

An Efficient Control Strategy for Three-Phase Inverter in Distributed Generation

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Abstract- The proposed control strategy composes of an inner inductor current loop, and a novel voltage loop in the synchronous reference frame. The inverter is regulated as a current source just by the inner inductor current loop in grid-tied operation, and the voltage controller is automatically activated to regulate the load voltage upon the occurrence of islanding. Furthermore, the waveform of the grid current in the grid-tied mode and the load voltage in the islanding mode are distorted under nonlinear local load with the conventional strategy. And this issue is addressed by proposing a unified load current feed-forward in this paper. Finally, the effectiveness of the proposed control strategy is validated by the simulation results.

Index Terms- Distributed generation (DG), Islanding, load current, seamless transfer, three-phase inverter.

I. INTRODUCTION

The need for electric energy is never ending. Along with the growth in demand for electric power, sustainable development, environmental issues, and power quality and reliability have become concerns. Electric utilities are becoming more and more stressed since existing transmission and distribution systems are facing their operating constraints with growing load. Green house gas emission has resulted in a call for cleaner and renewable power sources. Development in technology has been making the whole society more and more electricity dependent and creating more and more critical loads. Under such circumstance, distributed generation (DG) with alternative sources has caught people's attention as a promising solution to the above problems. Distributed generation is not a new concept since traditional diesel generator as backup power source for critical load has been used for decades. However, due to its slow efficiency, high cost, and noise and exhaust, diesel generator would be objectionable in any applications but emergency and fieldwork and it

has never become a true distributed generation source on today's basis. What endows new meaning to this old concept is technology. Environmental friendly renewable energy sources, such as photovoltaic devices and wind electric generators, clean and efficient fossil-fuel technologies, such as micro gas turbines, and hydrogen electric devices - fuel cells, have provided great opportunities for the development in distributed generation. Gas fired micro-turbines in the 25-100 kW range can be mass produced at low cost which use air bearing and recuperation to achieve reasonable efficiency at 40% with electricity output only and 90% for electricity and heat micro-cogeneration. Fuel cells have the virtue of zero emission, high efficiency, and reliability and therefore have the potential to truly revolutionize power generation. The hydrogen can be either directly supplied or reformed from natural gas or liquid fuels such as alcohols or gasoline.

A Distributed generation (DG) is emerging as a viable alternative when renewable or non conventional energy resources are available, such as wind turbines, photovoltaic arrays, fuel cells, microturbines [1], [3]. Most of these resources are connected to the utility through power electronic interfacing converters, i.e., three-phase inverter. Moreover, DG is a suitable form to offer high reliable electrical power supply, as it is able to operate either in the grid-tied mode or in the islanded mode [2]. In the grid-tied operation, DG delivers power to the utility and the local critical load. Upon the occurrence of utility outage, the islanding is formed. Under this circumstance, the DG must be tripped and cease to energize the portion of utility. However, in order to improve the power reliability of some local critical.

A fuel cell converts chemical energy of a fuel directly into electrical energy. It consists of two electrodes and an electrolyte, retained in a matrix. The operation

is similar to that of a storage battery except that the reactant and products are not stored, but are continuously fed to the cell. During operation the hydrogen rich fuel and oxidant are separately supplied to the electrodes.

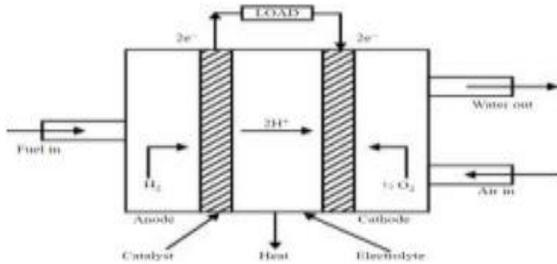


Fig 1: Basic Construction of a Fuel Cell

Fuel is fed to the anode and oxidant to the cathode, and the two streams are separated by an electrode electrolyte system. Electrochemical oxidation and reduction takes place at the electrodes to produce electricity. Heat and water are produced as by products. Fig 1 shows the basic construction of a fuel cell. The Flows and reactions in a Fuel Cell are shown in Fig 2.

