of these applications are located on large industrial buildings such as airport terminals or railway stations. Grid-connected applications, currently the biggest market segment, are expected to remain so for the foreseeable future. The substantial benefit of the grid-connected domestic market is the control which PV systems allow the consumer over their power supply. Not only is electricity generated at the point of demand, avoiding grid losses of electricity, but the consumer is effectively transformed into the operator of his or her own power station. There are two main topology groups used in case of grid connected PV systems and they are a) With galvanic isolation – Galvanic isolation can be done on the DC side, in the form of a high frequency DC-DC transformer or on the grid side in the form of a big-bulky AC transformer. b) Without galvanic isolation- Here, the transformer is omitted and is called as transformer-less topology.

II. PROPOSED SYSTEM

1. Photovoltaic System

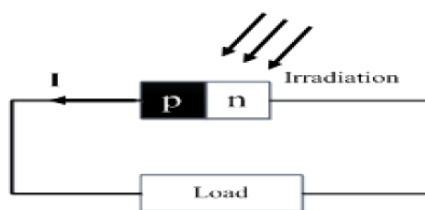
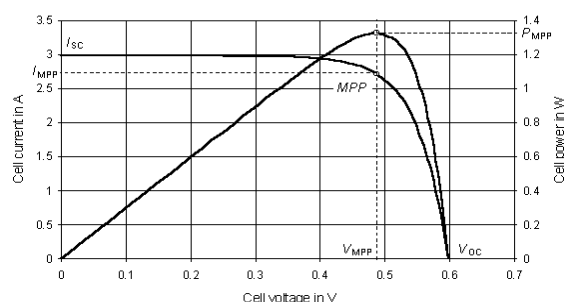
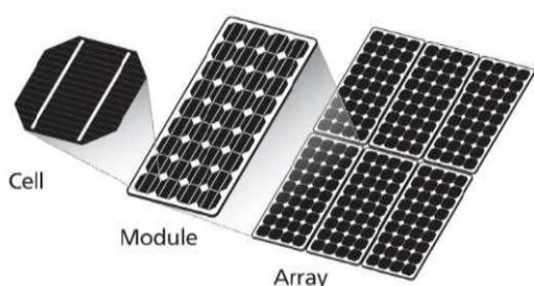


Fig.1: Solar Cell

The output of one crystalline silicon photovoltaic cell is approximately 0.5V. In order to produce a specific output voltage solar cells are connected in series. They are electrically connected and mechanically mounted in a frame to form a panel. When panels are wired in series or parallel the form an array. The solar panels are also equipped with necessary protective devices, such as bypass and blocking diodes in order to protect cells from the temperature rise under shady condition or to prevent it from reverse current owing back during night.



(a)

(b)

Fig.2: (a) PV Array & (b) I-V & P-V Characteristics of PV Cell

Photovoltaic cells uses the "photovoltaic effect" phenomenon to produce the electricity. The physics of PV cell is similar to conventional PN junction diode. Whenever the light falls on the junction, the energy of it is transferred to the electron-hole pair, thus the free charge carriers are generated. These charge carriers creates the potential gradient and gets accelerated under the electric field. This will cause the current to flow through the external circuit.

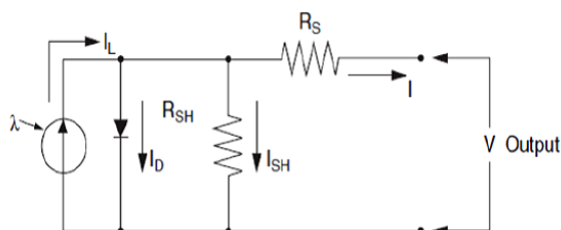


Fig.3: Basic Model of Solar Cell

2. HERIC Topology

The topology called “ Highly Efficient and Reliable Inverter Concept ” has been widely used due to its high performance . Basic construction of heric topology is shown in fig () in which by pass leg has been added in the AC side by means of two back to back IGBT operating at line frequency, Cdc is DC-link capacitor, L_1 and L_2 are filter inductance at grid side and C_0 is the filter capacitor. HERIC Employs two extra switches on the ac side of inverter. These additional switches have the two major functions: isolating the photovoltaic panel from the grid, and preventing the reactive power exchange between the filter inductors and capacitors during the zero voltage state, thus increasing efficiency. To keep the high efficiency and all the advantages given by the unipolar PWM, and low current distortion in case of the hysteresis current control, the H-Bridge topology has been modified as the Highly Efficient and Reliable Inverter Concept (HERIC) using unipolar hysteresis current control. The topology includes two extra switches (S5-S6) each connected in series with a diode. During the zero voltage vector, depending on the sign of the reference voltage, either S5 or S6 are turned ON, while S1, S2, S3 and S4 are all in their OFF state and the PV array is disconnected from the grid. This way there is a possibility of achieving the zero voltage vector and the output voltage will be unipolar, having the same frequency as the switching frequency and there will be no high frequency fluctuations present at the DC terminals of the PV array.

