
A New PV/Fuel Cell Based Bidirectional Converter for Microgrid Applications

T.Suman

Assistant Professor,EEE Dept.,MREC(A)
sumankumar2k@gmail.com

Abstract: *The penetration of renewable energy in modern power system, microgrid has become a popular application worldwide. In this paper bidirectional converters for AC and DC hybrid microgrid application are proposed as an efficient interface. To reach the goal of bidirectional power conversion, both rectifier and inverter modes are analyzed. In order to achieve high performance operation and single-phase bi-directional inverter with dc-bus voltage regulation and power compensation in dc-microgrid applications. This concept proposes a control design methodology for a multi functional single-phase bidirectional PWM converter in renewable energy systems. There is a generic current loop for different modes of operation to ease the transition between different modes, including stand-alone inverter mode, grid-tied inverter mode, ac voltage regulation is of importance because of the sensitive loads In dc-microgrid applications, a power distribution system requires a bi-directional inverter to control the power flow between dc bus and ac grid, and to regulate the dc bus to a certain range of voltages, in which dc load may change abruptly. This will result in high dc-bus voltage variations; the bi-directional inverter can shift its current commands according to the specified power factor at ac grid side. Parallel-connected bidirectional converters for AC and DC hybrid microgrid application are proposed as an efficient interface. To reach the goal of bidirectional power conversion, both rectifier and inverter modes are analyzed. The Simulation results are carried out by Matlab/Simulink to verify the performance of the proposed method.*

Index Terms: *Bidirectional converter, PWM technique, Phase-locked loop (PLL) system, Photovoltaic (PV) power systems, DG system*

1. INTRODUCTION

In dc-microgrid applications, a power distribution system requires a bi-directional inverter to control the power flow between dc bus and ac grid, and to regulate the dc bus to a certain range of voltages, in which dc load may change abruptly. In this different multi-loop-based control schemes are investigated and compared, especially between the load current feedback control, and capacitor current loop control. The main aim of this concept is control system for single-phase bidirectional PWM converters for residential power level micro grid systems which is robust and can tolerate transitions between the different modes of operation.

With the progress of industry application, problems caused by the gradually decreasing of fossil fuel and environment pollution are shown clearly nowadays. As a result, renewable energy sources are playing more important role in the modern energy system [1, 2]. With the rapid development of renewable energy technology, great attention is paid to ‘Microgrid’ worldwide. Microgrid is a kind of power grid area which is a combination of different kinds of power units which are usually based on renewable energy sources [3-6]. A hybrid microgrid can be made up of distributed renewable source, AC and DC common buses, interface circuit and local load. In the application of microgrid, power electronics converter is usually adopted as an interface circuit to guarantee the reliable and efficient connection of both AC and DC sides [7].

The control goal is to achieve a bidirectional ‘bridge’ in AC and DC hybrid microgrid. Also, it can be employed to connect energy storage units, in order to accomplish charging and discharging process. At the present stage, only standalone rectifier and inverter operation modes are analyzed. The transient results of switching between the two modes will be shown in the probable future work. To achieve high performance operation of bidirectional parallel converter system, hierarchical control in stationary frame is adopted. AC/DC voltage and current control and power sharing between the parallel converters are achieved. At the same time, reduction of deviation caused by droop controllers is also reached

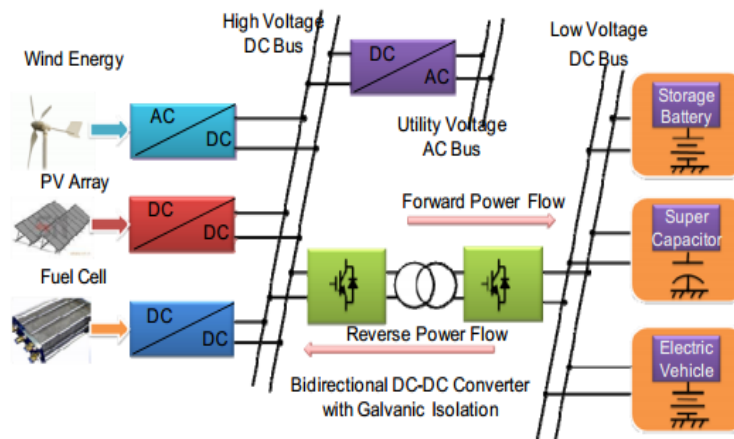


Fig.1 Typical application for power distribution in a microgrid renewable energy system

