Power Quality Improvement in an Autonomous Microgrid under Nonlinear Load using Control Strategies

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***Abstract*— Microgrid has come out as one of the key spots in research on distributed energy system. Since the definition of Microgrid is a paradigm for the first time, investigation in this area is growing continuously and there are numerous research projects this moment all over the world. This paper mainly focuses the concentration on power quality enhancement in an autonomous microgrid along with the nonlinear load. In this paper, a novel control strategy is proposed particularly when the microgrid is islanded. In particular the attention has been focused on the issues of power quality enhancement in microgrids with DG inverters. Vf regulation and power sharing are the two main performance parameters which are considered in this work. The control strategy is composed of an inner current control loop and an outer power control loop based on a synchronous reference frame and the conventional PI regulators. To verify the advantages and effectiveness of the control strategy, several simulation have been carried out and typical results have been presented with brief discussion.**

Keyword- Microgrid, Autonomous mode, Power quality, Distributed Generation (DG), Nonlinear load.

I. Introduction

The Microgrid can generally be viewed as a cluster of DG that made interconnected to the main utility grid. Through some of the power electronic devices like voltage source inverter (VSI), the DGs are interconnected to the grid. The development of microgrid represents a decentralized infrastructure environment to the existing utility grid due to the rapid increment of demand. Two modes of operation exists in microgrid namely, grid connected and autonomous mode. Distributed generation system is based on renewable energy sources such as solar energy, wind energy, hydro electric power, fuel cell etc. It emerges as an alternative quantity which develops green energy scenario for the extended supports of utility grid [1]. These sources are made interconnected through VSI along with pulse width modulation (PWM) technique creates a non linear voltage-current characteristic of power electronic components, which affects the power quality of the supply [2]. When the loads are made to transfer from grid connected to islanded, there arises power quality problems. This ability of islanding the generation and load has the potential of high reliability of the main grid [3].

An example of microgrid is shown in fig.1. Concerning the interfacing of a microgrid to the utility system is an important area of study. It also helps to investigate the impact of power quality problems [4]. If unbalance in voltage is serious, the solid state circuit breaker (CB) connected between the microgrid and utility grid will open to isolate the microgrid. When voltage unbalance is not so solemn, CB remains closed, resulting in sustained imbalance voltage at the point of common coupling (PCC) [5]. A robust control strategy is adopted to achieve high performance operation and meet power quality requirement. Consequently, the current control strategy of PWM – VSI system is one of the major aspects of modern power electronic converters. Current control strategy for VSI is more responsible to mitigate the power quality problems. VSI is made interconnected by widely used PWM, that have nonlinear voltage - current characteristics and high switching frequency which affect the quality of power supply [6]. Two main categories of current controllers are linear controller based open loop PWM and non linear controller based closed loop PWM. It is applied using feedback current control loop [7]. Generally non linear controller with hysteresis current control (HCC) is used for three phase grid connected VSI system. The error signal is fed to the HCC and compensation of current error is made along with the generation of PWM signal with acceptable error. Current error signal is controlled by self regulating the delay current, results in generation of large ripple current leading to the development of huge total harmonic distortion (THD) [8]. Even though linear current controller based on space vector pulse width modulation (SVPWM) are adopted and current error signals are compensated with conventional PI regulator or predictive control algorithm. This type of controller provides an excellent control of current signal along with proper compensation leading to the development of low ripple [9]. Recently, the power controller based on inner current control loop has been investigated for better microgrid configuration. The controller is described with the aim of ensuring the dynamic stability of the system and providing all the information needed for analysis and design [10-11]. It is important to analyse the power quality indices when loads are shifted or changed, which results in unbalance in voltage and frequency [12]. Power quality issues are made high concern on different types of loads with DGs, by controlling two independent parameters - voltage magnitudes and system frequency that leads to the power sharing among the DGs [13-14]. Analysis of microgrid in grid connected and autonomous mode has been investigated with an algorithm in [15].With proper control methods in microgrid result in improvement of power quality of the network [16].

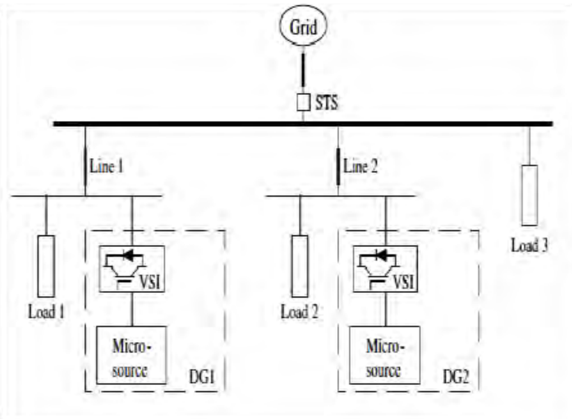

Fig.1. An Example of Microgrid.