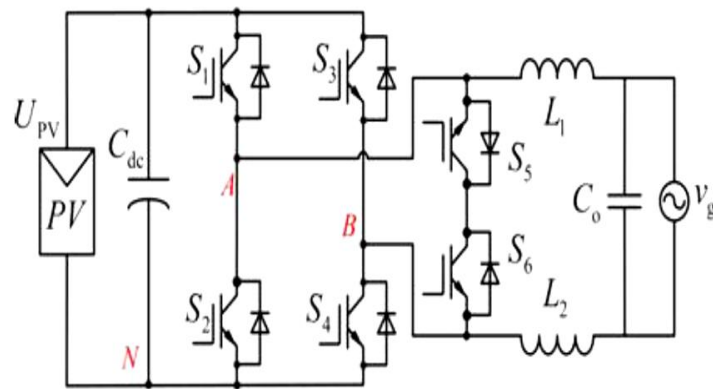
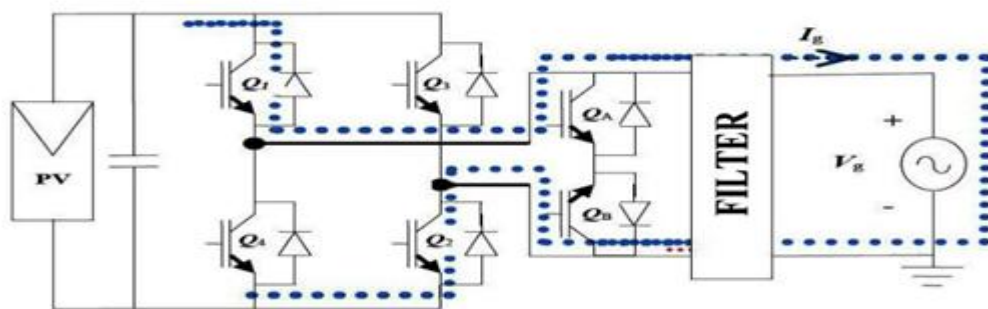
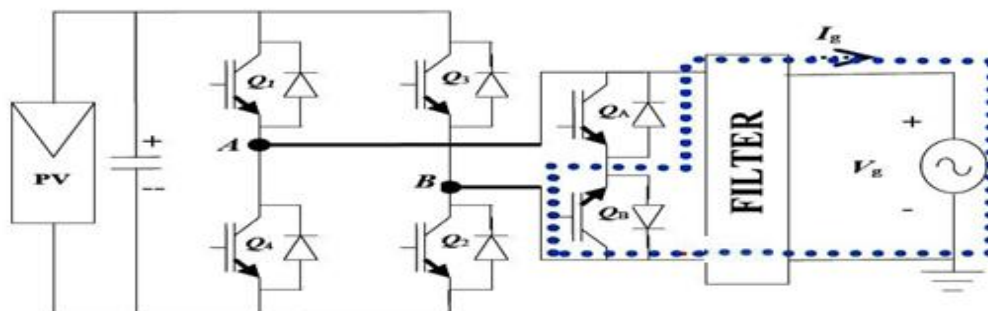


Fig.4: PV System Based Transformerless HERIC Inverter

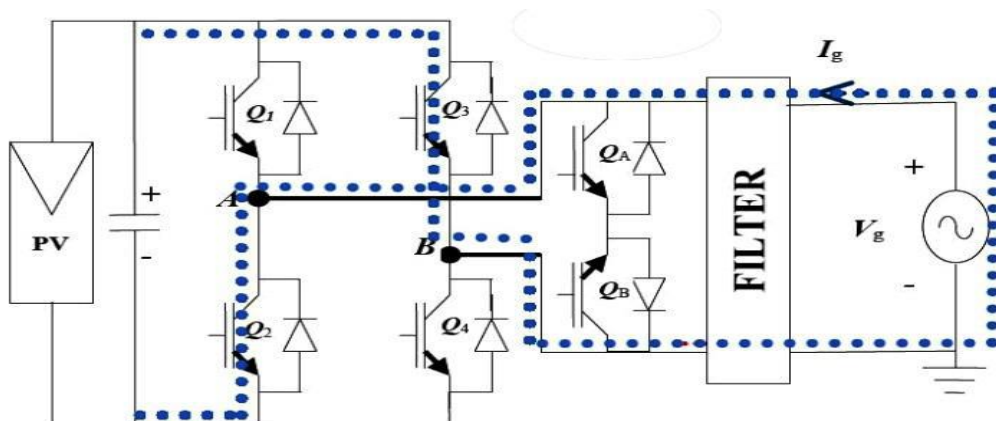
Conduction Mode of Transformerless HERIC Inverter Topology



(a)



(b)



(c)

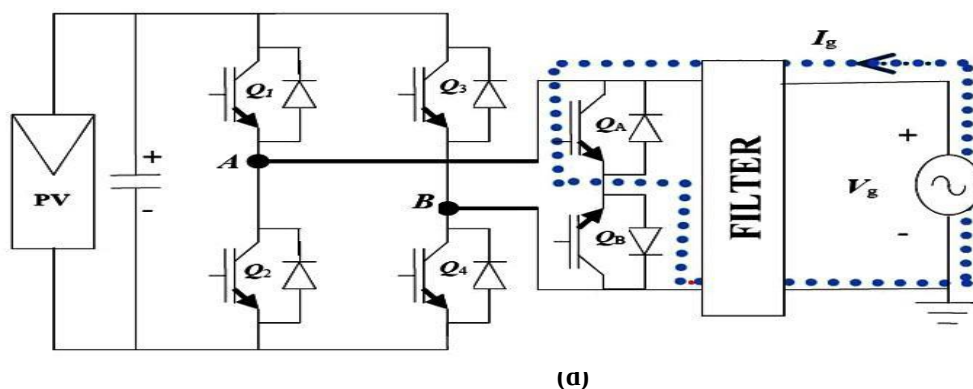


Fig.5. Modes of operation of HERIC inverter (a) mode I, (b) mode II, (c) Mode III, (d) Mode IV.

