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Fuzzy-PI Controllers for Grid-Connected and Islanded Operation of DG in a Microgrid

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Abstract

Islanding describes the condition in which a microgrid or a portion of the power grid, which consists of a load and a distributed generation (DG) system, is isolated from the remainder of the utility system. In this situation, it is important for the microgrid to continue to provide adequate power to the load. To demonstrate the operation of microgrid in grid connected mode and islanded mode, a simulink model has been designed with necessary parameters by connecting with the main grid allowing the sharing of different loads with reference to grid connection and disconnection. An islanding detection algorithm has been used to act as a switch between the two controllers so that the system operates under intentional islanded mode. This paper also proposes an algorithm of synchronization for grid reconnection. **.** *In addition, fuzzy logic controller and SVPWM have been used to reduce the THD of the inverter output.*

Index terms --- *Distributed generation (DG), grid-connected operation, intentional-islanding operation, islanding detection, synchronization.*

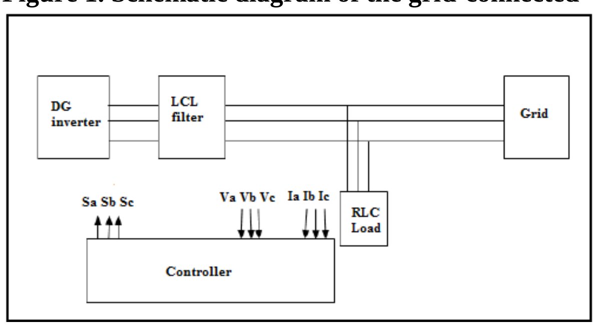
1. INTRODUCTION

Distributed generation is now becoming a popular power scenario in a de-regulated environment. Integration of distributed generation and incorporation of controllers lead conventional power network to operate as active power networks. Under disturbances these power network split and if a split part contains generators and loads and if the load demand can be matched with supply a power island is established [1].

Islanding is a condition in which a microgrid or a portion of the power grid, which contains both load and distributed generation, is isolated from the remainder of the utility system and continues to operate.

The disconnection of the DG once it is islanded is required by the IEEE Std. 929-2000 [2] and by the IEEE Std. 1547-2003 [3]. With the increasing competition among the power companies to secure more and more customers, the pressure to maintain a high degree of uninterrupted power service quality and reliability is felt by the utility companies [4]. Thus, in a deregulated market environment, current practices of disconnecting the DG following a disturbance will no longer be a practical or reliable solution.

Figure 1. Schematic diagram of the grid-connected



inverter system

During the grid-connected operation, each DG system is usually operated to provide or inject preset power to the grid, which is the current control mode in stiff synchronization with the grid [5], [6]. When the microgrid is cut off from the main grid, each DG system has to detect this islanding situation and has to be switched to a voltage control mode to provide constant voltage to the local sensitive loads [7], [8]. This paper describes a control strategy that is used to implement grid-connected and intentional-islanding operations of microgrids. Specifically, this paper proposes an islanding detection algorithm [9] for identifying the islanded condition and an algorithm for synchronization for grid reconnection [9]. For reducing the THD of the inverter output fuzzy logic controller [10], [11] and SVPWM has also been used.

2. ISLANDING DETECTION ALGORITHM

Islanding is a condition where the DG remains operative in the distribution system with utility disconnected. In the past years several islanding detection methods have been proposed and the detection methods can be categorized into two main groups: passive and active method. Passive method depends upon measuring system parameters and thresholds are set to these parameters to differentiate between an islanding and a non islanding condition. Active methods directly interact with the power system operation by introducing perturbation in the inverter output. But the disadvantage with active method is that the harmonic distortion introduced is more.