Today photovoltaic (PV) power systems are becoming more and more popular, with the increase of energy demand and the concern of environmental pollution around the world. Four different system configurations are widely developed in grid-connected PV power applications: the centralized inverter system, the string inverter system, the multi-string inverter system and the module-integrated inverter system. Generally three types of inverter systems except the centralized inverter system can be employed as small-scale distributed generation (DG) systems, such as residential power applications. The most important design constraint of the PV DG system is to obtain a high voltage gain. This paper proposes a photovoltaic (PV) system, which presents a set of advantages when compared to conventional stand-alone PV system. In the proposed system, the generated energy by the PV arrays is processed by multi-string step-up converters.

2. OPERATION AND PRINCIPLE OF PROPOSED SYSTEM

In recent years, due to the growing concern with energy shortage and network stability, the concepts of distributed generation (DG), microgrid systems, dc nanogrid systems, and ac/dc hybrid power systems have all become progressively more popular; especially with the decreasing costs of various clean renewable energy sources (RES), such as: wind, solar, and fuel-cells to name a few and more adoption of dc powered residential loads, such as solid state lighting. These DG systems would be connected to the utility grid under normal operating conditions, but also have the additional capability to sustain a local system (micro- or nanogrid) by sourcing power directly from the renewable energy sources and energy storage devices if necessary to make grid transmission level black- and brownouts seem transparent to the local system loads.

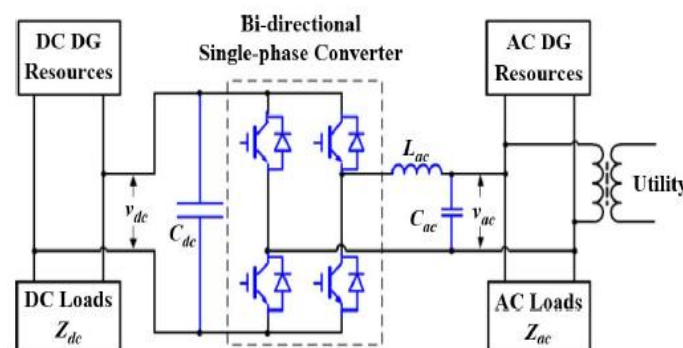


Fig.2 Single-phase AC/DC interactive renewable energy system

Using this type of system configuration, the ac/dc converter of a DHPS should operate in the following modes and sub-modes:

- 1) Stand-Alone Mode (SAM): When the grid is lost, the converter regulates the ac bus voltage and frequency feeding the ac loads while drawing energy from dc-side, supported by the renewable energy sources or energy storage on the dc-side. The RES on the ac side act as current sources in this case.
- 2) Grid-Connected Mode (GCM): When the grid is present, the converter acts as an ac current regulator, injecting or sinking power from the grid to achieve:

- a) Inverter sub-mode: Regulate the power flow (active and reactive) between the dc and ac sub-systems, while other dc sources regulate the dc bus voltage V_{dc} ,
- b) Rectifier sub-mode: Regulate the dc bus voltage and performs energy balancing to sustain dc bus integrity while other dc side energy sources operate as current sources.
- 3) Grid-Disconnected Mode (GDM): When the grid is lost, the converter still operates as GCM inverter/power flow control supplying ac loads. Normally, GDM is the transient state in mode transition between GCM and SAM; however, given the non detection zones (NDZ), GDM could exist for a while.

3. MODES OF OPERATION

Many of the existing methods require a different control system for each mode of operation, which increases the complexity and decreases the reliability of the system, as well as increasing the difficulty in transitioning between modes. Moreover, existing papers did not cover all of the probable modes of operation, neither the overall functionality nor the modeling and control design of all the aforementioned modes. As it will be shown, some of them are very different requiring different control approaches.

