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ISLANDING OPERATION OF MICRO GRID

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ABSTRACT

A Micro grid (MG) is an integrated energy system comprising of distributed energy resources and multiple electrical loads operating in a single and autonomous grid. Normally, micro grid operates in interconnected mode with the medium voltage network; however, scheduled or forced isolation can also take place. Hence, micro grid must have stable operations in such conditions.

When micro grid isolation takes place, its feasibility of control techniques to be adopted for its operation along with a new approach for islanding detection in distributed generation (DG) using Rate of Change of Phase Angle Difference (ROCPAD) is proposed here. Using synchronous transformation based algorithm, the process begins when retrieving of the voltage and current signals at the DG end is done followed by estimation of the phasors (amplitude, phase and frequency) which is very important for computation of the phase angle difference and ROCPAD for islanding detection.

The goals of this paper are to explain the principle of micro grid to clarify the main ideas and positive features of the micro grids by using islanding detection techniques mainly by ROCPAD islanding technique.

Keywords*: *Micro grid (MG), Distributed Generator (DG), Non-detection zone (NDZ), Rate of Change of Phase Angle Difference (ROCPAD), Rate of Change of Frequency (ROCOF).

I. INTRODUCTION

1.1 Concept of Islanding

According to (IEEE 2000) an island is “That part of a power system consisting of one or more power sources and load that is, for some period of time, separated from the rest of the system”. Islanding occurs when the main supply is disconnected and at least one DG in the disconnected system remains operational. If DG is allowed to remain on, customer benefits in terms of reduced outages obtained. However, islanding may increase the risk for personnel and equipment. Even it may cause reduction in performance standards for voltage and frequency. Thus, power quality in the island cannot be guaranteed, as well as, the non curtailment of loads. Moreover, coordination between islanded DG and utility system can cause equipment damage which is due to phase mismatch if automatic recloser tries to connect the islanded section with the main. Islanding of the Micro grid (MG) [1], [6] can take place by unplanned events such as faults in the Medium voltage network or by planned actions like maintenance requirements. In such case, modification of the local generation profile of the MG can be done in order to reduce the imbalance between local load and generation and reduce the disconnection transient [7]. So detection of islanding condition is a must.

1.2 Review of Islanding Techniques

The main objective behind the developing micro grid concept is integration of as much as renewable energy sources. The micro grid system acts like a plug and play power unit which can easily isolate itself during any grid disturbance or outage and continue to supply its loads in an islanded state. The micro grid controllers play an important role in maintaining the micro grid in its islanded state [3]-[5]. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. For that reason, distributed generators must detect islanding and immediately stop producing power; this is referred to as anti-islanding. The main objective of detection of an islanding situation is to monitor the DG output parameters and system parameters and also decide whether or not an islanding situation has occurred due to change in these parameters. Islanding detection techniques can be classified into remote and local techniques and local techniques can further be classified into passive, active and hybrid techniques as shown in *Figure 1.1*.

