Comparative Analysis of Passive Islanding Detection Methods for Grid-Connected Distrubted Generators

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***Abstract*—In a grid connected Distributed Generator (DG) system, islanding is the phenomenon wherein the DG keeps on supplying power to the load despite the grid tripping. To arrest the creation of this isolated island, anti islanding techniques are devised and implemented. An acceptable islanding technique must have a quick detection time as well as low Non detection zone (NDZ) area. This paper compares and analyzes three different passive anti islanding methods – Under Voltage (UOV), Under/Over Frequency (UOF/OUF) and the Positive Sequence Impedance method. All proposed methods are simulated on a suitable test bench model, their performance measured and compared by noting the speed of islanding detection. The results and findings are presented at the end.**

Keywords*—*distributed generator; islanding detection; positive sequence; non-detection zone; grid connected

I. INTRODUCTION

In the past few years, a pervasive and rapidly growing shift is taking place in the field of transmission and distribution - that of integrating distributed generation (DG) with the grid. Owing to ever growing worldwide energy consumption and limited fossil fuel reserves, integration of renewable energy sources like wind turbines, solar farms and hydro power is inevitable. However, the increased penetration of DGs into more and more grids has also led to the phenomenon of islanding, which is hazardous for safety and thus unwarranted.

The islanding phenomenon happens when supply or grid power source unexpectedly fails, causing the main grid breaker to open, thus cutting supply to the load. However, the DG keeps on supplying power to the load under these conditions because without any intimation, the inverter does not know weather or at what time the grid has been tripped off [1,2]. Islanding can be of two types – intentional and unintentional. Intentional islanding is beneficial in a way that it provides reliable and uninterrupted power for important loads which require power all the time, like a hospital however unintentional islanding is hazardous because it poses certain undesirable factors such as :

- Voltage and frequency across the load are liable to change and since not monitored, it could pose as serious risk to the loads connected
- Safety risk to linesmen and maintenance personnel
- Risk of damaging safety equipments

Thus due to the above reasons, it becomes very important to device and implement an islanding detection method which must take into account the requirements of the system and the grid. A good islanding detection method must be able to detect the tripping of the grid as quickly as possible and be reliable as well as robust in operation [3,4].

Islanding methods are broadly classified into two types – active and passive. Active methods measure changes in the grid parameters by injecting a live signal into the grid at different frequencies, based on which the controller gets active signal feedbacks and can hence come to know when the islanding has taken place. Though the Non Detection Zone (NDZ) of active methods is small, its main disadvantage is that it introduces harmonic distortion in the power grid. Such introduction of noise into the system often degrades the power quality. Passive methods on the other hand, are safe and robust methods wherein certain line parameters are closely monitored and tangible changes in these act as a signal that islanding has taken place [5]. This paper is aimed at comparing and analyzing three different passive methods for islanding detection – Positive sequence impedance, Over/Under voltage (OUV) and Over/Under Frequency(OUF) based upon important comparison parameters - breaker closing time and formulation of a safe threshold limit for each of the three quantities. While the Over/Under Voltage and the Over/Under frequency methods have been used extensively for quite some time, the positive impedance detection method is relatively new and not widely analyzed as well as implemented. All three methods are implemented using MATLAB SIMULINK model of a small scale grid connected DG system and important parameters as well as waveforms observed. All parameters are monitored at the Point of common coupling.

II. ISLANDING DETECTION METHODS

A. *Positive sequence impedance method*

Positive sequence is one of the three quantities used in symmetric and non symmetric analysis of single as well as three phase power signals. Positive sequence current and voltage represent normal three phase current and voltage measurements during steady state conditions. The equations for positive sequence V and I are :

