Islanding detection of Interconnected Grids based on Synchrophasor measurements (PMU)

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***Abstract*— This paper deals with the development of algorithm for islanding detection of Interconnected Grids as a result of Loss of interconnecting transmission line(s). The algorithm must also be able to segregate between the cases of islanding and cases of Loss of Parallel Feeder (LOPF), Generation Trip, and Load Trip. The new method uses 3 phase synchronized measurements obtained from Phasor Measurement Units (PMUs) for the detection of unbalanced islanding of Interconnected Grids. The model developed is simulated on two Area – two machine System in SIMULINK Environment. Furthermore, the algorithm is verified and tested on actual case study for the loss of the synchronization between NEW and SR grid of India.**

Keywords—Islanding; Phasor data concentrator; Synchronization; Synchrophasor Measurement; WAMS(Wide Area Measurement System).

I. Introduction

Islanding is the situation when a portion of the power system, which includes both generation and loads, gets isolated from the rest of the system but stay energized. The islanding becomes prominent in networks wherein the embedded generators (EG) are integrated in the utilities at distribution level [1]. Along with that, it plays an important role when the system is large, as during any large disturbances it is desired to have islands rather than collapsing as a whole. The most common condition occurs when few generators get isolated with a part of network load and continues to thrive on its own thus forming an 'island'. The major advantage of islanding is that whole system is not lost during severe occurrences and its restoration is easier. The primary disadvantage of islanding from system point of view is that the system integrity is lost, i.e. the system becomes weak and the system inertia reduces. The other disadvantages are safety hazards and customer equipment damage due to wide fluctuation in electrical parameters such as frequency and voltage.

As a system operator monitoring the grid it is very well desired that, they know the islanding events and its parameters at all the times. There have been several approaches for islanding detection earlier based on the state estimation of the Network from SCADA which is largely dependent on proper telemetry from site. Control room operators monitoring large grids came to know about islanding from conventional SCADA system a long time after its actual occurrence. There is a need of facilitation of automated islanding detection to control room operators, thus enabling them to take preventive and corrective actions.

With the introduction of Synchronized Measurement using Phasor Measurement Unit (PMU), there has been a great change in monitoring of the grid performance with the help of time-synchronized states of power system. Efficient and fast detection of Islanding in the power system is also possible with the help of PMUs. Detection of islanding using PMUs is faster, more reliable and has higher accuracy as compared to the conventional methods.

This paper focuses upon devising a new method to detect islanding using the system parameters obtained from PMUs. The system parameters considered are frequency and Rate of Change of Frequency along with the Phase shift. It utilizes the measurements obtained from PMUs installed as a part of WAMS to use the data for the purpose of fast islanding detection. Section II of the paper describes about the phasor measurement unit in brief. A concise overview of Islanding detection in section III is followed by section IV, which describes the algorithm and various parameters utilized by the authors for islanding detection. Section V emphasizes upon the simulation test case in MATLAB to verify the proposed algorithm. In the end, we present the validation of proposed methods based on Real time phasor measurements during the islanding observed in Indian Grid.

II. PHASOR MEASUREMENT UNIT

A phasor is a mathematical representation of a sinusoidal waveform in polar coordinate system. The phase angle at a given frequency is determined with respect to a time reference. Synchrophasor are phasor values that represent power system sinusoidal waveforms referenced to the nominal power system frequency and coordinated universal (UTC) time. The phase angle of a Synchrophasor is governed by the waveform, the system frequency, and the instant of measurement [2]. Thus, with a universal precise time reference, power system phase angles can be accurately measured throughout a power system. The global positioning system (GPS) technology provides an economic option for the same. An important advantage of the GPS technology is that its receiver can automatically detect accurate synchronization. The device that provides synchronized phasor measurements is called a Phasor Measurement Unit (PMU). As per IEEE standard, PMU is defined as 'A Device that produces Synchronized Phasor, Frequency, and Rate of Change of Frequency (ROCOF) estimated from voltage and/or current signals and a time synchronizing signal' [3] .The three major advantages of PMUs are:

1. The synchronised time stamping of data based on GPS from several nodes in power system enabling to know about the real time phase angle difference.
2. High resolution due to high sampling rate enabling the observability of dynamics in the system.
3. Direct angle measurements of nodes in the power system.