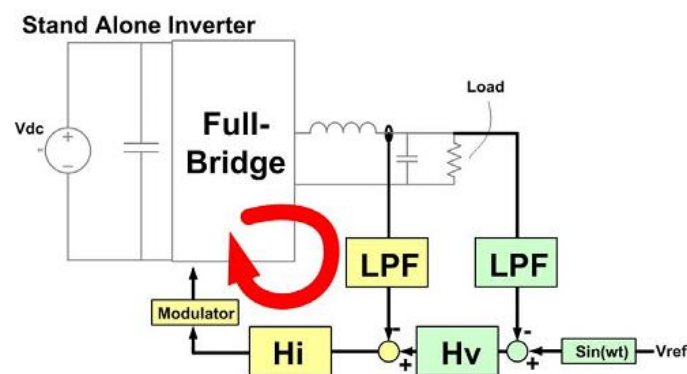


Fig.3. Stand-alone inverter mode control structure

- A. Grid-tied Rectifier mode
- B. Charger mode
- C. Discharger mode

3.1 Grid-tied Rectifier mode

The dc-link voltage is one of the state-variables for the grid-tied rectifier mode; the dynamic of the dc-link voltage should be taken into consideration, since it leads to the non-linearity for the rectifier mode. From the average state-space model, the state matrix is not constant, varying with the duty cycle. The Eigen-value of the system would be changing with the duty cycle. In other words, the characteristics of the system would vary all the time. We cannot obtain the small-signal model since it is hard to select a proper operating point to inject the perturbation. We will see that at low frequencies, the system dynamics would be more affected by the dc-link capacitor.

At high frequencies, the system dynamics are dominated by the line inductor. It is hard to model the middle frequency range since the system dynamics would be affected both by the dc-link capacitor and the ac line inductor. The fact is that our controller consists of an inner current loop and an outer voltage loop. It means that we don't really need to know the whole system dynamics. We only need to know the high-frequency response for the current loop design, and low-frequency response for the outer loop design. We also know that at high frequencies the ac inductor dynamics would be dominant, so we just can ignore the influence from the dc-link capacitor. At the same time, we only consider the dc-link capacitor dynamics when looking at the low-frequency system response. Hence we can decouple the inner loop and outer loop. Then we can design the current loop and voltage loop separately.

3.2 Control Structure

In this paper, all of the basic modes of operation for GCM and SAM are defined and modeled. A generic inner current loop based multi-loop control structure is proposed to integrate and simplify the

various modes of operation. A novel single-phase PLL and associated islanding detection algorithm is proposed for system level operation. The control structures for each mode are shown in Figures