The proposed controller is made externally interfaced to the current controller, which is based on synchronous reference frame. Hence the controller is adopted with conventional PI regulator along with feed forward compensation in order to achieve high dynamic response. When the microgrid switches to islanding mode or load changing condition, the Vf control mode is adopted to regulate the microgrid voltage and frequency regulation along with PQ control mode to produce sustained output power. The main objective of this work is to improve the quality of power supply by attaining adequate microgrid voltage and frequency along with tolerable power sharing among the DG units.

The organization of paper is as follows. Section II describes the modelling of microgrid in an autonomous mode with VSI. Section III explains the design of Control strategies. In section IV simulation results are analysed to verify the aim of these controllers. Finally conclusion is outlined at section V.

II. MODELLING OF AUTONOMOUS MICROGRID

A. Three phase grid connected VSI mode

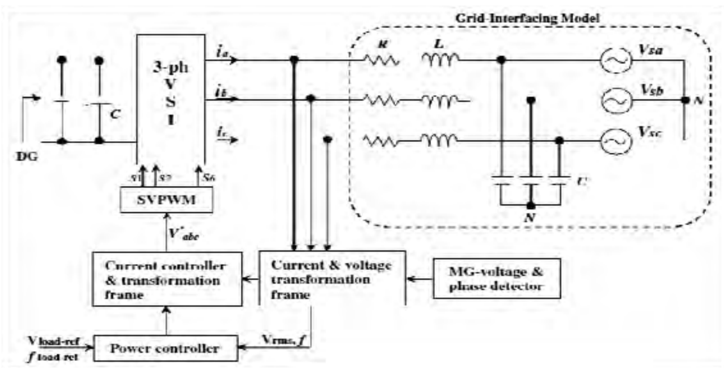

Fig.2. VSI model with grid connected

A classical model of three phase grid connected VSI along with the control technique and filter are shown in Fig.2.where R & L represent equivalent resistance and inductance of the filters, C is the filter capacitance.

The state space representation of system equivalent circuit in abc reference frame is given by [17].

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{R}{L}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L}\left(\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}\right) \tag{1}$$

Using Park's transformation, Eq. (1) can be framed as follows,

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

Where ω is the angular frequency. The Park's Transformation is defined as,

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

Where

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

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

III. DESIGN OF CONTROLLER

A. Proposed Power Control Scheme

The proposed power controller is shown in fig.3. The power controller comprises of two PI regulator which helps to generate the reference signals i_d^* and i_q^* along with dq reference frame. This controller has the capability of responding to sudden changes like load changing or switching to islanding operation mode. Here the DG has been adopted with Vf power control strategy, when the microgrid is islanded. The conventional PI regulator helps to regulate the voltage & frequency of the microgrid in order to produce the reference current vector i_d^* and i_q^*.

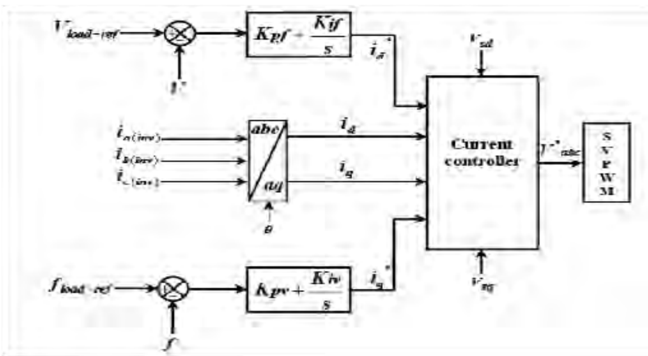

Fig.3.Power Controller Scheme

B. Current Control Scheme

The block diagram of current control loop is shown in Fig.4. The current control loop is designed based on synchronous reference frame. This controller is designed to ensure perfect follow up and short transients of the inverter output current. In order to implement park's transformation in the current controller the phase locked loop (PLL) is essential to measure the voltage phase angle. The elimination of current error is done by the conventional PI regulator. Therefore, the controller output is represented in dq reference frame, followed by inverse park's transformation that generate the needed six pulse for SVPWM to fire IGBT.