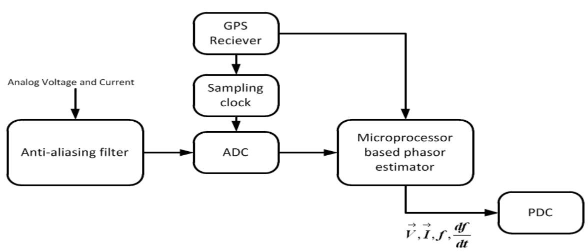

Fig. 1. Functional Block diagram of PMU.

Figure 1 shows the basic functional block diagram of Phasor measurement Unit. Most of the algorithms compute phasors from measured signals using a fixed time window of data samples and computing the phasor estimate using discrete Fourier Transform. The Estimated phasor measurement over a fixed time duration from all the PMUs are sent to Phasor data concentrator (PDC) which time align all the PMUs data and send it to visualization, historian and other real time applications. The communication channel selection is an important consideration for transmitting the PMU data. In India data, reporting rate of PMU is 25 samples per second based on availability of commination bandwidth and hardware & software processing speed. Any standard PMU provides six numbers of phasors of Voltages & Current, Frequency, and Rate of Change of Frequency (ROCOF). Such a high rate data with time synchronization enables system operator to analyze dynamic and transient states of the grid.

III. ISLANDING DETECTION

Islanding detection is a highly researched topic in domain of power system monitoring and control application. Based on the literature overview, the islanding detection methods can be divided in two categories:

A. *Passive Methods :* Passive methods of detecting loss of grid basically depend on direct measurements and some derived quantities. It is based on monitoring of one or more system parameters such as Frequency, Rate of change of Frequency (ROCOF), Active or Reactive power flow, Phase shift. Sudden islanding causes changes in these parameters and thus under frequency relays, under/over voltage relays can be used to detect islanding situation. Such methods will perform satisfactory in cases where the mismatch between local generation and demand is always known to be large [4].

B. *Active Methods:* The basis for many of the proposed active loss of grid methods is the use of a modified generator control scheme that, when islanded, will make the changes in frequency or voltage more easily [5]. Majorly used methods under this category are Reactive Power Export [6] Impedance measurement method [7], active frequency drift and current injection [8] .

Any fail-safe method of islanding detection should meets following requirements:

1. Should be capable of detecting and cease to energize the area within 2 seconds of the formation of island [9].
2. Should be capable of working under conditions such as short circuit, unbalanced islanding of Microgrids as well as large grids [10].
3. Should not falsely operate under the conditions of Loss of Parallel Feeder (LOPF), sudden generation trip, sudden Load trip.

Based on the above criteria's and Synchrophasor measurements, the next section describes an approach for detection of island in large power systems.

IV. PROPOSED ALGORITHM FOR ISLANDING DETECTION

The proposed algorithm considers the global electrical power system parameter measured from the PMU connected at a Bus. These global quantities include Frequency, ROCOF, Voltage Phase Angle and Voltage Magnitude. This algorithm does not include any local quantity such as Current, Active Power and Reactive Power, which varies from feeder to feeder. The characteristic of various parameters are described in detail to provide an overview as to how they are affected during islanding of a system.

*A. Frequency difference :*The Frequency of synchronized grids tries to imitate each other as closely as possible and have almost similar values. Under normal steady state operating conditions the frequency difference is of the order of 10^{-4} Hz. However, in case of unbalanced islanding i.e. the load-generation is not balanced in the islanded system, its frequency falls or rises depending upon whether the generation is less or more than the load in the said system, and system inertia. Hence due to change in frequency, the magnitude of frequency difference between the two systems increases and the systems become unsynchronized. It has been observed that if the average frequency difference is greater than 0.1 Hz, it may be the case of islanding [11]- [12].

