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Voltage and Frequency Regulation based Autonomous Microgrid Operation using Fuzzy Logic Control Scheme

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Abstract— *Recently, microgrid has become popular in the electric power industry and the important performance parameters considered, particularly when it is operating in islanded mode or under the load change condition, are voltage-frequency regulation, dynamic and steady-state response. In this paper, an intelligent optimal power control strategy, based on fuzzy gain scheduling of the conventional proportional-integral controller, is proposed for voltage-frequency control in an inverter based distributed generation unit. Simulations results, of the proposed control strategy, are compared against that of the conventional PI controller under islanded mode and under load change condition. It is evident that the proposed control strategy provides improved response.*

Keywords: *Microgrid, Islanded operations, Distributed Generation, Fuzzy logic, PI control*

1. INTRODUCTION

In recent years, changing electric power generating facilities are providing way to smaller, distributed generation (DG) because of the environmental concerns and depleting conventional sources. Because of the emerging potential of distributed generation, the concept of microgrid is becoming popular and the technologies related to micro grid are achieving widespread attention (Wei et al., 2010). A micro grid is a combination of different DG units having interfaces with an electrical distribution network. The micro grid can operate in two modes: grid connected and islanded. Most of the DG systems require power electronic converters for the purpose of power conversion, interconnection with grid and optimum control. In power electronics converter interface DG systems Pulse-width-modulated (PWM) voltage source inverters (VSI) are commonly used. Applications of Inverters are very critical in DG systems for optimum control functions as well as meeting the power quality requirements (Zeng and Chang, 2005).

An example of the micro grid is as shown in Fig. 1. A robust control methodology is essentially required to achieve improved performance and to satisfy power quality requirements in such type of systems. The current control technique of the PWM-VSI system is one of the important features of the modern power electronic converters where DG units are interconnected with the grid. Therefore, there are two main classes for current controllers: (a) nonlinear which is based on closed loop current type PWM; and (b) linear which is based on open loop voltage type PWM (Zeng and Chang, 2005). Both the techniques are implemented by using inner current feedback loop in the nonlinear controller and hysteresis current control (HCC) is used for a 3-phase grid-interconnect VSI type systems. The HCC compensates the current inaccuracy and provides PWM signals with suitable dynamic response. In the current controlled strategy, current is controlled individually with a control delay which results in a large current swell with high total harmonic distortion (THD) (Kwon et al., 1998). The linear current controller which is based on space vector PWM (SVPWM), is an acceptable controller, which compensates the error of current either by the proportional-integral (PI) controller or by predictive control system while the compensation and PWM signal generation can be done independently. This controller shows an efficient steady-state response, a high-quality sinusoidal waveform and low current ripple (Kazimierkowski and Malesani, 1998).

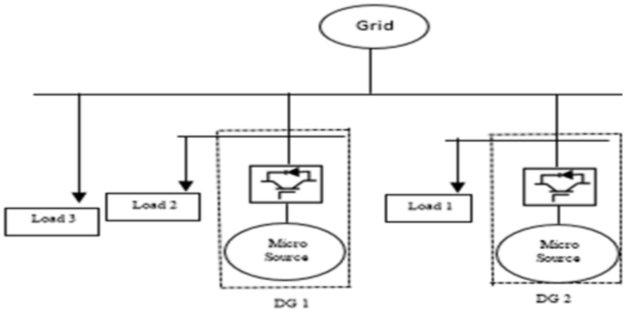


Fig. 1: An example of microgrid system.

The DG system can use either of the two power control schemes: active-reactive power control scheme where the grid is in connected mode, and voltage-frequency control scheme where it is in islanding mode. In this case, the DG system is projected to deliver maximum power and uphold system stability (Saedi et al., 2013).

For better microgrid configuration, researchers have investigated power electronics controllers which is based on an inner current control loop scheme. In (Deng et al., 2008), a controller is presented which seeks to confirm the system's stability and deliver all information required for study and design. In (Wang et al., 2010), the power control scheme is used for a microgrid which can analyze and match the two power control techniques.