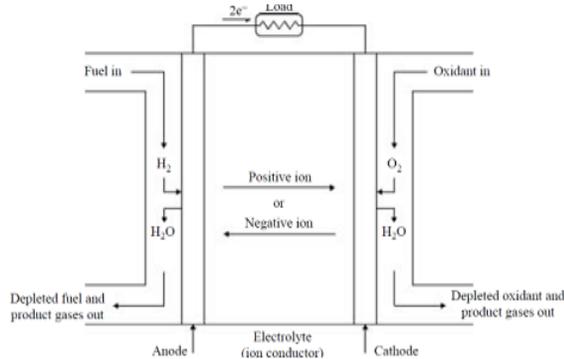


Fig 2: Flows and reactions in a fuel cell

This paper proposes a unified control strategy that avoids the aforementioned short comings. First, the traditional inductor current loop is employed to control the three-phase inverter in DG to act as a current source with a given reference in the synchronous reference frame (SRF). Second, a novel voltage controller is presented to supply reference for the inner inductor current loop, where a proportional plus-integral (PI) compensator and a proportional (P) compensator are employed in D-axis and Q-axis, respectively.

II. PROPOSED CONTROL STRATEGY

This paper presents a unified control strategy for a three-phase inverter in DG to operate in both islanded and grid-tied modes. The schematic diagram of the DG based on the proposed control strategy is shown by Fig. 3. The DG is equipped with a three-phase interface inverter terminated with a LC filter. The primary energy is converted to the electrical energy, which is then converted to dc by the front-end power converter, and the output dc voltage is regulated by it. Therefore, they can be represented by the dc voltage source V_{dc} in Fig. 3. In the ac side of inverter, the local critical load is connected directly.

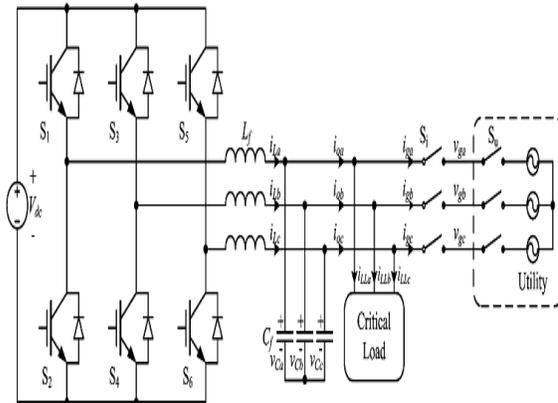


Fig. 3. Schematic diagram of the DG based on the proposed control strategy

Basic idea

With hybrid voltage and current mode control, the inverter is controlled as a current source to generate the reference power $P_{DG}+jQ_{DG}$ in the grid-tied mode. And its output power $P_{DG}+jQ_{DG}$ should be sum of the power injected to the grid P_g+jQ_g and the load demand $P_{load}+jQ_{load}$, which can be expressed followed by as assuming that the load is represented as a parallel RL circuit.

$$P_{load} = \frac{3}{2} \cdot \frac{V_m^2}{R} \dots \dots \dots (1)$$

$$Q_{load} = \frac{3}{2} V_m^2 \cdot \left(\frac{1}{\omega L} - \omega C \right) \dots \dots \dots (2)$$

In (1) and (2), V_m and ω represent the amplitude and frequency of the load voltage, respectively. When the non linear local load is fed, it can still be equivalent to the parallel RLC circuit by just taking account of the fundamental component.

Fig. 4 describes the overall block diagram for the proposed unified control strategy, where the inductor current i_{Labc} , the utility voltage V_{gabc} , the load voltage V_{Cabc} , and the load current are sensed. And

the three phase inverter is controlled in the SRF, in which, three phase variable will be represented by dc quantity. The control diagram is mainly composed by the inductor current loop, the PLL, and the current reference generation module. In the inductor current loop, the PI compensator is employed in both D and Q-axes, and a decoupling of the cross coupling denoted by $\omega_0 L_f / k_{PWM}$ is implemented in order to mitigate the couplings due to the inductor.

