

## Power quality Improvement using Ant colony optimization based control strategy in an islanded microgrid

<sup>1</sup>P.Priyadharshini , <sup>2</sup>N.Chitra

<sup>1</sup>PG-scholar, Dept.of Electrical & Electronics Engineering. SKP Engineering College,  
Tiruvannamalai 606611, India.  
p21riya@gmail.com

<sup>2</sup>Research scholar, Anna University. Asso.Prof.,Dept. of Electrical&Electronics Engineering,  
SKP Engineering College,  
Tiruvannamalai 606611, India.  
psk\_siva@hotmail.com

**ABSTRACT:** This paper bestows an optimal power control stratagem for an island microgrid. The foremost aim of this work is to improve the power quality of the microgrid. The primary performance parameters considered in this work are voltage regulation and frequency regulation, especially at the instant of shifting from grid tied mode to island mode of operation of the microgrid. An inner loop of current control and an outer loop of power control combined to form the projected control strategy. Ant colony optimization (ACO) based control strategy is proposed for self-tuning the control parameters. To validate the performance of the controllers, simulation is performed with the help of MATLAB/SIMULINK software.

**Keywords:** Microgrid, Power control stratagem, Current control stratagem.

### I. INTRODUCTION

Distributed generation (DGs) are normally linked through power electronic devices like Voltage Source Inverter (VSI) to the microgrid or main utility grid. Microgrid [1] is a group of interlinked distributed energy resources and loads in lucidly demarcated electrical boundaries. In accordance to the grid, the microgrid operates as a solitary controllable entity that disconnects and connects to the grid, in order to facilitate the microgrid to work in both grid-tied mode and autonomous mode. An enhanced power quality, reduced congestion in transmission lines, decreased energy losses and emission can be obtained by introducing the microgrids. Conventionally, when the microgrid operates autonomously, the inverters connected to it acts as voltage sources and as current sources when they are linked with the grid [2]. The quality of power supply problem arises at the moment of transferring the load from On-grid mode to Off-grid mode. The main utility grid has high reliability potential due to its adeptness of isolating the power generation and load from the grid [3].

A microgrid paradigm is shown in figure.1.

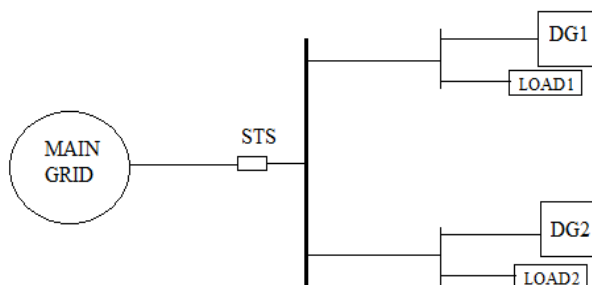


Figure 1: A microgrid with two DGs.

A meticulous fretfulness in microgrids is the issues of power quality, at the time of interfacing the microgrid to the main utility grid, which is a foremost area of research that also helps in exploring the effect of problems of power quality [4]. The circuit breaker linked between the main grid and the micro grid will open, when the unbalance in voltage is solemn, to isolate the micro grid. If voltage unbalance is not serious, the circuit breaker endures closed, which results in prolonged voltage imbalance at the PCC [5]. A robust control stratagem with the operation of hyperactive performance is adopted, so as to satisfy the requirement of power quality. Subsequently, an unique feature of the contemporary