MODE OF OPERATION

Mode (I) only (Q1, Q4, QB) are on

In this case, the current flow from PV to the grid through (Q1, Q4) while QB does not carry current as shown in Fig. 5-a. It is called active state mode.

Mode (II) only QB is on

In this case, the grid current freewheels through QB and DA, while the PV is disconnected from the grid as shown in Fig. 5-b. It is called zero state mode.

Mode (III) only (Q2, Q3, QA) are on

In this case, the current flow from PV to the grid through (Q2, Q3), while QA does not carry current as shown in Fig. 5-c. It is called active state mode.

Mode (IV) only QA is on

In this case, the grid current freewheels through QA and DB, while the PV is disconnected from the grid as shown in Fig. 5- d. It is called zero state mode.

III. CLOSED LOOP CONTROL

3.1 PI Controller

A PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. PI controller is mainly used to improve the performance of the system under disturbances. The dynamic performance of the PI controller can be improved by giving feedback to the converter to overcome the disturbances. The PI controller acts upon the error with parallel proportional and integral responses in an attempt to drive the error to zero. The block diagram representation of PI controller is shown on Fig.6.

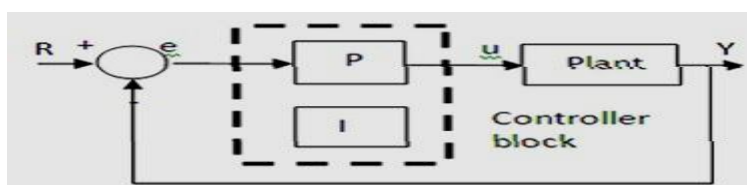


Fig.6. Block Diagram of PI Controller

$$u(t) = K_p e(t) + K_i \int e(t) dt$$

Where, K_p and K_i are the tuning knobs, are adjusted to get the necessary output.

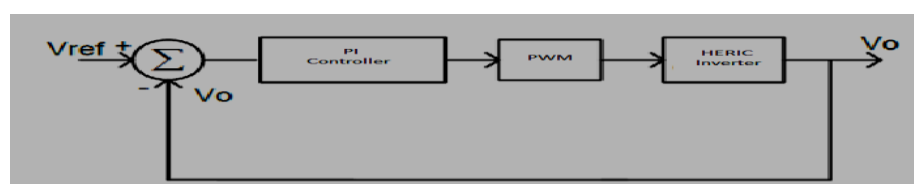


Fig.7. Closed Loop Control of PI with HERIC Inverter using PWM Technique

3.2 Sliding Mode Controller (SMC)

In control theory, sliding mode control, or SMC, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will slide along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode and the geometrical locus consisting of the boundaries is called the sliding (hyper) surface. In the context of modern control theory, any variable structure system, like a system under the SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes. The basic block diagram of the proposed converter is shown on Fig.8.

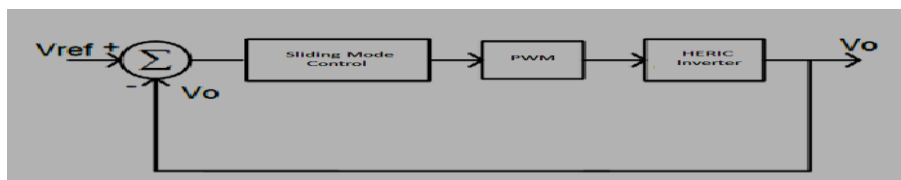


Fig.8. Closed Loop Control of SMC with HERIC Inverter using PWM Technique

The basic principle behind the SMC controlled system is to drive the converter to the steady surface called the sliding surface and maintain the stability of the system thus giving the regulated output voltage for any variations in the load or switching frequency.

