ACTIVE ISLANDING DETECTION USING AVERAGE ABSOLUTE FREQUENCY DEVIATION VALUE FOR GRID CONNECTED DISTRIBUTED GENERATION SYSTEM

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ABSTRACT

One of the important issue related to the interconnection of Distributed Generation (DG) systems to grid is islanding. An active islanding detection technique (IDT), which employs Average Absolute Frequency Deviation Value ($AFDV_{avg}$) for the detection of islanding condition, has been proposed in this work. The q-component of inverter's current is controlled using a current controller. A continuous and periodic signal is the reference signal for the current controller. At the point of common coupling (PCC), the deviation in the frequency is observed when the disturbances of frequency other than fundamental are injected during islanding. The active islanding detection method (IDM) provides lower NDZ (Non Detection Zone) compared to passive detection, thereby enhancing the detection of small deviation in the frequency at the PCC. By measuring the value of deviation in the frequency ($AFDV_{avg}$), the condition for islanding is detected. The islanding condition is reconfirmed by the proposed technique. The reconfirmation of the islanding condition helps to eliminate the false detection of island due to non-islanding switching events. The effectiveness of the technique employed is analyzed with the help of simulation using MATLAB/ Simulink.

Keywords: islanding detection technique, distributed generation, non detection Zone, average absolute frequency deviation value ($AFDV_{avg}$).

1. INTRODUCTION

With the increase in demand, the need of generation is increased. This leads to the increase of transmission and distribution (T&D) cost. With the advent of Distributed Generation (DG), the cost needed to be incurred on T&D is reduced, as Distributed Resource technologies can be implemented at a lesser rate [1]. One of the main interconnection issue regarding interconnection of DG to grid is islanding. A state in which a part of an Electric Power System (EPS) gets electrically separated with load energized solely by the local sources (DG's) is called Islanding. Islanding can either be intentional or unintentional. The unintentional islanding is more important in the aspect of worker's safety and the damage incurred to the power system equipment. Islanding should be avoided as it may produce several undesirable effects. Primarily, the operating personnel may not be aware that the islanded portion is still energized and hence prone to hazardous electric shock. Next, out of phase reclosing can happen and there is a possibility of flow of large surge currents upon reconnection to grid. For these reasons, islanding should be identified [2].

During unintentional islanding, the power system operator loses control over the voltage and current in the island. This may result in hazardous operating condition for workers and equipment. To avoid such adverse effects, the islanding condition should be detected as quickly as within 2 seconds. There are various islanding detection techniques (IDT's) developed to detect islanding [3-5].

Broadly, there are two types of islanding detection technique. The classification of the IDT is depicted in Figure-1. They are local techniques and remote techniques respectively. The local detection technique is further classified into three types namely, active, passive and hybrid detection techniques. The remote detection technique uses data of the system for the detection. The data is gathered with the help of SCADA. The remote techniques are reliable when compared to all other techniques, but those techniques are costly due to the employment of highly precise communication network.

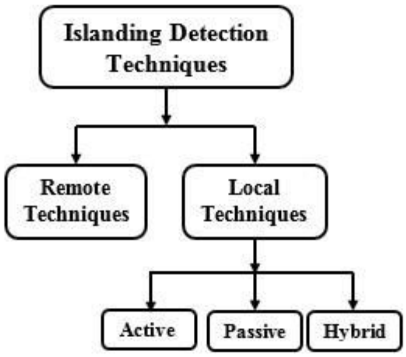

Figure-1. Classification of IDT.

On the other hand, local detection techniques uses measurement of parameters at the DG end. It is less expensive. Hence local IDT's are commonly used. The effectiveness of the detection technique is decided based on NDZ (Non Detection Zone). The active detection technique gives better detection as it provides low NDZ when compared with passive detection schemes [6]. Even active IDT's are difficult to implement, they are preferred to passive IDT's due to their faster response and lower

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NDZ. But, the only disadvantage is that it affects the power quality to some extent.

An active IDT for DG systems interfacing to the grid via inverter is proposed in this paper. The active IDT employs the perturbation in the selected system parameter and observes the deviation in the parameter. The deviation is used for the detection of islanding. The parameter can be voltage, frequency, phase, etc. The parameter considered here is the frequency of the voltage at the PCC. Here, the perturbation of the frequency is done by injecting a disturbance signal of frequency other than the fundamental frequency at the inverter end through a classical q-axis current controller[7-10]. The technique proposed here uses an Average Absolute Frequency Deviation Value ($AFDV_{avg}$). By taking the absolute value, the negative deviation becomes positively detectable. The averaging of the frequency deviation over 5 to 6 cycles reduces the possibility of non-detection [11].

