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A STUDY OF VARIOUS ISLANDING DETECTION METHODS IN MICROGRIDS

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Abstract: The microgrids are generally a network consisting of small scale generators supplying a small area but they are not entirely isolated but also connected to the national grid in most of the cases. Islanding is an emergency condition where the main grid goes off while the DG is still connected to the system. This causes potential threat to the whole system. The system may collapse if it is not detected fast and remedial action is not taken. This research work tries to do a systematic study of common methods of islanding detection available and draw necessary conclusions.

Keywords: *ANN, Fuzzy, Islanding, Microgrid, Zone of nondetection, Active, Passive*

I. INTRODUCTION

With the modern emerging technologies, the power system has been transforming itself from its previous giant, bulky form to small, smart functional units which are more reliable and convenient. While doing so, more and more new concepts are being introduced like renewable distributed generation, microgrids etc. The microgrids are mostly consisting of renewable sources (wind power plants, solar PV, micro plants, cell based systems etc.) which are also connected to the main grid. This brings the necessity to analyze the system during dynamic conditions like islanding. Since there is no option to keep operating reserve in some of the renewable sources like wind power, their speed regulation and automatic generation control becomes very difficult. Islanding situations may occur due to many reasons, the most common being fault in a tie-line between transmission and distribution network. Islanding causes the following adversities in a power system:

- It prevents automatic re-connection of the devices.
- Fatal accidents may occur when some workers may not know that the system is still alive even after the grid supply has been disconnected.
- Load vs. generation imbalance may occur in the system.
- The system may be subjected to abnormal voltage and frequency fluctuations.

Due to all these reasons, the islanding situation should be very much detected well and system should be disconnected from all type of sources for its safety. In some specific, specially designed microgrids, the system can be allowed to go for islanding. In such cases, the DG's should be capable enough to handle the total load, in absence of the main grid supply. It is recommended that all DG's should be equipped with devices to detect the islanding situation and prevent it from occurring. Studies are going on to find better techniques of islanding detection.

II. LITERATUE REVIEW

In recent times, power supply system has been undergoing a lot of changes from the previous bulk power production to small scale consumer oriented productions. In this picture distributed generation has come into play and the concept of "microgrids" has emerged. These microgrids are nothing but small scale grids which can operate either independently or in conjunction with the main grid of that area. These microgrids generally consist of renewable sources out of which most widely discussed and applied are wind turbine plants, solar PV, micro hydro plants, cell based systems etc. With more and more penetration of these renewable sources to the system the entire system orientation has been changed. This increases the security and reliability of the system as one does not need to solely depend upon a grid connected bulk supply system.

With the increasing importance of distributed generation more and more new terms are being introduced and being used by researchers worldwide which did not even exist in the literature of electrical engineering maybe 50-60 years ago. Such terms include distributed generation, embedded generation, de-centralized generation, demand side management, remote area power supply, islanding, situational awareness etc. The renewable resources that get more importance in India are small power wind generators, solar PV systems, biomass gasifier based power generation, micro hydro plants etc. The history of renewable energy research in India is more than a century old but it became prominent only during the 70's when the oil crisis occurred and it led to search of new renewable alternatives. At present renewable energy contributes 18.37% of the total installed power capacity in India as reported in 2017. The Ministry of New and Renewable Energy (MNRE) is trying to come up new projects in remote areas which are not accessed by the national grid yet. The process continues and India shows a significant growth in renewable energy source installations in recent years. Researches are going on in numerous directions in the field of distributed generation with renewable sources. Extensive research is going on in the area of developing islanding detection algorithms. Delberis A. Lima and Jayme E. Silva Filho have come up with a dynamic assessment of islanding detection in distributed renewable generation under different condition of load and generation. They have presented a new scheme based on telecommunication-aided synchrophasor measurement for sensitivity and speed optimization.[1] Aziah Khamis Hussain Shareef Erdal , Bizkevel Tamer Khatiba has come up with a survey of various islanding detection techniques and their advantages and disadvantages.[2]Anila Antony and Devika Menon has prosoped different islanding detection techniques for distributed Generation[7] Other significant work include Emilio J. Estébanez and Víctor M. Moreno's study to evaluate the performance of active islanding-detection algorithms in distributed-generation Photovoltaic Systems.[8] While in islanding situation the power system parameters (voltage, frequency etc.) undergoes changes. Safdar Raza and Hazlie Mokhlis have come up with a sensitivity analysis of different power system parameters during islanding detection which becomes helpful for future researchers. [11] Another important research has been done by Ajit A. Renjit and his team who have analysed the frequency dynamics in islanded microgrids. [14]