B. Voltage Angle Difference: The Voltage Angle difference at adjacent buses of a grid is a measure of amount active power flowing from one bus to the other. The power flows from the bus with leading angle towards the bus with lagging angle. During steady state the angle difference remains approximately constant over time as the frequencies of the synchronized buses closely follow each other. Higher the angle difference, higher will be the stress on the transmission line connecting the two buses. Thus, the angle difference is normally kept within 10 degrees. During the state of islanding, the buses become unsynchronized, as a result of which the voltage phasors move relative to each other and hence the angle difference fluctuates between -180°to 180°. It has been found that if the average angle difference between two buses goes beyond a limit of 30°, it may indicate islanding [12].

C. ROCOF (Rate of Change of frequency): The ROCOFs in synchronized grids have approximately similar values and the frequencies of the grids tend to follow each other. But in case of an unbalanced islanded system where load-generation is imbalanced, i.e. either load is more than generation or vice versa, upon islanding the frequency of former system decreases making ROCOF negative, while the frequency of the latter increases making ROCOF positive [6]. Thus, it can be concluded that the product ROCOF of average frequencies of two systems is found to be negative for a short duration after the actual islanding has occurred until the steady state of both systems is reached. Hence, Product of ROCOF can also be used as a parameter indicative of islanding.

The algorithm which is used for Islanding detection uses Frequency difference, Angle difference & product of ROCOFs of two adjacent buses. The conditions chosen are as follows:

Either

- Condition A: The Average value of Voltage Angle difference at adjacent buses interconnecting two areas is greater than 30° and frequency difference of the two areas is more than 0.1 Hz for consecutive five readings.

Or

- Condition B: Product of ROCOF of average frequencies is negative and Average value of Voltage Angle difference at adjacent buses is greater than 30° for consecutive five readings.

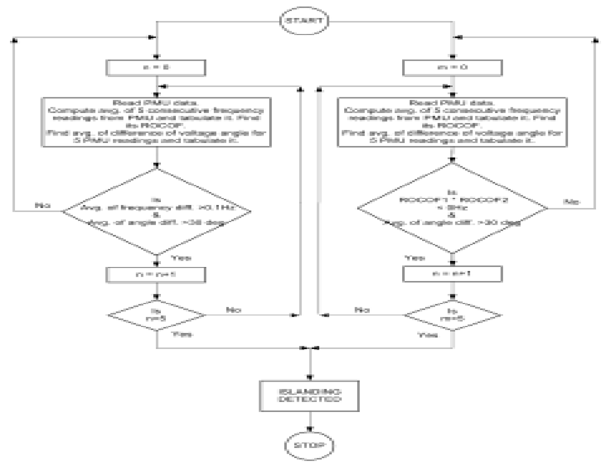

Fig. 2. Flowchart of the Proposed Islanding detection based on synchrophasor measurement..

1. Figure 2 shows the flowchart of the proposed algorithm. It can be observed that the above islanding detection scheme is based on the field measurements available from synchrophasor units. In the next section, the proposed method is tested based on MATLAB Simulation Model.

V. SIUMLATION MODEL

To validate the proposed algorithm, simulation of Two Machine-Two Area system is performed in MATLAB, Simulink environment. The system has two areas. Area 1 has one generator unit of 11 kV, 800 MVA. While Area 2 has one generator unit of 11 kV 200 MVA. At the transmission level, the voltage level is stepped up to 400 kV. The length of 400 kV double circuit transmission lines connecting the two areas is 220 km with typical 400 kV ACSR conductor. Figure 3 shows the MATLAB Simulink model for the foregoing system. Both areas have one load each, which can be varied for various simulation cases. Table 1 shows the various parameters for generator used for simulation purpose.

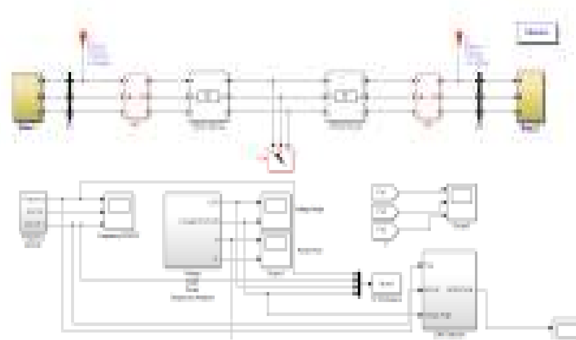

Fig. 3. Simulink Model of the two area system.