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$$V_1 = \frac{1}{3}(V_a + a \cdot V_b + a^2 \cdot V_c) \tag{1}$$

$$I_1 = \frac{1}{3}(I_a + a \cdot I_b + a^2 \cdot I_c) \tag{2}$$

This method banks upon the concept of measurement of impedance when positive sequence voltage and currents are obtained as a result of the system transposed positive, negative and zero sequence quantities which can be obtained from the original waveforms [6]. This can also be achieved by the sequence analyzing the impedance waveform directly, which is in first place obtained by dividing the voltage and current quantities. It should be noted that all the values should be noted at the PCC or point of common coupling [7]. Thus by using Ohms law, we can calculate the positive sequence impedance of the system as a function of the positive sequence voltage and current :

$$Z_+ = \frac{V_+}{I_+} \tag{3}$$

It is so observed that that is a significant difference in positive sequence impedance between the normal (grid connected) and the islanding or the breaker opening condition. Positive sequence impedance normally remains near constant in the grid connected mode and suddenly decreases sharply to a very small value as soon as islanding occurs. Based on this observation, an islanding detection method has been accordingly designed as elaborated in the simulation system description.

B. Over/Under Voltage (OUV/UOV) method

Once islanding takes place, the DG provides as much power generated by it to the load, which causes a massive change in loads for the system, because it rarely happens that the DG's generating power matches the load requirement exactly [8-10]. Due to this mismatch of loads, several grid parameters experience a change, one of them being Voltage.

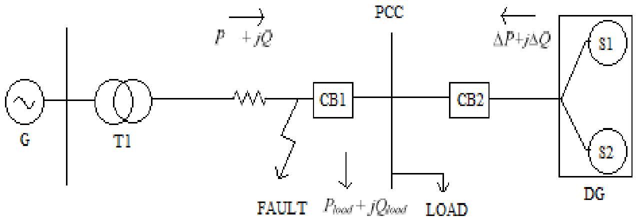

Fig. 1. Single line diagram (SLD) of the simulated system

Consider the system shown in figure 1. Power flows from the main grid and the DG to the point of common coupling (PCC) from where it goes to the RLC load, which is $P_{load} + Q_{load}$ The power equations corresponding to the given model are :

$$\Delta P = P_{load} + P \tag{4}$$

$$\Delta Q = Q_{load} + Q \tag{5}$$

Further, the equations when the DG is connected to the model can be expressed as (V_0= DG Voltage):

$$P_{load} - \Delta P = V_0 I$$

$$\therefore I = \frac{P_{load} - \Delta P}{V_0} \tag{6}$$

But also,

$$V_{pcc} = IR \tag{7}$$

Therefore, from equations (6) and (7), we can write

$$V_{pcc} = \left(\frac{P_{load} - \Delta P}{V_0}\right)\frac{V_0^2}{P_{load}}$$

$$\therefore V_{pcc} = V_0\left(1 - \frac{\Delta P}{P_{load}}\right) \tag{8}$$

From the above equation, we can therefore conclude that $V_{pcc} \propto V_0$. When $\Delta P \neq 0$, an imbalance in the voltage level follows. If delta P is greater than 0, the amplitude of V_{pcc} is greater than V_0 and vice versa if ΔP is less than 0. This factor can be utilized for setting up of a suitable threshold limit for islanding detection.

C. Under / Over frequency (UOF/OUF) method

One of the important parameters also changing with islanding is frequency. From the above described grid connected DG model, we can also write:

$$Q_{load} = Q = V_0^2\left(\frac{1}{\omega_0 L} - \omega_0 C\right) \tag{9}$$

$$\omega_0 = \frac{-\frac{Q}{CV_0^2} \pm \sqrt{\left(\frac{Q}{CV_0^2}\right)^2 + \frac{4}{LC}}}{2} \tag{10}$$

From equation (10), it is evident that as soon as the voltage level across the load will change, it will cause the frequency level in both the current and voltage waveforms to change, creating a parameter for detection of islanding state [11].