converters based on power electronics is the VSI accompanied by a PWM current control stratagem. It is more reliable in alleviating the problems of power quality. The VSI is interlinked by using PWM, the nonlinearity in VSI's V-I characteristics and an elevated switching frequency are the major causes for disturbance in power quality [6]. An open loop PWM based linear control and a closed loop PWM based nonlinear control are the two types of current controllers [7]. In a network of three phase grid connection, a VSI designed with a nonlinear control based on hysteresis current control (HCC) is employed. 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. An enormous amount of total harmonic distortion (THD) is developed from a huge ripple current generation resulting from the self-regulation of delay current in order to control the signal of current error [8]. Although a sine pulse width modulation (SVPWM) is employed in linear current controller, an algorithm of predictive control or standard PI regulator is used in compensating the current error signals. This type of controller provides an excellent control of current signal along with proper compensation leading to the development of low ripple [9]. In order to enhance the microgrid voltage and frequency, a power control based on an inner loop of current control is investigated. To provide information involving analysis and design and to guarantee the system's dynamic stability is the controller's aspiration [10-11]. When changing or shifting the loads, a voltage unbalance and deviation in frequency occurs. So it is necessary to investigate power quality [12]. To interpret the problem of optimization and to tackle the problem of nonlinearity, exploration of various optimization techniques have been done. On the basis of their searching type and objective function, the techniques are classified as linear programming and nonlinear programming. Generally, linear equality constraints are used in linear programming (LP) targeting at linear objective function [13]. In the same way, pointing at nonlinear objective function, nonlinear programming (NLP) is employed. Normally, linear and nonlinear programming is expressed along with the objective function [14].

In this work, the control parameters of power controller are optimized in real time, which is done through in islanded microgrid. The power controller is externally interlinked to the synchronous reference frame based current controller. Feed forward compensation is accompanied to a standard PI controller to attain high dynamic performance. The moment when the microgrid shifts to load change or island mode from grid tied mode, to normalize the voltage and frequency regulation of micro grid, the Vf control mode is espoused accompanied by PQ control among the distributed generation units. In this work, the foremost aim is to enhance the power quality by means of achieving the adequate frequency and voltage of micro grid as well as acceptable power sharing between the DG's.

## II. MODELING OF ISLAND MICROGRID

### A. Voltage source inverter

A typical VSI model linked with a three phase grid accompanied by a control stratagem is depicted in fig.2.

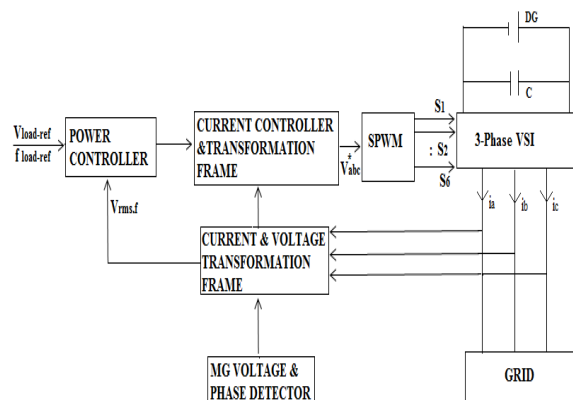


Figure 2: Grid connected model of VSI

Where, C signifies the capacitance of filter.

R and L connotes the resistance of filter and inductance of the filter.

In abc reference frame, the state space depictions of the system equivalent circuit are represented by [15];

$$\begin{aligned} di_a/dt &= (Ri_a + V_{sa} - V_a)/L \\ di_b/dt &= (Ri_b + V_{sb} - V_b)/L \\ di_c/dt &= (Ri_c + V_{sc} - V_c)/L \end{aligned} \quad (1)$$

Equation (1) can be delineated by utilizing Park's transformation as,

$$\begin{aligned} di_d/dt &= -Ri_d/L + i_q \omega + (V_{sd} - V_d)/L \\ di_q/dt &= -Ri_q/L + i_d \omega + (V_{sq} - V_q)/L \end{aligned} \quad (2)$$

Where, ' $\omega$ ' represents the angular frequency.