The fuzzy control is an important intelligent control technique that is increasingly being used for control problems. In this paper, a power controller based on fuzzy tuning is presented for an inverter based DG system in a microgrid. Here the controller, based on a synchronous reference frame, is interfaced with the current control loop. In this work Conventional PI controller is used and feed-forward compensation is given to the inner control loop to get better dynamic response. Whether the microgrid shifts to under load change condition or the islanding mode condition, the V-f control mode based Fuzzy gain scheduled controller method is suitable for the DG system in order to adjust the voltage and frequency of the system. The Fuzzy gain scheduling method is utilized for real-time tuning of PI controller parameters, with Integral Time Absolute Error (ITAE) as an objective function. The goal of this work is to enhance the power quality by achieving of the frequency and voltage within the acceptable limits. This paper is organized into five sections. In section 2, mathematical base of a three-phase grid-interconnect VSI model is described. Section 3 describes the power control scheme required in a microgrid. In the Section 4, the proposed control scheme is described. Simulation results are analyzed in section 5. At last the conclusions are drawn in section 6.

2. THREE-PHASE GRID CONNECTED VSI SYSTEM

A systematic model of the three-phase grid-connected VSI is shown in Fig. 2. VSI is connected with an LC filter where L_s and R_s symbolize the equivalent lumped inductance and resistance of the filter and the grid as sensed by the inverter. Here filter capacitance and the grid voltage is indicated by C and V_s respectively.

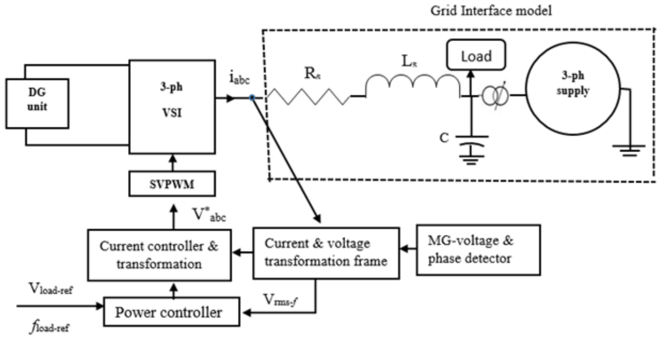


Fig. 2. 3-Phase grid-connected VSI model

The state space equations of the system equivalent circuit in the *abc* reference frame are as (Chung et al., 2008):

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{R_S}{L_S}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_S}\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

Conversion in dq reference frame of equation (1), by using Park's transformation as:

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R_S}{L_S} & \omega \\ -\omega & -\frac{R_S}{L_S} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_S}\left(\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} - \begin{bmatrix} V_d \\ V_q \end{bmatrix}\right) \tag{2}$$

Here ω is the coordinate angular frequency, and the Park's conversion can be defined as

$$i_{dq0} = T i_{abc} \tag{3}$$

$$i_{dq0} = \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}, i_{abc} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{4}$$

$$T = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{5}$$

$\theta = \omega_S t + \theta_0$ is the synchronous rotating angle, θ_0 represents the initial angle value.

3. V-F CONTROL STRATEGY

The problems with wind energy system and photovoltaic system, are that their generation powers get directly affected with wind speed and solar irradiation respectively. With this DG units can be categorized into three energy resource types: variable speed source such as wind energy resource, high speed resource such as micro-turbine generators, and direct energy alteration resources such as fuel cells and photovoltaic system. Due to these reasons, it is required to use a VSI to interface the DG resource to the grid and deliver flexible operation (Mohamed, 2008). As shown in Fig. 2, the network of the VSI centered DG resource unit is connected with the control configuration, so the controlled process of the DG unit depends on the inverter control mode. In grid-connected mode, voltage and frequency regulation are not essential since the grid voltage is fixed, the DG unit works as a PQ generating unit and the inverter must be able to track the active-reactive power (PQ) control mode. But in the islanded condition, the voltage and frequency are not fixed, therefore, a suitable power control mode may provide the high performance operation of the DG unit with a view that the DG resource units meet the load demand with good quality of power. For a better and reliable functioning of microgrid, it is required to confirm the different operation modes of microgrid, and also keep a balance operation for these operating modes in terms of varying voltage and frequency in order to satisfy the requirement of maintaining the voltage and frequency. For these cases the V-f control mode has to be adhered to by one or more DG resource units (Mohamed, 2008). The configuration of VSI based power controller is shown in Fig. 3.

