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New ways to protect and recognize the island for DG

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ABSTRACT

Electricity demand has increased pressure on extension of generation and distribution capacity, all around the world. This is an undesirable stage in modern restructured electrical industry which is trying to improve efficiency at the minimum cost. The obvious economical solution is avoiding conventional development and utilizing distributed generation capability which provides nearby consumer with needed power. Using this category of power generators in the grid has various advantages as well as its problems. One of the problems, which is usually caused by distributed generation, is islanding phenomenon. In this study a novel approach is proposed to detect islanding phenomenon for small scaled generators. Experimental results prove its speed and precision in detection of islanding phenomenon. Here, grid will continue its operation by using load shedding. When islanding is detected, special control system designed for DG synchronization is exploited to reconnect DG after fault compensation.
KEYWORDS: Distributed generation, islanding, smallscale generators, voltage protection, frequency protect

INTRODUCTION

This Electricity demand has increased pressure on development of generation and distribution capacity, all around the world. The economical obvious solution is avoiding conventional development and utilizing distributed generation capabilities [1]. Based on IEEE1547 and UL1741, anti-islanding protection standards are essential for operation of DG [2-4]. Power quality problems, interference in grid protection and even people's health danger are reasons for this emphasis on anti islanding protection. Generally, common anti islanding protection methods may be categorized in three main groups; active, passive and remote control.

Passive method, which is used widely owing to its simple implementation, merely measures system parameters and compare them to upper and lower limits to detect islanding. Its most popular applications include voltage protection, frequency protection and phase jump detection [5-6].

Magnitude of upper and lower thresholds considered in voltage and frequency protection are used to avoid interrupt in systems caused by usual disturbances of grid. Unfortunately, for loads near to DG output power, frequency or voltage does not exceed thresholds and islanding is not distinguishable [5,7]. As a result, passive methods suffer from a large non-detection zone. In order to overcome this issue hybrid methods are applied which are based on voltage imbalance monitoring and THD [8].

Active method injects a deterministic distortion to grid and monitors its response. Islanding is detected according to this response. Active methods consist of slip mode frequency shift [9], frequency bias or active off-frequency [10] and Sandia frequency shift [5]. These methods have smaller non-detection zone; nevertheless, they decrease power quality of the system. Other active methods based on intentional negative sequence current injection [11] and distortion injection via d or q axis of current controller [12], are investigated as well.

Remote methods introduce significantly small non-detection zone. Their higher cost comparing to mentioned methods is one of disadvantages. The aim of this study is proposing a novel method for detection of islanding to simultaneously decrease non-detection zone and detection time. It must be mentioned that all simulations are performed in MATLAB SIMULINK environment. In the next section islanding phenomenon is discussed. Afterwards, novel detection method and its simulations in SIMULINK are presented.

1. Islanding phenomenon

Islanding phenomenon is a result of distributed generation in distribution grid. It occurs when one or more distributed generators supply a portion of load which is disconnected from grid. Islanding might be stochastic or based on a plan. It severely affects system in many cases; therefore, it must be detected in specific time intervals defined by standards. Even though it is based on a plan, it should be detected in the least possible time so that distributed generator controller could provide a soft transition from connected to grid control mode into islanding mode [13,14]. It is clear why islanding mode should not continue, because it causes problems listed below.

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- Power quality disturbance
- negative effect on important loads
- health danger for staff or local residents
- slight or drastic fluctuations in voltage or frequency of delivered power because there is no grid to maintain voltage amplitude and frequency
- High probability of damage to distributed generation when it comes back to grid and imposing injection current to generator because of asynchronous magnitude and phase of two sides voltage.

Hence, in absence of upstream grid, distributed generators should detect disconnection and their islanding operation. Then they should change their operation mode as soon as possible [15,16].

2. Test network

Simulations are performed considering the system shown in figure (1). System, distributed generation and loads parameters are presented in table (1).