The decision making algorithm is very vital in ruling out the non-islanding switching events such as capacitor switching, sudden change in load, etc. Hence, the IDT should be carefully coupled with the decision making algorithm.

2. SYSTEM DESCRIPTION

The single line diagram of the grid connected inverter interfaced Distributed Generation system is shown in the Figure-2. The grid and the DG system is connected via a circuit breaker with a local load connected at the point of common coupling.

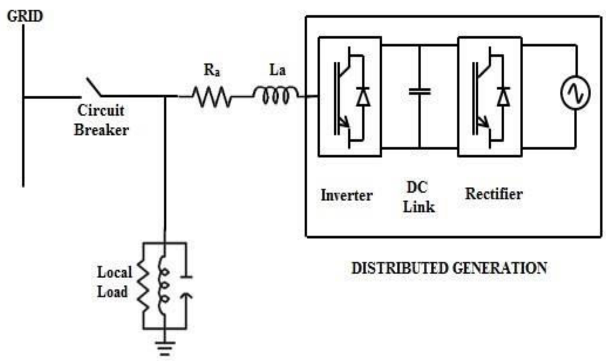

Figure-2. Inverter interfaced grid connected DG.

The system parameters are listed in Table-1. The synchronizing of the utility voltage and that of the inverter used to interface DG with the utility is done with the help of a 3-phase phase locked loop (PLL). It provides the required data for the abc to dq transformation.

The inverter's instantaneous real and reactive power in dq reference frame can be expressed as (1) and (2)

$$p_p = \frac{3}{2} v_{pd} i_{vd} \quad (1)$$

$$q_p = \frac{3}{2} v_{pd} i_{vq} \quad (2)$$

where i_{vd} and i_{vq} are the inverter current's d-q components, v_{pd} and v_{pq} are the d-q components of the voltage at PCC.

By applying KVL for the system considered, the voltage equations in the dq reference frame can be written as (3) and (4)

$$v_{vd} - v_{pd} = i_{vd} R_a + L_a \frac{di_{vd}}{dt} + \omega_0 L_a i_{vq} \quad (3)$$

$$v_{vq} - v_{pq} = i_{vq} R_a + L_a \frac{di_{vq}}{dt} - \omega_0 L_a i_{vd} \quad (4)$$

where v_{vd} and v_{vq} are the d-q components of the voltage at the inverter end and ω_0 is the fundamental grid frequency.

Table-1. System parameters.

V_p line-line	575 V
I_{va} line-line	6.816 kA
P_{vsc}	4.8 MW
V_{dc}	1200 V
f_o(grid)	60 Hz
R_a	5.95 mΩ
L_a	11.75 µH
f(resonance)	60 Hz
R	68.88 mΩ
L	0.182 mH
C	38529 µH
f(PWM)	1620 Hz
Q factor	1
k_p	0.3
k_i	6

The PI controller regulates the q-component of the voltage at PCC (v_{pq}) to zero and hence the equation (4) can also be written as (5)

$$\frac{d}{dt} i_{vq} = -\frac{R_a}{L_a} i_{vq} + \frac{1}{L_a} \left[v_{iq} - \omega_0 L_a i_{vd}\right] \quad (5)$$

Let,

$$\left[v_{iq} - \omega_0 L_a i_{vd}\right] = y \quad (6)$$

Where

$$y = \left(k_p + \frac{k_i}{s}\right)\left(i^*_{vq} - i_{vq}\right) \quad (7)$$

The Laplace transformation of the equation (5) gives

$$i_{vq}(s) = \frac{1}{[sL_a + R_a]} y(s) \quad (8)$$

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By observing the equations (8) and (2), it is obvious that independent control of i_{vq} and therefore q_p can be performed. The block diagram of the inverter's q-axis current controller is depicted in the Figure-3.

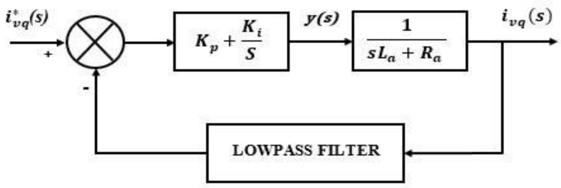

Figure-3. Inverter's q-axis current controller.