IV. SIMULATION MODEL AND RESULTS

4.1 PI with HERIC Inverter using R Load

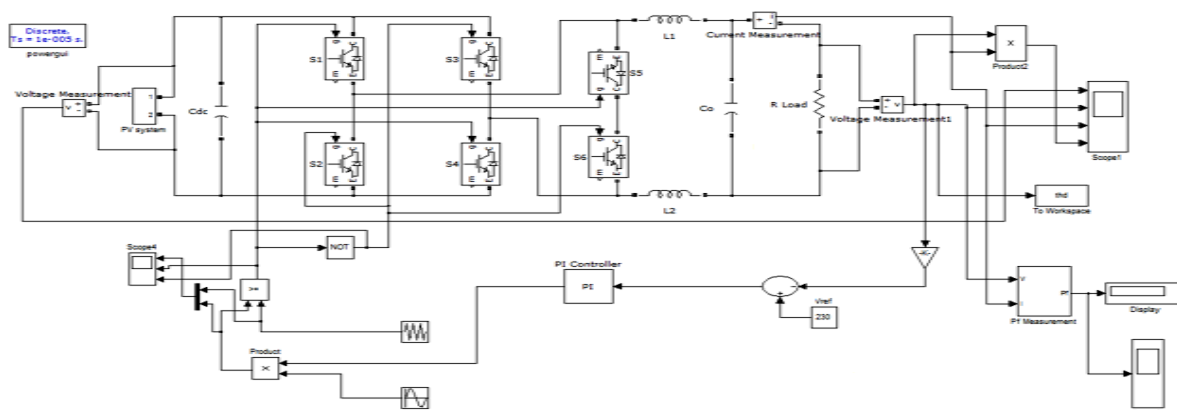


Fig.9. Simulation of PI with HERIC Inverter using R Load

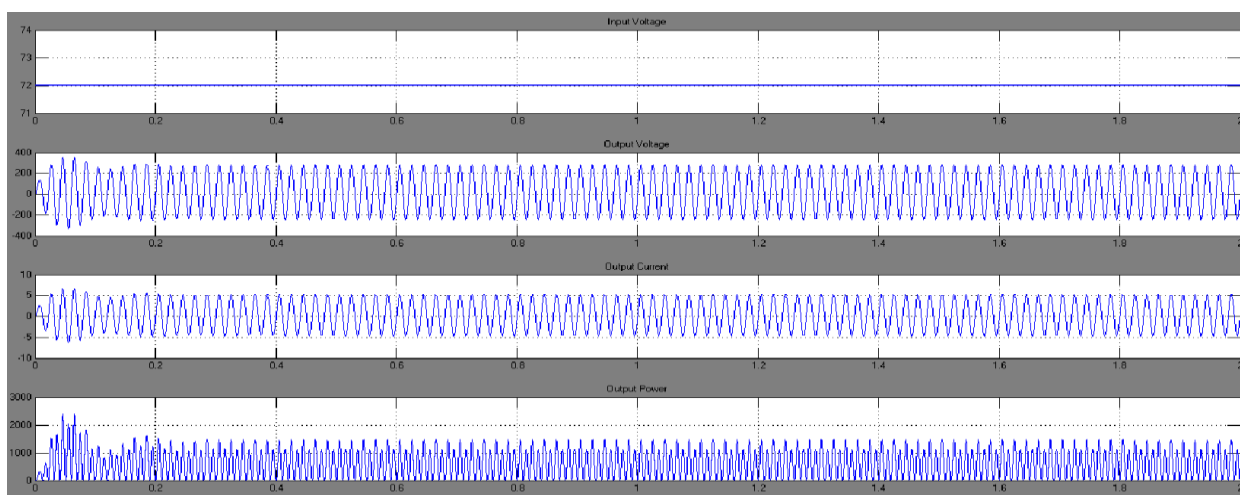


Fig.10. Simulation Output of PI with HERIC Inverter using R Load

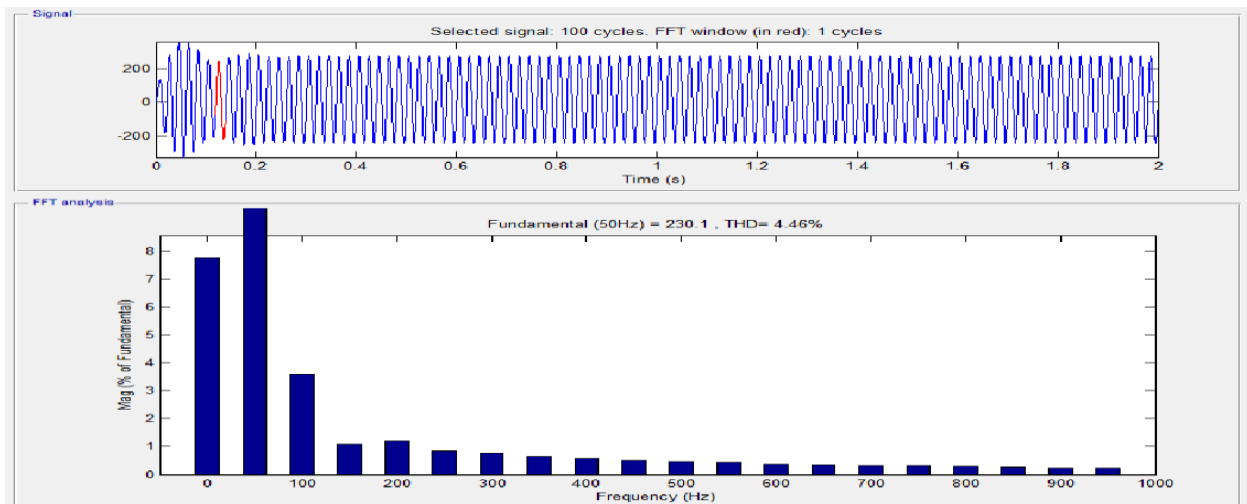


Fig.11. THD Value of PI with HERIC Inverter with R Load

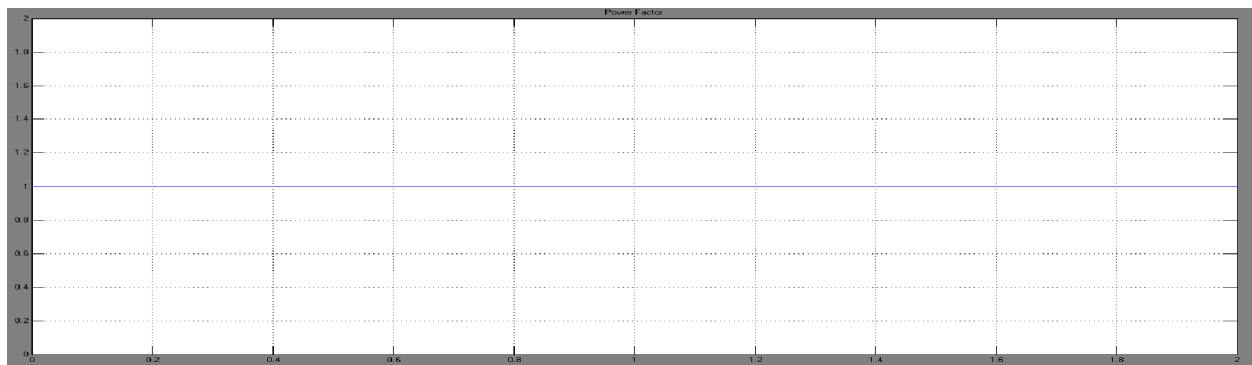


Fig.12. Power Factor of PI with HERIC Inverter with R Load

4.2 PI with HERIC Inverter using RL Load

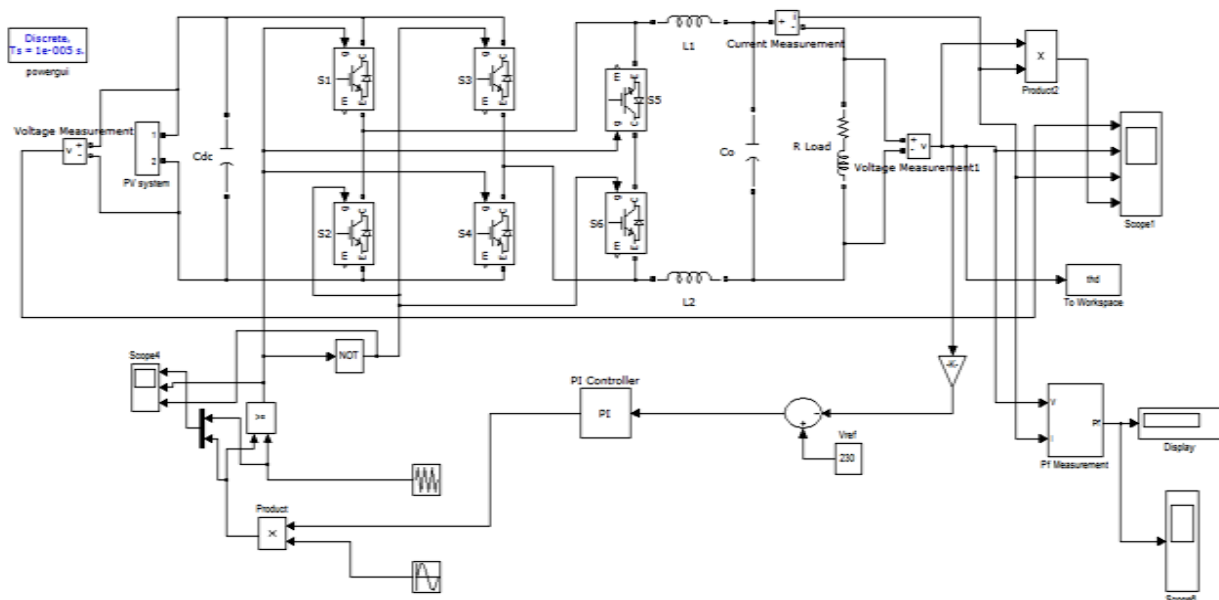


Fig.13. Simulation of PI with HERIC Inverter using RL Load

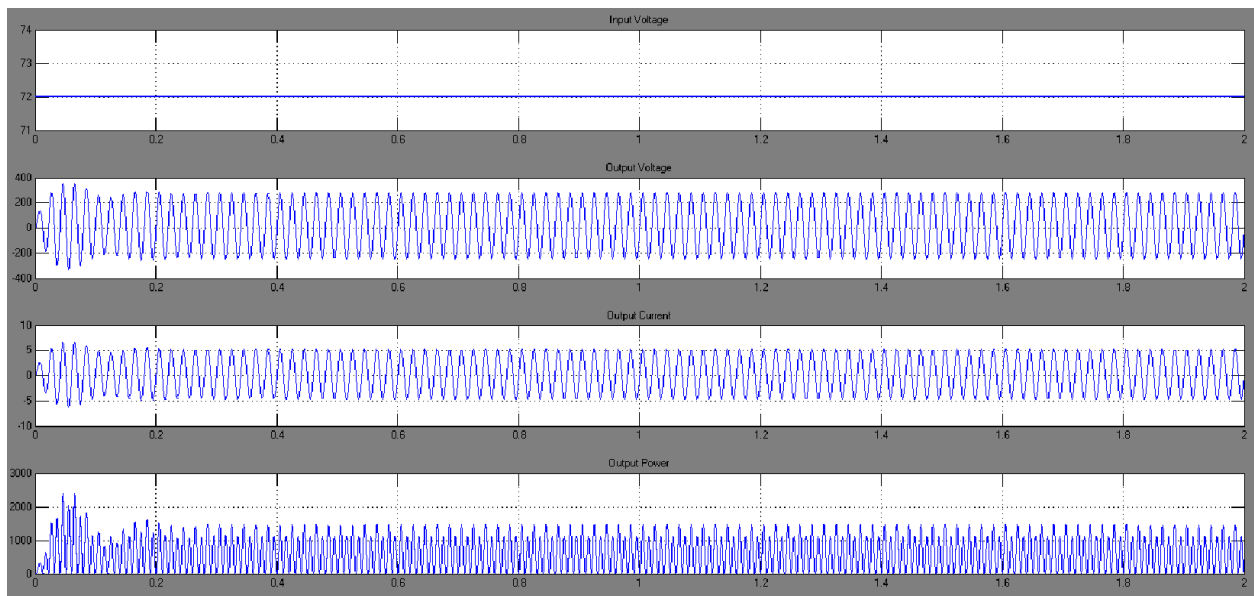


Fig.14. Simulation Output of PI with HERIC Inverter using RL Load

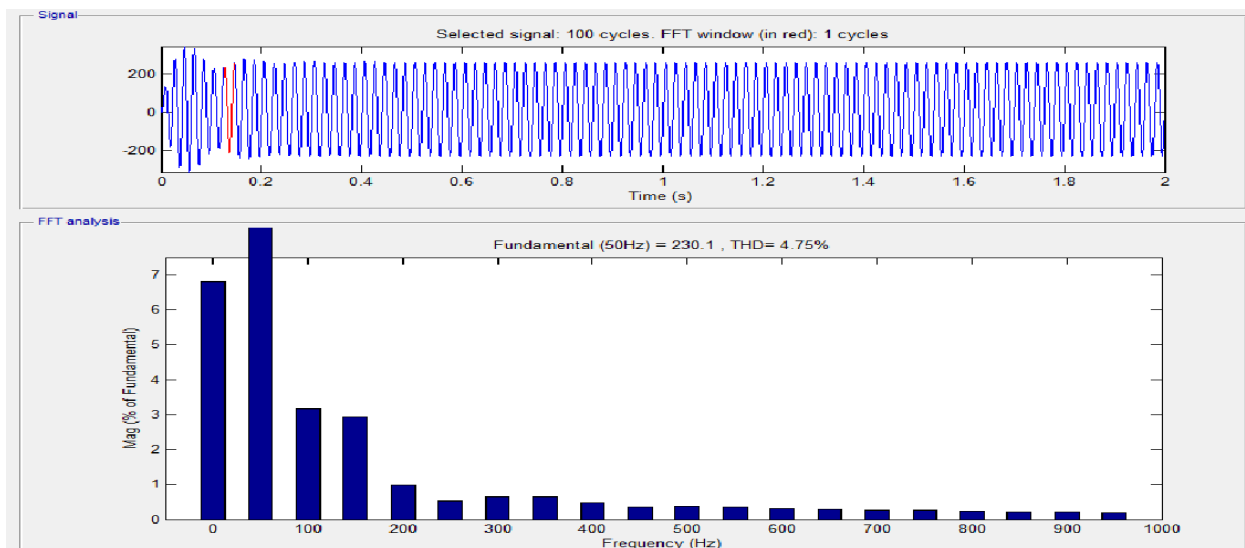


Fig.15. THD Value of PI with HERIC Inverter with RL Load

