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# ZERO STEADY STATE ERROR FOR SINGLE PHASE GRID CONNECTED INVERTER USING HERIC

R.Raghavi[1], M.Kiran kumar[2], R.Ramesh Krishnan[3], P.Shantha kumar[4]
Assistant Professor[1], UG Scholar[2, 3, 4], Dept. of EEE,
MAM School of Engineering, Trichy[1, 2, 3, 4],
kirann407@gmail.com[2].

***Abstract:***

Feed forward control is reliable for rejecting fast and dynamic voltage disturbances in the grid. Mainly this scheme is implemented based on phase voltages of the wyes connected configuration. Under unbalanced and distorted grid-condition, the online conversion of line-to-line values into the phase values is unworkable. In order to exploit full advantages of feed forward controller, an appropriate modulator is needed. In this paper the feed forward of grid line-to-line voltages is used in lieu of phase voltages. The introduced feed forward method is implemented with implicit zero-sequence discontinuous pulse width modulation (IZDPWM) technique that is compatible for grid-connected inverters. Regardless the grid topology, IZDPWM exactly copies the distorting harmonics of the grid voltage. Hence, a sinusoidal current is injected to the grid. Moreover, for measuring the grid line-to-line voltages two sensors are required; hence overall system cost is reduced and control system reliability is increased. The time-domain simulation in MATLAB/Simulink and experimental results from a Hardware based laboratory prototypes are in good agreement, which verify the effectiveness of the proposed generalized method.

***Keywords:*** unified integral controller, Synchronous; grid-connected inverters, unbalanced and distorted conditions

## I. INTRODUCTION

A single phase grid connected DC/AC inverter with reactive power (VAR) control for residential photovoltaic (PV) applications. In this work, the foci are on the control of the inverter and the grid synchronization technique. Another challenge involves the reduction of the size of the DC-link capacitor in order to use long life film capacitor in a low cost manner. First, a brief background on the single phase PV grid connected inverter is presented along with the motivation of this work. Then, a literary review on the PV inverter system configurations, controls, DC-link capacitor reduction techniques and the grid synchronization methods are presented. The objective of this paper is to develop an enhanced PI control, which integrates PI control with a simple feedback term to eliminate the steady-state error with no need of additional complex algorithms such as the synchronous reference frame (SRF) transformations. It has a very simple structure and can be easily implemented in practical applications. In addition, the resonant frequency of the controller is easy to adjust. This is especially attractive for applications like frequency droop controlled micro grids, in which the frequency is changed according to the active power participation of each inverter.

That means that the output frequency reference of the inverter can change the fundamental and harmonics resonant frequencies of their respective controllers. Under the micro FIT program, they will be paid a much higher price for the electricity that the projects produce comparing to the standard price people pay for their electricity. Particularly, for PV rooftop generation, the contract price paid is 80.2 cents/kWh, whereas the blended rate of electricity in Ontario is 7.74 cents/kWh in the summer period. Therefore, with the help of such stimulation programs. The PV modules are connected in series, also referred to as PV strings, in order to provide sufficient output voltage. The PV strings are then connected in parallel through string diodes in order to achieve high power production. In this configuration, the centralized DC/AC inverter is subjected to handle, maximum power point tracking (MPPT), grid current control and voltage amplification if necessary. Although the configuration is simple, the drawbacks are substantial. One of the biggest is the poor energy harvesting capabilities of the centralized MPPT due to shading, panel mismatch and degradation factors.