TABLE I. SIMULATION CASE STUDY RESULTS

Case No	Case	Area 1						Area 2			Tie line flow from Area 1 to Area 2 (MW)	Condition A	Condition B
				Load 1		Load 3			Load 2				
		G1 (MVA)	G3 (MVA)	P	Q	P	Q	G2 (MVA)	P	Q			
I	**Loss of Interconnecting Line**	1000	0	950	750	0	0	200	8	6	-130	Yes	Yes
	Loss of Interconnecting Line	1000	0	850	637	0	0	200	110	80	-40	Yes	Yes
	Loss of Interconnecting Line	1000	0	805	600	0	0	200	158	110	-2	Yes	No
	Loss of Interconnecting Line	1000	0	600	450	0	0	200	360	275	155	Yes	Yes
II	**Loss of Parallel Feeder**	1000	0	950	750	0	0	200	8	6	-130	No	No
III	**Load Loss**	1000	0	750	562	200	150	200	8	6	-130	No	No
IV	**Generator Loss**	800	200	950	750	0	0	200	8	6	-130	No	No

* P is in MW , Q is in MVAr.

It should be noted that the above model has been designed so as to detect the islanding by implementing the proposed methods, and to distinguish it from the cases of LOPF (Loss of Parallel Feeder), Generation trip and Load trip. For generation and load trip case an excess generation/load has been introduced in one of the areas (G3, Area 1 in this case). While for parallel feeder tripping case, one more interconnection (tie-line) was modelled between the two areas. In this way, all the four cases are simulated and analysed.

A. *Case I Variation of Load in the areas and tripping of the interconnecting feeders:* Under this case, many sub -cases were considered by varying tie line power flow between the areas. From table I, it can be verified that even for a tie line active power flow as small as 2 MW, the proposed algorithm can successfully detect the islanding.

B. *Case II Loss of parallel interconnecting line (LOPF) :* Under this case, one more interconnection (tie–line) was added between the two areas and its tripping was simulated which resulted in non-satisfaction of the foregoing two developed conditions. Case V in table 1 depicts the same.

C. *Case III Loss of Load in one of the Area :* Under this case, a load was introduced in area 1 whose tripping was simulated to validate the algorithm in case of large change in system. Case VI in table 1 represents that the algorithm is not susceptible to such a large load change and does not malfunction.

D. *Case IV Loss of Generator in one of the Area :* Under this case, a generator was introduced in area 1 whose tripping was simulated to validate the algorithm in case of large change in system. Case VII in table 1 represents that the algorithm is not susceptible to such a large generation change and furnishes correct information.

In all the cases of islanding, the algorithm was able to detect it in within the stipulated period of 2 seconds. The next section describes the used case of islanding in Indian Power System and the validation of the proposed algorithm with the field data.

VI. ALGORITHM VALIDATION USING REAL TIME CASE STUDY IN INDIAN GRID

Indian power system is amongst the largest synchronized grids in the world. It consists of Northern, North Eastern, Eastern Western and Southern Grid. First four are collectively known as the NEW grid. The Southern grid (SR) and the NEW grid were initially synchronized via a 765 kV link which was later further strengthened by an addition of one more 765 kV link.

On 29 May 2014, when the SR and NEW grid were synchronized via a single 765 kV Solapur – Raichur link, the tripping of the line has resulted in islanding of SR grid from the NEW grid. The loss of synchronization can be observed from figure 4 where frequency of NEW grid (Solapur) and SR grid (Somanhalli) are found to be different.

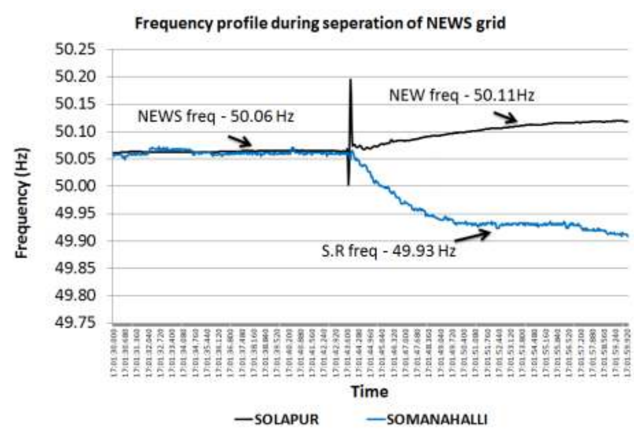

Fig. 4. Frequency of NEW and SR grid duirng loss of synchronization of 29th May 2014.