The low pass filter is used to attenuate the generated harmonics during switching under islanding condition.

3. MODELLING OF Q-AXIS CURRENT CONTROLLER

The influence of current controller reference current (i^*_{vq}) on the frequency of inverter is studied here. In conventional q-axis current controller, to obtain unity power factor the reference current is chosen as zero. The steady state inverter current $i_{v,}$ in the dq frame of reference is

$$\begin{bmatrix} \mathbf{i_{vd}} \\ \mathbf{i_{vq}} \end{bmatrix} = \begin{bmatrix} \mathbf{i^*_{vd}} \\ \mathbf{i^*_{vq}} \end{bmatrix} \tag{9}$$

The abc-coordinate system can be obtained by taking inverse Park's transformation of the equation (9) is

$$\begin{bmatrix} i_{va} \\ i_{vb} \\ i_{vc} \end{bmatrix} = \begin{bmatrix} i^*_{vd}(\cos\omega_0 t) - i^*_{vq}(\sin\omega_0 t) \\ i^*_{vd}(\cos\omega_0 t - 2\pi/3) - i^*_{vq}(\sin\omega_0 t - 2\pi/3) \\ i^*_{vd}(\cos\omega_0 t + 2\pi/3) - i^*_{vq}(\sin\omega_0 t + 2\pi/3) \end{bmatrix} \tag{10}$$

The inverter's q-axis current controller is modelled with a small periodic current i^*_{vq} and is given by the equation (11)

$$i^*_{vq} = I_q(\cos\omega_q t) \tag{11}$$

where I_q is the magnitude of the inverter's reference current frequency signal ,chosen such that it is only 1% of the rated DG current and f_q be the frequency except fundamental frequency [7].

The phase 'a' current of the inverter can be expressed as

$$i_{va} = i^*_{vd}(\cos\omega_0 t) - I_q(\cos\omega_q t)(\sin\omega_0 t) \tag{12}$$

Or

$$i_{va} = i^*_{vd}\cos(\omega_0 t) - \tfrac{1}{2} I_q[\sin(\omega_1 t) + \sin(\omega_2 t)] \tag{13}$$

Where

$$\omega_1 = 2\pi(f_0 - f_q) \tag{14}$$

$$\omega_2 = 2\pi(f_0 + f_q) \tag{15}$$

The frequencies f_0 and f_q are the fundamental and q-axis reference current frequency, respectively.

Since they are forced to flow through the load, at frequency $\omega 1$ and $\omega 2$ the current components becomes effective during islanding. At the corresponding frequencies, the individual current components of (13) are multiplied to the respective impedances. By superimposing the voltages at corresponding frequencies, the PCC voltage of phase "a" is obtained as in equation (16).

$$v_{pa} = v_p(\omega_0) + v_p(\omega_1) + v_p(\omega_2) \tag{16}$$

Where

$$v_p(\omega_0) = R i^*_{vd}(\cos\omega_0 t) \tag{17}$$

$$v_p(\omega_1) = -\frac{I_q}{2\left\{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega_1 C - \frac{1}{\omega_1 L}\right)^2}\right\}} \sin(\omega_1 t + \varphi_1) \tag{18}$$

$$v_p(\omega_2) = -\frac{I_q}{2\left\{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega_2 C - \frac{1}{\omega_2 L}\right)^2}\right\}} \sin(\omega_2 t + \varphi_2) \tag{19}$$

$$\varphi_1 = -\tan^{-1}\left[\frac{R(\omega_1^2 LC - 1)}{\omega_1 L}\right] \tag{20}$$

$$\varphi_2 = -\tan^{-1}\left[\frac{R(\omega_2^2 LC - 1)}{\omega_2 L}\right] \tag{21}$$

When the q-axis reference current is a periodic signal with a frequency other than the fundamental frequency, the frequency of the voltage at PCC will deviate from nominal system frequency. The equation (16) shows that when the reference current is injected into the system, the frequency of the PCC voltage will get deviated [11].