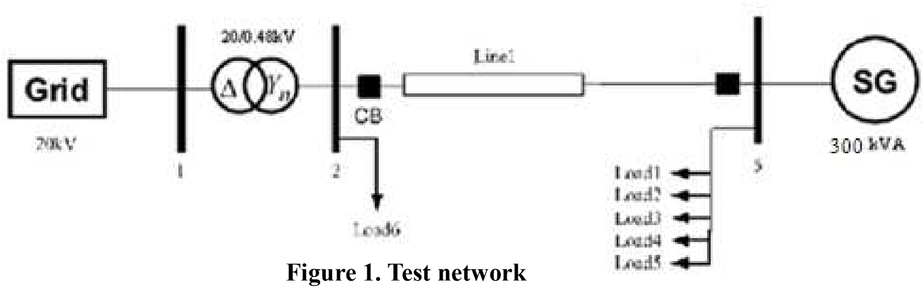

Figure 1. Test network

Table 1. System parameters

Parameters	capacity
DG power	300 KVA
Voltage (line to line)	480 V
Frequency	50 HZ
X to R ratio	10
Load 1	50 KW
Load 2	40 KW
Load 3	80 KW
Load 4	100 KW
Load 5	60 KW
Load 6	40 KW

In figure (1), upstream grid is modeled by an infinite bus. However, as bus infinity is relative, in system modeling, upstream grid is modeled with ideal voltage and impedance. Change in power and topology of grid is also modeled by Thevenin equivalent impedance. In other words it is modeled by a change in short circuit power of grid. Obviously, a grid with lower Thevenin impedance is more similar to infinite bus and considers more powerful grid and vice versa. Additionally, distributed generation is equipped with control system and connected to the system in point PCC. In sample system of figure (1), 100 kW load number 4 is considered as sensitive load which should never be shutdown and other loads considered as insensitive loads. Output power of distributed generation is 330 KVA.

3. Proposed method and simulation results

In this section we present implementation of proposed method as well as its operation in connect and disconnect mode of upstream grid, in presence of different loads. In steady state, load is supplied by grid. If this balance is disturbed, system frequency will experience transient mode according to equation (1).

$$P_{SYS} + P_{SG} - P_L = \frac{2H}{f_0} \cdot \frac{df}{dt} \quad (1)$$

Where PL is power consumption, PSYS is grid power, PSG is power of DG, F0 represents grid frequency and H is inertia constant of synchronous machine.

With disconnecting main grid, equation (1) turns into equation (2), because in this situation power supplied by the grid is eliminated and generators are connected and support loads.

$$P_{SG} - P_L = \frac{2H}{f_0} \cdot \frac{df}{dt} \tag{2}$$

At the beginning, output power of generator does not change so much and when the grid is being disconnected according to equation (2) amount of variation rate changes frequency and pushes it out of permitted range. Principles are as follows, after disconnection of the grid and change of frequency, if frequency variation rate is positive, terminal voltage is reduced by control system which leads to frequency increase. Inversely, after disconnection of the grid, it results in frequency decrease by increasing power consumption of loads. Simulated circuit of studied grid in SIMULINK is shown in figure (2).