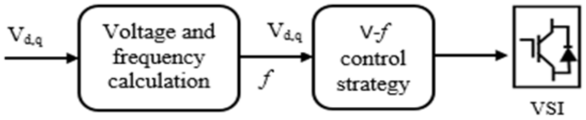


Fig. 3: VSI based V-f power controller.

As the reference values for voltage and frequency can be defined locally or by the Micro grid Control Centre (MGCC) the Phase-Locked-Loop (PLL) measures and the V_{rms} is obtained as (Y. Wang et al., 2010)

$$V_{rms} = \sqrt{{V_d}^2 + {V_q}^2} \tag{6}$$

4. PROPOSED CONTROL STRATEGY

In the Fig. 4, proposed controller scheme for a three phase grid-connected VSI system is shown.

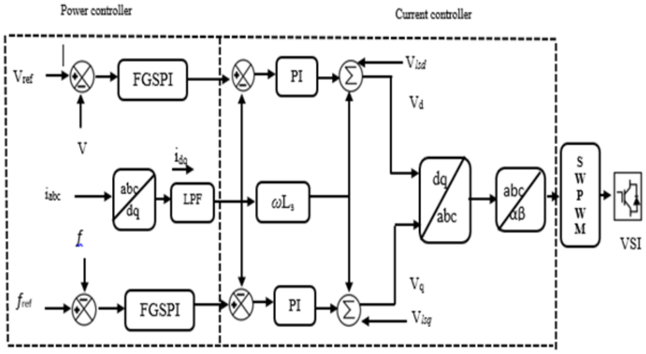


Fig. 4: The proposed power controller scheme.

Scheme includes three blocks, namely; power controller, current controller, and Fuzzy tuned PI controller. The functionality of each block is described in the following subsections.

A. Power control scheme

To improve the quality of power, the Power control scheme is utilized. To generate the reference current vectors i_d^* and i_q^* , the outer control loop which is based on two PI regulators is shown in Fig. 4. A relatively small alteration in the reference current would make certain high quality of the inverter output power which is indicative of the fact that the control objective has been achieved. In this work, the V-f control scheme based on the Fuzzy tuned PI strategy is proposed for the VSI based DG unit. Maintaining the voltage and frequency are the main objectives which must be achieved for different working conditions i.e. islanding mode or sudden load disturbances. The controller adjusts the voltage and frequency according to their reference values (V_{ref} and f_{ref}), and the Fuzzy tuning of parameters is an intelligent controlling process which provides optimal control of parameters in order to provide desired reference current vectors. Based on *dq* reference frame and two PI regulators, the reference current vectors can be expressed as:

$$i_d^* = \left(V_{ref} - V\right)\left(K_{pv} + \frac{K_{iv}}{s}\right) \tag{7}$$

$$i_q^* = \left(f_{ref} - f\right)(K_{pf} + \frac{K_{if}}{s}) \tag{8}$$

B. Current control scheme

The current control loop, which is based on a synchronous reference frame, is shown in Fig. 4. The main role of this loop is to ensure precisel follow up and minimization of the transients of the inverter output current. To implement Park's transformation in the control scheme the PLL block is used to sense the phase angle of the voltage. The current loop and the grid voltage feed-forward loop both are utilized to improve the steady state and dynamic performance of the system by using PI controllers which result in reduction of error. Output signals of the controller are the reference voltage signals in the *dq* frame. It is generating the reference voltage signals in *αβ* stationary frame, by the inverse Park's and Clarke's transformation, so that the controller produces pulses for the SVPWM to fire the Insulated-gate Bipolar Transistor (IGBT) inverter. Based on Eq. (2), the reference voltage signals, in the synchronous *dq* frame, are expressed as:

$$\begin{bmatrix} V_d^* \\ V_q^* \end{bmatrix} = \begin{bmatrix} -K_p & -\omega L_s \\ \omega L_s & -K_p \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} K_p & 0 \\ 0 & K_p \end{bmatrix}\begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} + \begin{bmatrix} K_i & 0 \\ 0 & K_i \end{bmatrix}\begin{bmatrix} X_d \\ X_q \end{bmatrix} + \begin{bmatrix} V_{sd} \\ V{s_q} \end{bmatrix}$$

(9)

Where the ''*'' denotes the reference values,

$\frac{dX_d}{dt} = i_d^* - \ i_d$ and $\frac{dXq}{dt} = i_q^* - i_q$

By Clarke's transformation, eq.(9) can be converted into αβ stationary frame as :

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{10}$$

Also, the inductor current is achieved using a Low Pass Filter (LPF) (Deng et al., 2008). The LPF is expressed as a first-order transfer function as shown

$$f\frac{1}{1+sT_i} = f_l \tag{11}$$

Where, filter input value is f and f_l is the filtered value and the time constant isT_i.