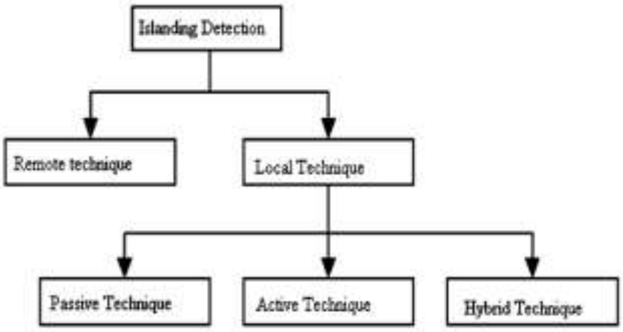

Figure 1.1: Islanding Detection Techniques of Micro Grid

II. ISLANDING DETECTION BY ROCPAD ESTIMATION

2.1 Estimation of Rate of Change of Phase Angle Difference (ROCPAD)

Detection of an islanding condition is the subject of considerable research. In general, these can be classified into passive methods, which look for transient events on the grid and active methods which probe the grid by sending signals of some sort from the inverter or the grid distribution point. ROCPAD [2] is one of the passive islanding techniques. Phasor estimation requires measurement of three parameters such as amplitude, phase angle and frequency. The proposed technique works on ROCPAD, and thus phase angle of respective voltage and current signals must be estimated accurately. The proposed algorithm uses synchronous transformation, based phasor estimation of the retrieved instantaneous voltage and current signals for computation of ROCPAD. The power signal x(t) is represented as follows:

$$x(t) = \sum_{k=1}^{\infty} Ak \sin\left(2\prod kft + \partial k\right) \qquad \textbf{(2.1)}$$

where, A_k & ∂_k are amplitude & angle of kth order waveform.

f = The power system real frequency.

Now, based on synchronous transformation, the three phase quantities (a, b, c) can be transformed in to d and q by d-q transformation as follows:

$$\begin{bmatrix} xd \\ xq \end{bmatrix} = \begin{bmatrix} \sin w_\circ t & -\cos w_\circ t \\ -\cos w_\circ t & -\sin w_\circ t \end{bmatrix} \mathrm{X} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} xa \\ xb \\ xc \end{bmatrix} \qquad \textbf{(2.2)}$$

where, $w_0 = 2\pi f_0$ & f_0 is the power system nominal frequency (50 Hz).

Substituting (2.1) in (2.2), at mth order sample time i.e., $t = mT_s$ $(m = 0,1,2,\ldots.)$,

where, T_s = sampling interval, this results to:

$$\begin{bmatrix} xd\,(m) \\ xq\,(m) \end{bmatrix} = 3/2 \begin{bmatrix} \sum_{k=1}^{\infty} Ak\ \cos[\,2\pi\,(kf - f\circ)mTs + \delta k\,] \\ -\sum_{k=1}^{\infty} Ak\ \sin[\,2\pi\,(kf - f\circ)mTs + \delta k\,] \end{bmatrix} \tag{2.3}$$

For k = 1, the fundamental quantities are given as,

$$x_{d1}(m) = 1.5\,A_1 \cos\,[2\pi\ (f - f_0)\ mT_s + \partial_1] \tag{2.4}$$

$$x_{q1}(m) = -1.5\,A_1 \sin\,[2\pi\ (f - f_0)\ mT_s + \partial_1] \tag{2.5}$$

From the above d-q quantities, the amplitude (A_1), phase (∂_1) and frequency (f) are calculated as follows:

$$A_1 = 2/3\sqrt{(x^2_{d1} + x^2_{q1})} \tag{2.6}$$

$$\partial_1 = \text{arc tan}\,[-x_{q1}(0) / x_{d1}(0)] \tag{2.7}$$

$$f = [\{\partial_1(m) - \partial_1(m-p)\} / 2\pi pT_s] + f_0 \tag{2.8}$$

where, p = 0, 1, 2…

The phase **(**2.7) and frequency (2.8) are required to estimate the ROCPAD as follows:

$$\text{ROCPAD} = [\Delta\,(\partial_V - \partial_i)] / \Delta\,t \tag{2.9}$$

Figure 2.1 and *Figure 2.2* shows the complete MATLAB implementation block for estimating the voltage and current phasors (amplitude and phase). Initially the instantaneous current and voltage signals are fed to the sampling device and, sampled voltages and current V_{abc} and I_{abc} respectively are cascaded to the synchronous transformation based phasor estimation algorithm to estimate respective values of voltages and current V_p, I_p and phase angle difference. Hence, ROCPAD is estimated. The frequency is accomplished using the frequency block shown in *Figure 2.2*. The phase angle difference and corresponding ROCPAD are estimated using the estimation block as shown in *Figure 2.3*. (2.6), (2.7), (2.8), (2.9) helps in estimation of ROCPAD.