At the both ends of this 765 kV link, synchrophasor units have been installed. The data from both these PMUs was taken and the algorithm was tested on the data. Figure 4, 5, 6 shows the Frequency difference, voltage angle difference, ROCOF product respectively.

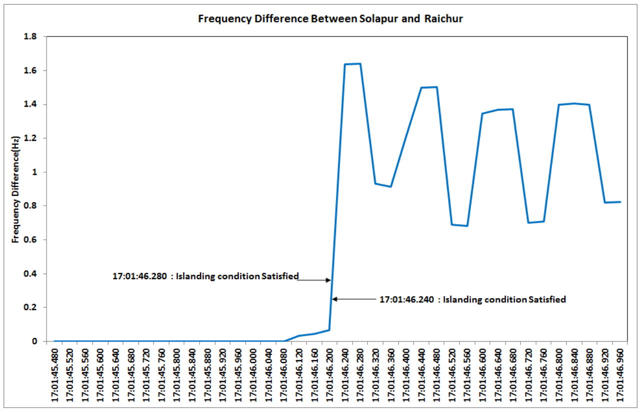

Fig. 5. Frequency difference condition check for 29th May 2014 case

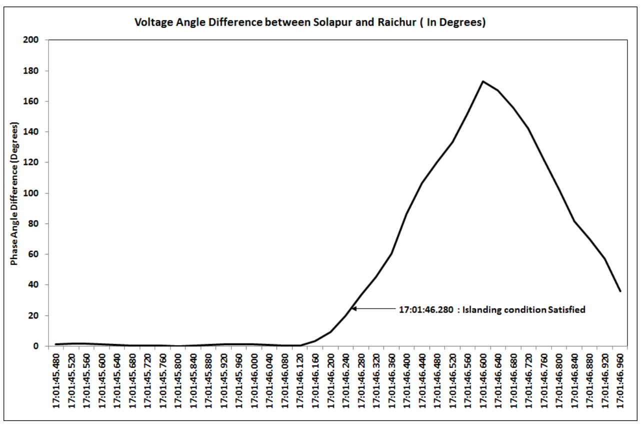

Fig. 6. Voltage angle difference condition check for 29th May 2014 case

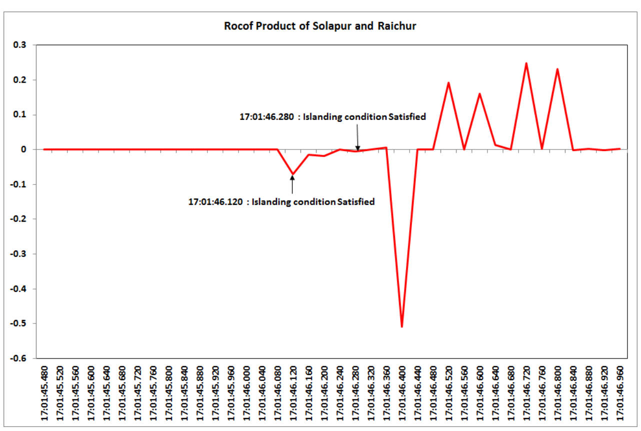

Fig. 7. ROCOF product condition check for 29th May 2014 case

From the figures 4, it can be noticed that the real time islanding occurred at 17:01:46.080, which was confirmed at 17:01:46:280 by the proposed algorithm. There was a delay of 200 ms because five consecutive signals were analyzed and averaged as per the algorithm before asserting the island detection. Hence, the proposed method was validated based on real time case study.

VII. Conclusion

This paper shows a method of islanding detection based on the global parameters of the electrical grid. The method describes and validates that how synchrophasor measurements from PMUs can be utilized for detection of islanding in the grid. The proposed algorithm was independently validated using MATLAB simulation as well as the real time case study based on synchrophasor measurements from the PMUs

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