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# Transformerless Split Inductor Neutral Point Clamped Nine Level Inverter Using Hysteresis Time Based Modulation Technique for PV Grid

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**ABSTRACT:** A neutral point clamped three level inverter (NPCTLI) is suitable for the transformerless photovoltaic (PV) grid connected system.. The new topology is referred to as split inductor NPCTLI (SI –NPCTLI). An improved nine level grid connected inverter is proposed based on the SI-NPCTLI which avoids the shoot through problem. The hysteresis modulation for power electronic converters is attractive in many different applications because of its unmatched dynamic response and wide command tracking bandwidth. Hysteresis time based modulation technique is developed in proposed system. This study will provide a useful framework and point of reference for the future development of hysteresis modulation for multilevel converters. The operation mode ,control strategy, simulations results are verified.

**KEYWORDS:** neutral point clamped three level inverter (NPCTLI), split inductor (SI), photovoltaic (PV) grid connected inverter, transformerless, multiband (MB).

## I. INTRODUCTION

The photovoltaic (PV)power generation systems is playing an important role in the development of distributed electric power systems. In order to achieve low cost and compactness, as well as increased reliability and efficiency, the concept of the transformerless PV grid-connected nverterwas proposed . In recent years, the ransformerless PV gridconnected inverters (TLI), already well-accepted in European markets, have draw more and more attention in other parts of the world. Key issues related to TLI are leakage current suppression and reliability improvement. Depending on the inverter topology, there exist potential fluctuations between the solar cell array and the ground, and the fluctuations are square-wave voltages at the switching frequency. Due to the galvanic connection between power grid and solar cell array, the stray capacitors to ground formed by the surface of the PV array form a path for the leakage current. Energized by a fluctuating potential, the stray capacitors lead to leakage currents. A person connected to the ground and touching the PVarray,may conduct the capacitive current to the ground, causing an electrical hazard. At the same time, the conducted interference and radiated interference are brought in by the leakage current; furthermore, the in-grid current harmonics and losses are increased.

Neutral point clamped three-level inverter (NPCTLI) is widely adopted in a transformerless PV system The NPCTLI’s topology can overcome the problems of leakage current and restrict the dc component injected to the grid NPCTLI also suffer from shootthrough risk as do other bridge-type inverters, which is a major obstacle to the reliability for power-conversion system. So, it is worth considering reliability enhancements to NPCTLIs. Based on the half-bridge-type transformerless PV grid connected inverter, a novel split-inductor NPCTLI (SI-NPCTLI) with variable hysteresis band fixed-frequency control is proposed in this paper. There are no leakage current and shoot through problems in the proposed inverter. The voltage stress of power devices in an SI-NPCTLI is the same as in an NPCTLI, and an SI-NPCTLI can be also operated with unipolar modulation. The variable hysteresis band fixed-frequency control offers an excellent current reference tracking performance and fast transient response ability in comparison with other current controllers.

The hysteresis modulation for power electronic converters are preferred for applications, where performance requirements are more demanding such as to achieve good dynamic response, unconditional stability, and wide command-tracking bandwidth In this approach, the controlled system variable is compared against hysteresis band(s) to create the switching commands for the converter. This control has been widely used to control the conventional two-level converter, showing its robustness and simplicity in a lot of applications A brief description of the standard two-

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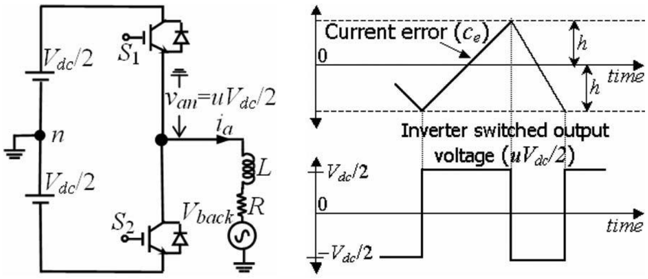
level hysteresis control for output current regulation is presented in the following. The objective of standard two-level hysteresis current control is to switch the converter ransistors in such a manner that the converter load current tracks a reference within a specified hysteresis band. Consider a single-phase half-bridge inverter, as shown in Fig. 1(a) for two-level hysteresis current control. In fig1,two dc sources of magnitudes Vdc/2 are considered at