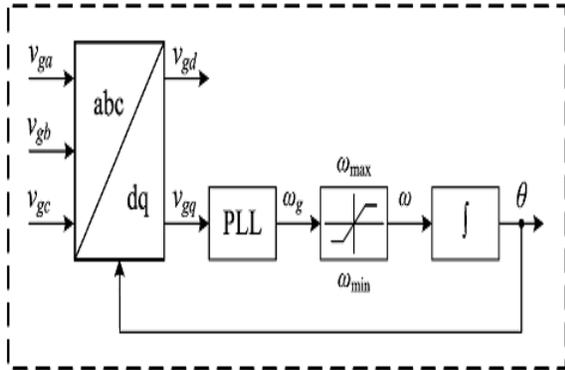


Fig. 4. Overall block diagram of the proposed unified control strategy.

The output of the inner current loop ddq together with the decoupling of the capacitor voltage denoted by $1/k_{PWM}$, sets the reference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that kPWM denotes the voltage gain of the inverter, which equals to half of the dc voltage in this paper.

III. OPERATION PRINCIPLE OF DG

The operation principle of DG with the proposed control strategy will be illustrated in detail in this section, and there are in total two states for the DG, including the grid-tied mode, the islanded mode.

A. Grid-Tied Mode: When the utility is normal, the DG is controlled as a current source to supply given active and reactive power by the inductor current loop, and the active and reactive power can be given by the current reference of D- and Q-axis independently. First, the phase angle of the utility voltage is obtained by the PLL, which consists of a Park transformation expressed by (3), a PI compensator, a limiter, and an integrator

$$\begin{pmatrix} x_d \\ x_q \end{pmatrix} = \frac{2}{3} \begin{pmatrix} \cos \theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin \theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \end{pmatrix} \times \begin{pmatrix} x_a \\ x_b \\ x_c \end{pmatrix} \quad (3)$$

Second, the filter inductor current, which has been transformed into SRF by the Park transformation, is

feedback and compared with the inductor current reference i_{Lrefdq} , and the inductor current is regulated to track the reference i_{Lrefdq} by the PI compensator G_I . The reference of the inductor current loop i_{Lrefdq} seems complex and it is explained as below. It is assumed that the utility is stiff, and the three-phase utility voltage can be expressed as

$$\begin{cases} v_{ga} = V_g \cos \theta^* \\ v_{gb} = V_g \cos(\theta^* - \frac{2\pi}{3}) \\ v_{gc} = V_g \cos(\theta^* + \frac{2\pi}{3}) \end{cases} \quad (4)$$

where V_g is the magnitude of the grid voltage, and θ^* is the actual phase angle. By the Park transformation, the utility voltage is transformed into the SRF, which is shown as

$$\begin{cases} v_{gd} = V_g \cos(\theta^* - \theta) \\ v_{gq} = V_g \sin(\theta^* - \theta). \end{cases} \quad (5)$$

The control diagram of the inverter can be simplified as Fig. 5 in the grid-tied mode, and the inverter is controlled as a current source by the inductor current loop with the inductor current reference being determined by the current reference I_{grefdq} and the load current I_{LLdq} . In other words, the inductor current tracks the current reference and the load current. If the steady state error is zero, I_{grefdq} represents the grid current.