C. Design of hybrid fuzzy-pi controller

From many years, due to its simple structure, easy design and low cost, the conventional controllers are most widely used in industrial applications. But, in spite of these benefits, the conventional controllers result in poor performance when the controlled system is extremely nonlinear and vaguely defined. Therefore, retaining the advantages of the PI controller, in this work, a Fuzzy tuned PI controller is proposed which is shown in Fig. 5. The controller output is expressed as (R. Narne et al., 2012)

$$u(t) = K_p\Delta u + K_i\int e(t)dt \tag{12}$$

Where $K_p$and K_i are proportional and integral gains of the conventional PI controller and Δu represents the output of the Fuzzy logic controller. The inputs to the fuzzy logic system are error ($e(t)$) and derivative of error $(de(t)/dt)$ and one output. The control structure of the fuzzy tuning of PI controller is as shown in Fig. 5. The fuzzy logic controller involves the following components: Fuzzification, Inference, Fuzzy rule base and Defuzzification.

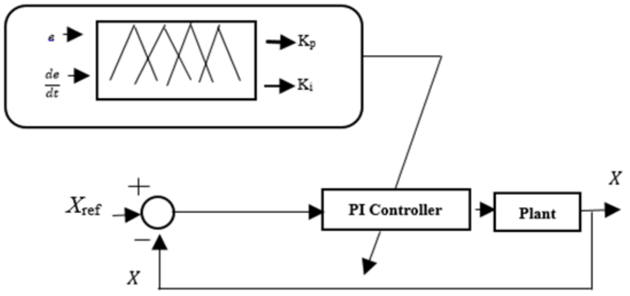


Fig. 5: Configuration of Fuzzy gain scheduled PI

5. FUZZIFICATION

In this process the input variables are mapped onto fuzzy variables. Every fuzzified variable has a definite membership function. The membership functions used here for both inputs are triangular membership functions which are shown in Fig. 6. The input membership functions are represented by seven fuzzy sets namely; VS (very small), MS (medium small), S (small), Z (Zero), B (big), MB (medium big), and VB (very big).

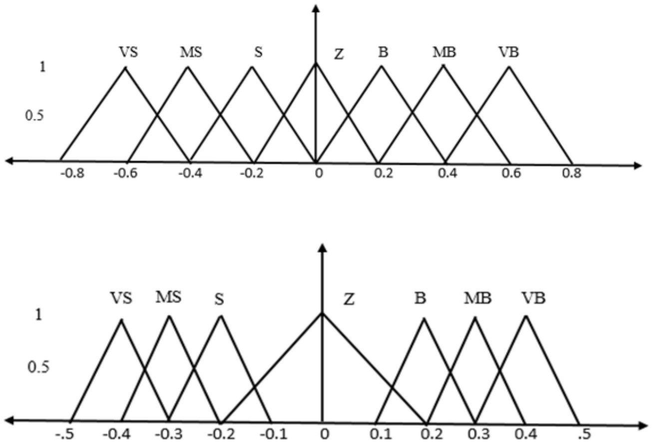


Fig. 6: Membership functions of $e(t)$ and $de(t)/dt$

6. INFERENCE

The inference mechanism delivers a set of control actions according to fuzzified inputs. To regulate the degree of membership function of output variables, the inference mechanism used in this work is Mamdani type.

7. FUZZY RULE BASE

It is developed based on the desired transient and steady state responses. The appropriate fuzzy rule base used is shown in table-I.