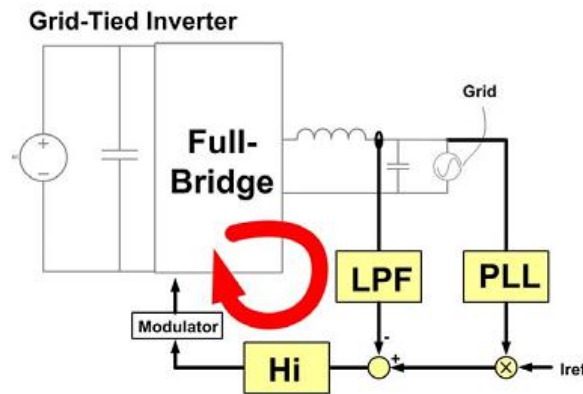


Fig.4 Grid-tied inverter mode control structure

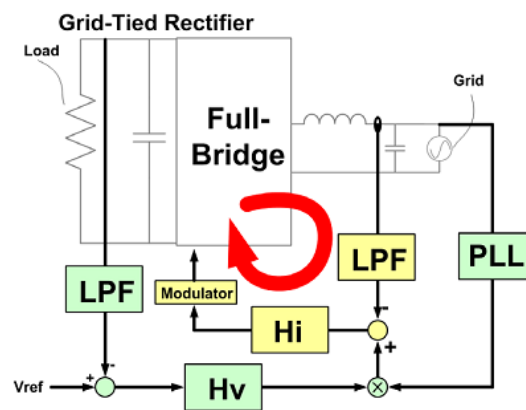


Fig.5. Grid-tied rectifier mode control structure

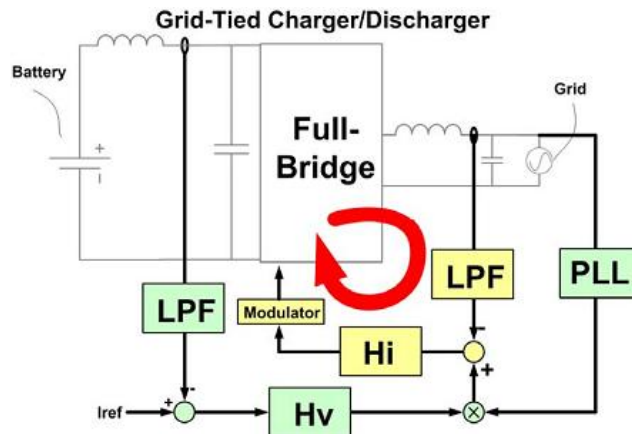


Fig.6. Grid-tied charger/discharger mode control structure

Photovoltaic System & Fuel Cell

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices.

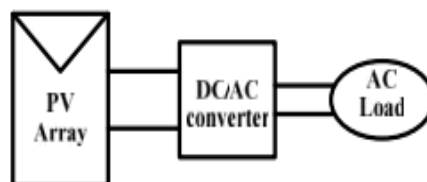


Fig.7. Block diagram representation of Photovoltaic system

This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig.7.

A. Photovoltaic cell A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited1

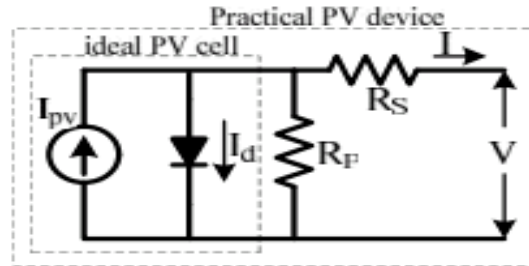


Fig.8. Practical PV device

The equivalent circuit of PV cell is shown in the fig.8. In the above figure the PV cell is represented by a current source in parallel with diode. R_s and R_p represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V . The I-V characteristics of PV cell are shown in fig.9. The net cell current I is composed of the light generated current I_{pv} and the diode current I_d .

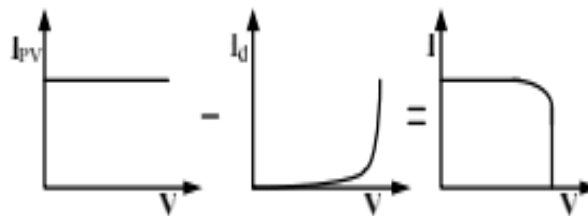


Fig.9. Characteristics I-V curve of the PV cell

Various equivalent circuit models of a PV cell have been proposed. For obtaining high power, numerous PV cells are connected in series and parallel circuits on a panel, which is a PV module. A PV array is defined as a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. This paper presents a single-phase bi-directional inverter with dc-bus voltage regulation and power compensation in dc-microgrid applications. In dc-microgrid applications, a power distribution system requires a bi-directional inverter to control the power flow between dc bus and ac grid, and to regulate the dc bus to a certain range of voltages, in which dc load may change abruptly. This will result in high dc-bus voltage variation. The bi-directional inverter can shift its current commands according to the specified power factor at ac grid side.

Pressurized hydrogen gas (H_2) enters cell on anode side. Gas is forced through catalyst by pressure. When H_2 molecule comes contacts platinum catalyst, it splits into two H^+ ions and two electrons (e^-). Electrons are conducted through the anode. Make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell. On the cathode side, oxygen gas (O_2) is forced through the catalyst Forms two oxygen atoms, each with a strong negative charge. Negative charge attracts the two H^+ ions through the membrane, Combine with an oxygen atom and two electrons from the external circuit to form a water molecule (H_2O).

How a fuel cell works: In the polymer electrolyte membrane (PEM) fuel cell, also known as a proton-exchange membrane cell, a catalyst in the anode separates hydrogen atoms into protons and electrons. The membrane in the center transports the protons to the cathode, leaving the electrons behind. The electrons flow through a circuit to the cathode, forming an electric current to do useful work. In the cathode, another catalyst helps the electrons, hydrogen nuclei and oxygen from the air recombine. When the input is pure hydrogen, the exhaust consists of water vapor. In fuel cells using hydrocarbon

fuels the exhaust is water and carbon dioxide. Cornell's new research is aimed at finding lighter, cheaper and more efficient materials for the catalysts and membranes.