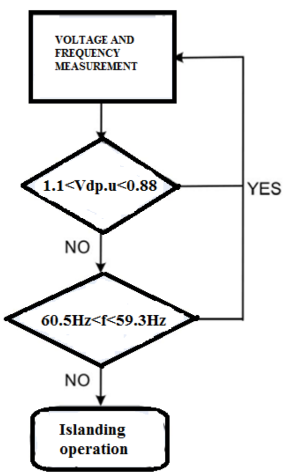


Figure 2. Islanding detection Algorithm

The islanding detection algorithm is used to act as a switch between the two controllers so that the algorithm effectively detects islanding situation and is able to switch between the two controllers.

3. CONTROLLER

Figure 1 shows the main circuit topology. This system consists of the microsource that is represented by the dc source, the conversion unit which performs the interface function between the dc bus and the three-phase ac world, and the LCL filter that transports and distributes the energy to the end use and the load [12], [13]. The controller presented provides a constant DG output and maintains the voltage at the point of common coupling (PCC) before and after the grid is disconnected.

Under normal operation, each DG system in the microgrid usually works in a constant current control mode in order to provide a preset power to the main grid. When the microgrid is cut off from the main grid, each DG inverter system must detect this islanding situation and must switch to a voltage control mode. In this mode, the microgrid will provide a constant voltage to the local load.

3.1. Grid-Connected Operation Mode

For grid-connected operation, the controller shown in Figure 3 is designed to supply a constant current output [14]. A phaselocked loop (PLL) is used to determine the frequency and angle reference of the PCC [15], [16].

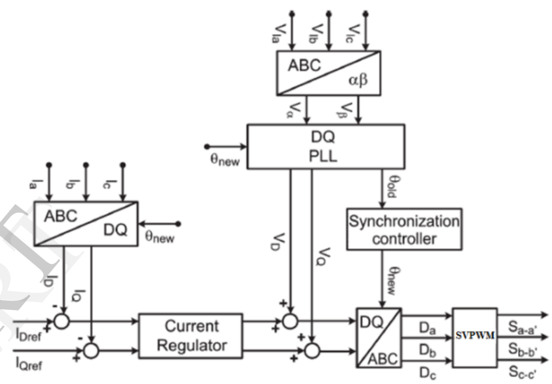
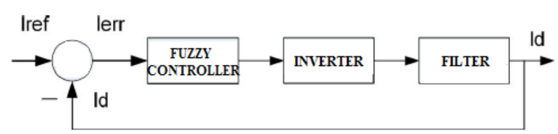


Figure 3. Block diagram for current controller for grid connected mode

To simplify the design and operation of the controller, the control of the system is designed in a synchronous reference frame. Figure 4 shows this control topology employing synchronous frame current control.

Figure 4. Block diagram of current



controlled inverter

The inverter currents are transformed into a synchronous frame by Park's transformation (1) and regulated in dc quantity is fed back and compared with the reference currents I_{DQ} ref. This generates a current error that is passed to the current regulator (FUZZY controller) to generate the voltage references for the inverter. In order to get a good dynamic response, V_{DQ} is fed forward. This is done because the terminal voltage of the inverter is treated as a disturbance, and the feedforward is used to compensate for it [17].

The voltage references in dc quantities V_{DQ} ref are transformed into a stationary frame by the inverse of Park's transformation (2) and are utilized as command voltages in generating high frequency pulsewidth-modulated voltages.

$$\begin{bmatrix} X_D \\ X_Q \\ X_O \end{bmatrix} = \frac{2}{3}\begin{bmatrix} -\cos\theta & -\cos(\theta + {}^{2\pi}/_{3}) & -\cos(\theta - {}^{2\pi}/_{3}) \\ \sin\theta & \sin(\theta + {}^{2\pi}/_{3}) & \sin(\theta - {}^{2\pi}/_{3}) \\ \frac{1}{2} & {}^{1}/_{2} & {}^{1}/_{2} \end{bmatrix} * \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad (1)$$