Equation (3) defines the Park's Transformation as,

$$i_{dq0} = T i_{abc} \quad (3)$$

where,

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

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

## B. Power controller

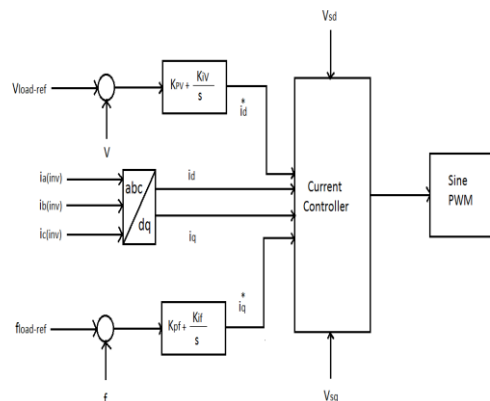


Figure 3: Power control stratagem.

With reference to the control objective mode, the power controller helps in improving the power quality. This controller is adopted to elicit the vectors of reference current  $i_d^*$  and  $i_q^*$  together with dq reference frame by using the two standard PI controllers. At the instant of change in load or commencing of autonomous mode, this controller reacts to the impulsive changes. Vf control stratagem supports the DG's at the time of microgrid islanding. PI regulator helps in regulating the frequency and voltage of microgrid, to generate  $i_d^*$  and  $i_q^*$  vectors of reference currents.

**C. Current controller**

Fig.4 reveals the current control loop’s block diagram. On the basis of synchronous reference frame, the design of current control loop is done. The minimum current error generated from applying voltage on inductive R-L impedance can be ensured by this controller design. The standard PI controller eradicates the current error. The IGBT based on SVPWM is triggered with the pulse generated from the inverse park’s transformation of the dq reference frame output of the controller.

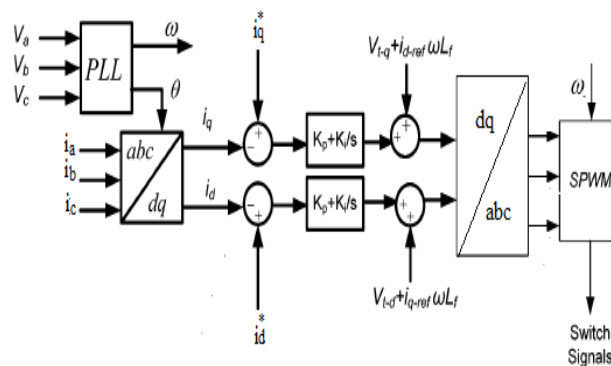


Figure 4: Current control stratagem.

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

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

**III. ANT COLONY OPTIMIZATION**

In 2004, Dorigio and Stuzle [16] developed a stochastic optimization technique based on population is known as Ant Colony Optimization (ACO). This technique is a metaheuristic, which is stimulated by ant colonies foraging behavior. Pheromone trails are used by ants to form their route, the briefest distance among the food source and their nest can be find by the pheromone trail’s ability of indirect communication. For resolving an optimization problems of discrete combination, an allegory of ants is utilized while implementing the process of search [17-18]. For exploring all feasible solution’s search space, artificial ants are accrued. With randomly choosing a solution, the algorithm instigates within the problem decision space. In this, with discrete intervals of time the search headways. Pheromones that are deposited on trails makes the ants to follow on the assuring solution [19]. The near optimal or optimal solution can be achieved with this method, by biasing the ACO search progressively headed for further search space’s enviable region [20]. In engineering problems of the real world, ACO is applied widely for its robustness while attuning the objective function. For solving the problems of power quality without considering their complexity for an existing power system simulation models, ACO algorithm can be connected similarly as other metaheuristic. An equation is applied in problem of ACO, in order to make ACO intrinsically suitable for attuning of the problems of power quality. ACO adoption for problems of power quality can be enabled by an unique formulation which is created in this subdivision. The following flowchart shows (figure 5) the ACO algorithm in step by step organization.