Table I: Fuzzy rules for FGSPID controller

e / $\frac{de}{dt}$	**VS**	**MS**	**S**	**Z**	**B**	**MB**	**VB**
VS	VS	VS	VS	Z	MS	S	SB
MS	VS	VS	VS	Z	Z	SB	MB
S	VS	VS	MS	Z	Z	MB	B
Z	VS	MS	S	Z	MB	B	VB
B	MS	S	Z	Z	B	VB	VB
MB	S	Z	S	Z	VB	VB	VB
VB	Z	S	MS	Z	VB	VB	VB

8. DEFUZZIFICATION

The centroid of area method is the most well-known method for defuzzification and is used here to determine the output crisp value (Narne et al., 2012).

9. FUZZY LOGIC CONTROLLER FOR PROPOSED POWER CONTROLLER

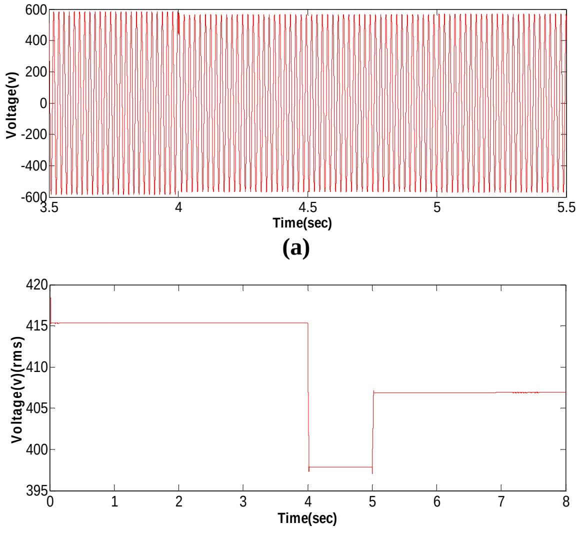
Power controller is based on two PI regulators for the design of the fuzzy tuned PI based power controller. Load end voltage deviation (ΔV) and derivative of voltage deviation are selected as input vectors for first FGSPI controller and load end frequency deviation (Δf) and derivative of frequency deviation are selected as input vectors for second FGSPI controller. The fuzzy tuned PI controllers demonstrate efficient control of the voltage and frequency of the system.

10. SIMULATION RESULTS

A three-phase grid-connected VSI system with the proposed FGSPI controller is simulated under MATLAB/Simulink environment. The system parameters used are defined as follows: L_s= 5 mH, R_s= 1.4 Ω, f= 50 Hz, filter capacitance C= 1500μF, and the input capacitor of the dc side is set to 5000μF. One DG unit with rating 180 kW is used. Typically, the current control parameters are set to K_p= 7 and K_i = 10 and the load connected is 150 KW. For the SVPWM based current controller, switching and sampling frequency are fixed at 10 kHz and 500 kHz, respectively. For the micro grid system under investigation, following case studies are investigated.

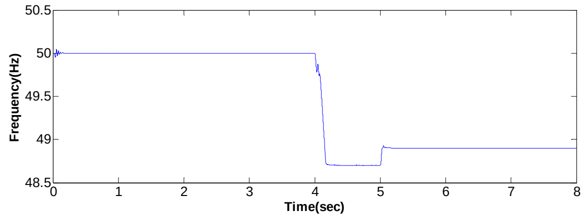
A. Variation in Load

For evaluating the proposed control scheme, the simulation starts in the grid-connected mode. At 4th sec a load of 30 KW is injected and at 5th sec load of 20kw is rejected at the distribution side. Sudden load increment and rejection causes sag and swell in voltage and frequency respectively. Results showing different performance parameters for conditions when simple PI controller is used and the when the proposed FGSPI controller is used in the power controller, are shown in fig. 7 and 8 respectively.



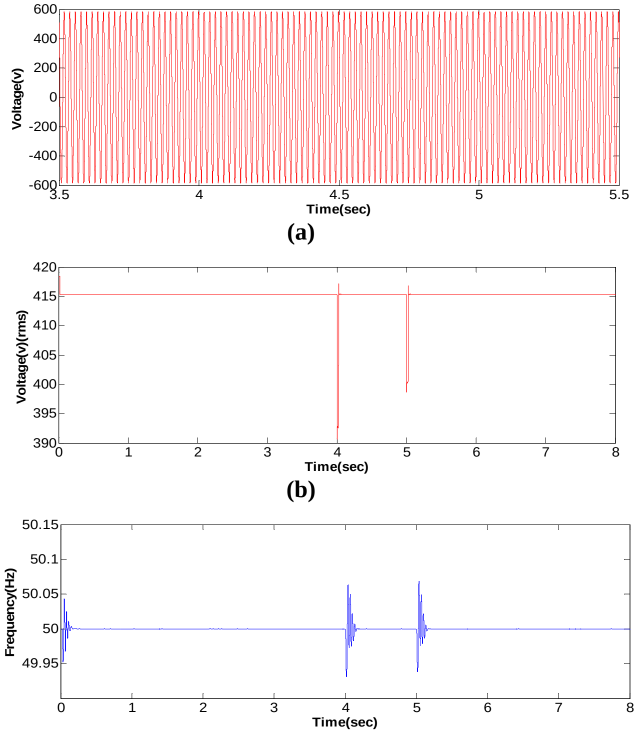
(a)