In this manner studies are going on in all the aspects, with this new scope of research has opened up, new facts are being established and all these sum up in making the distributed renewable generation

III. CLASSIFICATION OF DIFFERENT METHODS OF ISLANDING DETECTION

Though in recent time, microgrids have been equipped with various kinds of renewable sources, the most considerable are solar PVs and wind power plants. In this particular paper we would like to concentrate on islanding detection of PV systems. The connection of the PV systems to the grid may cause several technical problems. The feasibility of such an interaction depends of various factors e.g. the layout of the inverters, type of anti-islanding techniques used, load vs. power generation balance, change in the behavior of the load connected etc.

The exact number of islanding detection methods that actually exist is very difficult to detect. It is an area of research which is advancing at a very rapid pace. Everyday some new method has been emerging out. The methods are roughly divided into the following categories: Active methods, Passive methods, Hybrid methods, Methods using communication techniques and lastly Advanced Methods using Artificial Intelligence. They can be defined as below.

Active methods can be defined as those methods which introduce a small signal of disturbance to the system in order to detect possible islanding conditions. For this, it is needed to monitor the changes the properties of that signal undergo.

These properties include voltage, frequency, impedance etc.

Different types of active islanding detection method are:

- Impedance measurement
- Negative sequence current injection
- Slip mode frequency shift
- Frequency bias
- Active frequency drift
- Voltage feedback etc.

Active methods are simple and robust, have a small ZND (Zone of none-detection) Passive methods are those methods where we try to introduce some component which will take into account the transient changes on the grid and by using that information, it decides whether the grid has failed or not by comparing it with some predetermined threshold value. . This method mainly monitors the changes in various system parameters. These changes are possibly,

(i) Under voltage/overvoltage
(ii) Under frequency/over frequency
(iii) Rate of change of frequency
(iv) Rate of change of voltage
(v) Rate of change of real power(P)
(vi) Rate of change of reactive power(Q)
(vii) Harmonics Detection
(viii) Impedance monitoring
(ix) Voltage phase jump

Passive methods are generally simple low cost methods which require little hardware. Using passive method, the power quality of the distribution network remains unaffected. These methods possess the disadvantages of a large ZND(Zone of non-detection) .

Hybrid methods are a combination of both active and passive methods. They tend to utilize the best features of both of these. They have a very small ZND and signals are injected only at certain intervals of time. This helps in retaining the power quality of the system. But with increasing complexity of the system, the islanding detection time sufficiently increases.

In methods using communication techniques, PLC and SCADA are being implemented. The signals communicated between the PV Inverters and utility are processed and this gives a status of the system. If islanding occurs, there will be certain changes in these signals which will be reflected in SCADA. This is a more advanced method with less chance of errors but it is difficult to implement practically and not cost effective.