Where $\theta = \omega t$ and ω is the frequency of the electric system

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \frac{2}{3}\begin{bmatrix} -\cos\theta & \sin\theta & {}^{1}/_{2} \\ -\cos(\theta - {}^{2}/_{3}) & \sin(\theta - {}^{2\pi}/_{3}) & {}^{1}/_{2} \\ -\cos(\theta + {}^{2}/_{3}) & \sin(\theta + {}^{2\pi}/_{3}) & {}^{1}/_{2} \end{bmatrix} * \begin{bmatrix} X_D \\ X_Q \\ X_0 \end{bmatrix} \quad (2)$$

3.1. Grid disconnected mode

The voltage closed-loop control for intentional-islanding operation is shown in Figure. 5. The control works as voltage regulation through current compensation. The controller uses voltage compensators to generate current references for current regulation.

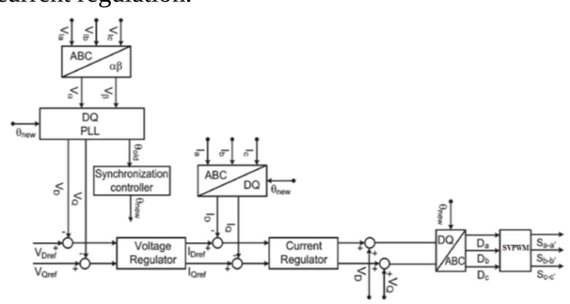


Figure 5. Block diagram of the voltage controller for grid disconnected operation

As shown, the load voltages (V_D and V_Q) are forced to track its reference by using a PI compensator (voltage regulator). The outputs of this compensator (I_D ref and I_Q ref) are compared with the load current (I_D and I_Q), and the error is fed to a current regulator (PI controller). The output of the current compensator acts as the voltage reference signal that is fed to the sinusoidal pulsewidth modulator to generate the high frequency gating signals for driving the three-phase voltage source inverter. The current loop is included to stabilize the system and to improve the system dynamic response by rapidly compensating for near-future variations in the load voltages. In order to get a good dynamic response, V_{DQ} is fed forward. This is done because the terminal voltage of the inverter is treated as a disturbance, and the feedforward is used to compensate for it [17].

3.2. Synchronization for grid reconnection

When the grid-disconnection cause disappears, the transition from islanded to grid-connected mode can be started. To avoid hard transients in the reconnection, the DG has to be synchronized with the grid voltage [18]-[20]. The DG is operated in the synchronous island mode until both systems are synchronized. Once the voltage in the DG is synchronized with the utility voltage, the DG is reconnected to the grid, and the controller will pass from the voltage to the current control mode. This synchronization is achieved by implementing the following algorithm.

1. Assume that the phase difference between the grid and inverter voltages is given by

$$\theta = \angle V_G - \angle V_I \quad (3)$$

2. In order to obtain the information of θ, two sets of voltage values are used

$$k = V_{Ia}V_{Ga} + V_{Ib}V_{Gb} + V_{Ic}V_{Gc} = \frac{3}{2}\cos\theta \quad (4)$$

$$g = V_{Ia}V_{Gb} + V_{Ib}V_{Gc} + V_{Ic}V_{Ga} = \frac{3}{4}\left[-\cos\theta + \sqrt{3}\sin\theta\right] \quad (5)$$

Using the variables k and g, $\sin\theta$ can be found as

$$\sin\theta = \frac{\frac{4}{3}g + \frac{2}{3}k}{\sqrt{3}} \quad (6)$$

Figure 6 shows how $\sin\theta$ is used to obtain the new phase angle for which the grid and inverter voltages are synchronized.

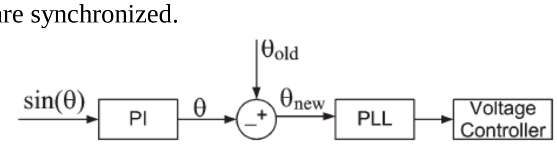


Figure 6. Synchronization controller

4. SIMULATION RESULTS

The converter fed microgrid consisting of a dc source, LCL filter and RLC load is modeled and analyzed in MATLAB/SIMULINK. This is shown in Figure 7. The RLC load is modeled so as to consume

125kW active power and zero reactive power. The system is tested under the following conditions.