4. ACTIVE ISLANDING DETECTION TECHNIQUE

The active islanding detection is done using $AFDV_{avg}$ value for inverter interfaced grid connected Distributed Generation systems. For a perfectly matched load condition, the deviation in frequency during islanding is very low such that it falls inside NDZ. The injection of a disturbance signal of frequency other than the fundamental frequency of small magnitude will reflect in the PCC frequency thereby the islanding can be discovered.The frequency deviation measurement is calculated by using an average absolute frequency deviation value ($AFDV_{avg}$). It is given by

$$AFDV_{avg} = \frac{1}{N} \sum_{n=1}^{N} |F_D(n)|$$

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$$N = \frac{M_w}{T_s}$$

where
F_D - Instantaneous frequency deviation
M_w - Measurement window
T_s - Sampling Time
N - Total number of samples

A measurement window of 50 ms can be chosen so as to cover to the least of three cycles of a 60 Hz signal. The sampling time chosen for the discrete Matlab simulation model is 50 μs. Therefore, there will be in total of 100 samples [11]. Under perfectly matched loading condition, the deviation will be a periodic deviation due to the injected periodic disturbance signal. The frequency deviation will be sinusoidal and hence, the $AFDV_{avg}$ can be approximated to $2\pi f_m$as it is similar to full wave rectified sinusoidal waveform [11].

4.1 Algorithm for the proposed technique

The flow of algorithm through which the islanding detection is executed is shown in the Figure-4 [11]. The proposed technique uses an algorithm which detects the island formation primarily and reconfirms it.The average absolute frequency deviation ($AFDV_{avg}$) should be within the threshold value and less than 0.25 Hz after the injection of first disturbance signal of frequency other than the fundamental frequency. If the $AFDV_{avg}$ is not violated, then there is no islanded condition.

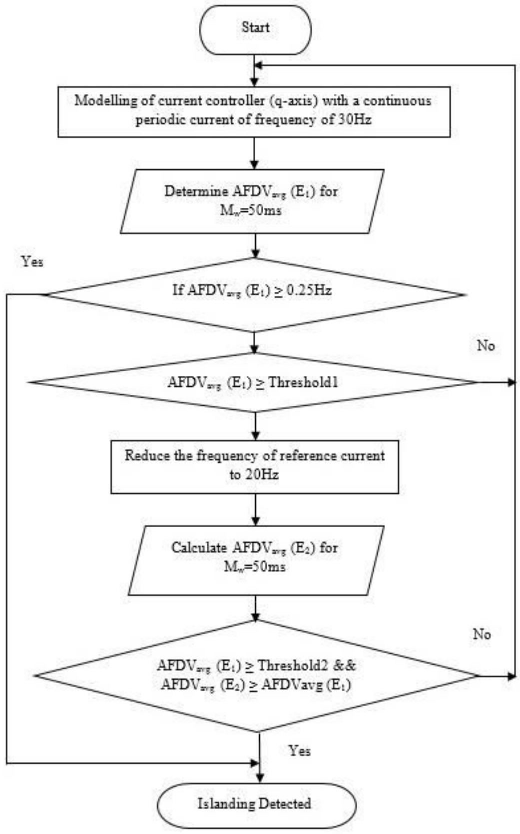

Figure-4. Flowchart of the proposed technique.

If the $AFDV_{avg}$ is violated, then the islanding condition is suspected. Then, the frequency of the disturbance signal is reduced to reconfirm the occurrence of islanding, as the deviation in the frequency can be due to some of the non-islanding switching events. Thus, avoiding the false detection of island formation and prevents the unnecessary ceasing of power from DG. In the event of violation of threshold level, then the inverter has to be given control to cease the power generation from DG.

The single line diagram of the system considered in Figure-2 incorporated with the q-axis current controller has been modelled in the Simulink platform as in the Figure-5.

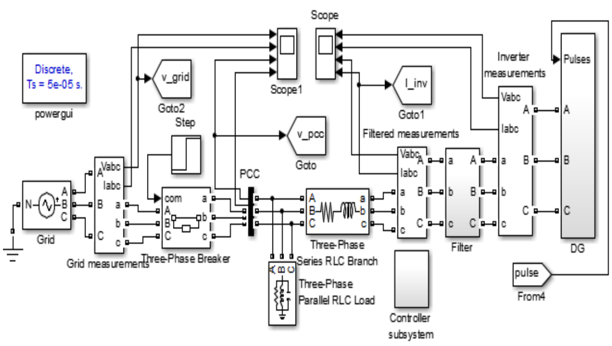

Figure-5. Simulink model of proposed technique for grid connected inverter interfaced DG.