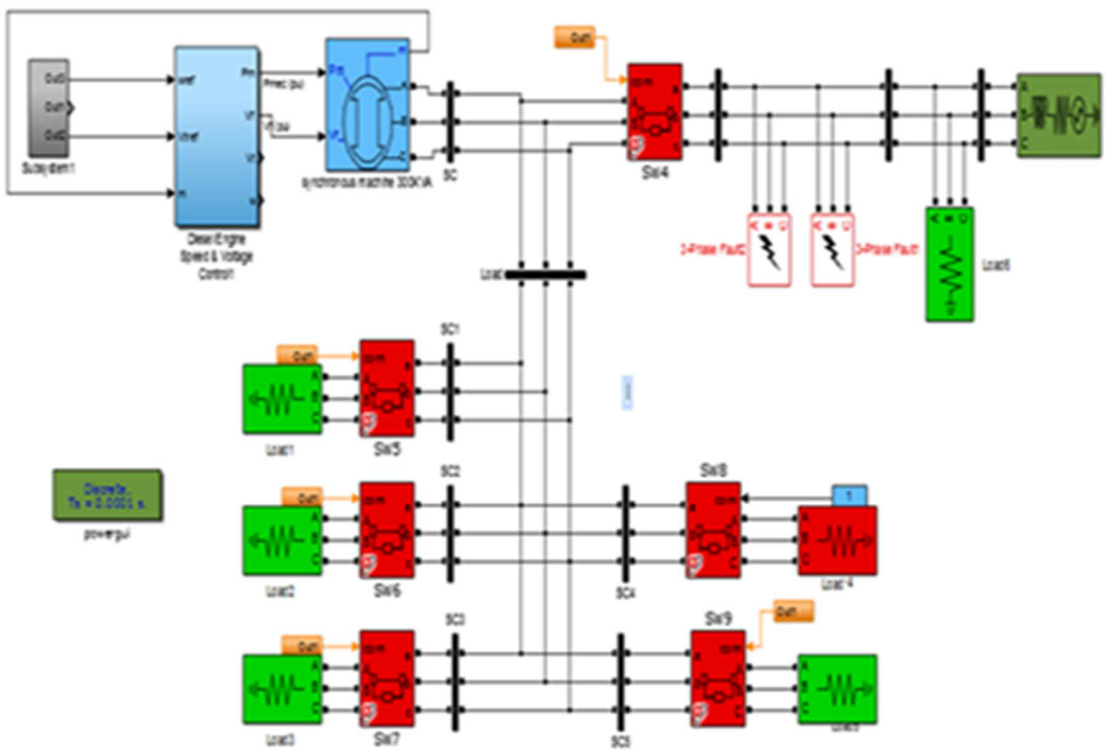

Figure 2. Simulation of test network in SIMULINK environment

Firstly, island mode of the system should be detected. To accomplish this task, voltage amplitude in each moment is compared to its previous amount and if they are not the same, generator frequency will decrease to 0.98. When it is connected to grid, as in infinite grid frequency is constant, no frequency change is observed as a result islanding mode does not occur. So if frequency decreases islanding has happened.

Short circuit and faults are most drastic disturbances in power systems. In time t=1 (s) a severe three phase fault with a resistance of 0.001 ohm occurs with a duration of 0.005 (s) which is 0.25 of a cycle [17]. Figure (3) depicts frequency variations of the grid. As it is shown in figure (3), since the duration of fault is too short, frequency does not change considerably and stays stable so islanding has not happened. As there is no islanding, voltage amplitude is unchanged and load shedding is not performed.

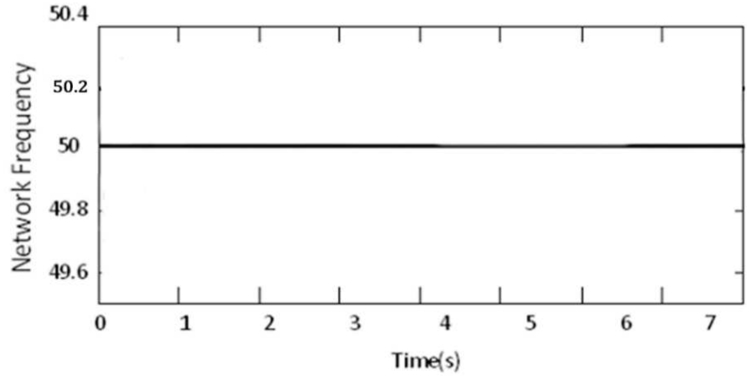

Figure 3. Changes of generator frequency

3.1. Islanding phenomenon

In time t= 3 (s) a three phase fault occurs with a 0.9 ohm resistance and duration of 0.1 (s) which is 5 cycles [17]. As it is shown in figure (4), due to long duration of fault, system frequency changes about 2 Hz. This variation causes oscillation of synchronous machine and unstable mode in the system. Controller mode changes protection system, subsequently, sense abnormal voltage and frequency variations and islanding mode is developed. Figure (6) depicts islanding mode which occurs in t = 3 (s). The circuit for detection of islanding mode can be found in figure (7).