(a) (b)

Fig. 1. (a) Two-level half-bridge inverter. (b) Two-level hysteresis control

the dc link of inverter and their common point (n, neutral point) is grounded. The net controllable output voltage of the inverter is uVdc/2, where u is defined as the control input and represents the switching logic of inverter. It assumes the values +1 and −1 for the two-level inverter of Fig. 1(a). The inverter output voltage van can be represented as follows:

van = uVd/2= Ria + dia/dt+ vback (1)

where ia is the load current, vback is the back EMF voltage, and L and R are the load inductance and resistance, respectively[see Fig. 1(a)]. As vback increases or as larger reference current slopes are required, larger average values of van need to be used. Since the voltage across the load resistance is often small, this value can often be neglected. Introducing a term diref /dt, where iref is the current reference to be tracked, (1) becomes as follows:

d(ia − iref )/dt≈ uVdc/2 – vback/L− diref/dt . (2)

It is evident from that the current error (ce = ia − iref ) can be reduced by increasing or decreasing van, depending on the polarity of ce . Fig. 1(b) represents the implementation logic for this correct voltage-level selection for a two-level inverter using hysteresis control. It can be seen that as the measured current (ia ) becomes greater than its reference (iref ) by the hysteresis band "h," the inverter output voltage (uVdc/2) is switched to its lowest level (−Vdc/2, u = −1) in order to decrease the current [according to (1)]. Likewise, when ia becomes less than iref by "h", uVdc/2 is switched to its highest level (Vdc/2, u = +1) in order to increase the current. For the inverter of Fig. 1(a), u assumes the value +1 for the switching logic S1 = 1, S2 = 0 and −1 for S1 = 0 and S2 = 1. A three-phase system can also be simply implemented using three independent single-phase hysteresis current regulators. Based on the two-level hysteresis control logic described earlier, the control input u can be defined as follows:

if (ce (t) ≥ +h) , then u(t) = −1

else if (ce (t) ≤ −h) , then u(t) = +1.

In proposed system Three Level Split inductor Neutral point clamped inverter is modified into nine level inverter using hysteresis time based modulation techniqueThe hysteresis modulation for power electronic converters is attractive in many different applications because of its unmatched dynamic response and wide command-tracking bandwidth. Its application and benefits for two-level converters are well understood, but the extension of this strategy to multilevel convertersis still under development. By using the recently developed multilevel hysteresis modulation approaches, the advantages of using several accessible dc potentials in a multilevel inverter have been fully exploited.

It should be noted that h is a suitable hysteresis band, whose size is determined by the maximum allowable switching frequency of the switching devices, as well as the maximum permitted level of current distortion. A low value of h may lead to increased switching actions, henceforth, larger switching losses, while a large value of h may result in increased distortion in the controlled current. Therefore, a trade off is always required in designing the hysteresis band size. This control strategy can be extended to any multilevel inverter structure, even in the case of n-level voltage waveforms and three-phase systems. It can be expected that with further investigation of the (multilevel hysteresis modulator) MHM methods and the development of modern technology, the hysteresis modulation will gain more popularity for controlling the multilevel converters in different applications.

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## II. SPLIT INDUCTOR NEUTRAL POINT CLAMPED THREE LEVEL INVERTER

The midpoint of capacitor's bridge leg and the midpoint of PVcluster must be connected to the neutral line of the grid. The output current flow through the split inductor L1 & L2. InFig2.1, the instantaneous voltage across points 1 and 3 is defined as u13 and the nstantaneous voltage across points 2 and 3 is defined as u23. In Fig. 2.2 waveforms of the switch driving signals and the output current of the SI-NPCTLI are illustrated. Compared with the NPCTLI, the SI-NPCTLI has the advantages of reduced inductor current stress and, most importantly, no shoot-through problem except the duple filter inductors.