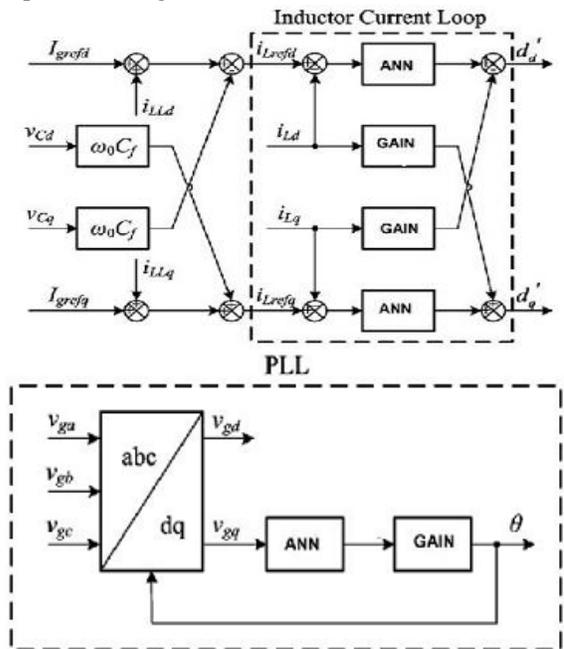


Fig. 5. Simplified block diagram of the unified control strategy when DG operates in the grid-tied mode.

B. Transition From the Grid-Tied Mode to the Islanded Mode

When the utility switch S_u opens, the islanding happens, and the amplitude and frequency of the load voltage will drift due to the active and reactive power mismatch between the DG and the load demand. The transition, shown in Fig.6, can be divided into two time interval. The first time interval is from the instant of turning off S_u to the instant of turning off S_i when islanding is confirmed. The second time interval begins from the instant of turning off inverter switch S_i .

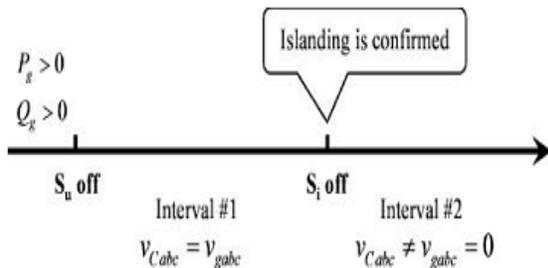


Fig.6. Operation sequence during the transition from the grid-tied mode to the islanded mode.

C. Islanded Mode

In the islanded mode, switching S_i and S_u are both in OFF state. The PLL cannot track the utility voltage normally, and the angle frequency is fixed. In this situation, the DG is controlled as a voltage source, because voltage compensator GVD and GVQ can regulate the load voltage V_{Cdq} . The voltage references in D and Q-axis are V_{max} and zero, respectively.

D. Transition From the Islanded Mode to the Grid-Tied Mode

If the utility is restored and the utility switch S_u is ON, the DG should be connected with utility by turning on switch S_i . However, several preparation steps should be performed before turning on switch S_i . First, as soon as utility voltage is restored, the PLL will track the phase of the utility voltage. As a result, the phase angle of the load voltage V_{Cabc} will follow the grid voltage V_{gabc} . If the load voltage V_{Cabc} is in phase with the utility voltage, v_{gd} will equal the magnitude of the utility voltage according to (5). Second, as the magnitude of the load voltage V_{max} is larger than the utility voltage magnitude V_g , the voltage reference V_{ref} will be changed to V_g by toggling the selector S from terminals 1 to 2. As a

result, the load voltage will equal to the utility voltage in both phase and magnitude. Third, the switch S_i is turned on, and the selector S is reset to terminal 1.

IV. SIMULATION AND EXPERIMENTAL RESULTS

To investigate the feasibility of the proposed efficient control strategy, the simulation has been done in SIMULINK. The power rating of a three-phase inverter is 3kW in the simulation. In the grid-tied mode, the dynamic performance of the conventional voltage mode control and the proposed control strategy is compared by stepping down the grid current reference. The simulation results can be seen that the dynamic performance of the proposed control strategy is better than the conventional voltage mode control. During the transition from the grid-tied mode to the islanded mode, the proposed control strategy is compared with the hybrid voltage and current mode control. The SIMULINK model for the proposed control strategy is shown in the below Fig. 6.