III. SYSTEM DESCRIPTION AND MODELING

For the islanding detection study, a detailed grid connected DG model was designed in MATLAB SIMULINK as shown in figure 2. This model consists of a 120 kV, 48 MVa generator with base impedance connected to the grid. A step down transformer is installed next, which steps down the voltage to 25 kV level. The outputs of the transformer are then connected to a three phase circuit breaker CB1, which is responsible for automatic closure once a fault is sensed by it. A grounding transformer with additional R = 4.5 ohms is used for grounding purposes. After going through a 20 Km feeder, the voltage is stepped down again to 575 V with the help of a 12 MVa, 25kV/575V transformer. The outputs of the transformer then is connected to the PCC wherein the current is divided to a parallel connected 5MW, 2Mvar RLC load and the other to two 575 V, Wind turbines, producing total power output of 1.5MW which act as the DG system. The second breaker CB2, placed between the DG and the PCC is given external control for switching, which is determined by the anti islanding algorithms that have been put in place. The base frequency of the model is taken to be 50Hz throughout.

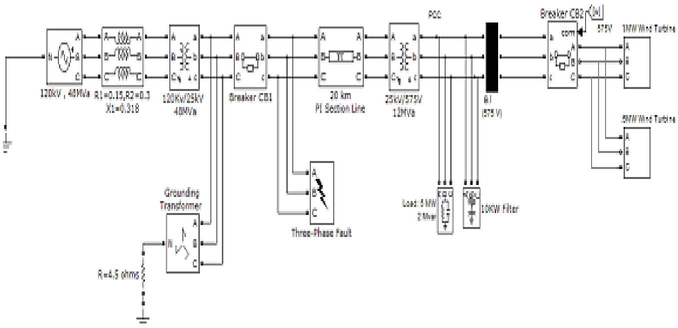

Fig. 2. MATLAB SIMULINK model for the grid connected DG system

The test bench consists of two 575V Wind turbines of 1MW and 0.5MW respectively acting as the DG of the system. The wind turbine, as shown in figure 3 consists of a permanent magnet synchronous generator connected to two sets of IGBT controllers, which act as grid control and generator controls respectively. The wind turbine controls include speed actuator, which is actually a rotor speed controller employing PID controls. Suitable values of controller constants K_p, K_i and K_d are taken. The grid side controller enables signals from the grid (V,I) to be fed to a phase locked loop (PLL) which in turn gives pulse generate signal to a 3 phase PWM generator with a unit delay. The same method is employed for machine side controller. The pitch of the turbine is also externally controlled by an independent PID controller, which makes use of a controlled feedback loop consisting of suitable gain, and integrator block. The DG power is overall controlled to be constant.

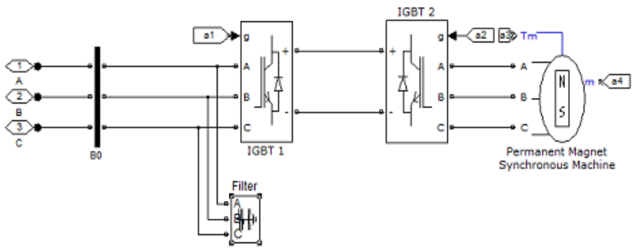

Fig. 3. DG design in MATLAB SIMULINK

When a three phase fault is generated in the test bench, the breaker CB1 automatically closes, thus creating an islanding situation with the main grid tripping but the DG still generating power and supplying the load. To check this, we have put three types of islanding methods – positive sequence impedance detection, under/over voltage and under/over frequency and tested them one by one initally, noting the breaker closing time in each case. It should be noted that for this simulation, the load connected (5MW, 2MVar) has a power demand of much less as compared to the total generated power i.e. $P_{load} < (P + \Delta P)$.

The first detection system employed, shown in figure 4 is the Positive sequence impedance measurement. Here, the devised method compares the instantaneous value of positive sequence impedance to the one recorded 0.025 seconds before. This is achieved by placing a variable time delay block, and outputs of both the time delay block and the instantaneous impedance are fed to the divider block. The resultant ratio then decides the threshold limit of the tripping. Normally, the ratio remains during normal operation near 1, however during islanding it decreases sharply, causing the ratio to change abruptly. On this basis, a certain threshold limit has been found out and fed to the comparator switch which gives the tripping signal to the breaker CB2.