1) Output frequency: 60 Hz
2) Filter inductor L1: 0.4mH
3) Filter inductor L2: 0.4mH
4) Filter capacitor C: 2mF
5) DC voltage: 600 V
6) Breaker operation: [0.4 0.7]
7) Output capacity: 125 kW

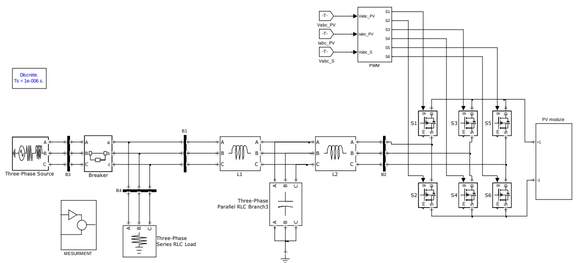


Figure 7. Overall simulated system

The RLC load was adjusted to be resonant at 60 Hz and to consume 125kW. The DG system was designed to supply 125 kW active power and zero reactive power. The system was initially operated in grid connected mode. The grid was disconnected at 0.4 sec and this event was detected by the islanding detection algorithm at 0.41 sec. The grid is again reconnected at 0.7 sec. Let us first consider the case when there is no voltage controller.

CASE 1: WITH CURRENT CONTROLLER ALONE AND NO VOLTAGE CONTROLLER

During the grid connected mode, the current controller supplies the load. Since we are analyzing the case with no voltage controller, from 0.41 sec to 0.7 sec, the inverter ceases to energize the RLC load. The simulation results are as below.

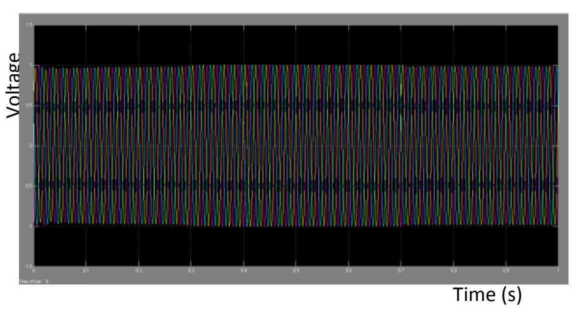


Figure 8. Grid voltage

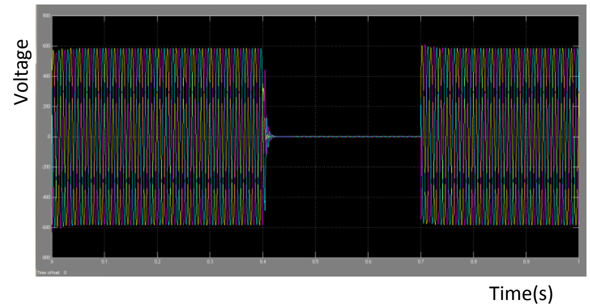


Figure 9. Inverter voltage

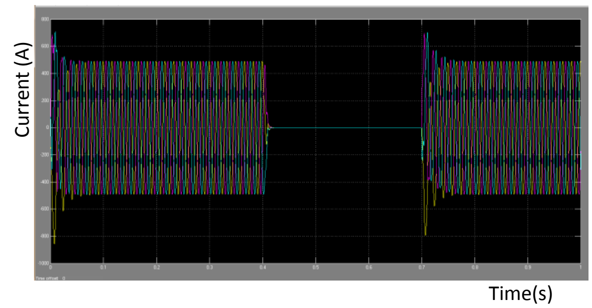


Figure 10. Inverter current

CASE 2: WITH BOTH THE CONTROLLERS

The grid was disconnected at 0.4 sec and this event was detected by the islanding detection algorithm at 0.41 sec. After 0.41 sec the control mode was changed from current to voltage controlled operation. The grid is again reconnected at 0.7 sec. The proposed synchronization algorithm successfully forces the voltage of the DG to track the voltage of the grid. After synchronization with the grid, the microgrid will supply 125 kW of active power into the grid. So from 0.7 sec onwards the active power is again increased to 250 kW. Once the synchronization is complete the controller was switched from voltage to current control mode. The simulation results are shown below.