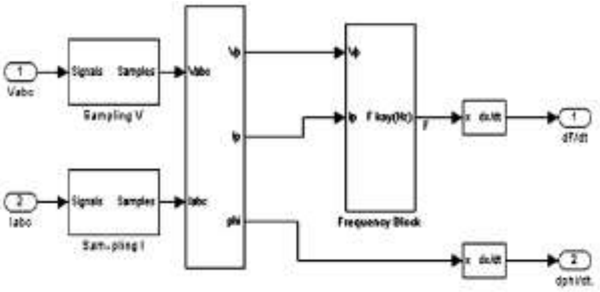

Figure 2.1: Synchronous Transformation Based Phasor Estimation Algorithm

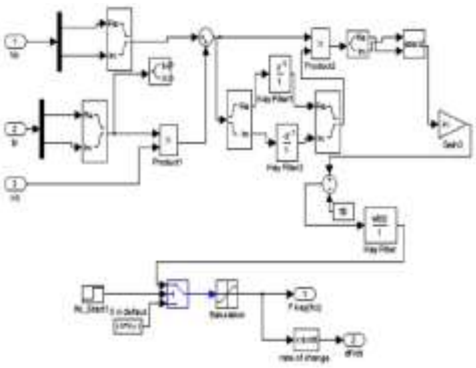

Figure 2.2: Frequency Block Estimating the Frequency

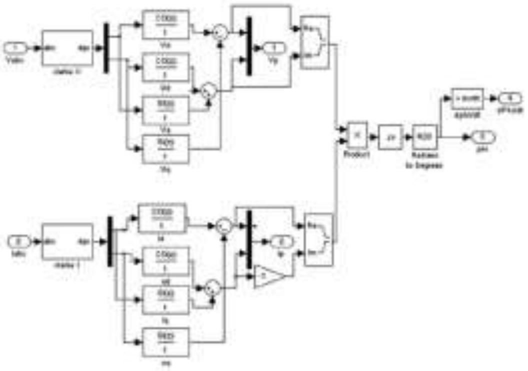

Figure 2.3: Estimation Block of ROCPAD

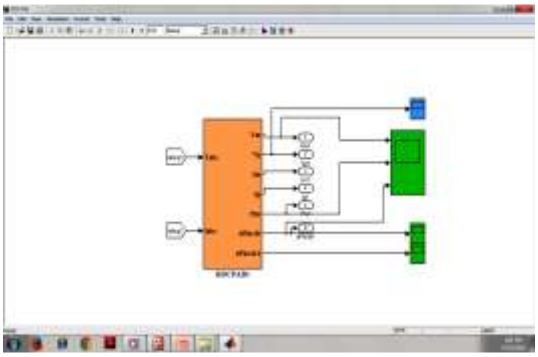

Figure 2.4: Proposed ROCPAD in MATLAB/Simulink

2.2 Sample Studied System

The sample studied system is shown in *Figure 2.5* whose base power is chosen as 10MVA. The studied system consists of a radial distribution system with 4 DG units (3 wind farms and 1 emergency diesel generator) which are connected to the main supply system through PCC. The DG units are placed at a distance of 20 km with distribution lines of pi-sections and the operating voltage of the micro grid is 25kV.

The details of the generator, DGs, transformers, distribution lines and loads are mentioned as below:

1. Generator:
   Rated short circuit MVA = 1000, f = 50Hz, rated kV = 120, V_{base} = 120kV.
2. Distributed Generations (DGs):
   a) DG-1, DG-2, DG-3: Wind farm (9MW) consisting of six 1.5MW wind turbines.
   b) DG-4: Emergency Diesel Generator, 5MW, 400V.
3. Transformer:
   a) TR-1: Rated MVA = 50, f = 50Hz, rated kV = 120/25, V_{base} = 25kV, R_1 = 0.00375p.u., X_1 = 0.1p.u, R_m = 500p.u, X_m = 500p.u.
   b) TR-2, TR-3, TR-4, TR-5: Rated MVA = 10, f = 50Hz, rated kV = 25 kV/575V, V_{base} = 25kV, R_1 = 0.00375p.u, X_1 = 0.1p.u, R_m = 500p.u,X_m=500p.u.
4. Distribution lines (DL):
   DL-1, DL-2, DL-3, DL-4: PI-Section, 20km each, rated MVA = 20, f = 50Hz, rated kV = 120/25, V_{base} = 25kV, R_0 = 0.1153ohms/km, R_1 = 0.413ohms/km, L_0 = 1.05e-3H/km, L_1 = 3.32e-3H/km, C_0 = 11.33e-009F/km, X_1 = 5.01e-009F/km.
5. Normal Loading data: L1=15MW, 5Mvar; L2, L3, L4, L5 = 8MW, 3Mvar.

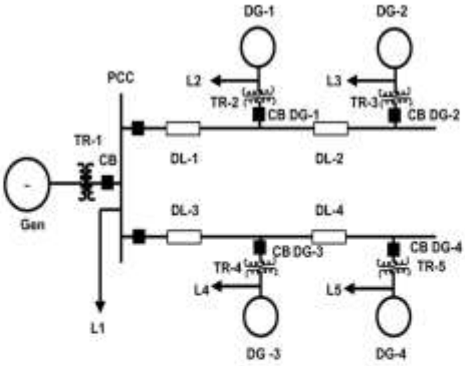

Figure 2.5: Single line Diagram: Sample Studied System

The voltage and current signals are retrieved at the target DG location during islanding and non islanding conditions (other disturbances). The relays for each DG units are placed at the DG end. The system model is simulated at 1.0 kHz (20 samples per cycle on 50 Hz base frequency). The complete simulation is carried out using MATLAB/Simulink package.

The possible situations of islanding and non islanding conditions studied are given as follows:

- Tripping of main circuit breaker (CB) for islanding conditions.
- Any breakers between the power system and DG are opened.
- Loss of power on the PCC bus.
- Events that could trip all breakers and reclosers that could island the DG under study.

The single line diagram as shown in *Figure 2.5* can be represented in MATLAB/Simulink by implementation of ROCPAD as shown in *Figure 2.6.*