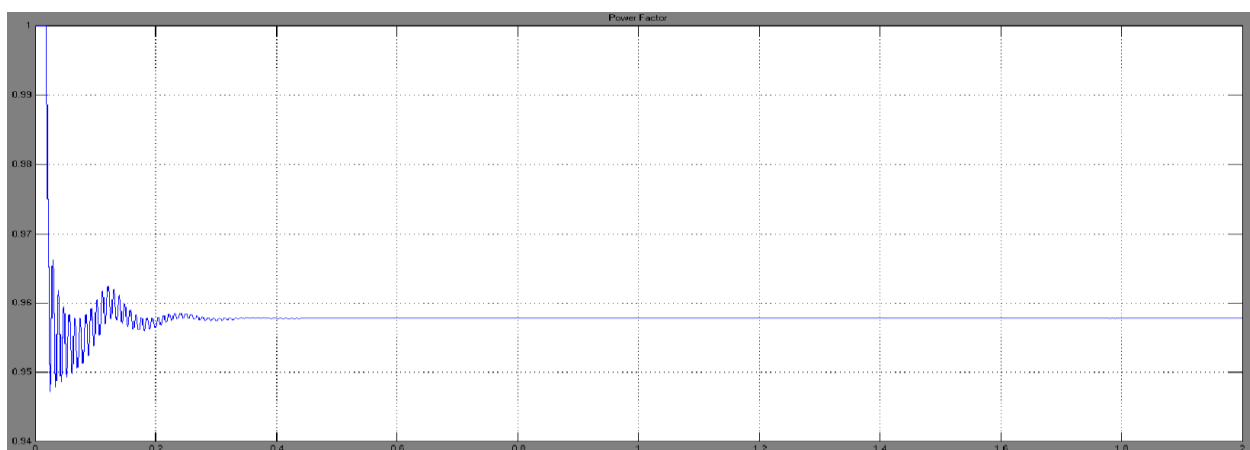


Fig.16. Power Factor of PI with HERIC Inverter with RL Load

4.3 SMC with HERIC Inverter using R Load

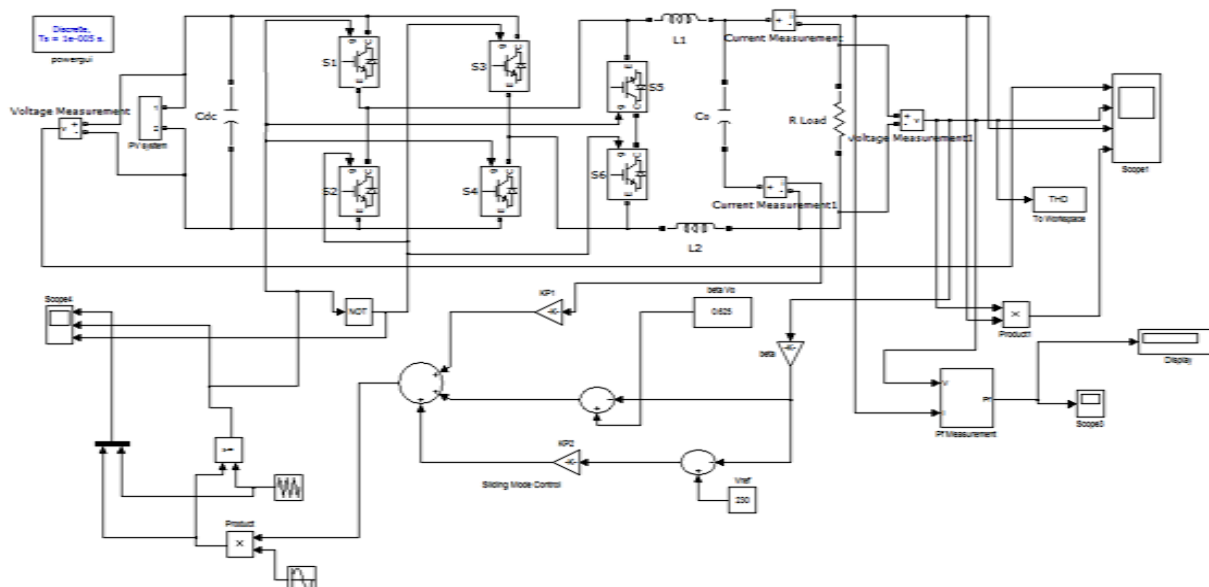


Fig.17. Simulation of SMC with HERIC Inverter using R Load

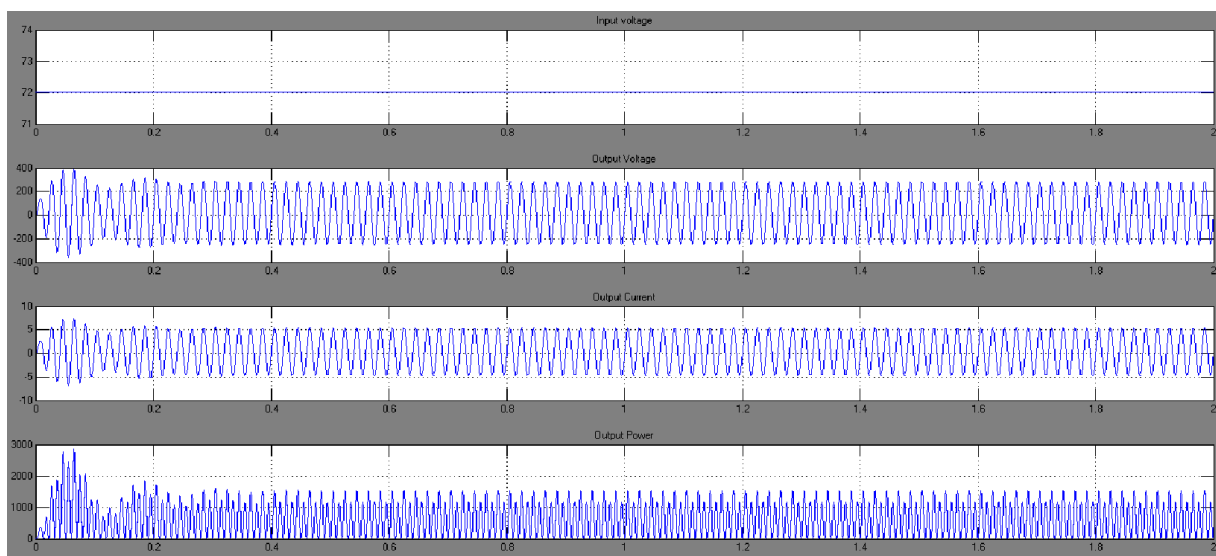


Fig.18. Simulation Output of SMC with HERIC Inverter using R Load

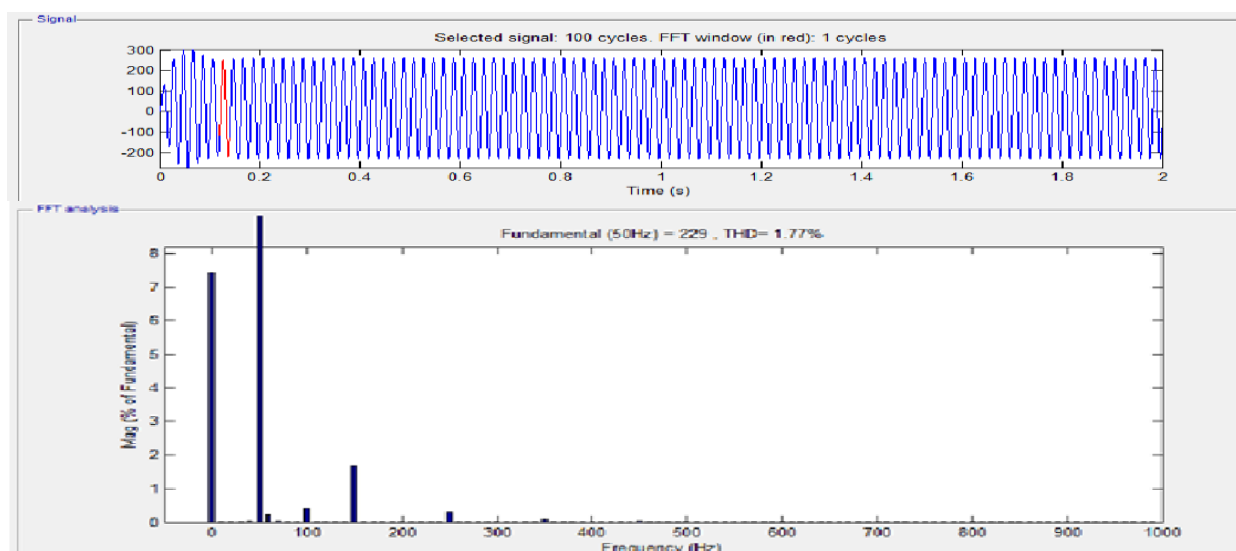


Fig.19. THD Value of SMC with HERIC Inverter with R Load

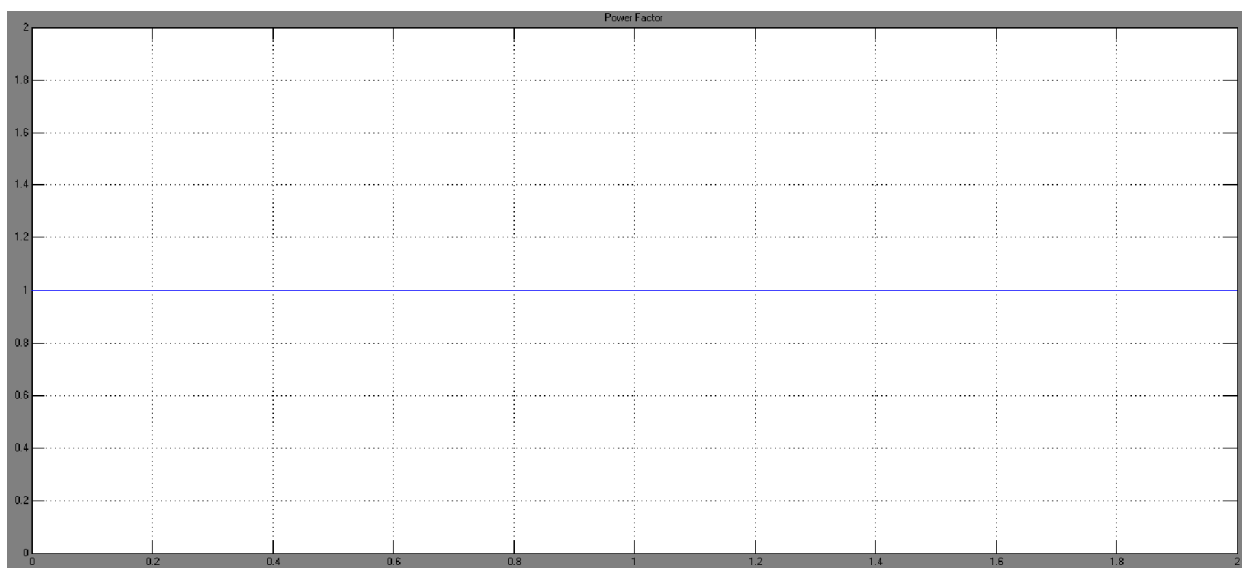


Fig.20. Power Factor of SMC with HERIC Inverter with R Load

Sl. No.	PV Input Voltage (V)	R Load								Switching Frequency (KHz)	L ₁	L ₂	C _{dc}	C _o
		SMC				PI Controller								
		Output Voltage (V)	R Value (Ω)	THD %	Power Factor	Output Voltage (V)	RL Value (Ω)	THD %	Power Factor					
1	72	228.5	1000	1.77	1	228.1	1000	4.46	1	50KHz	4.75 m H	4.75 m H	100 mF	100 0μF