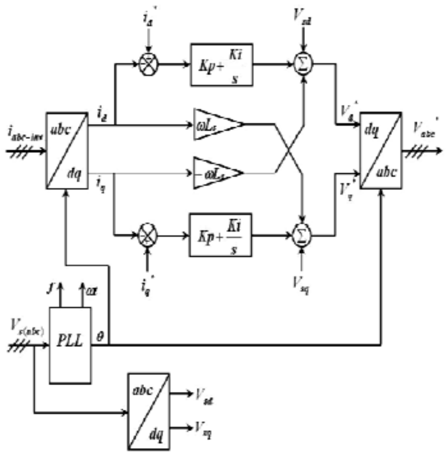

Fig.4. Current Controller Scheme

In dq reference frame based on eq. (2), reference voltage signal can be expressed as follows,

$$\begin{bmatrix} V_d^* \\ V_q^* \end{bmatrix} = \begin{bmatrix} -K_p & -\omega L_s \\ \omega L_s & -K_p \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} K_p & 0 \\ 0 & K_p \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} + \begin{bmatrix} K_i & 0 \\ 0 & K_i \end{bmatrix} \begin{bmatrix} X_d \\ X_q \end{bmatrix} + \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} \quad (6)$$

IV. Simulation Results

Several simulations are carried out in MATLAB/ Simulink environment for the complete layout of an inverter based DG in an autonomous mode, to study the effectiveness of the controllers under non linear load. The model parameters are defined as follows: inverter based DG is designed for an about 4 kW and are connected to the load. Each DG unit is represented by DC voltage source along with VSI. The sampling frequency and the switching frequency are 100 KHz & 10 KHz respectively. Fig.5 to Fig.11 shows the results of the simulation models. All the results are in p.u. system and the following objective are investigated.

A. *Active & Reactive Power Delivered by DGs.*

In this work, the microgrid operation has been investigated during autonomous mode. The power dispatch among the DGs is shown in fig.5 and fig.6. In this fig, it is assumed that DG_1 and DG_2 were generating 0.92 p.u. and 0.4 p.u. respectively which is feeding into the RL load. To study the effect on the unbalance characteristic of the network, the RL load has been replaced with the nonlinear load (induction motor). The nonlinear load is a combination of unbalanced and harmonic load. It is assumed that at 2.0 sec, load change is applied in the distribution network. In order to establish voltage and frequency close to their reference values, the power controllers of both the DG units are switched to Vf control mode. However at the load change, the first DG unit operates in Vf control mode to maintain voltage anf frequency regulation, whereas the second DG unit switch over to PQ control mode in order to maintain constant output power.

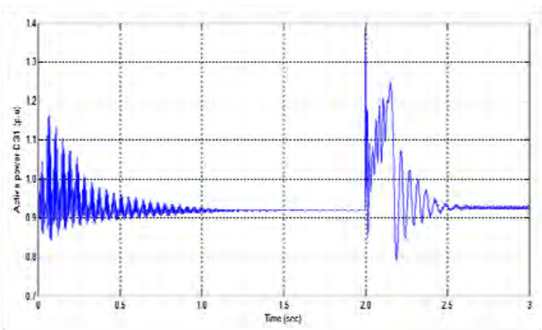

Fig.5. Active Power Delivered by DG_1 in islanded mode.

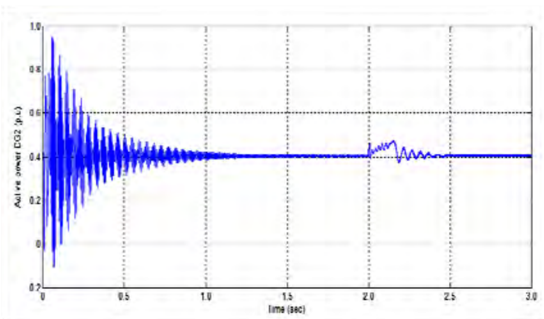

Fig.6. Active Power Delivered by DG_2 in islanded mode.

As shown in Fig.7 & 8. The reactive power are set to 0.3 p.u. and 0.26 p.u. respectively by DG_1 and DG_2.During this stage both DG units operate in Vf control mode. At 2.0 sec load variation is made and the reactive power supplied to the load are shown.