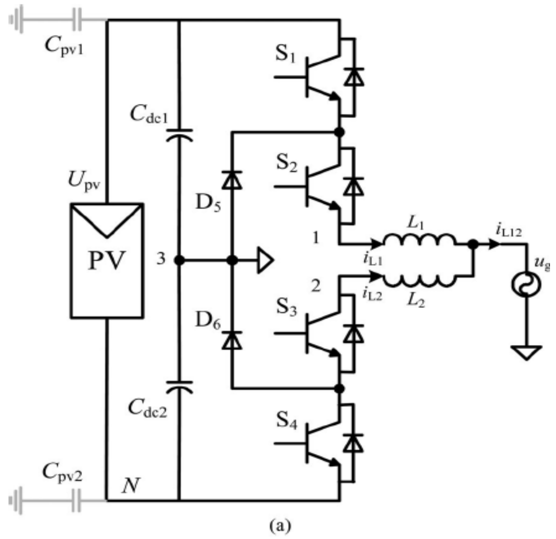


Fig2.1 Split inductor neutral point clamped three level PV grid connected inverter.

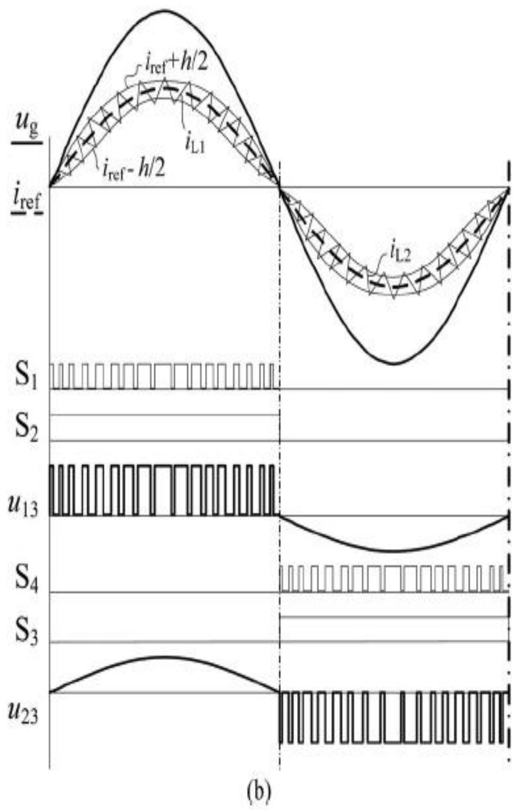


**Fig 2.2 Key waveforms and driving signals.**

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**2.3 Operating principle of SI-NPCTLI**

Before analysis, the following assumptions are Given

1) All inductors and capacitors are ideal, and $C_{dc1} = C_{dc2}$, $L_1 = L_2$ ; and

2) The inverter operates at the unity power factor, i.e, the inductor current $i_{L12}$ is in phase with the grid voltage $u_g$. The operation during the negative half-cycle is similar to the positive one.

- Mode 1: With switches $S_1$&$S_2$ ON, and $S_3$ & $S_4$ OFF, the output voltage of the bridge leg is the voltage of capacitor $C_{dc1}$, i.e.,

$$u_{13} = (1/2)U_{pv}$$
$$Ldi_{L1}/dt = 1/2U_{pv} - u_g$$

- Mode 2: With $S_1$ OFF, $S_2$ ON, and $S_3$ & $S_4$ Still OFF, the voltage on $S_1$ is clamped to the half of the input voltage by the diode $D_5$, and the output voltage of the bridge leg is zero ,i.e., $u_{13} = 0$. At this duration, the current of inductor states in the freewheeling stage and $i_{L1}$ decrease

$$Ldi_{L1}/dt = 0 - u_g$$

- So, during the positive half- cycle of the grid voltage, the output-voltage levels of the bridge leg include Zero and $(1/2)U_{pv}$ Similarly, during the negative half-cycle, the output voltage gets the two levels of zero and $-(1/2)\,U_{pv}$ .
- Mode3 : In the negative half cycle $S_1$&$S_2$ is off and $S_3$ & $S_4$ is on.
- Mode4 : $S_1$&$S_2$ is off , $S_3$ is on and $S_4$ is off .

