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Ant Colony Optimization Adopting Control Strategies for Power Quality Enhancement in Autonomous Microgrid

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ABSTRACT

Microgrid has comes out one of the key spot in research on distributed energy system. Since the definition of Microgrid is paradigm by the first time, investigation in this area is growing continuously and there are numerous research projects in this moment over the world. This paper mainly focused on Power quality improvement in autonomous microgrid. Herein an optimal power control strategy for an autonomous microgrid is carried out in a real time self tuning method. Voltage frequency (Vf) regulation and Harmonic analysis are the main performance parameter which is consider in this work, particularly from grid connected to islanding operation mode. Especial design of controller scheme is composed of an inner current control loop and an outer power control loop in synchronous reference frame. Ant colony optimization (ACO) is an intelligent searching algorithm, which is applied for real time self tuning of control parameter. The simulation result shows that the proposed controller offers an excellent response to satisfy the Power quality improvement.

General Terms

Modeling, Simulation and Ant Colony Optimization.

Keywords

Microgrid, Autonomous mode, Power Quality, Power controller, Current controller and ACO

1. INTRODUCTION

Microgrid can generally be viewed as a cluster of distributed generation (DG) connected to the main utility grid, usually through some of the voltages source inverter (VSI) based interfaces [1-2]. Recently this scenario represents a complementary infrastructure to the utility grid due to rapid increase of the load demand. Distributed generation system based on renewable energy sources such as solar energy, wind turbines, hydro electric power, fuel cells etc. are used. They offer many advantages for power system. Concerning the interfacing of a microgrid to the utility system is an important area of study and to investigate the impact of Power quality problems [3].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 unbalance voltage at the point of common coupling (PCC) [4]. 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 important aspects of modern power electronic converters. Current control strategy for VSI is more responsible to mitigate the power quality problem. VSI is made interconnected by widely used PWM, which have nonlinear voltage - current characteristics and high switching frequency both affect the quality of power supply [5]. Therefore current control strategy of PWM – VSI is need. Two main categories for current controller is nonlinear control based on closed loop current type PWM and linear controlled based on open loop voltage type PWM, both are applied using inner current feedback loop [6]. Generally nonlinear controller, with hysteresis current control (HCC) is used for three phase grid connected VSI system. The HCC compensate the current error and generate PWM signals with acceptable dynamic response [7]. Even though, linear current controller based space vector pulse width modulation (SVPWM) is adopted, which is used to compensate the current error neither by proportional – integral (PI) regulator nor predictive control algorithm while compensating and PWM generation can be done. These controllers provide excellence steady – state response. 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 [8].

To decipher the optimization problem, a numerous optimization techniques have been explored to address the nonlinear problems. These techniques are categorized based on their type of searching and the objective function. Generally, for linear objective function, Linear programming (LP) is used with linear equality constrains [9]. Likewise, for nonlinear objective function, nonlinear programming (NLP) is utilized. Typically objective function are stated with linearity and nonlinearity programming, but they optimize the function achieved when all constrains are linear [10]. To solve adopted objective function intelligence searching algorithm is adopted.

Recently, computational intelligence algorithm such as genetic algorithm (GA) and ant colony optimization (ACO) have been employed to different power system problems with impressive success [11].However, some deficiency in GA performance such as premature convergence have been recorded. On the other hand, ACO has been widely implemented and stamped as one of the promising optimization technique due to its simplicity, computational efficiency and robustness. In this paper, a power controller based real- time optimization is proposed in autonomous microgrid. This controller is interfaced with the current control loop based on synchronous reference frame. Conventional PI regulator is used in this scheme. When the microgrid is switches to islanding mode or load change condition, the Vf control mode based on ACO algorithm is adopted to regulate the microgrid voltage and frequency regulation. The aim of this work is to improve the quality of power supply by providing satisfactory microgrid Voltage and frequency regulation.

The organization of the paper is follows. Section II describes modeling of microgrid in autonomous microgrid along with proposed controller strategy. Section III presents the implementation of ACO algorithm for tuning of control parameter. In Section IV, simulation results are analysed to verify the aim of this controllers. Finally conclusions are outlined at Section V.