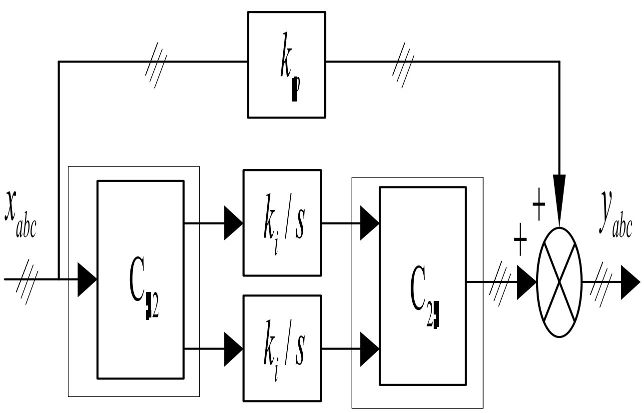


***Fig. 1. Three - Phase SRF control scheme.***

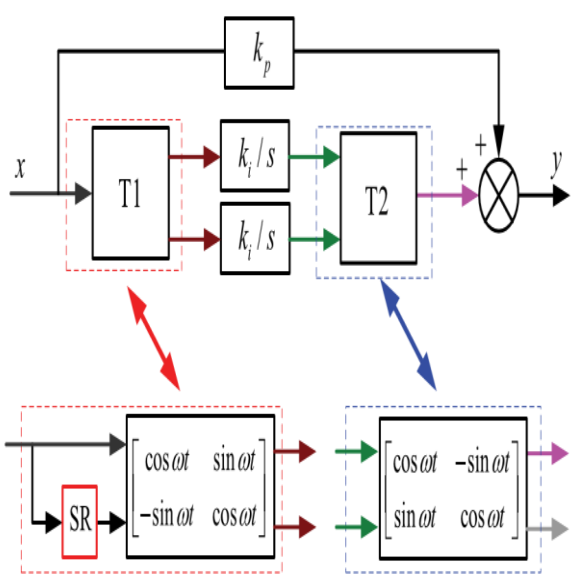


***Fig.2. Single-Phase SRF control scheme with virtual αβ frame.***

## A. TWO STAGE INVERTERS

In order to improve the energy harvesting capabilities and design flexibility, dedicated DC/DC converters, which perform MPPT for each PV string can be connected in the middle between the PV modules and the DC/AC inverter [8], Figure 1.2. The system shown in Figure 1.2(a) has its PCC at the AC terminal. This system type benefits from its modularity and the capability of plug-and-play installation by users that possess limited knowledge of electrical systems. The output from the DC/DC converter in this configuration can be either a low ripple DC voltage, or a modulated current that follows a rectified sine wave. In the latter case, the DC/DC converter handles MPPT and output current regulation while the DC/AC inverter switches at the grid frequency to unfold the rectified sine wave. Reference [10] is an example of the unfolding configuration. The SPWM control has a long history and is easy to implement. The traditional method of SPWM control uses a proportional-integral (PI) compensator in the feedback loop to regulate the output current. However, while PI compensators have excellent performances on regulating DC quantities, tracking a sinusoidal current reference would lead to steady state magnitude and phase errors [19]. Then, over the past two decade, researchers have explored use of proportional-resonant (PR) controller, while can provide "infinite" gain at the reference signal's oscillating frequency [20] [21]. The PR controller.

## B. HERIC TOPOLOGY

The topology called "Highly Efficient and Reliable Inverter Concept" (HERIC), commercialized by Sunways, derives directly from the Full-Bridge converter, in which a bypass leg has been added in the AC side by means of two back-to-back IGBTs operating at grid frequency. The HERIC circuit is shown in

Fig. 2.1, where Cin is the DC-link capacitor, Lfi and Lfg are the output filter inductors, respectively on the inverter-side and gridside, and Cf is the filter capacitor. The bypass branch has two important functions: decoupling the PV array from The grid (using a method called "AC decoupling"), Avoiding the presence of high-frequency voltage Components across it and preventing the reactive power exchange between the filter inductors and Cin during the zero voltage state, thus increasing efficiency [2]. The converter operates as it follows (see Table I): during the positive half-cycle S+ remains connected, whereas S1 and S4 commutate at switching frequency in order to generate both active and zero vectors. When an active vector is present (S1 and S4 are ON), current flows from the PV panels to the grid, while, when a zero vector occurs, S1 and S4 are switched OFF and the current flows through S+ and D-, this is the freewheeling situation. On the other hand, when the negative cycle is coming, S+ goes OFF and S- goes ON, whereas S3 and S2 commutate at switching frequency.

## II. CONSTRUCTION

The control of grid-connected inverter plays an integral role in power processing in DG systems. In such applications the inverter need to inject high quality current into the utility grid. For this reason feed forward control is proposed to reduce the effect of the grid voltage distortion over the grid current. The mentioned objective is achieved by employing IZDPWM that creates the same harmonics existing in the grid line-to-line voltages.