It assumes that the inverter works with the unity power factor, i.e., the inductor current iL12 is in phase with the grid voltage ug . This assumption is reasonable under the requirement of the unity power factor between the in-grid current and the grid voltage, when applied to a PV grid-connected inverter. However, as the freewheeling diodes of bridge leg in the DBHBI are omitted, in order to ensure safe operation, the inductor current needs to be reliably dropped to zero before the zero crossing of the grid voltage. The hysteresis current control can achieve accurate tracking to the inductor current. In order to ensure the zero inductor current before the zero crossing of the grid voltage.

**2.4 Operation Principle of Hysteresis Modulation**

The hysteresis modulation is a feedback current control method where the motor current tracks the reference current within a hysteresis band. The above figure shows the operation principle of the hysteresis modulation. The controller generates the sinusoidal reference current of desired magnitude and frequency that is compared with the actual line current. If the current exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and the lower switch is turned on. As a result, the current starts to decay.

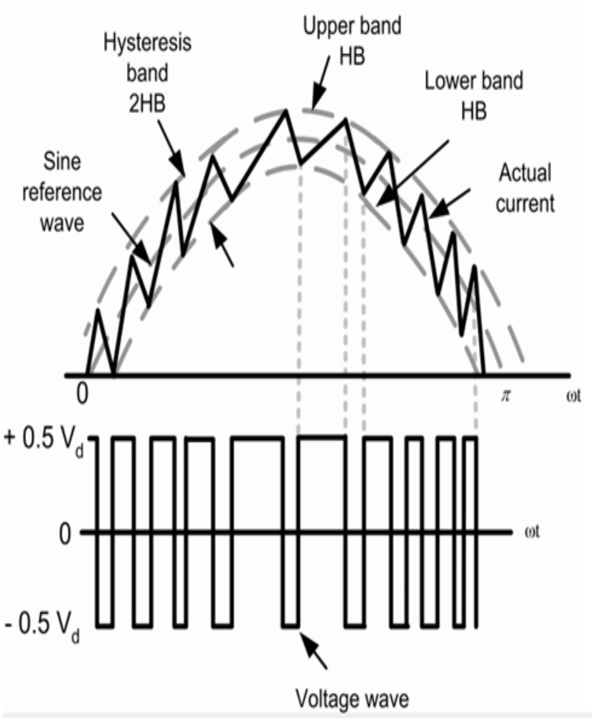


Fig 2.3 Hysteresis modulation

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. If the current crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. Hence, the actual current is forced to track the reference current within the hysteresis band.

## III. PROPOSED SCHEME

Our proposed scheme is three Level Split inductor Neutral point clamped inverter is modified into nine level inverter using hysteresis time based modulation technique.

The hysteresis modulation for power electronic converters are preferred for applications, where erformance requirements are more demanding such as to achieve good dynamic response, unconditional stability, and wide command-tracking bandwidth.

Multiband technique is used for tracking the current error and generate the multilevel output voltage. Compared with the NPCTLI, the SI-NPCTLI has the advantages of reduced inductor current stress and, most importantly, no shoot-through problem except the duple filter inductors. assumes that the inverter works with the unity power factor, i.e., the inductor current iL12 is in phase with the grid voltage ug . This assumption is reasonable under the requirement of the unity power factor between the in-grid current and the grid voltage, when applied to a PV grid-connected inverter.