2. MODELING OF MICROGRID IN AN AUTONOMOUS MODE

A typical model of microgrid in autonomous mode is consisting of VSI along with controllers connected to the loads as shown in Fig. 1.

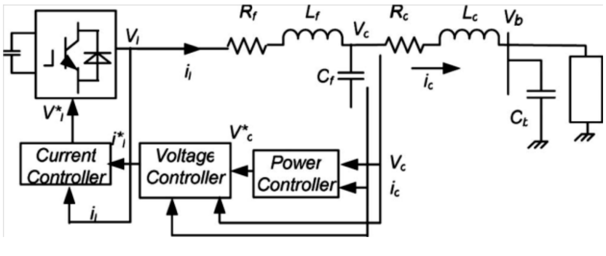

Fig.1. Microgrid in autonomous mode

2.1 Modeling of VSI and its Controllers

Modeling of VSI is attained by designing of Power, voltage, and current controllers have been used to control the microgrid inverter in an autonomous mode, as shown in Fig. 1. First, the active and reactive powers are calculated using the measured output current and voltage of the VSI. An external power control loop sets the magnitude and frequency (and hence, phase) for the fundamental component of the inverter output voltage according to the droop characteristics set for the real and reactive powers [12]. Then, the voltage and current controllers are designed to reject high-frequency disturbances and provide sufficient damping for the filter [13].

2.2 Power Controller

In a conventional power system, synchronous generators share any increase in the load by decreasing the frequency according to their governor droop characteristic. In the autonomous mode, the inverter emulates the behavior of a synchronous machine. Therefore, the angle δ can be controlled by regulating P, while the output voltage is controllable through Q. Control of frequency dynamically controls the power angle, and thus, the real power flow. For stable operation, the real and reactive power output of the inverters should be properly controlled. First, the measured output voltage and current are used to calculate the instantaneous active and reactive power.

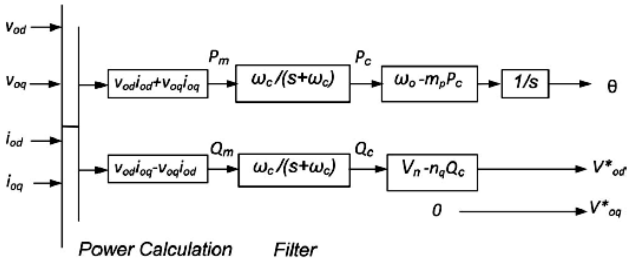

Fig.2. Block diagram of power controller.

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$$\tilde{P} = v_{od} i_{od} + v_{oq} i_{oq} , \tilde{Q} = v_{od} i_{od} + v_{oq} i_{oq} \tag{1}$$

Second, the real and reactive powers, Pc and Qc, corresponding to the fundamental components are obtained after passing these powers through low-pass filter. Finally, the frequency ω and the output d-axis voltage magnitude reference v_{od}^* can be determined as

$$\omega = \omega_n - m_p P_{c,} \theta = \omega \tag{2}$$

$$v_{od}{}^* = v_n - n_q Q_c , v_{oq}{}^* = 0 \tag{3}$$

Where m_p and n_q are the real and reactive power sharing coefficients. The different droop characteristics show that the three inverters can share the total real and reactive power.

2.3 Voltage Controller

The voltage controller block diagram including all feed-back and feed-forward terms. Output voltage control is achieved with a standard PI controller.

$$\dot{\phi}_d = v_{od} - v_{od} , \qquad \dot{\phi}_q = v_{oq} - v_{oq} \tag{4}$$

Along with the algebraic equations

$$\begin{gathered} i_{ld}^* = F_{i_{od}} - \omega_n C_f v_{oq} + k_{pv} \left(v_{od}^* - v_{od} \right) + k_{iv} \phi_d \\ i_{lq}^* = F_{i_{oq}} + \omega_n C_f v_{oq} + k_{pv} \left(v_{oq}^* - v_{oq} \right) + k_{iv} \phi_q \end{gathered} \tag{5}$$

where F is the feed forward voltage controller gain k_{pv} and k_{iv} are the PI controller parameters.