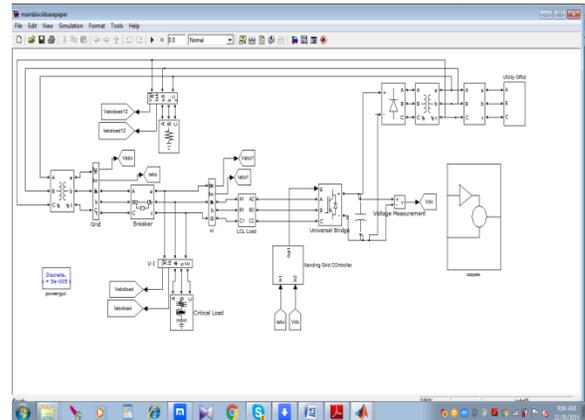


Fig 7 . SIMULINK model

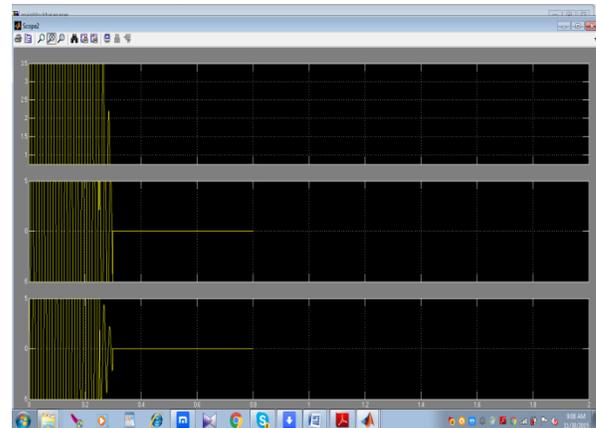


Fig.8

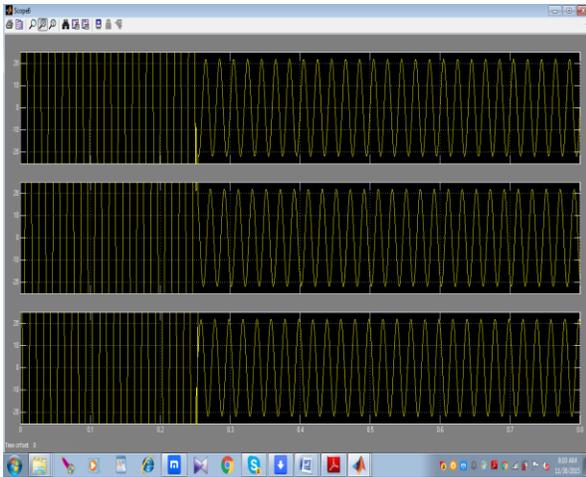


Fig.9

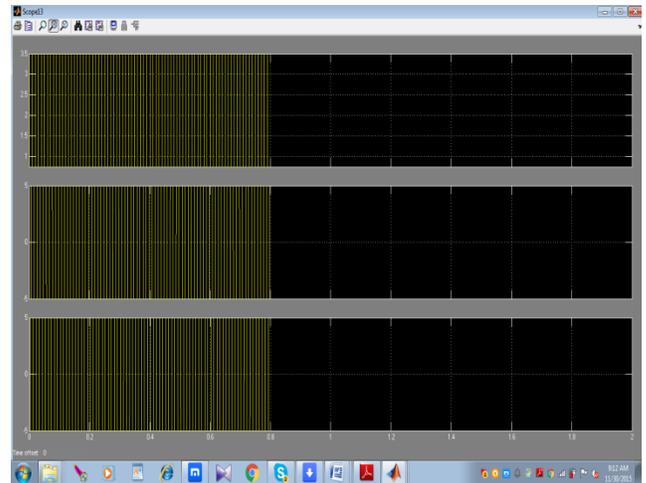


Fig.12

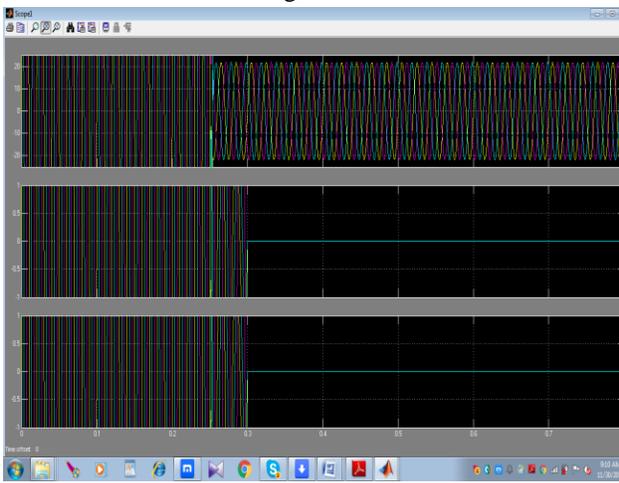


Fig.10

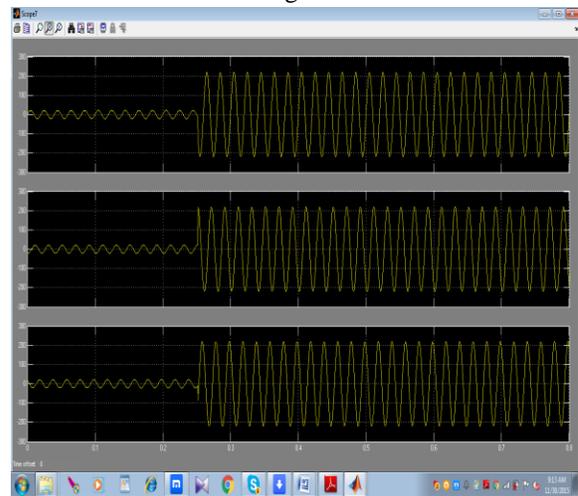


Fig.13

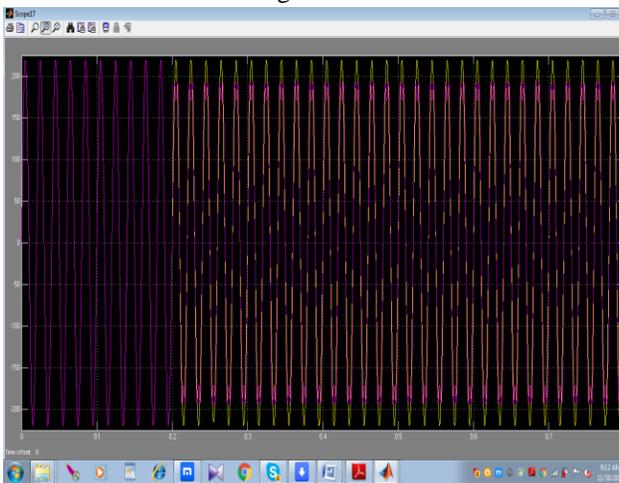


Fig.11

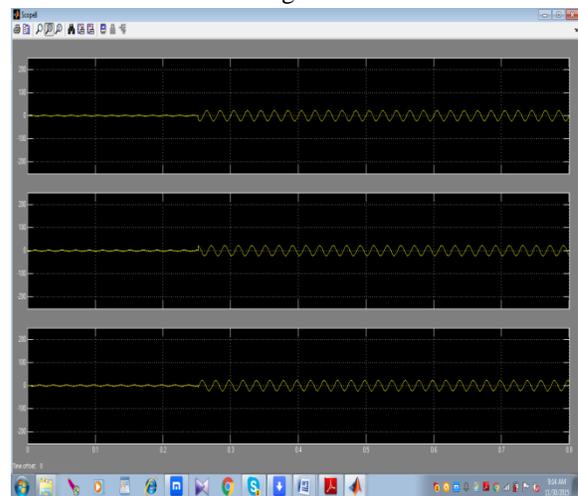


Fig.14

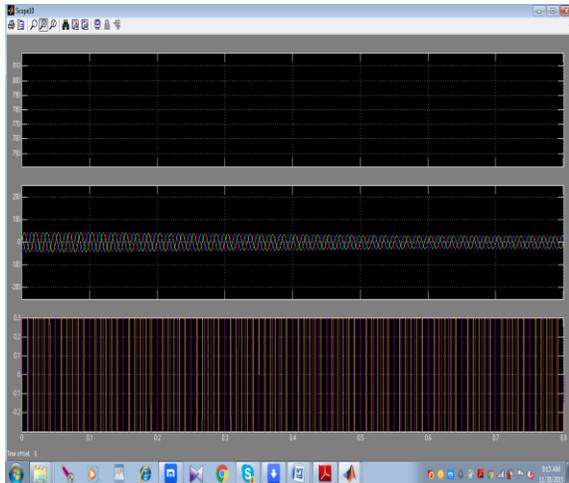


Fig.15

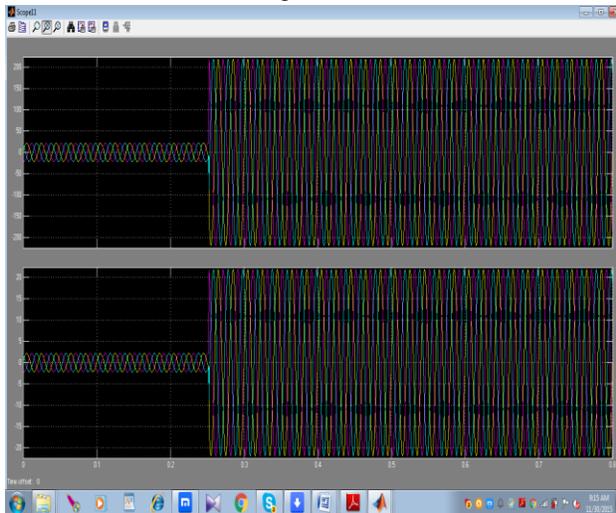


Fig.16

V. CONCLUSION

An efficient control strategy was proposed for three phase inverter in DG using Artificial neural networks to operate in both islanded and grid-tied modes, with no need for switching between two different control architectures or critical islanding detection. The voltage controller is inactivated in the grid-tied mode, and the DG operates as a current source with fast dynamic performance. Upon the utility