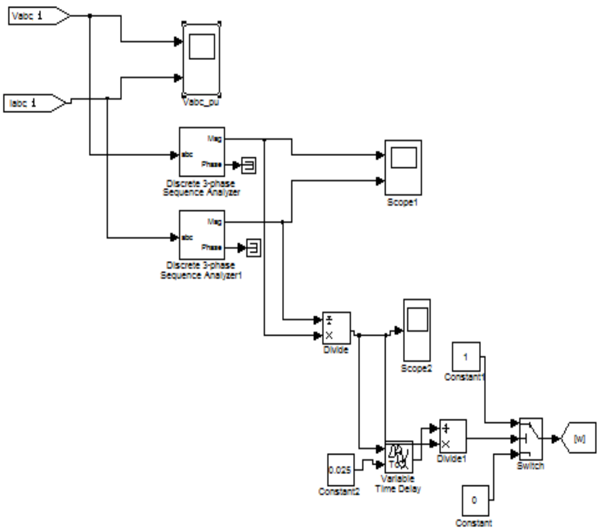

Fig. 4. Model for the positive sequence impedance method

Under Voltage method makes use of the fact that voltage of the grid connected system changes abruptly as islanding occurs. The Voltage signal from PCC is made to undergo park transformation in a rotating frame which results in the following signals :

$$Vd = \frac{2}{3}(V_a sin(\omega t) + V_b sin(\omega t - 2\pi/3) + V_c sin(\omega t + 2\pi/3)) \quad (11)$$

$$Vq = \frac{2}{3}(V_a cos(\omega t) + V_b cos(\omega t - 2\pi/3) + V_c cos(\omega t + 2\pi/3)) \quad (12)$$

$$V_0 = \frac{1}{3}(Va + Vb + Vc) \quad (13)$$

V_d and V_q are then fed into magnitude block which calculates the resultant V. This resultant voltage experiences a sudden change in magnitude (decreases in this case) for a short time following creation of an island. Because we have here only considered the case where load power is less than supply power, overvoltage logic relay is of no use (as it would not pick up voltage abruptions) and hence is not implemented in design. This change in voltage acts as a creation of threshold for detection of islanding. It should be noted that creation of a safe threshold limit is imperative to avoid false tripping as parameters like voltage and frequency also undergo slight change for a short time due to intentional loading or unloading. The detection system is shown in figure 5.

Under/Over frequency utilizes the fact that frequency changes when an island is created in a grid connected DG system. In this case where the load power is less than the supply power, the frequency is observed to dip slightly for a short time and then regain its original magnitude. Now since it was observed experimentally that a sudden change in load also causes the frequency to dip, the threshold limit was carefully chosen to avoid false tripping. A compare to constant block was used to compare the incoming frequency signal to the fixed threshold level and send the tripping command if the frequency went below the threshold level. The under frequency model implementation is shown in figure 6.