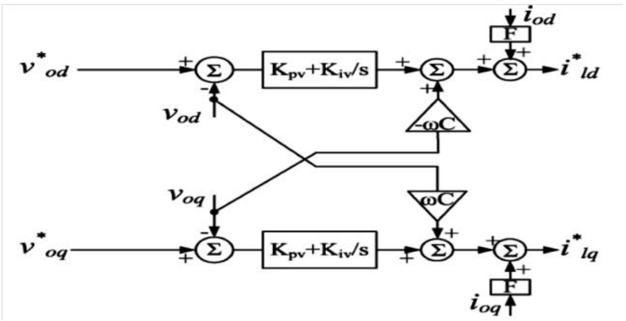

Fig.3. Voltage controller in autonomous mode

2.4 Current Controller

The PI current controller structure is shown in Fig.4. The corresponding state-space model is

$$\dot{\gamma}_d = i^*_{ld} - i_{ld} \quad , \quad \dot{\gamma}_q = i^*_{lq} - i_{lq} \tag{6}$$

$$v^*_{ld} = -\omega_n L_f i_q + k_{pc}(i^*_{ld} - i_{ld} + k_{ic}\gamma_d$$

$$v^*_{ld} = -\omega_n L_f i_q + k_{pc}(i^*_{ld} - i_{ld} + k_{ic}\gamma_d \tag{7}$$

Where k_{pc} and k_{ic} are the PI current controller parameters.

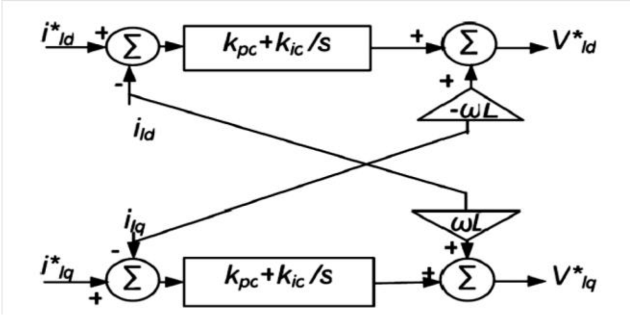

Fig.4. Current control in autonomous mode

2.5. LC Filter and coupling inductance

The LC filter and the coupling inductance model can be described with the following state equations, assuming that inverter produces the demanded voltage.

$$\dot{i}_{ld} = -\frac{R_f}{L_f} i_{ld} + \omega i_{lq} + \frac{1}{L_f}\left(v_{ld} - v_{od}\right)$$

$$\dot{i}_{lq} = -\frac{R_f}{L_f} i_{lq} + \omega i_{lq} + \frac{1}{L_f}\left(v_{lq} - v_{oq}\right) \tag{8}$$

$$\dot{v}_{od} = \omega v_{oq} + \frac{1}{C_f}\left(i_{ld} - i_{od}\right)$$

$$\dot{v}_{oq} = \omega v_{od} + \frac{1}{C_f}\left(i_{lq} - i_{oq}\right) \tag{9}$$

$$\dot{i}_{od} = -\frac{R_c}{L_c} i_{od} + \omega i_{oq} + \frac{1}{L_c}\left(v_{od} - v_{bd}\right)$$

$$\dot{i}_{oq} = -\frac{R_c}{L_c} i_{od} + \omega i_{od} + \frac{1}{L_c}\left(v_{oq} - v_{bq}\right) \tag{10}$$

2.6. Complete inverter model

To build the whole model of the system, the output variables of each inverter should be converted to the common reference frame using the following transformation:

$$f_{DQ} = T_i f_{dq} \tag{11}$$

$$T_i = \begin{bmatrix} \cos\left(\delta_i\right) & -\sin\left(\delta_i\right) \\ \sin\left(\delta_i\right) & \cos\left(\delta_i\right) \end{bmatrix} \tag{12}$$

The bus voltage that is the input signal to the inverter model should also be expressed on the common reference frame using reverse transformation.