outage, the voltage controller can automatically be activated to regulate the load voltage. Moreover, the load current feed forward can improve the waveform quality of both the grid current in the grid-tied mode and the load voltage in the islanded mode.

REFERENCES

- [1] R. C. Dugan and T. E. McDermott, "Distributed generation," *IEEE Ind. Appl. Mag.*, vol. 8, no. 2, pp. 19–25, Mar./Apr. 2002.
- [2] R. H. Lasseter, "Microgrids and distributed generation," *J. Energy Eng.*, vol. 133, no. 3, pp. 144–149, Sep. 2007.
- [3] C. Mozina, "Impact of green power distributed generation," *IEEE Ind. Appl. Mag.*, vol. 16, no. 4, pp. 55–62, Jul./Aug. 2010.
- [4] IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, *IEEE Standard 929-2000*, 2000.
- [5] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, *IEEE Standard 1547-2003*, 2003.
- [6] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, *IEEE Standard 1547-2003*, 2003.
- [7] J. Stevens, R. Bonn, J. Ginn, and S. Gonzalez, *Development and Testing of an Approach to Anti-Islanding in Utility-Interconnected Photovoltaic Systems*. Liver more, CA, USA: Sandia National Laboratories, 2000.
- [8] A. M. Massoud, K. H. Ahmed, S. J. Finney, and B. W. Williams, "Harmonic distortion-based island detection technique for inverter-based distributed generation," *IET Renewable Power Gener.*, vol. 3, no. 4, pp. 493–507, Dec. 2009.
- [9] T. Thacker, R. Burgos, F. Wang, and D. Boroyevich, "Single-phase is-landing detection based on phase-locked loop stability," in *Proc. 1st IEEE Energy Convers. Congr. Expo.*, San Jose, CA, USA, 2009, pp. 3371–3377.
- [10] S.-K. Kim, J.-H. Jeon, J.-B. Ahn, B. Lee, and S.-H. Kwon, "Frequency-shift acceleration control for anti-islanding of a distributed generation inverter," *IEEE Trans. Ind. Electron.*, vol. 57, no. 2, pp. 494–504, Feb. 2010.

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