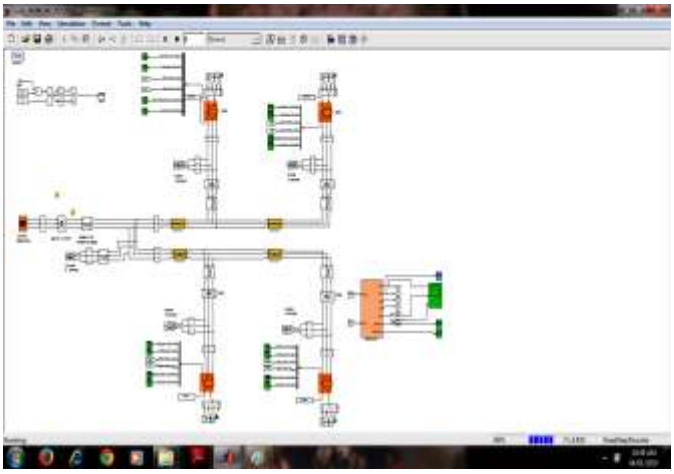

Figure 2.6: Implementation of ROCPAD on Sample Studied System in MATLAB/Simulink

III. SIMULATION RESULTS AND DISCUSSION

3.1 Proposed ROCPAD for Islanding Detection

ROCPAD is estimated from *Figure 2.3* and *2.4.* As phase information of voltage and current signals undergo larger deviations during islanding, thus ROCPAD is chosen as the tracking signal for islanding detection. It is observed that the magnitude of ROCPAD sharply changes during islanding compared to non-islanding condition as shown in *Figure 3.1* to *Figure 3.6*. Thus, a threshold of (may be 50 degree/s or 100 degree/s) can be set to issue the tripping signal. Even the threshold shifts from 50 degree/s to 100 degree/s, the response time changes by 3 ms (less than a quarter cycle), which is accepted for relaying purpose. The response time of the ROCOF is within 15 ms from the event inception with 100 degree/s as threshold, which is less than one cycle (20 ms) from the islanding inception. It is observed that the impact of load change on the performance of ROCPAD is marginal as shown in *Figure 3.3* and *Figure 3.4*, where the non-islanding events are load switching at DG-2 end (L-3) and section-2 completely cut off, respectively. The most important issue is to evaluate the performance of the ROCPAD for islanding detection with lower active power imbalance (power mismatch). It is observed that even if the power imbalance goes down to 10%, the magnitude deviation of ROCPAD is similar to that of 40% power imbalance case and a same threshold can be set to issue the tripping signal. Similar observation can be made for power imbalance of 0 and 80%. This shows that setting one absolute threshold (may be 100 degree/s) works effectively for islanding detection for wide range of active power imbalance.

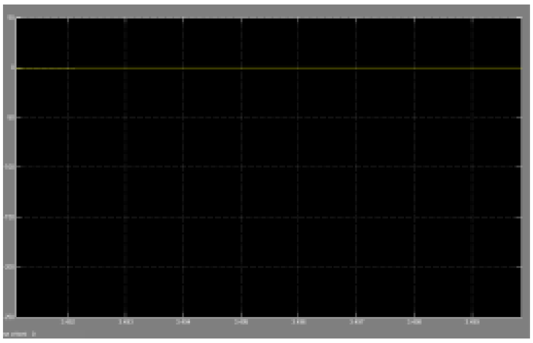

Figure 3.1: Non-islanding case for DG-1 for Designed Micro grid in MATLAB/Simulink

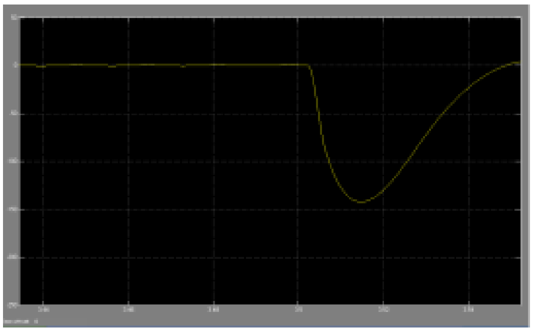

Figure 3.2: Islanding case for DG-1 for Designed Micro grid in MATLAB/Simulink

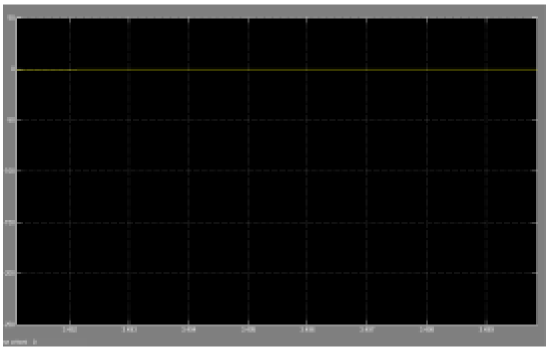

Figure 3.3: Non-islanding case for DG-2 for Designed Micro grid in MATLAB/Simulink