IV. SOME ADVANCED METHODS OF ISLANDING DETECTION

Artificial Intelligence can act as a successful tool for islanding detection techniques. Artificial Intelligence comes handy when the existing conventional systems fail to give satisfactory results. Mainly there are two areas where vast research has been going on. These two areas are:

i) Artificial neural network based islanding detection
ii) Fuzzy controller based islanding detection

Artificial neural network (ANN) has proven itself as a great solver for solving complex problems related to science and engineering. In power system, ANN has proved itself to be a path breaking tool for many new innovations. It is being applied in various fields of power system e.g. power system operation and control, stability, security etc. An ANN is a network consisting of neurons which are similar to biological neurons of human brain. In a human brain, a neuron is connected to thousands of other neurons. Each neuron is capable of collecting information from thousands of neurons and sending the same to thousands of other neurons. Similar to this, the neurons of ANN also collect data from other neurons, do some processing on the data and then pass on the data to other neurons or nodes through links. Each link is associated with a certain weight. There are generally two types of network structure of ANN known as Feedforward and Feedback. In power system problems, multilayer Feedforward networks are generally adopted the block diagram of the same is shown below.

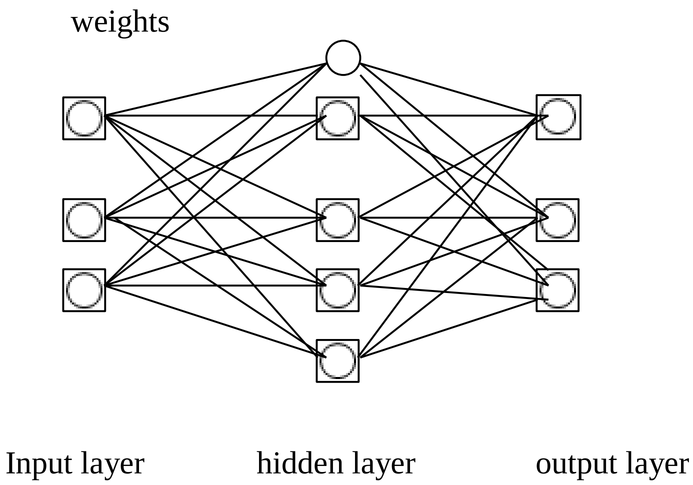

Fig.1 A three layer ANN with input, output and hidden layer

The network shown in fig.1 mainly consists of layers and nodes. There are three layers and several nodes. The middle layer is called hidden layer while the other two layers are input and output layer respectively. The flow of information is always left to right and there is no feedback path. The output of the ANN can be adjusted by adjusting the weight of the links connecting the links. If the desired output has been obtained then there is no need of adjustment of the weights. This phase of adjusting the weights of the ANN to get the desired output is known as the training phase. The next phase is the testing phase where the ANN is tested with random unknown inputs to check its efficiency.

While doing the testing part, some algorithm must be there which will link the output of any node in the output layer to the input node. Such algorithms are known as Activation Functions. The activation functions detect the lapse between the desired output and the actual output and put a command to the input node so that weight adjustments can be done to minimize the error and get the desired output. For detection of islanding condition, the power system network will be re-structured as a multilayer feed-forward ANN. Now a certain parameters will be chosen e.g. rate of change of frequency, rate of change of voltage, rate of change of real power(P), rate of change of reactive power(Q) etc.

The test system is simulated using software after applying different scenarios of load and operating conditions. Output of these simulations show values of the parameters mentioned above under different conditions. The simulations for islanding cases are done by disconnecting the main grid supply at different load levels and checking the values of the parameters at these conditions. Other conditions applied to the network may be different types of faults (LG, LLG, and LLLG). The fault conditions are applied on different buses and the effect of the parameters are checked for each fault on each bus.

The output of the software will be applied to the ANN network and ANN will automatically detect whether islanding has occurred or not. For this, a matrix is formed whose elements will be the data obtained from the simulation software. The rows of the matrix will indicate the number of different scenarios of system disturbance whereas the columns will indicate the rate of change of parameters and finally the output column will indicate 1 if islanding occurs and 0 if there is no islanding.