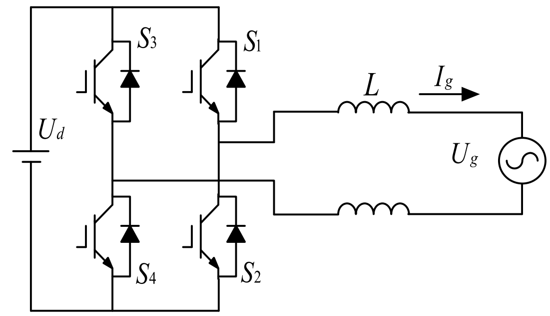


***Fig.3. L-type grid connected inverter.***

In [10] the feed forward controller for the *L*-type grid-connected inverter has been developed, however, the implemented SVPWM-based predictive current controller is more complicated comparing with scalar PWM methods. The full-feed forward scheme that employs *LCL*-type inverter was introduced in [11]. Beside the *LCL* filter resonance hazard, full-feed forwarding is considered sophisticated; due to the existence of proportional, derivative, and second derivative parts. Moreover the *L*-type grid-connected inverter is much less susceptible to instability, and faults. The performance of the proposed feed forward controller is studied on the L-type grid-connected inverter shown in When 2 = 0, from equation 3 we can say that maximum emf is induced in coil S. But from2 equation 8, it is observed that the coil - to coil voltage ES3S1 is zero. This position of the rotor is defined as the electrical zero of the transmitter.

## III.WORKING

The generated emf of the synchro transmitter is applied as input to the stator coils of control transformer. The rotor shaft is connected to the load whose position has to be maintained at the desired value. Depending on the current position of the rotor and the applied emf on the stator, an emf is induced on the rotor winding. This emf can be measured and used to drive a motor so that the position of the load is corrected.

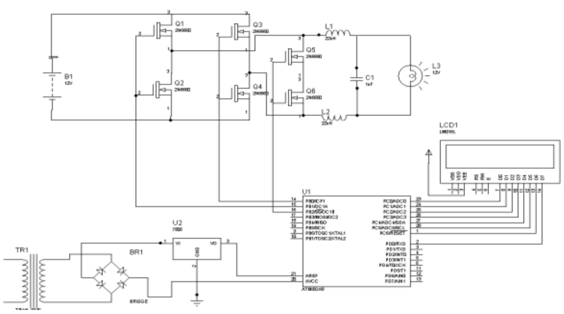

**Fig.4. Circuit Diagram**

## IV.EXPERIMENTAL RESULTS

**Inverter Output Linearity Range**

In the precedence of implementing IZDPWM-based feed forward controller, the feasibility of IZDPWM need to be ensured as an open loop inverter controller. Thus IZDPWM was applied on the VSI shown in Fig. 1. The power circuit was simulated in MATLAB/Simulink power block set software, and its prototype was manufactured.

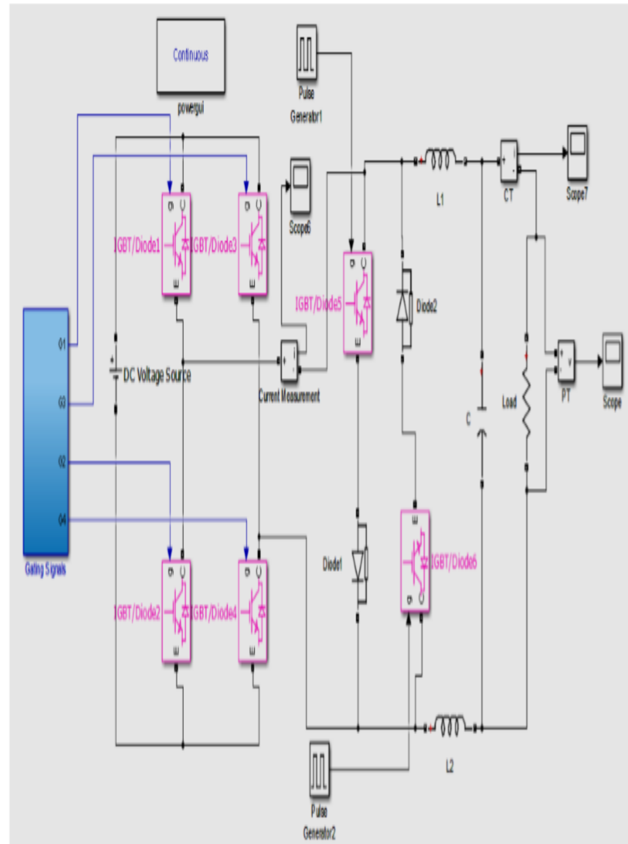


**Fig.5. Simulation Circuit**

| | |
|---|---|
| DC Supplies | TDK-Lambada 630 V, 5 A |
| IGBTs | G4PH50UD 24 A, 1200 V |
| Controller | **PIC 16F877A** |
| Lf | 1.5 mH |
| Cf | 10 uF |
| Resistive Load (Y) | 2.4 KW, 380V, 61.25Ω |