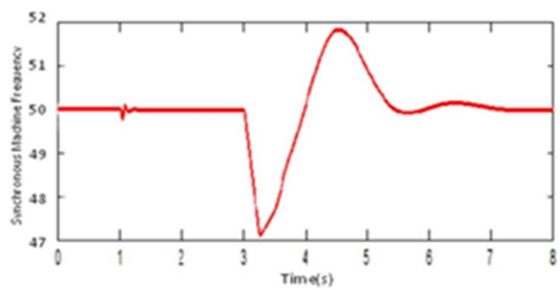

Figure 4. Frequency changes of synchronous machine

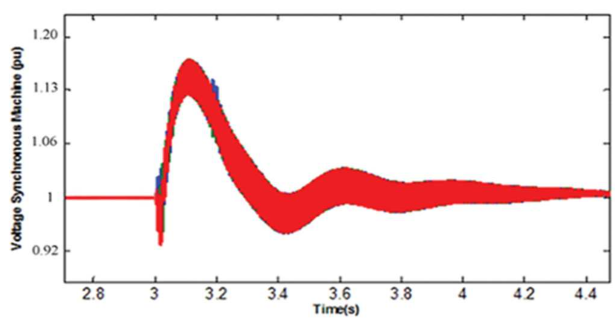

Figure 5. Voltage magnitude changes of synchronous machine

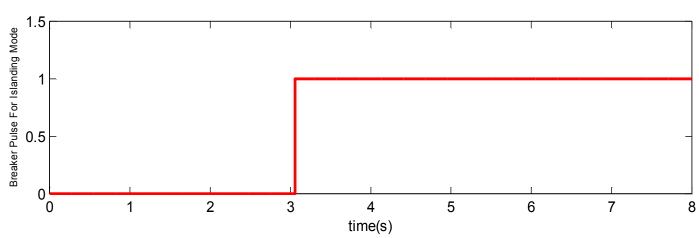

Figure 6. Islanding mode detection

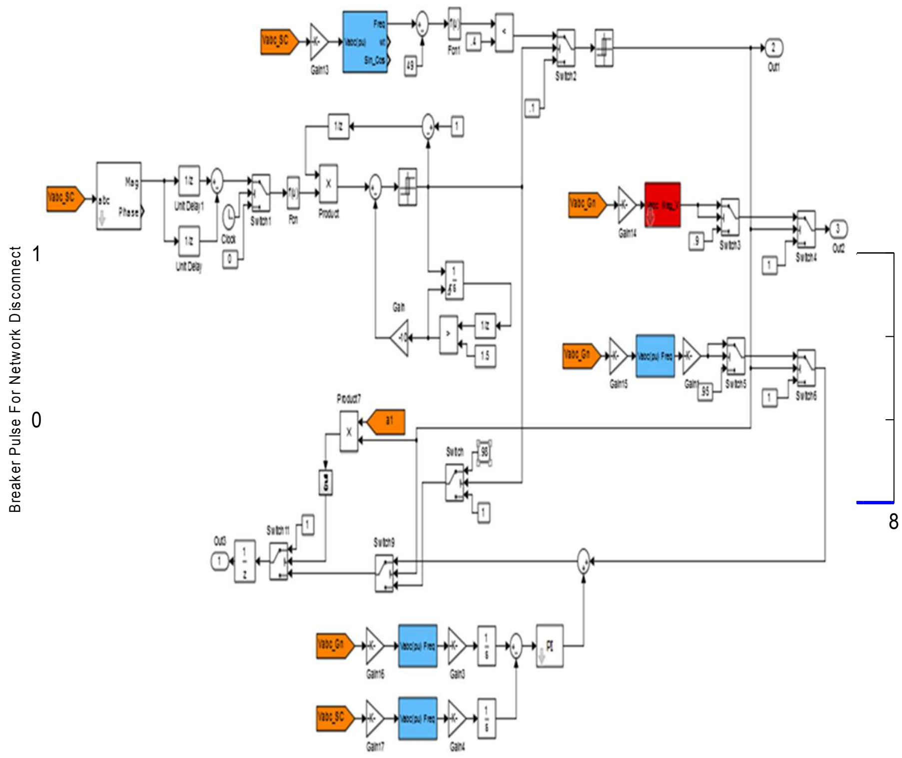

Figure 7. Simulation related to Islanding mode detection and setting of generator parameters

When signal is transmitted by islanding protection system at connection time, control system strategy alters and distributed generation controller changes its mode into islanded utilization mode. As islanding mode is detected, the islanded system should be disconnected from upstream grid and fulfills load requirements lonely. Thus, breaker bus, which connects grid to islanded system, needs to generate trip command. The moment of disconnection can be seen in figure (8).