2.7. Line model

The state equations of line current of *i*th line connected between nodes *j* and *k* can be expressed on a common reference frame as follows:

$$i_{lineDi} = -\frac{\gamma_{linei}}{L_{linei}} i_{lineDi} + \omega i_{lineQi} + \frac{1}{L_{linei}}\left(v_b D_j - v_{bDk}\right) \tag{13}$$

$$i_{lineQi} = -\frac{\gamma_{linei}}{L_{linei}} i_{lineQi} + \omega i_{lineQi} + \frac{1}{L_{linei}}\left(v_b Q_j - v_{bQk}\right) \tag{14}$$

2.8. Load model

The state equations of the RL load connected at i^{th} node are given as follows

$$i_{lineDi} = -\frac{R_{loadi}}{L_{loadi}} i_{loadDi} + \omega i_{loadQi} + \frac{1}{L_{loadi}}\left(v_{bDi}\right) \tag{15}$$

$$i_{lineQi} = -\frac{R_{loadi}}{L_{loadi}} i_{loadQi} + \omega i_{loadDi} + \frac{1}{L_{loadi}}\left(v_{bQi}\right) \tag{16}$$

The load voltages are also given as follows:

$$\dot{v}_{bDi} = \omega v_{bQi} + \frac{1}{C_f}\left(i_{oDi} - i_{loadDi} \pm i_{lineDi,j}\right) \tag{17}$$

$$\dot{v}_{bQi} = \omega v_{bDi} + \frac{1}{C_f}\left(i_{oQi} - i_{loadQi} \pm i_{lineQi,j}\right) \tag{18}$$

The sign in above equation (17) & (18) depends on the current direction in the line.

3. ANT COLONY OPTIMIZATION

Ant colony optimization (ACO) is a population based stochastic optimization technique developed by Dorigo and Stuzle [14] in 2004. ACO is a metaheuristic inspired by foraging behavior of ant colonies. Ants are used to make their path with pheromone trails, they have the capability to communicate indirectly with other and find the shortest distance between their nest and a food source when foraging for food. While adapting this search process, metaphor of ants is used to solve discrete combinational optimization problems. Artificial ants are accumulated to explore the search space of all possible solution. The ACO searching algorithm begins with a random solution (biased by heuristic information) within the decision space of the problem. Herein the search progresses over discrete time intervals. Ants are followed by the deposited pheromone on the components of promising optimal solution [15]. By this way, the ACO search is progressively biased towards more desirable region of the search space, thus optimal or near optimal solution could be attained. Due to its robustness in optimizing the objective function, ACO has been applied recently to and obtained with some approaching optimized results for real world engineering problems, such that design of optimal distributed systems.

Likewise in this case with other metaheuristic, ACO can be linked with existing simulation models of power system, regardless with their complexity, while solving power quality problems. In addition, the unique way in which ACO problems is implemented by using an equation which makes ACO inherently suitable for optimizing power quality problems. In this section, a novel formulation is made which enables ACO to be adopted for power quality problems.

4. SIMULATION RESULTS

As shown in Fig. 1. The complete model of autonomous mode of microgrid with VSI system and the proposed controller are simulated using MATLAB / Simulink environment. In this controller ACO algorithm is implemented through a MATLAB / M-file program, and the model parameters are defined as follows: inverter based DG is designed for about 50KW and are connected to the load through coupling inductance Lc and the lines are shown in Fig.1. DG unit is represented by dc voltage source and VSI. A nonlinear load of about 50KW is considered for operation. The switching and sampling frequency are 10 KHz and 500 KHz, respectively. Fig.5 to Fig.9 shows the results of the simulation models. All results are in p.u. system and the following objectives are investigated.

4.1. Voltage regulation

Fig.5. shows that voltage is not regulated and also it contains distortion in its waveform. Along with this distortion it can’t be capable to feed load, since it causes damage to load. In order to regulate this voltage, Vf control mode is adopted to offer an excellence behavior to regulate voltage, which is shown in Fig.6.