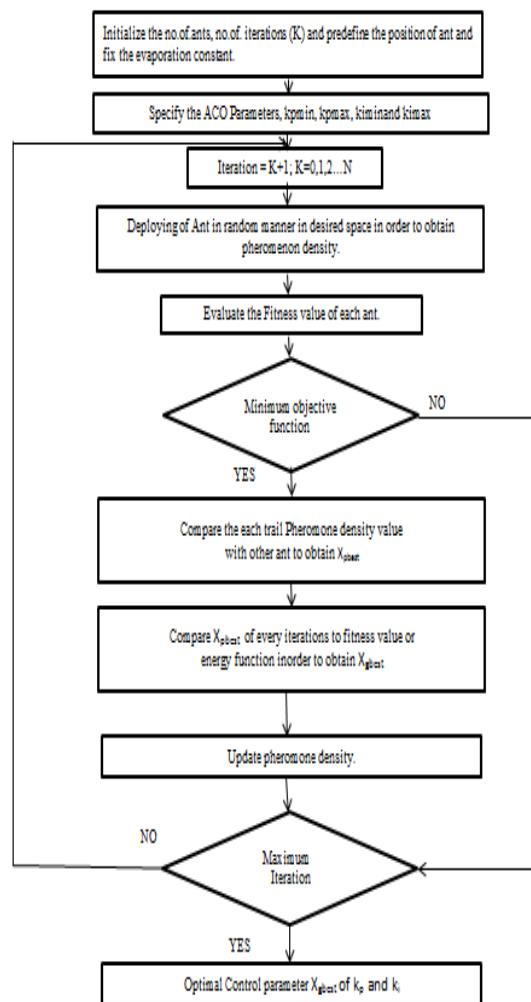


Figure 5: Flow chart of ACO Algorithm.

For solving the problems of power quality without considering their complexity for an existing power system simulation models, ACO algorithm can be connected similarly as other metaheuristic. An equation is applied in problem of ACO, in order to make ACO intrinsically suitable for attuning the problems of power quality. A fitness function or objective function for an optimal solution is examined by searching within the free space using an iterative algorithm known as ACO [21]. On the basis of the movements of ants, a self-evaluation of ACO algorithm is made. Every ant with their own knowledge moves randomly.  $X_{pbest}$  particle for each and every iteration is obtained. To acquire  $X_{gbest}$  compatible with the tuning control parameters objective function, the  $X_{pbest}$  is compared with another  $X_{pbest}$  particle acquired from every single iterations [22].

#### IV. OBJECTIVE FUNCTION

In the optimization techniques such as GA, PSO and ACO, an automatic iterative search will be evaluated with the help of a specific criterion called as objective function. In this case, with the concern of control objectives, the best pertinent function for minimizing the error-integrating function are Integral Time Absolute Error(ITAE), Integral Absolute Error (IAE), Integral Time Squared Error (ITSE) and Integral Square Error(ISE) [24]. Out of these error integrating function, IAE criterion is employed in our work.

$$IAE = \int_0^T |e(t)| dt \quad (6)$$

The above equation defines the performance index of IAE mathematically.  
 Where,  
 't' – time  
 e(t) – difference between the reference set point and controlled signal.  
 The IAE highlights the error value by weighing it with time.

**Execution principle**

Generally, the ACO algorithm’s execution principle can take place either when a suitable fitness value is accomplished or when the highest number of iterations is completed. In order to find the optimum control parameters, the objective function’s minimization is deliberated with the highest number of iterations in this work. The number of ants are set to 10 and iterations are set to 50, and Table 1 condenses the remaining ACO algorithm parameters.