The hysteresis current control can achieve accurate tracking to the inductor current [22]. In order to ensure the zero inductor current before the zero crossing of the grid voltage, the highfrequency switching signals must be stopped at the time xπ, and the inductor current may be forced to zero by the grid voltage. Hysteresis current control, which is a nonlinear control method, possesses high performance, simple realization circuit, high stability, inherent current-limiting capability, and fast dynamic response.

Parameter Tabulation

| | |
|---|---|
| Input Voltage/V | 800 |
| Grid Voltage/V | 240 |
| Frequency | 50 |
| DC Capacitor Cdc1,Cdc2/µF | 470µF/450V |
| Power Devices S1-S6 (MOSFET) | IXFN36N100 |
| Filter Inductance L1/L2 | 4mH |

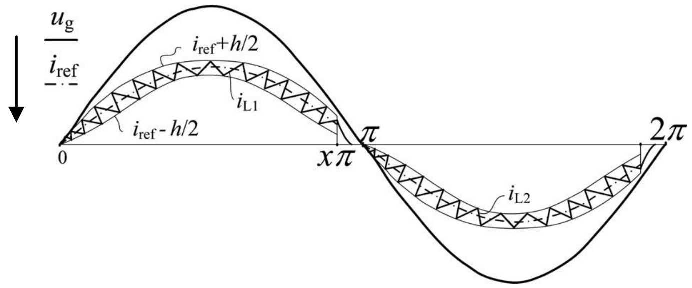


Fig. 3. Phase control of inductor current iL12 .

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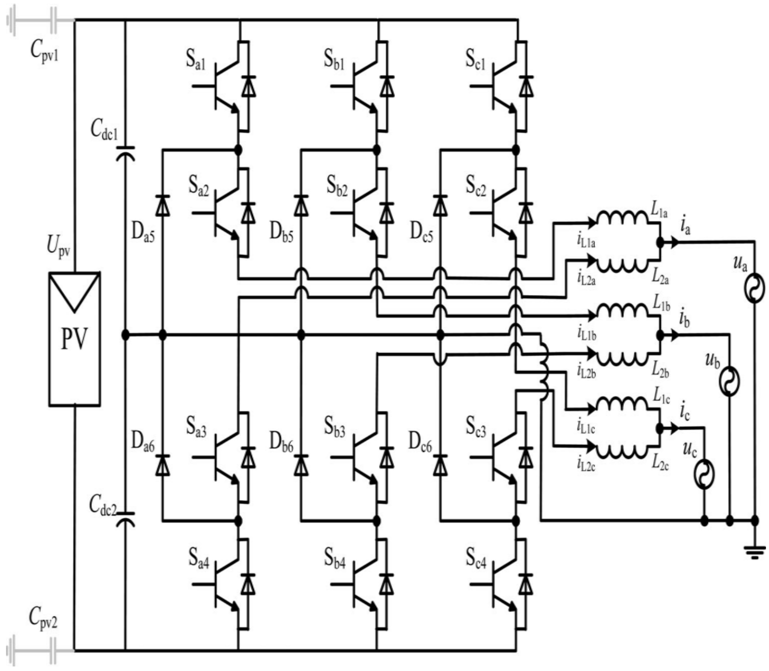
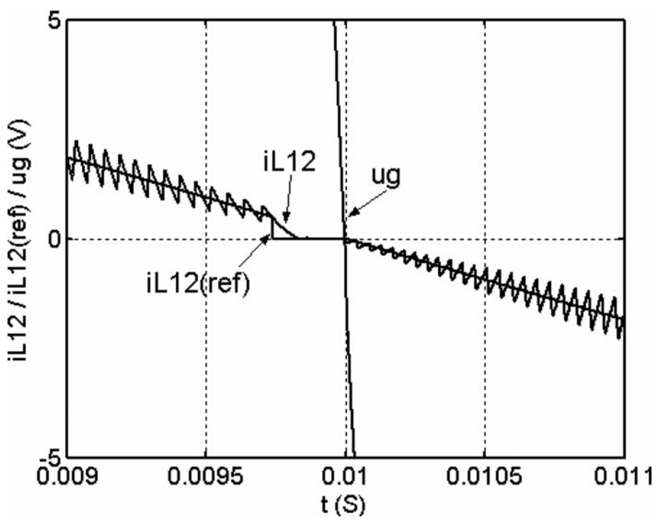



Fig. 5. SI-NPCTLI three-phase inverter with neutral.