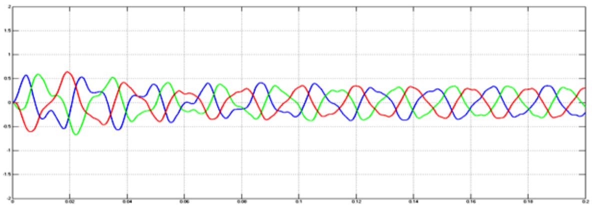

Fig.5. Microgrid voltage without Vf- controller

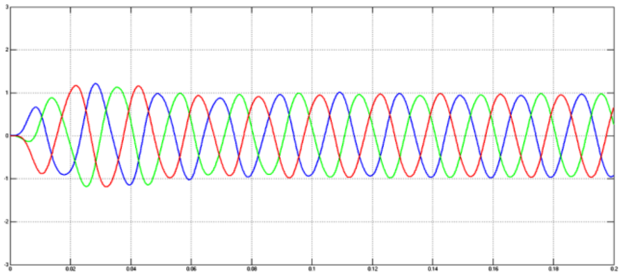

Fig.6. Microgrid voltage with Vf- controller

4.2. Frequency regulation

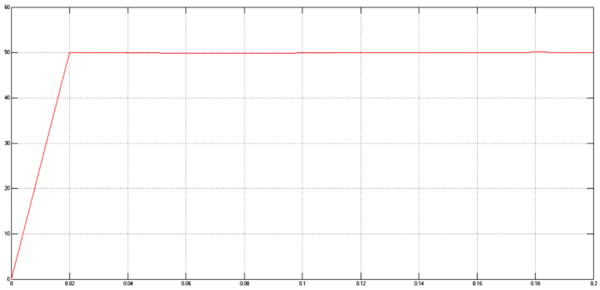

Fig.7. Frequency regulation

In Fig.7. it is observed that microgrid frequency is made regulated at 50Hz.

4.3. Harmonic analysis

The current controller strategy is important in an autonomous microgrid. The controller proposed to mitigate the Total Harmonic Distortion (THD) in microgrid. Herein PI controller scheme is implemented in synchronous rotating reference frame is used. This learning control method provides an alternative to reduce THD. From Fig.8 and Fig.9 it is observed that THD is reduced from 35.43 % to 4.63 % by proposed controller.

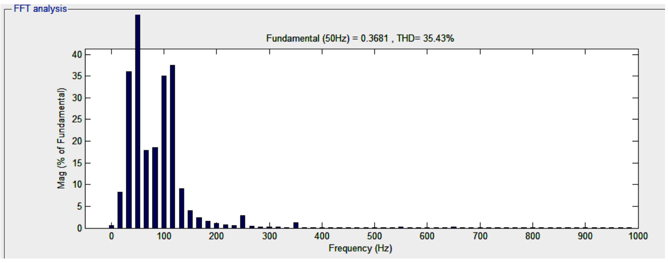

Fig. 8. THD without controller

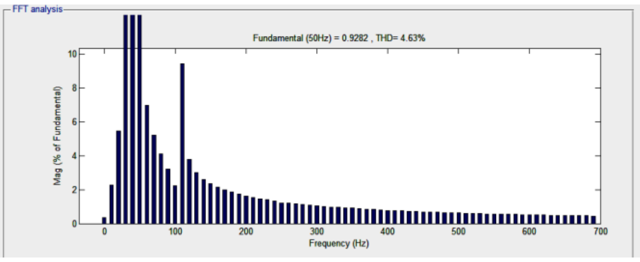

Fig.9. THD with controller

5. CONCLUSION

In this paper, an optimal power control strategy has been proposed for an autonomous microgrid operation. Hence the controller is composed of an inner current control loop and outer power control loop. In this work Vf control strategy is adopted when microgrid in autonomous mode in order to maintain the microgrid voltage and frequency within acceptable limits and THD are minimized. The simulation results shows that the proposed strategy offers an excellent response in regulate microgrid voltage and frequency in autonomous mode.

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