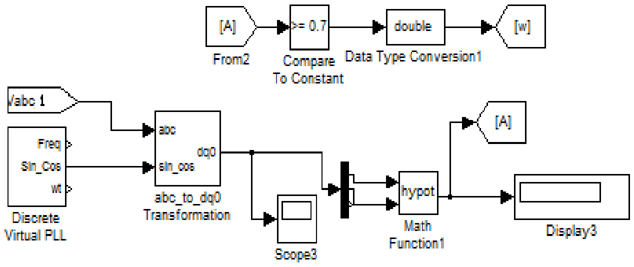

Fig. 5. Model for Under Voltage method

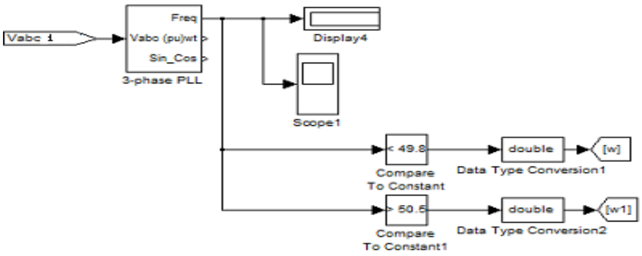

Fig. 6. Model for Under/Over frequency method

IV. SIMULATION RESULT

At t = 0.3 seconds , an islanding situation is created by simulating a 3 phase fault in the grid , causing breaker CB1 to close and the grid tripping off. Figure 7 displays the waveforms of Voltage (3 phase) and Current (3 phase) during the normal operation initially, and then as the island is formed at 0.3 seconds. The waveforms are noted at PCC. Figure 8 displays the Voltage across the breaker contacts CB1.

All three methods are employed one by one and the breaker closing time for each is noted. It should be noted that for this simulation, the power generated is larger than the local load power. All the parameters namely, positive sequence impedance, Voltage and frequency were first closely observed for the entire run time of the simulation without the tripping of CB2. Sudden connection of a large load was also done in each case to identify islanding and hence set safe threshold limits for tripping signal to CB2. For the positive sequence impedance waveform, given in figure 9, it is noted that after islanding occurs, the impedance dips sharply to a very low magnitude in a short period of time (0.025 seconds). For this reason, the variable time delay is set for 0.025 seconds. The ratio threshold is set at 0.75, beyond which the relay will give tripping command to CB2. Voltage waveform at the PCC when the positive sequence impedance logic for islanding detection is applied is shown in figure 10.

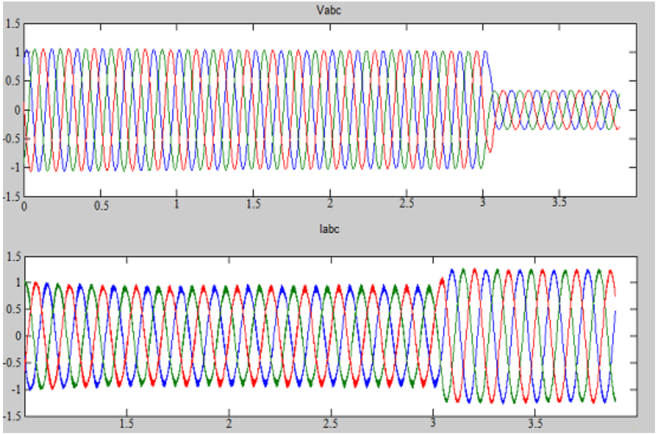

Fig. 7. Voltage and Current waveforms at PCC

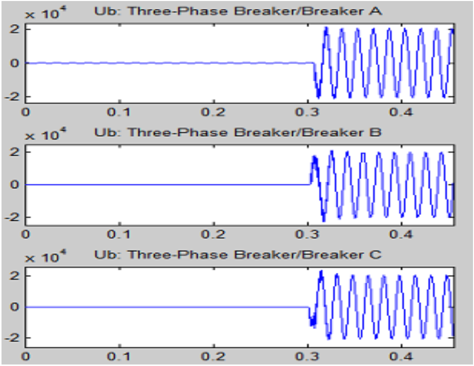

Fig. 8. Voltage across the breaker contacts CB1 which closes after sensing a fault at T=0.3 seconds.

For the Under Voltage relay, the output Voltage obtained by the park transformation has a near constant magnitude (0.98pu – 1pu). This Voltage sharply decreases to a negligible value as soon as islanding happens. Accordingly, a threshold limit was set for the under voltage relay. The voltage waveforms at the PCC when the Under Voltage logic is applied for islanding detection are shown in figure 10. For the Under/Over Frequency relay, the frequency dipped slightly below 50 Hz for a short time when the islanding took place. Thus, a frequency threshold limit of 49.8 Hz was set accordingly for the under/over frequency relay. Since load power was less than the generated power, the over frequency relay failed to pick up any changes in frequency. Figure 10 displays the Voltage waveform across PCC as the under frequency logic is applied for islanding detection and figure 11 shows the graphical representation of frequency as a function of time.