From Fig. 9, it can be also found that the inductor current iL12 achieves the capability of high-precision tracking to the given reference. For the grid-connected applications, the performance of current tracking under different grid-current reference, especially light-load and zero-grid-current reference.

For a five-level inverter, van in (1) may be
defined as van = nVdc, where n = 1/2, 1/4, 0, −1/4, and −1/2,
as a five-level inverter may select between voltage levels Vdc/2,Vdc/4, 0, −Vdc/4, and −Vdc/2 for the net dc-link voltage of Vdc. Then, in a similar manner as described earlier, ce can be kept limited to a specified band by selecting a higher or lower voltage level than its present output depending on the polarity. The MB hysteresis modulation scheme for the multilevel converters uses symmetrical hysteresis bands to control the switching so that the inner band causes switching between adjacent levels, while the outer band causes an additional switching level change whenever necessary.

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An advantage of this MB hysteresis control is that the (n − 1) bands used here for an n-level inverter center about the zeroerror axis. In this case, the average value of the current error approaches zero even when current ripple periods are considered. Therefore, no dc-tracking error is introduced into the output current

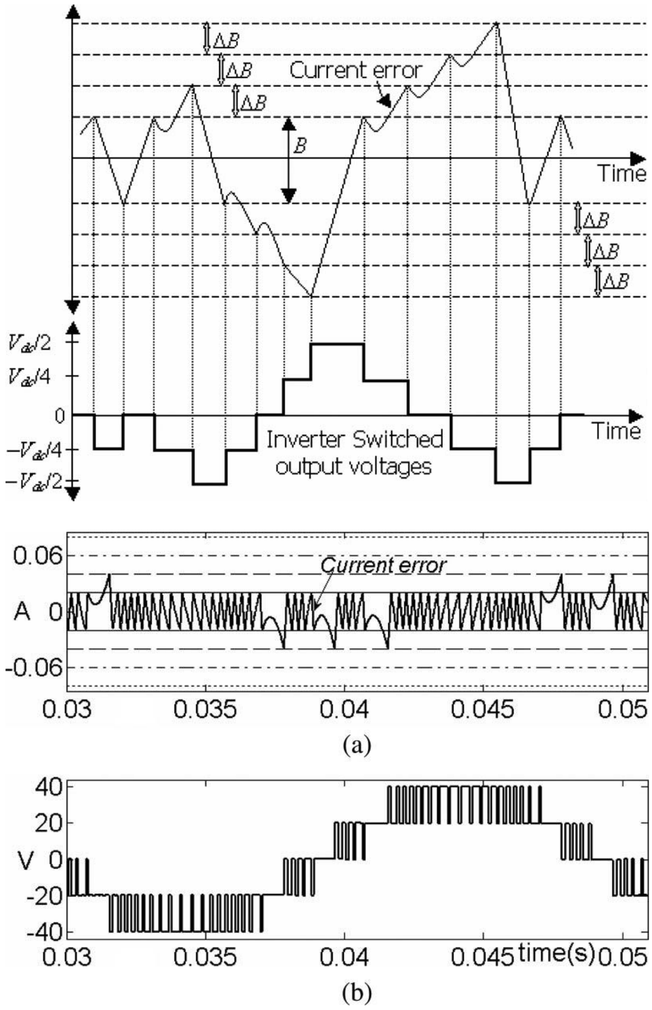


**Fig 2.17 MB five-level hysteresis modulation. (a) Current error and hysteresis band plots. (b) Inverter output voltage.**