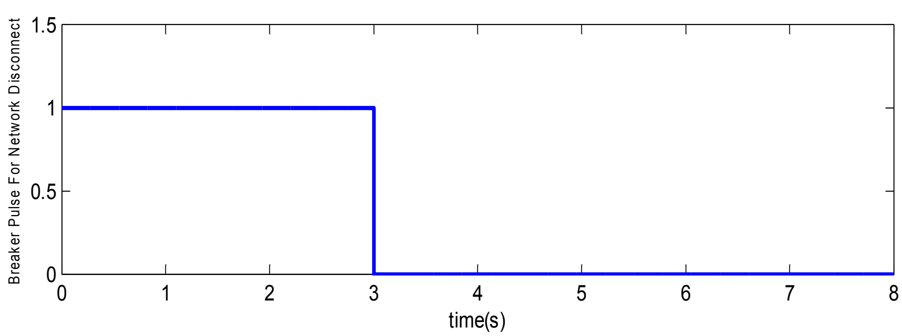

Figure 8. Break time of upstream network from island

3.2. Load shedding

Because distributed generator is islanded, it should supply all power demands of loads by itself. It should be investigated whether it is able to support the whole loads or not. If it is not capable of supplying all of them, load shedding should be done. SIMULINK diagram of this section is shown in figure (9). If load capacity is more than generated power, frequency will drastically decrease. As a result, control system shuts down the minimum loads from grid and if frequency continues to decrease another load, which has the least amount among remained ones, is disconnected; nonetheless, there is a sensitive load in simulated system which should be connected all the time. At t=3 (s) the second load which is 40 kW is opened. According to equation (2), load shedding results in frequency increase and controller fixes system frequency by means of adjusting generator parameters.

Before t=3 (s) when system is not islanded yet, load power is supplied by the grid. At t=3 (s) while island mode is detected, island utilization mode controller tries to maintain voltage and frequency but due to existence of extra load in the system, there will be voltage and frequency variations.

At the beginning speed is 1 per unit which decreases as fault occurs in t=3 (s) and control system increases speed to meet load requirements. After synchronization grid frequency becomes as the same as load frequency at 8 (s). Afterwards, grid is connected and generator output power is reduced. Figure (10) demonstrates loads power receiving 330 kW before islanding which is reduced to 290kW by means of load shedding.

In islanded mode, loads of the system should be protected against all conditions of abnormal voltage and frequency variations. As long as system frequency is maintained at 50 Hz in islanded mode, system voltage is measured. If the measured voltage exceeds standard limits for more than 300 ms, disconnect command will be generated. Delay unit is utilized in this section to avoid system disconnection because of oscillations while operation mode is changed.

3.3. DG Synchronization with network

In order to be reconnected to upstream grid, distributed generator must be synchronized with the grid. In proposed control system, control loops check voltage magnitude, frequency and phase. If these three parameters are the same for generator and grid, it will be reconnected.

PLL and Positive Sequence Fundamental Value blocks in SIMULINK are exploited which are depicted infigure (11) and (12).

PLL is a system in which output signal frequency tracks a reference frequency given to it as an input. The loop equalizes frequency of both signals which are fed to phase detector while there might be a phase difference between them. The fact that PLL is capable to be locked on a specific signal, even if the signal is noisy, introduce it as a noise filter. PLL receives one input and provide three outputs. Input includes vector of three phase normalized signal Vc,Vb,Va. Output 1, 2 and 3 are measured frequency, wt slope between 0 and 2 and [sin(wt) cos (wt)] vectors, respectively.