**Table.1** ***System Construction***

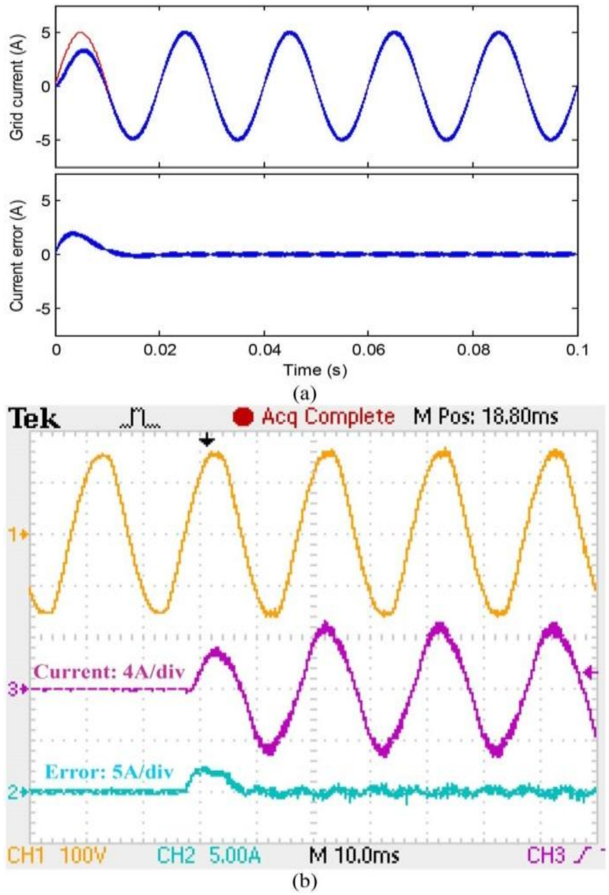


***Fig. 16. Test results with solution B. (a) Simulation result. (b) Experimental results.***

### *Hardware*

***Fig6. Hardware Implementation***

### *Signal Quality*

IZDPWM0 was compared with DPWM0 in terms of THD of line-to-line voltage at switching frequency fs=9 kHz. As depicted in Fig. 7, the use of IZDPWM0 shows an appreciable output compared with DPWM0 at different modulation indices. The better result in terms of THD in IZDPWM0 is attributed to the employed modulating and carrier signals. The THD measured from the experimental setup is dropped the THD to 0.24% for . As shown in Fig. 7, THD= 0.94% obtained from simulated test is not consistent with the experimentally found value. Such dissimilarity is attributed to the power analyzer's resolution (bandwidth: 0.0 KHz to 10.6 KHz) that prevents accurate measurement of high frequency components.

## V. CONCLUSION

The feed forward of line-to-line voltages grid connected three-phase three-wire two level VSIs is presented for the purpose of dealing with fast and dynamic grid voltage disturbances. The grid-connected inverter is modulated using IZDPWM0 that takes the line-to-line voltages as reference signals. In initial tests that deal with the inverter open loop operation; IZDPWM0 provided the desired output at balanced, unbalanced and distorted reference voltages. IZDPWM based feed forward controller is capable to control the inverter under weak grid condition without extracting grid voltage harmonics. Regardless grid topology, IZDPWM showed robustness in grid-connected operation mode. The presented control scheme by simulation and experimental tests. With the proposed feed forward scheme appreciable results were attained; and the injected grid current harmonics caused by the grid voltage distortion are significantly reduced. Since the line-to-line voltages were considered in the modulation, PWM significantly contributed in reducing the number of sensors. Hence, high reliability control is achieved with decreased overall system cost.

## FUTURE WORK

The future work of this research can extend to design the front end DC/DC converter so that a two stage PV inverter system can be built for the analysis of the inverter's response when it is connected to a power source that is generated from the PV modules instead of a constant DC current source that is used in the lab. This research furthermore opens up the topic of actively exchanging reactive power with the utility grid at the distribution level. The control and communication methods between these type of local DRs and the central dispatch would be a useful area of study.

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