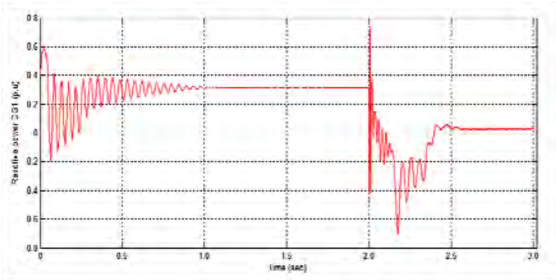

Fig.7. Reactive power delivered to load by DG_1

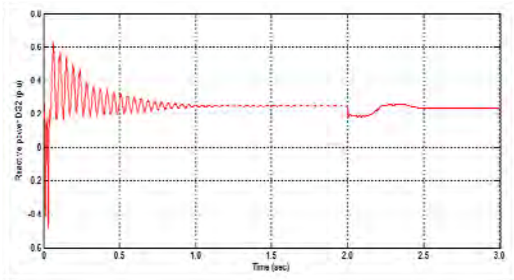

Fig.8. Reactive power delivered to load by DG_2.

B. *Voltage and Frequency Regulation*

In this mode, the Vref and Fref of both DG units are set to 1 p.u. To evaluate the control strategy, simulation is started in island mode. The microgrid voltage and frequency are regulated at 1 sec. At 2 sec, the microgrid undergoes the load change. In order to mitigate the voltage drop and to avoid a severe deviation of the frequency caused by the load change, both DG units adopt Vf power control mode. It can be noticed that the power controller restores the microgrid voltage and frequency close to their reference values at 3.0sec and 2.5 sec respectively. As a result, Vf control mode offers an excellent behaviour and maintains the microgrid voltage equal to 0.9p.u. and frequency around 0.95 p.u. as shown in fig.9 and fig.10 respectively.

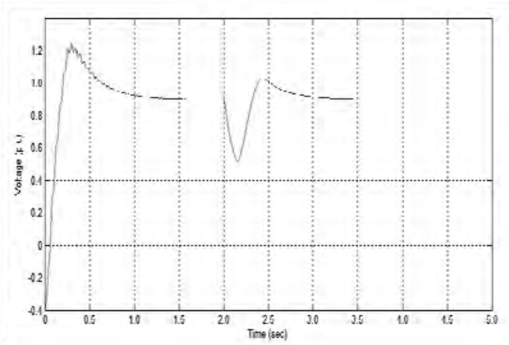

Fig.9. Microgrid voltage regulated by Vf control

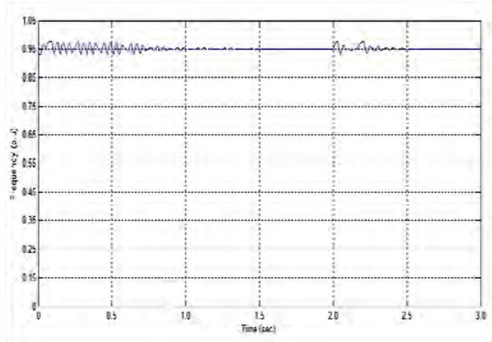

Fig.10. Microgrid frequency regulated by Vf Control mode

C. *Speed Regulation*

Fig.11. shows the speed of the induction motor. Due to the load variation at 2.0 sec, the DG_1 operates under Vf control mode in order to regulate the speed at 1550 RPM.

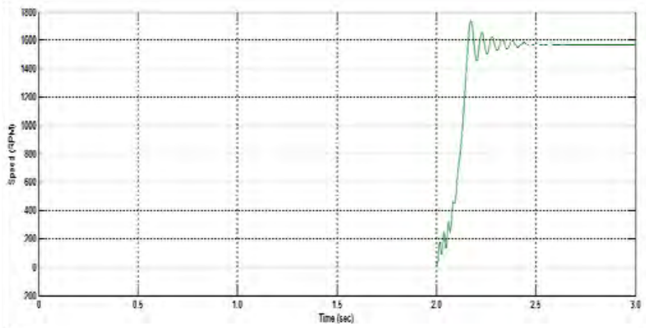

Fig.11. Speed Regulation

V. CONCLUSION

The power quality improvement in an autonomous microgrid under nonlinear load has been discussed in this paper. A novel power control strategy has been employed for the operation of the microgrid. The control strategy make use of two control loops: inner current control loop and the outer power control loop. In order to maintain the microgrid voltage and frequency within the regulating limit when the microgrid operates in islanding mode, Vf power control strategy is implemented. Similarly to maintain the sustained output power, the PQ power control strategy is adopted by the second DG unit during the load change. The simulation results prove that the proposed control strategies offer an excellent response in voltage & frequency regulation under islanding mode and also in attaining adequate power sharing.

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BIBLIOGRAPHY

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