(b)



(c)

Fig. 7: Load side Parameters when PI controller is present (a) Line voltage (b) rms voltage (c) Frequency



(a)

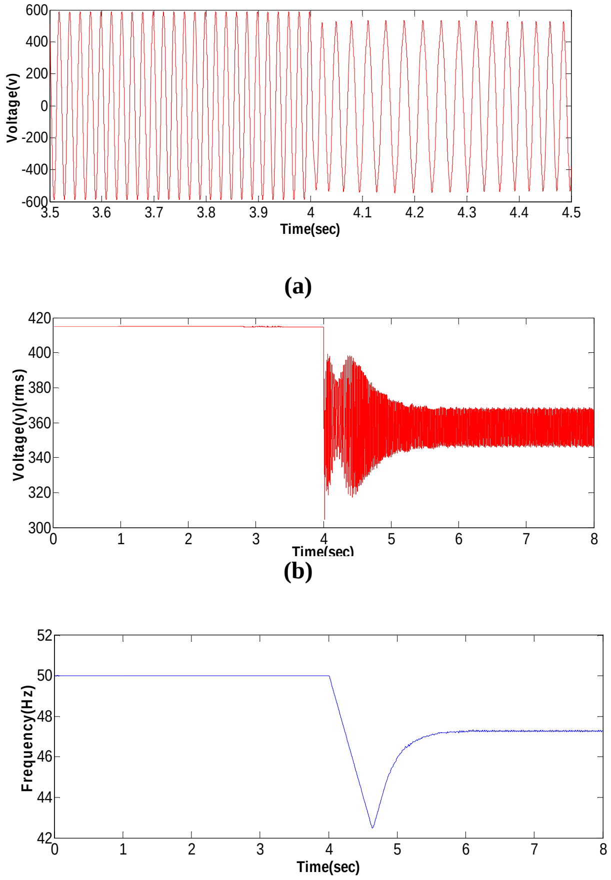
(b)

(c)

Fig. 8: Load side Parameters when FGSPI controller is present (a) Line voltage (b) rms voltage (c) Frequency

B. Islanded condition

It has been considered that due to some abnormal condition grid gets disconnected with the DG unit and the connected load. This situation is called islanded condition. At 4th sec, the microgrid switches to the islanding operation mode and no other disturbances of load occurs. Due to grid disconnection, which was primarily responsible for maintaining voltage and frequency profiles, a large deviation of voltage and frequency occurs as shown in fig.9. Now the controller comes into action to eliminate these fluctuations in voltage and frequency during the islanding mode and tries to restore voltage and frequency within the acceptable limits. The results for islanding condition are shown in fig.9 and 10 when PI and FGSPI controllers are used respectively.

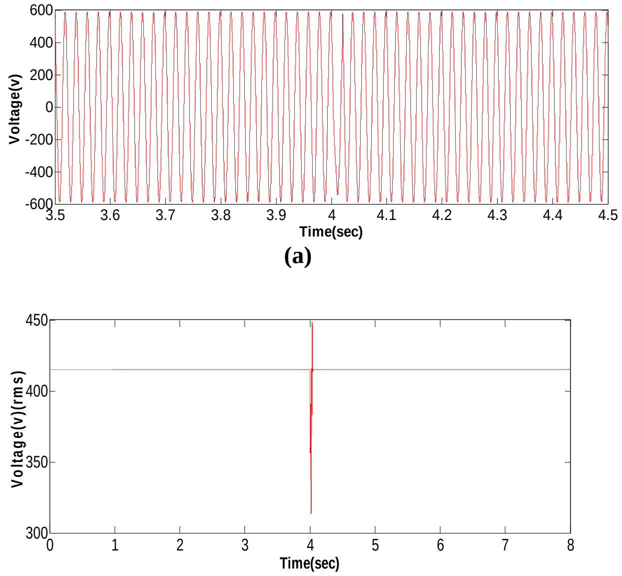


(a)