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The circuit breaker is tripped at 0.8 seconds to realize the islanding condition by using a step signal. The synchronization of the inverter and the grid is done with the help of a three phase PLL (Phase Locked Loop). The abc components of the voltage at PCC is converted into dq frame using abc to dq0 transformation. Similarly the inverter current is converted into its corresponding dq0 components. The inverter current's quadrature axis component is regulated to zero and a disturbance signal is injected at the inverter end through the current controller. The disturbance signal is generated using Matlab function block.

5. RESULTS AND DISCUSSIONS

The simulation of the system considered for islanding detection was simulated on Matlab Simulink.

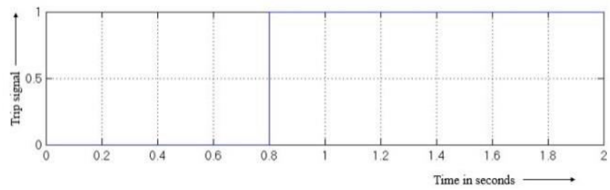

Figure-6. Trip signal to circuit breaker.

The islanding condition is achieved by giving a trip signal to open the circuit breaker at 0.8 seconds as in Figure-6. The frequency of the utility/ grid depicted in Figure-7 is maintained at nominal value of 60 Hz prior and after the occurrence of islanding.

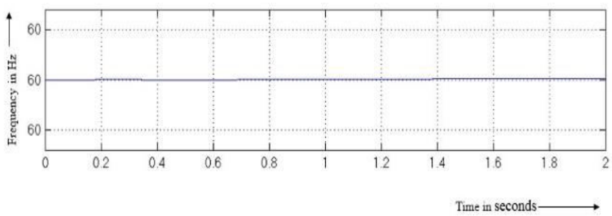

Figure-7. Frequency of the utility.

The frequency of the voltage at the Point of common coupling is observed as in Figure-8.

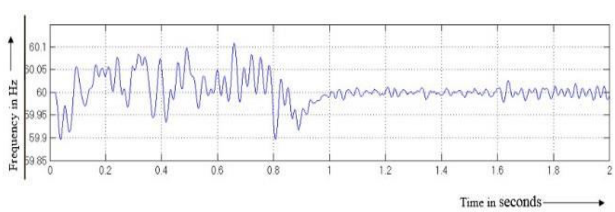

Figure-8. Frequency at PCC.

Figure-9 shows the injection of the disturbance signal (reference current) through the current controller is at the frequency of 30 Hz initially and once when the islanding condition is suspected, the frequency of the disturbance signal is reduced to 20 Hz to terminate the operation of the DG.

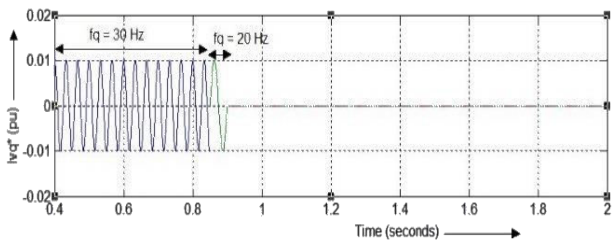

Figure-9. Disturbance signal.

This is controlled by the control signal depicted in Figure-10.

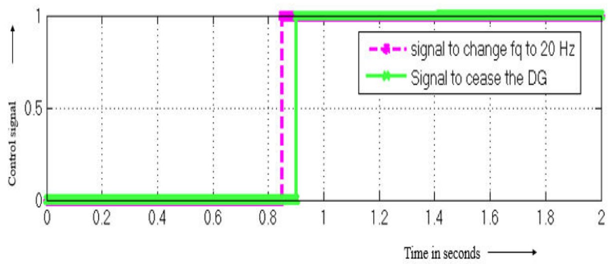

Figure-10. Control signal.

6. CONCLUSIONS

The simulation of the proposed active islanding technique is developed in Matlab platform. The generation of control signal for the proper injection of reference current with different frequencies have been done effectively. Thus, generating the disturbance signal of required frequencies is achieved properly. The proper injection of disturbance signal of frequencies other than the fundamental frequency through the current controller helps in identifying the deviation in the frequency at the point of common coupling. The $AFDV_{avg}$ calculated using the frequency deviation at the PCC and it is used for the detection of islanding using the algorithm proposed. The cessation of the DG operation can be done once the islanding is reconfirmed.

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