Hysteresis time based modulation technique has no dc tracking error problem,good tracking erformance,increased robustness,extra control over the maximum allowable swithching frequency, suitable for varying load pplications, multiple swithching at the boundaries of the inner bandcan be avoided**.**

**SIMULATION ANALYSIS**

A simulation model of the single-phase grid-connected
SI-NPCTLI has been established with MATLAB/Simulink
A. Validation of Steady-State Characteristics
When the single-phase grid-connected SI-NPCTLI operates under the hysteresis current control with a fixed band, the waveforms of the grid current and voltage and the energy spectrum of the grid current are shown in Fig. 7. the grid-current reference is always less than the hysteresis band and the converter acts no high-frequency switch actions, which ensures high precision tracking to the grid-current reference and, furthermore, realizes the zero max utility backfeed current.
Verification of the Dynamic Performance

Fig. 11 shows the dynamic response waveforms of the singlephase grid-connected SI-NPCTLI under the variable bandwidth hysteresis current control, when the grid-current reference iL12(ref) rises and drops suddenly. It can be seen that the SINPCTLI represents a very good dynamic response performance. When the grid voltage and PV input voltage

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change suddenly, variable-band hysteresis current control arithmetic can realize constant-frequency control by changing the hysteresis band h

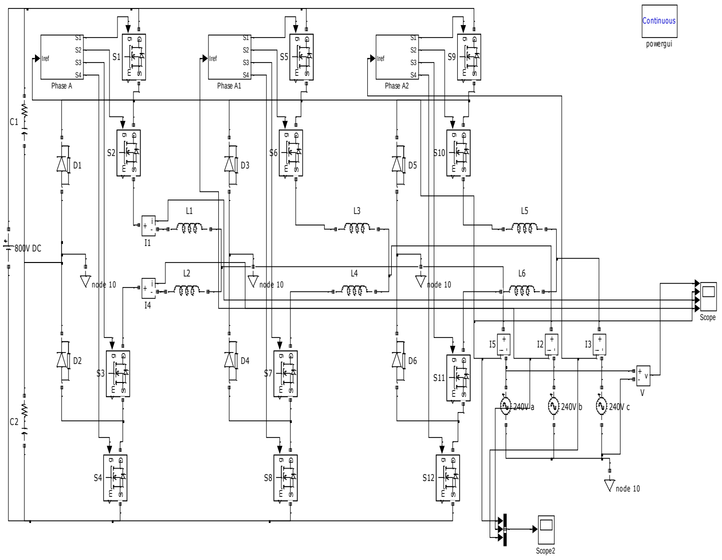
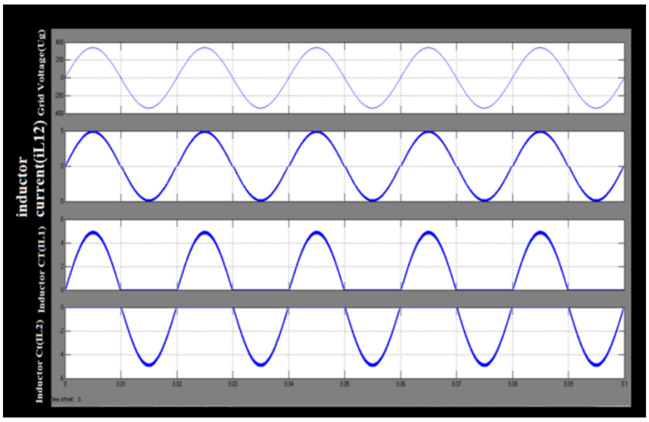
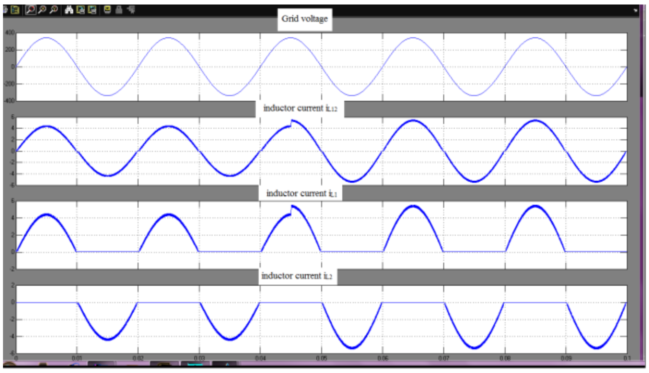