(b)

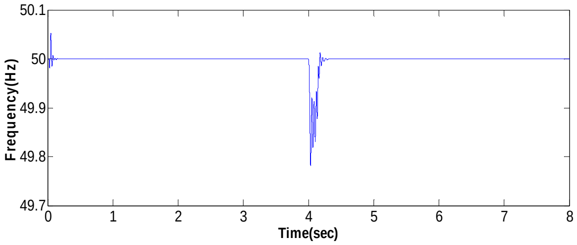
(c)

Fig. 9: Load side Parameters when PI controller is present (a) Line voltage (b) rms voltage (c) Frequency



(a)

(b)



(c)

Fig. 10: Load side Parameters when FGSPI controller is present (a) Line voltage (b) rms voltage (c) Frequency

In this work, the inverter output filter is utilized to bypass switching harmonics. The LPF with low enough cut-off frequency is able to ensure sufficient attenuation for the harmonic content of the *dq* current vectors.

11. CONCLUSION

In this paper, for an inverter based DG unit in a microgrid structure, an intelligent fuzzy based power control scheme is proposed. In order to improve the voltage and frequency profile of the power supply, especially when the microgrid transits to the islanding operation mode or during load change, FGSPI scheme has been incorporated into the V-f control mode. The simulation results indicate that the proposed FGSPI intelligent control scheme provides an excellent performance for regulating the microgrid voltage and frequency, and achieves short transient time with a suitable level. Therefore, this controller may be utilized by grid interface DG unit in a microgrid scenario, considering the power sharing issue.

REFERENCES

[1] Chung, I.Y., Liu, W., Cartes, D. A., 2008.Control parameter optimization for a microgrid system using particle swarm optimization, in Proc. IEEE ICSET, Tallahassee, FL, pp. 837–842.

[2] Deng, W., Tang, X., Qi, Z., 2008. Research on dynamic stability of hybrid wind/PVsystem based o n Micro-Grid Electrical Machines and Systems, ICEMS. pp. 2627– 2632.

[3] Kazimierkowski, M., Malesani, L., 1998.Current Control Techniques for Three- Phase Voltage-Sourcc Converters: A Survey, IEEE Transactions on Industrial Electronics Vo1.45 No 5.

[4] Kwon, B., Min, B., Youm, J., 1998. An Improved Space-Vector-Based Hysteresis Current Controller, IEEE Trans. Ind. Electron., Vol.45, pp. 752-760.

[5] Mohamed Y.A.R.I.,2008, New Control Algorithms for the Distributed Generation Interface in Grid-Connected and Micro-grid Systems, PhD thesis University of Waterloo, Ontario, Canada.

[6] Narne, R., Therattil, J. P. and Panda, P. C., 2012 Improving power system transient stability by PSS and hybrid fuzzy-PI based TCSC controllers, Students Conference on Engineering and Systems, pp. 1-6.

[7] Saedi, W.A., Lachowicz, S. W., Habibi, D., Bass, O., 2013.Voltage and frequency regulation based DG, unit in an autonomous microgrid operation using Particle Swarm Optimization, International Journal of Electrical Power & Energy Systems, Volume 53, pp. 742-751.

[8] Wang, Y., Lu, Z., Yong, Y.M., 2010. Analysis and comparison on the control strategies of multiple voltage source converters in autonomous microgrid, IET International Conference on Developments in Power System Protection, pp. 1-5.

[9] Wei, Y., Chengyong, Z., Yi, L. and Gang, L., 2010 .A scheme of connecting microgird to AC grid via flexible power electronics interface,in Power System Technology (POWERCON), 2010 International Conference on, , pp. 1-6.

[10] Zeng, Q. and Chang, L., 2005.Study of advanced current control strategies for three-phase grid-connected PWM inverters for distributed generation, Proc. of IEEE Conference on Control Application, pp. 1311-1316.