4. SIMULATION RESULTS

The performance of the proposed control strategies was evaluated by computer simulation using Matlab/Simulink Platform. Here simulation is carried out in different cases; proposed system would be in voltage control technique as well as current controlled technique.

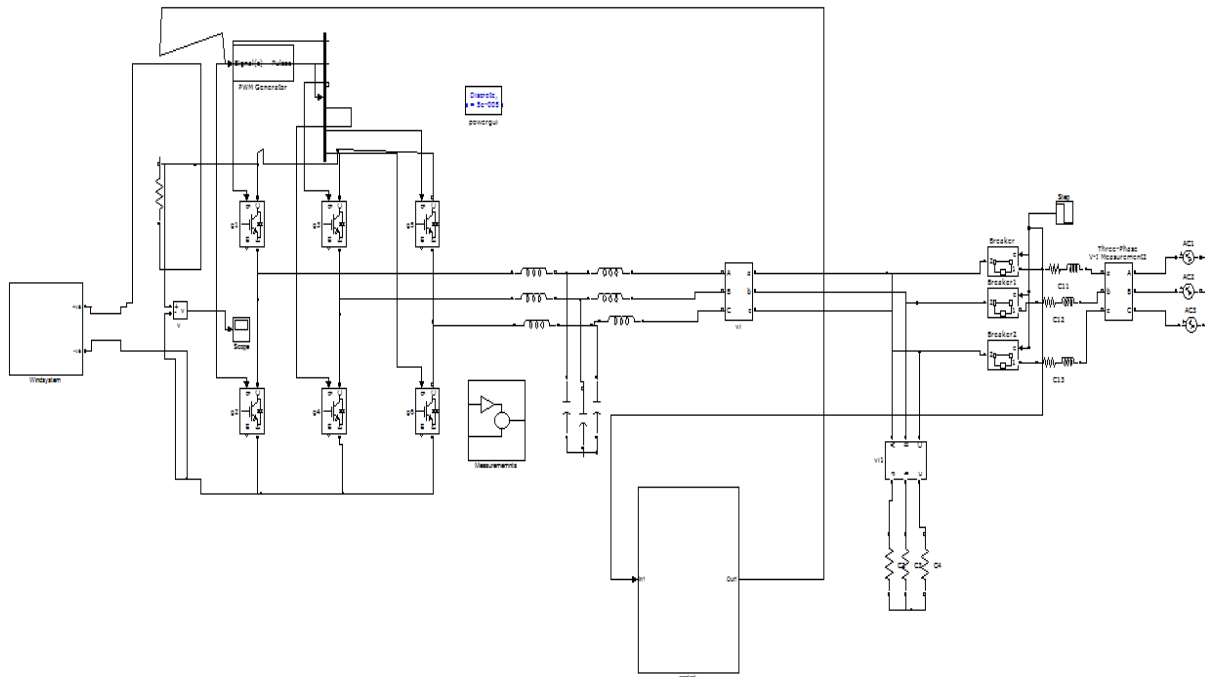


Fig.10. Matlab/Simulink Model of proposed Grid Connected Distribution Generation Interfacing using RES system.

Fig.10 shows the Matlab/Simulink Model of proposed Grid Connected Distribution Generation Interfacing using RES system using Matlab/Simulink Platform.



Fig.11. Source Voltage, Load Voltage, Load Current, Grid Voltage

Fig.11 shows the Source Voltage, Load Voltage, Load Current, and Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under voltage control mode.

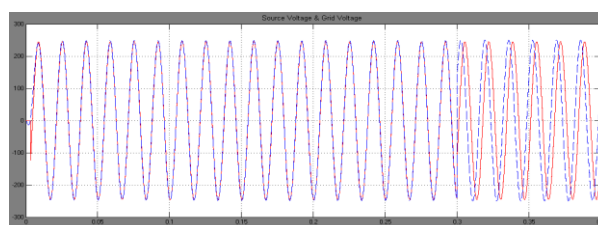


Fig.12. Synchronization of Source Voltage & Grid Voltage

Fig.12 shows the Synchronization of Source Voltage & Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under voltage control mode.