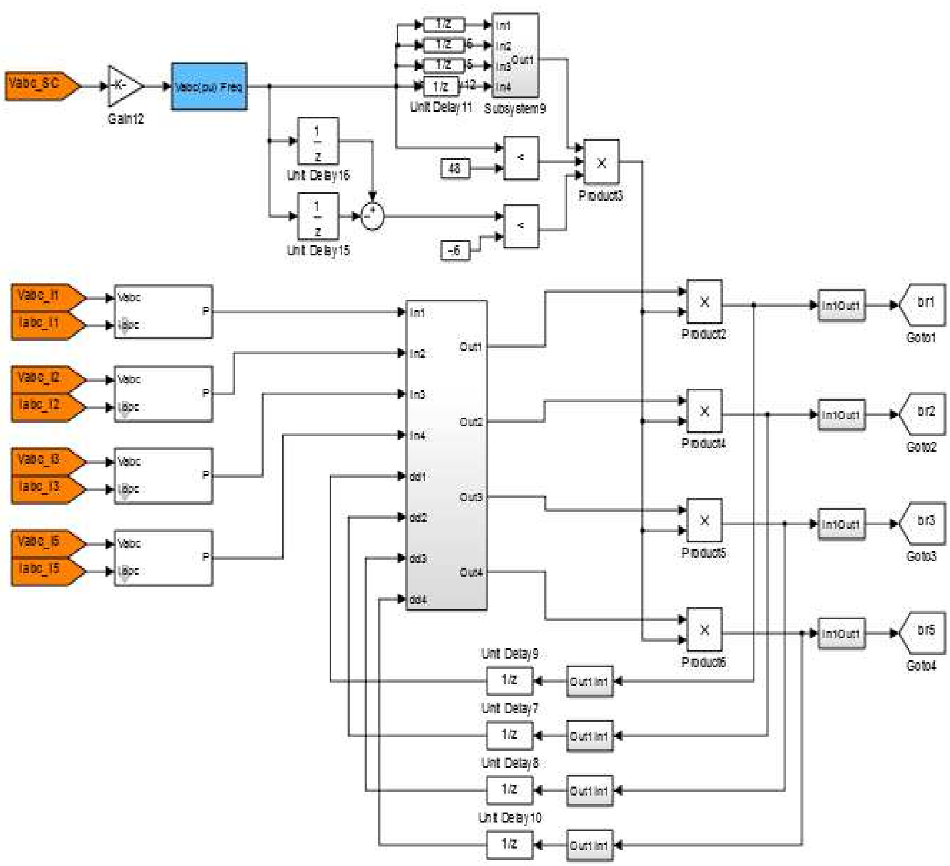

Figure 9. Simulation related to load shedding after islanding

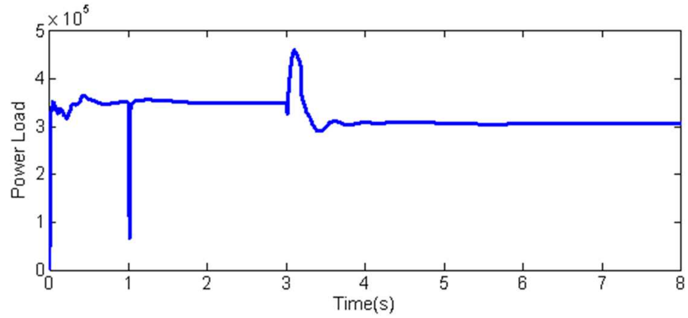

Figure 10. Power that injected to loads

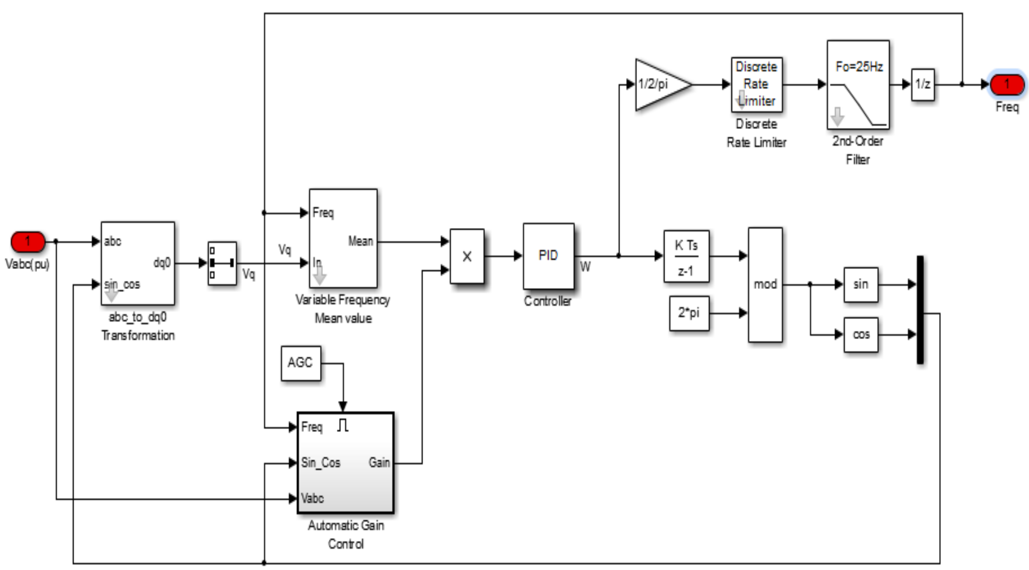

Figure 11. PLL block in SIMULINK

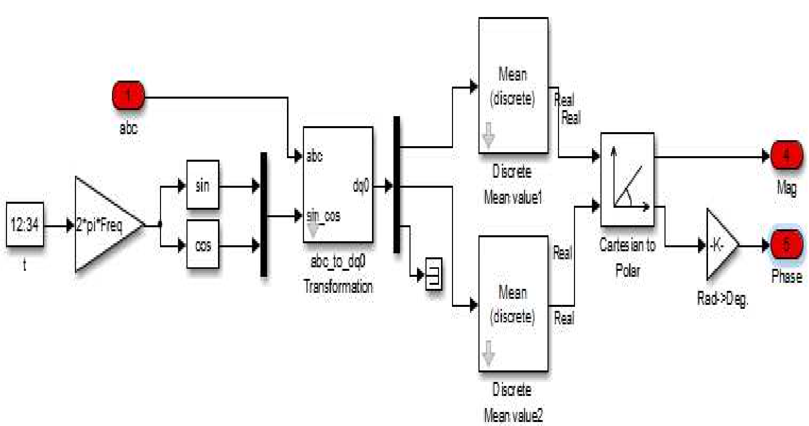

Figure 12. Positive sequence fundamental value block in SIMULINK

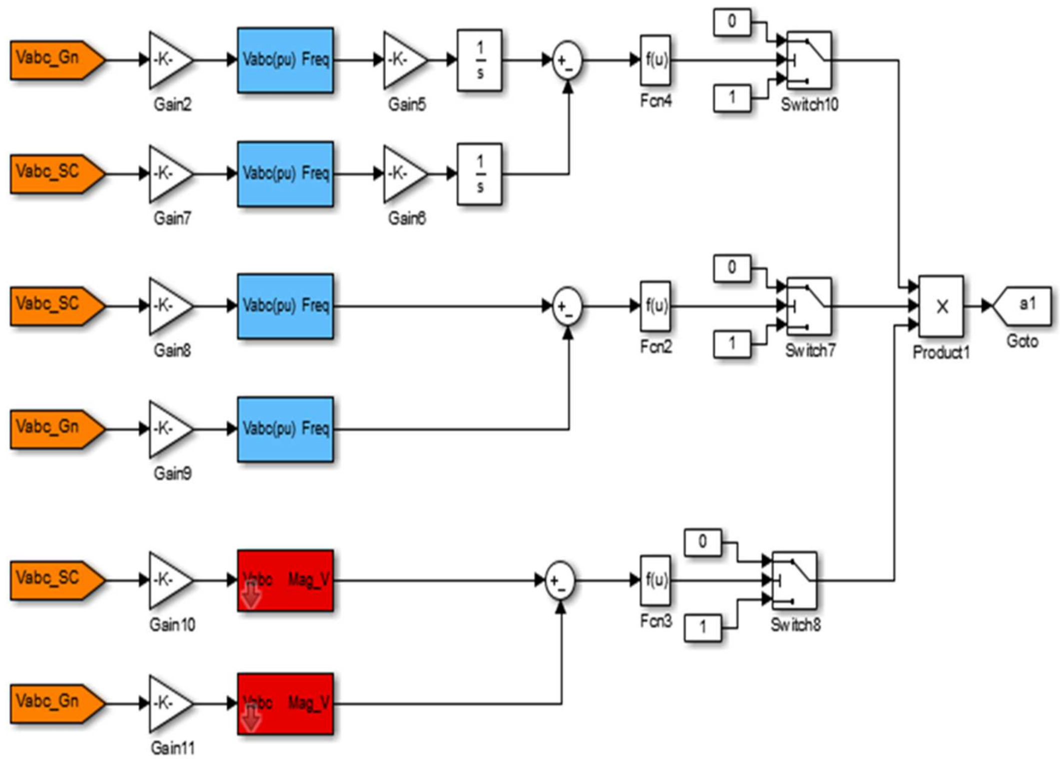

Figure 13. Detecting synchronization for reconnecting generator to grid after islanding, in SIMULINK

As it is shown in figure (13), to detect synchronization, three phase voltages are sampled to obtain VSG and VSC points, frequency, amplitude and phase. With subtracting measure amounts for grid and distributed generator, error values are derived which are compared to 0.003, 0.005 and 0.05 [17], respectively. If all three conditions are satisfied, synchronization pulse is produced

3.4. Connection of generator to grid