TABLE 1. ACO control parameters

ACO control parameters	Values
$K_{pv}$	0.014
$K_{iv}$	0.023
$K_{pf}$	0.045
$K_{if}$	0.00025

Tuning Function of Frequency

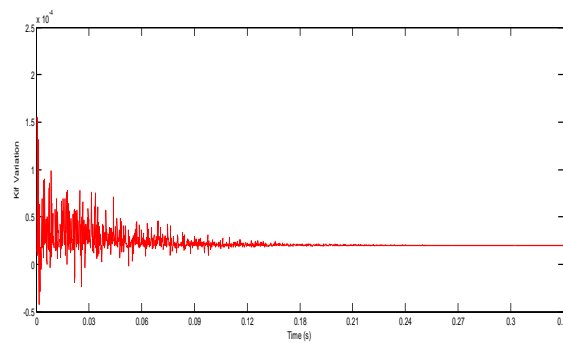


Figure 6: Variation of Kif based ACO Tuning function

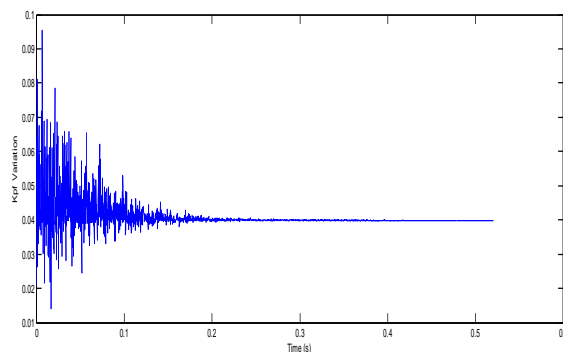


Figure 7: Variation of  $K_{pf}$  based ACO Tuning function.

Fig.6 and 7, illustrates the  $K_{pf}$  and  $K_{if}$  variation of frequency based on tuned ACO parameters. It is clearly noted that the fitness function of  $K_p$  and  $K_i$  parameter are tuned finely after some time periods. Finally, both

parameters attain its fitness function at the time period of 0.2s and the gbest particle is about 0.00025 and 0.045 respectively.

#### Tuning function of voltage

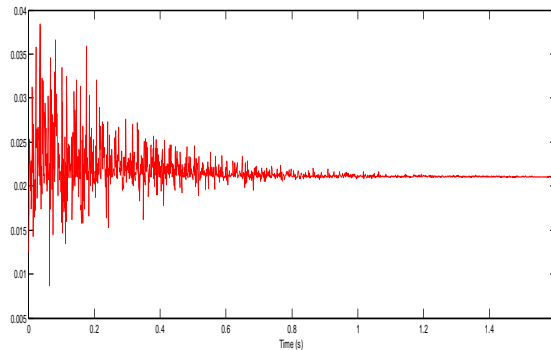


Figure 8: Variation of  $K_{iv}$  based ACO tuning function.

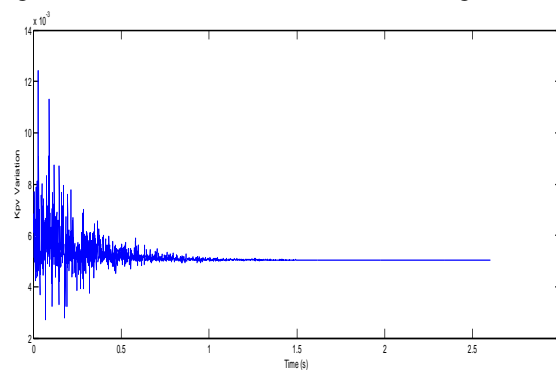


Figure 9: Variation of  $K_{pv}$  based ACO tuning function.

Fig.8 and 9, shows the  $K_{pv}$  and  $K_{iv}$  variation of voltage based on tuned ACO parameters.  $K_p$  and  $K_i$  variation are tuned based on their fitness function and attain its fitness value at 1s nearly. And they get the gbest particle is about 0.023 and 0.014 respectively.

## V. SIMULATION RESULTS

Simpower system tool box of MATLAB/ Simulink is used for simulation results. Ideal DC sources are considered as DGs. In this work, island (autonomous) mode operation of the microgrid has been explored. To assess the controller performance and also the voltage regulation and frequency regulation of the DGs, the simulation was performed.