2	72	226	2000	1.63	1	225.8	2000	4.22	1					
3	72	220.5	3000	1.54	1	219.7	3000	3.78	1					
4	72	216.6	4000	1.41	1	215.6	4000	3.12	1					
5	72	211.4	5000	1.26	1	212.4	5000	2.38	1					

Table 1: Parameter Specifications

Sl. No.	PV Input Voltage (V)	RL Load								Switching Frequency (KHz)	L ₁	L ₂	C _{dc}	C _o
		SMC				PI Controller								
		Output Voltage (V)	R Value (Ω)	THD %	Power Factor	Output Voltage (V)	RL Value (Ω)	THD %	Power Factor					
1	72	228.5	1000	1.85	0.981	228.1	1000	4.75	0.985	50KHz	4.75 mH	4.75 mH	100 mF	1000 μF
2	72	226	2000	1.73	0.972	225.8	2000	4.31	0.977					
3	72	220.5	3000	1.67	0.965	219.7	3000	3.84	0.969					
4	72	216.6	4000	1.53	0.951	215.6	4000	3.33	0.958					
5	72	211.4	5000	1.42	0.943	212.4	5000	2.45	0.946					

Table 2: Parameter Specifications

V. CONCLUSION

In this paper, High Efficiency and Reliable Inverter Concept (HERIC) transformerless inverter topologies using pulse width modulation (PWM) with PI & sliding mode controller (SMC) has been proposed. The closed loop control of PI & SMC controller is introduced to suppress the common mode leakage current for the grid tied transformerless inverter. The precise outputs are obtained through this controller and harmonics are also reduced considerably. The system efficiency is improved through continuous sampling of error signals controlled by PI & SMC Controller. The proposed topology is best suitable where there is a problem of ripples in output waveforms and affecting the grid parameters. The promising performance in the elimination of leakage current, this concept of closed loop PI & SMC controller provides a hopeful solution for the grid connected transformerless inverters. In steady state region both the control methods give the same performance. In Transient region voltage and current overshoot are very low in SMC. In line variation SMC is insensitive to the input variations. For wide range of load variation SMC is more stable when compared to PI controller. SMC provides several advantages over other control methods: Robustness, stability for even very large line and load variations, good dynamic response and simple implementation. The advantage of using sliding mode controller is highlighted. It is shown that the sliding mode controllers generate more consistent transient responses for a wide operating range as compared to conventional PWM controllers. However the proposed system efficiency is slightly less than the conventional HERIC one.

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