Fig  Simulation diagram for with grid connected




Simulated result of with grid connected




Simulated result of dynamic response

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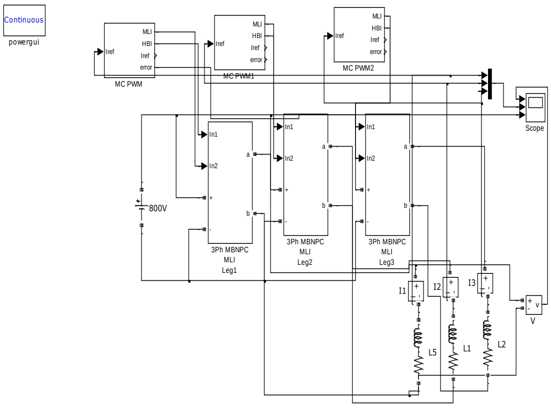
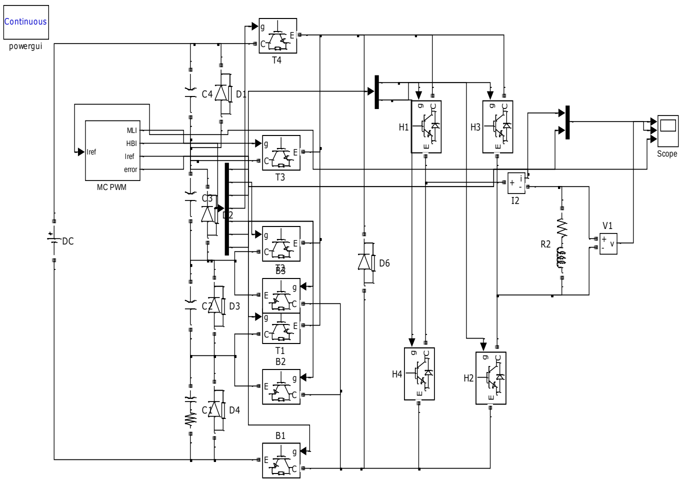
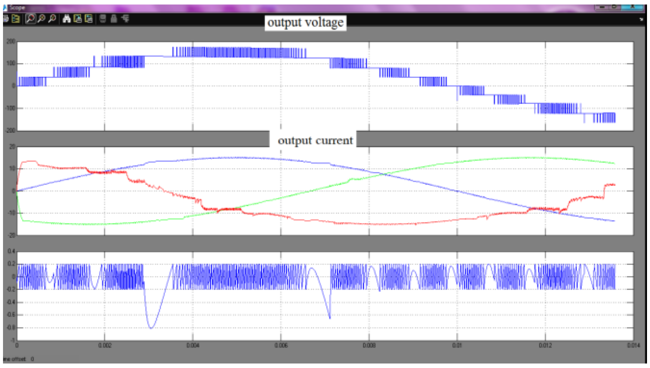



Simulation diagram for nine level inverter




Simulation diagram for nine level inverter




Simulated result of nine level inverter

## IV. CONCLUSION

A Split Inductor three level grid connected inverter with high reliability current characteristics is presented in this project.Simulation output of with and without grid connected performance is analyzed.Simulation output of dynamic performance is analyzed. This inverter can achieve high efficiency ,low cost, low leakage current,and high reliability to satisfy the requirements of the transformerless PV Grid connected inverter.

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