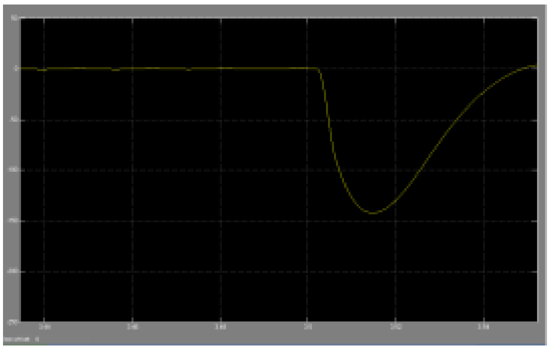

Figure 3.4: Islanding case for DG-2 for Designed Micro grid in MATLAB/Simulink

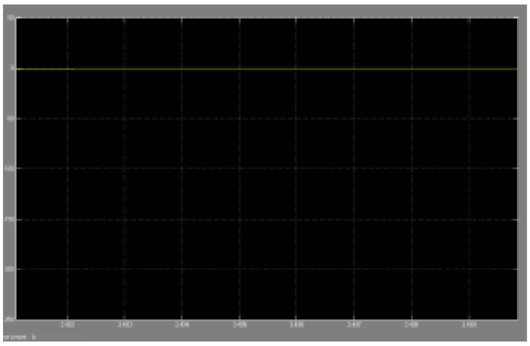

Figure 3.5: Non-islanding case for DG-3 for Designed Microgrid in MATLAB/Simulink

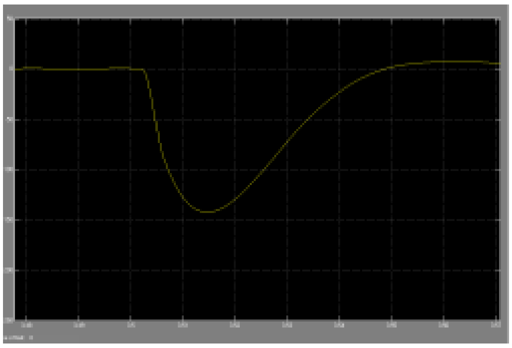

Figure 3.6: Islanding case for DG-3 for Designed Micro grid in MATLAB/Simulink

IV. CONCLUSION

This paper presents a new passive technique for islanding detection in distributed generation using ROCPAD. Moreover, it also evaluates the islanding and non-islanding conditions for all conditions for the sampled studied system. Distributed power systems offer a potential increase in efficiency by localizing power generation. Distributed power also offers increased reliability, uninterruptible service, and energy cost savings. The ROCPAD works effectively where the ROCOF fails. The response time of ROCPAD is within one cycle from the event inception, showing fastness of the proposed algorithm compared to ROCOF relays. The most important observation is the ability of ROCPAD to perform with active power imbalance of 0%, thus reducing the non-detection zone (NDZ) compared to existing ROCOF relays. It is observed that active power imbalance plays vital role in islanding detection in case of ROCOF relays. ROCOF relays work effectively with active power imbalance at higher end and fails in case of active power imbalance falls below 15% during islanding. An important observation is made on the response time of ROCPAD, which is less compared to ROCOF, showing the fastness of the proposed ROCPAD for islanding detection. Also the ROCPAD works with 0% active power imbalance, indicating the reduction of non-detection zone (NDZ). The main challenge in passive islanding detection technique is to derive the most significant parameter and to set an absolute threshold on the same for effective islanding detection. This is achieved by the proposed ROCPAD relay algorithm which performs effectively based on a set threshold. The most important observation is the ability of ROCPAD to perform with active power imbalance of 0%, thus reducing the non-detection zone (NDZ) compared to existing ROCOF relays. As the implementation is easier, thus DSP/FPGA based ROCPAD anti-islanding relay can be developed for safe and secure micro grid operations. The implementation of the ROCPAD relay is easier on DSP or FPGA platform as this is based on synchronous transformation based phasor estimation. The study of such issues would require extensive real-time and off line research, which can be taken up by the leading engineering and research institutes across the globe. As a future work, the effect of these dynamics on the islanding detection and control of islanded systems can be studied. As the implementation is easier, thus DSP/FPGA based ROCPAD anti-islanding relay can be developed for safe and secure micro grid operations.

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