### Regulation of frequency and voltage

At 0.001sec, the microgrid transfers from grid tied mode to islanding mode of operation. At this moment, both DGs espouse the Vf mode of power control stratagem so as to alleviate the frequency deviation and the voltage drop.

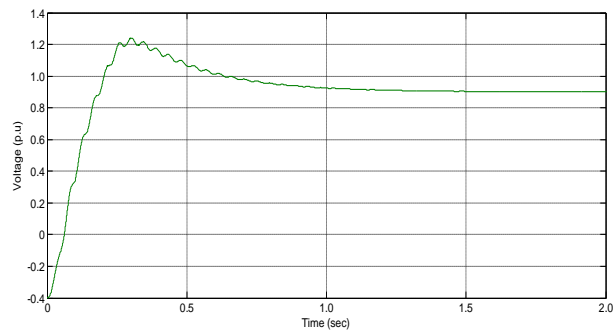


Figure 10: Regulation of voltage.

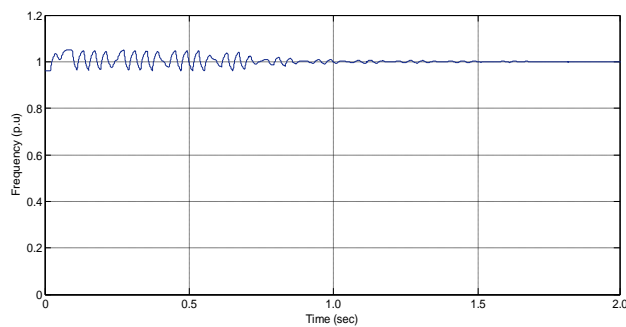
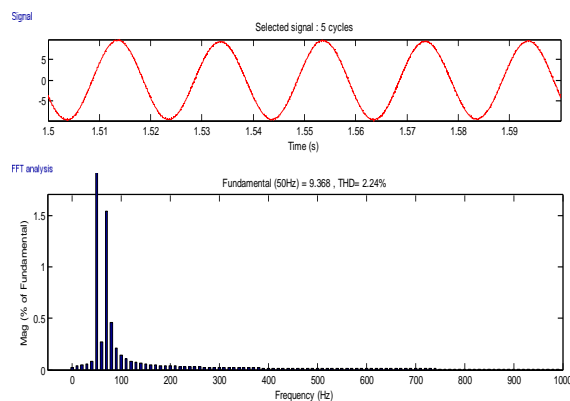


Figure 11: Frequency regulation

Figures 10 and 11, illustrate the regulated voltage and frequency of the microgrid. The above figures clearly show that the projected controllers respond to commencing of autonomous mode and affords, following a short transient, the voltage and frequency meets a value of 0.9 p.u and 1 p.u.

#### Total Harmonic Distortion Analysis

In general harmonic distortion is occurred due to the use of non-linear load devices such as induction motor, electronic ballasts and variable speed drives etc. A microgrid with an induction motor load introduces harmonic of all orders in the AC source currents. This causes the harmonic power to be dissipated in the load and that implies harmonic injection into the supply voltage waveform. Simulation results shows that when system simulation is carried on with RL load. The Figure 10 shows the harmonic spectra of the microgrid load current. The recorded THD of the line current is 2.24 %.





## VI. CONCLUSION

A novel power control strategy for a microgrid particularly when microgrid is islanded in an autonomous mode has been proposed in this work. The proposed control strategy composed of two control loops. First one is current control loop based on a synchronous reference frame which acts as an inner loop and another one is power control loop based on the conventional PI regulators which acts as an outer loop. In order to maintain the microgrid voltage and frequency within the regulating limit during autonomous mode,  $V_f$  power control strategy is implemented. The results have been proved that the microgrid is able to handle different operating conditions effectively during load change. The results also show that the proposed controller offers a satisfactory harmonic distortion level, thus improving the overall stability and reliability of the microgrid.

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