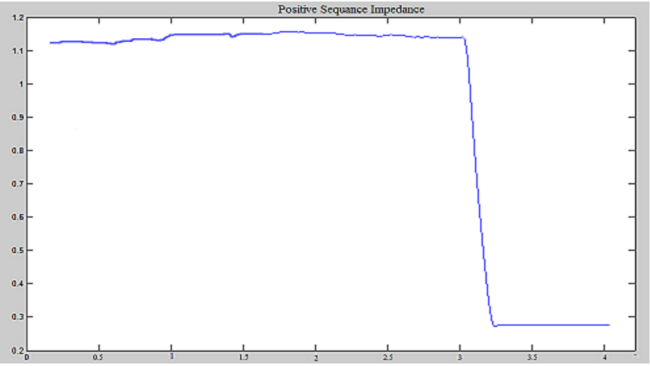

Fig. 9. Positive sequance impedance waveform

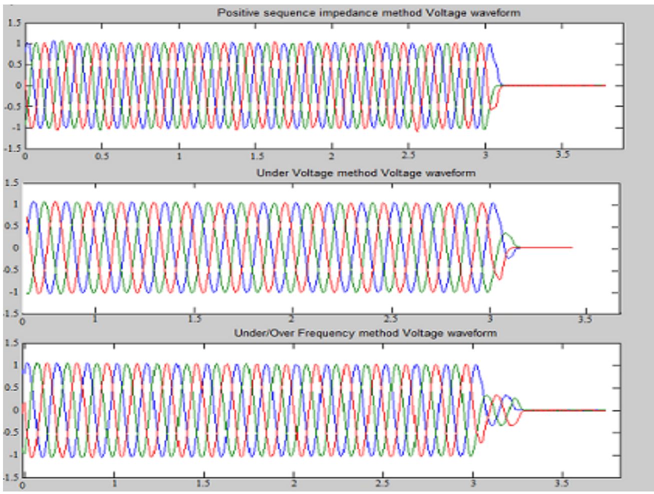

Fig. 10. Voltage waveforms at PCC corresponding to all three methods

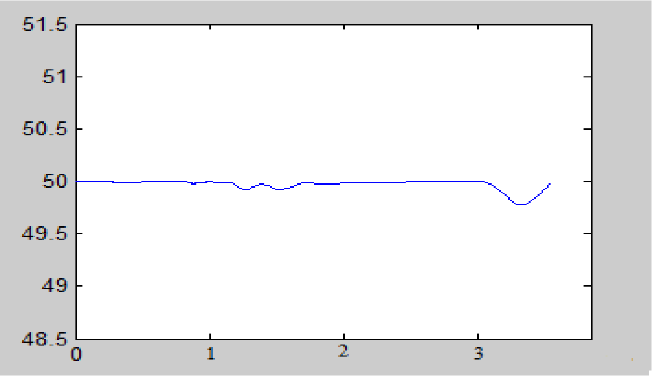

Fig. 11. Frequency vs time plot

The breaker closing time (measured in seconds), corresponding to the speed of island detection is chosen as the performance index parameter for comparing the three simulated methods. The breaker closing time of all the three anti islanding methods is shown in table 1.

TABLE I. BREAKER CLOSING TIMES OF DIFFERENT METHODS

Method employed	**Status of relay**	**Breaker closing time (s)**
Positive sequence impedance	1	0.012
Under Voltage detection	1	0.017
Under frequency detection	1	0.032
Over frequency detection	0	-

V. CONCLUSION

The paper presented three different methods of islanding detection and compared them. On the basis of Breaker CB2 closing time, the positive sequence impedance method was the quickest, the breaker closing clocked at 0.012 seconds. Breaker CB2 closed at 0.017 seconds corresponding to the Under Voltage relay. The slowest breaker closing time was that of the Under/Over frequency logic at t = 0.032 seconds. It is observed that the positive sequence impedance method has the quickest response of the three as far as islanding detection is concerned.

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