After changing to islanded mode, voltage and frequency of generator are compared to grid parameters and fed to control system. As shown in figures (14) and (15), with adjusting stimulation voltage and generator speed, its voltage and frequency are equalized to grid parameters which make it possible to reconnect generator to the grid.

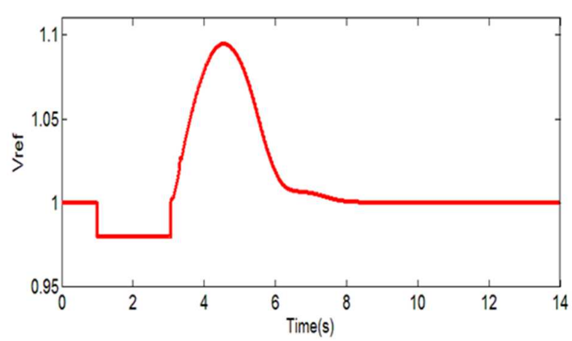

Figure 14. Reference speed of generator for synchronization

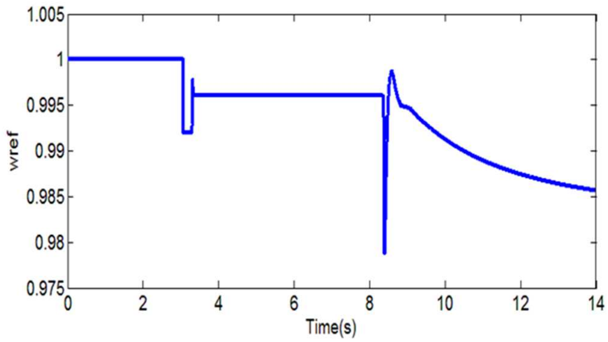

Figure 15. Reference excitation voltage for synchronization

In figure (14), at the first moment speed is 1 per unit which is limited to 0.992 due to fault occurrence. Control system increases speed to 0.997 so that generator can supply loads. After synchronization grid frequency becomes equal to load frequency which happens at t=8 (s). Subsequently, grid is connected and power generated by generator is reduced which results in speed reduction. In figure (15) voltage is 1 per unit at t=1 (s) because of fault occurrence, voltage is reduced by 0.02. Then, by changing to islanded mode, voltage increases 10 percent and control systems makes it 1 per unit at t= 8 (s).

4. Conclusion

Islanding phenomenon detection techniques which are based on communications are costly but they are effective and without non-detection zone. Passive methods are low cost techniques with simple implementation while they have a large non-detection zone. Active methods have smaller non-detection zones in comparison with passive methods; however they reduce power quality. So all these methods have disadvantages. As a result, in this paper we proposed a method to effectively detect islanding mode. Afterwards, a control circuit was designed to maintain stability of distributed generation at the time of connection or disconnection. Then, another controller was proposed which synchronizes generator with the grid and reconnects it to the grid.

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