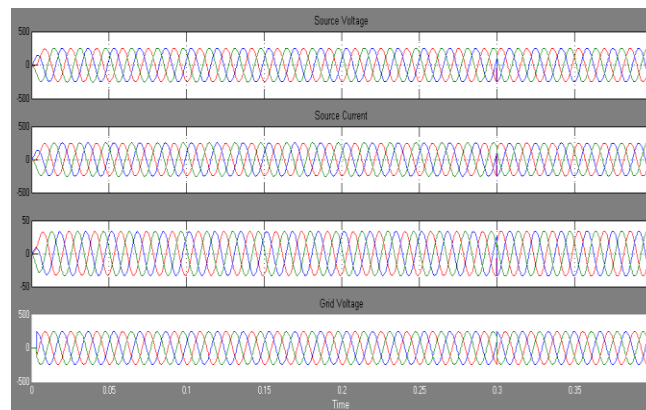


Fig.13. Source Voltage, Load Voltage, Load Current, Grid Voltage

Fig.13 shows the Source Voltage, Load Voltage, Load Current, and Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under Current control mode.

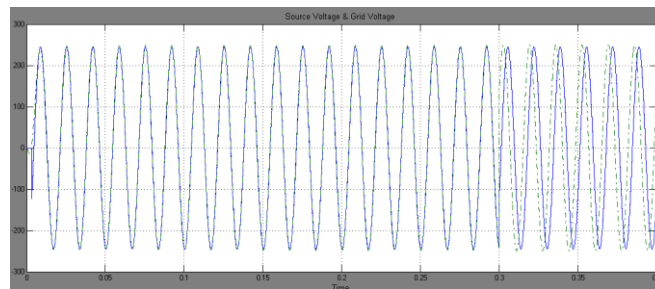


Fig.14. Synchronization of Source Voltage & Grid Voltage

Fig.14 shows the Synchronization of Source Voltage & Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under current control mode.



Fig.15. Source Voltage, Load Voltage, Load Current, Grid Voltage

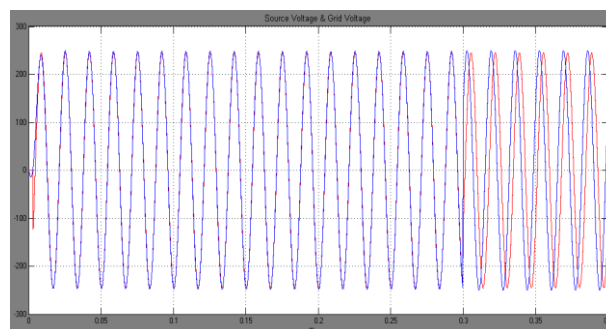


Fig.16. Synchronization of Source Voltage & Grid Voltage

Fig.16 shows the Synchronization of Source Voltage & Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under voltage & current control mode.



Fig.17. Source Voltage, Load Voltage, Load Current, Grid Voltage

Fig.17 shows the Source Voltage, Load Voltage, Load Current, and Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under voltage & current control mode with hybrid PV-Fuel based energy system.

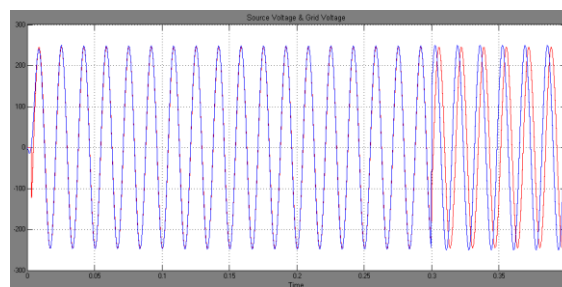


Fig.18. Synchronization of Source Voltage & Grid Voltage

Fig.23 shows the Synchronization of Source Voltage & Grid Voltage of proposed Grid Connected Distribution Generation Interfacing using RES system under voltage & current control mode with hybrid PV-Fuel based energy system.

5. CONCLUSION

In general, the energy source in a distributed power scheme is a fuel cell, a micro turbine, or a photovoltaic cell. These energy conversion devices produce a dc voltage, which must be converted to an ac voltage for residential or industrial application. A voltage & current controller was designed with interfacing control techniques one for grid-connected operation and the other for intentional islanding operation. An islanding-detection algorithm, which was responsible for the switch between the two controllers, was presented. The simulation results showed that the detection algorithm can distinguish between islanding events and changes in the loads and can apply the load-shedding algorithms when needed. The re-closure algorithm causes the DG to resynchronize itself with the grid. In addition, it is shown that the response of the proposed control schemes is capable of maintaining the voltages and currents within permissible levels during grid connected and islanding operation modes. The simulation results showed that the proposed control schemes are capable of maintaining the voltages within the standard permissible levels during grid-connected and islanding operation modes.