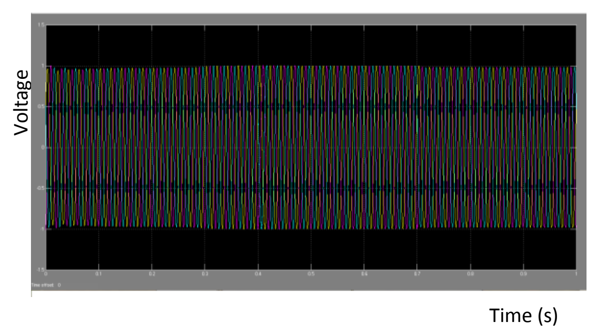


Figure 11. Grid voltage

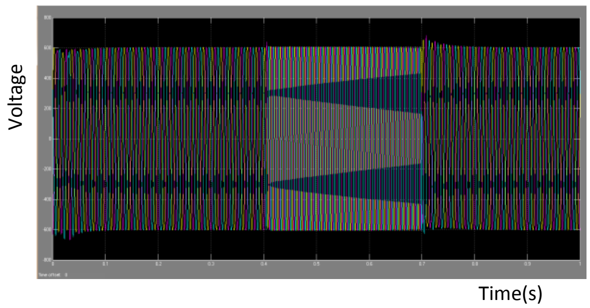


Figure 12. Inverter voltage

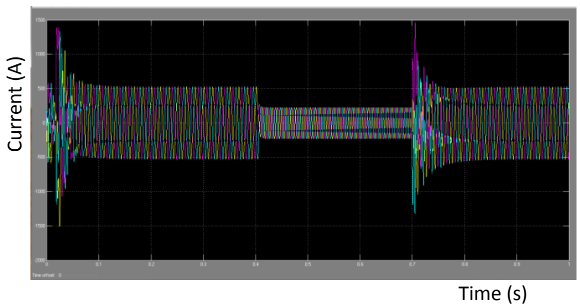


Figure 13. Inverter current

5. FFT ANALYSIS OF THE INVERTER

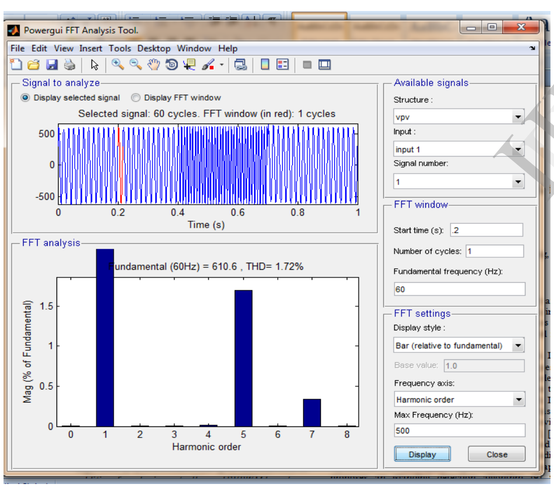


Figure 14. FFT analysis of the inverter

FFT analysis of the inverter shows that the inverter has operated with a THD of 1.72 %.

6. CONCLUSION

Through this paper, the control, islanding detection, and reclosure algorithms have been proposed for the operation of grid-connected and islanding mode of DGs. A controller was designed with two interface controls: one for grid-connected operation and the other for 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. The reclosure algorithm causes the DG to resynchronize itself with the grid. The experimental 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. In addition, it was shown that the use of fuzzy logic controller and SVPWM has reduced the THD of the inverter output.

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