REFERENCES

- [1] F. Blaabjerg, R. Teodorescu, M. Liserre and A.V. Timbus. "Overview of control and grid synchronization for distributed power generation systems," IEEE Transactions on Industrial Electronics, Vol.53, No.5, 2006:1398-1409.
- [2] E. Figueres, G. Garcera, etc. "Sensitivity study of the dynamics of three-phase photovoltaic inverters with an LCL grid filter," IEEE Transactions on Industrial Electronics, Vol. 56, No. 3, 2009:706-717.

- [3] J. M. Guerrero, J. C. Vasquez, J. Matas, etc. "Control strategy for flexible microgrid based on parallel line-interactive UPS system," *IEEE Transactions on Industrial Electronics*, Vol.56, No.3, 2009:726-736.
- [4] I.Y. Chung, W.X. Liu, etc. "Control methods of inverter-interfaced distributed generators in a microgrid system," *IEEE Transactions on Industry Applications*, Vol.46, No.3, 2010:1078-1088.
- [5] J.C. Vasquez, J.M. Guerrero, A. Luna, etc. "Adaptive droop control applied to voltage-source inverters operating in grid-connected and islanded modes," *IEEE Transactions on Industrial Electronics*, Vol.56, No.10, 2009:4088-4096.
- [6] Y.W. Li, D.M. Vilathgamuwa, P.C. Loh. "A grid-interfacing power quality compensator for three-phase three-wire microgrid applications," *IEEE Transactions on Power Electronics*, Vol.21, No.4, 2006:1021-1031.
- [7] F. Blaabjerg, Z. Chen, S.B. Kjaer. "Power electronics as efficient interface in dispersed power generation systems," *IEEE Transactions on Power Electronics*, Vol.19, No.5, 2004:1184-1194.
- [8] Z. Ye, A. Kolwalkar, Y. Zhang, P. Du, and R. Walling, "Evaluation of anti-islanding schemes based on nondetection zone concept," *IEEE Trans. Power Electron.*, vol. 19, pp. 1171–1176, Sep. 2004.
- [9] IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems, , IEEE Std 1547-2003.
- [10] H. M. Kojabadi, B. Yu, I. A. Gadoura, L. Chang, and M. Ghribi, "A novel DSP-based current-controlled PWM strategy for single-phase grid connected inverters," *IEEE Trans. Power Electron.*, vol. 21, pp. 985–993, Jul. 2006.
- [11] H. Gu, Z. Yang, D.Wang, and W.Wu, "Research on control method of double-mode inverter with grid-connection and stand-alone," in *Proc.2006 IEEE Power Electron. Motion Control Conf.*, pp. 1–5.
- [12] Y.-Y. Tzou, S.-L. Jung, and H.-C. Yeh, "Adaptive repetitive control of PWM inverters for very low THD AC-voltage regulation with unknown loads," *IEEE Trans. Power Electron.*, vol. 14, pp. 974–981, Sep.1999.
- [13] S.-L. Jung and Y.-Y. Tzou, "Sliding mode control of a closed-loop regulated PWM inverter under large load variations," in *Proc. 1993 IEEE Power Electron. Specialists Conf.*, pp. 616–622.
- [14] Y. Nishida, O. Miyashita, T. Haneyoshi, H. Tomita, and A. Maeda, "A predictive instantaneous-current PWM controlled rectifier with AC-side harmonics current reduction," *IEEE Trans. Ind. Electron.*, vol. 44, pp. 337–343, Jun. 1997.
- [15] C. Zhou and M. M. Jovanovic, "Design trade-offs in continuous current-mode controlled boost power-factor correction circuits," *Proc.1992 Virginia Power Electron. Seminar*, pp. 57–68.

AUTHOR'S BIOGRAPHY

T. Suman received the B.Tech degree in 2005, and M.Tech degree from Madha Engineering College, Anna University, Chennai, India in 2008. Currently he is working as an Assistant professor in Malla Reddy Engineering College (Autonomous), Kompally, Secunderabad. His research interests in Power electronics, HVDC & Digital Signal processing