The concept of fuzzy logic can be applied for islanding detection in conjunction with the passive way of detection where the changes in certain parameters are monitored to check whether islanding has occurred or not. Application of fuzzy logic concepts has increased tremendously in recent years in almost every aspect of research. It is a multivalued logic which is becoming popular day by day because of its analogy to the logical reasoning done by human mind. Here we can apply linguistic values to the variables using membership functions. The main component of a fuzzy system is the *fis* i.e. fuzzy inference system. Each fis will have certain rule bases. There will be certain input variables and certain output variables. The output variable will be linked to the input variables with the help of fuzzy IF-THEN rule. Using ifthen rules, the output may be expressed in terms of inputs not by any mathematical equations but with the help of logical reasoning. Each of these input/output variables will possess their own membership functions. Generally triangular or trapezoidal membership functions are used. Other important component of a fuzzy system is the fuzzifier and the defuzzifier. The fuzzifier converts the crisp or numerical value to be processed by the fis into a fuzzy value (linguistic term). After completing the processing of the value again it is converted from crisp value into fuzzy value.

V. ISLANDING DETECTION METHODS

Island recognition techniques Island location strategies are for the most part partitioned into nearby and distant strategies. Local strategies depend on estimating a few boundaries or factors on the microgrid side, including detached strategies and dynamic techniques including voltage, current, recurrence and stage for island identification. Dynamic strategies purposefully infuse an unsettling influence to check whether it is influencing voltage, recurrence, force, or impedance boundaries. Distant strategies depend on correspondence between the microgrid and the fundamental organization to screen the switches right away. Far off strategies have almost no NDZ, which no affects power quality. Distant techniques are extremely powerful in multi-inverter frameworks; however, they require enormous ventures. It's not efficient in little systems.

A) Passive strategies

- **Detection of voltage and current harmonic detection (HD**)

This strategy depends on the estimation of the Total Harmonic Distortion (THD) in PCC to recognize island when the THD surpasses the edge under ordinary conditions, when the microgrid is associated with the framework, PCC The voltage is a standard sine wave and along these lines the sounds produced by the heap are immaterial. Since the matrix impedance is little, the music produced by the inverter are moved to the framework without bending in the PCC. Condition, the current music created by the inverter will be communicated to the heap and the hysteresis impact of the transformer will additionally irritate the symphonious contortion in the PCC which can distinguish islands. This strategy enjoys the benefit that its adequacy doesn't change when a few DGs are associated in equal on a similar PCC and it is not difficult to execute: The recognition time is approx. 45 ms at high location speed and in a wide assortment of circumstances. Also, the edge for this technique is hard to pick since network disturbances can undoubtedly prompt disappointment discovery. This technique is inclined to mistake when NDZ is huge for loads with an enormous Q factor. Q is characterized as Eq. In this way, the consonant identification technique is hard to apply in little single frameworks.

- **Overvoltage/Undervoltage and Over frequency/Underfrequency (OUV/OUF)**

This procedure depends on building up a permissible reach for voltage and recurrence The voltage deviation after the microgrid has been turned off is essentially because of the energy befuddle between decentralized age and the heaps in the microgrid at the PCC:

ΔP = Pload - PDG

ΔQ = Qload – QDG

In network activity, ΔP and ΔQ are taken care of in from the principle network to adjust the viable - and to keep responsive force. the recurrence digresses up to ΔP = 0 and ΔQ = 0.Therefore, OUV/OUF can distinguish islands by recognizing voltage and recurrence deviations. This minimal expense technique no affects power quality. Shortcomings are those where NDZ is moderately huge and time identification is hard to foresee. 4 ms to 2 s, considerably in excess of 2 s the identification speed is identified with the distinction in execution among DG and burdens, so this technique is reasonable for microgrids with a specific force unevenness.

- **Rate of change of frequency (ROCOF)**

When the microgrid is disengaged from the matrix with a force contrast, the recurrence changes With the worth of df/dPl estimated in a couple of cycles, the island can be perceived and the inverters switch off if a set limit is surpassed. ROCOF is more delicate than VUE/OUF and its identification speed is quicker. At the point when the force jumble among DG and burden is enormous, this technique is truly solid and timely. The recognition time is up to 24 ms. Regardless of whether the force among DG and burden is in balance, any aggravation brought about by load changes can break this equilibrium, bringing about recurrence changes for island location. ROCOF's shortcomings are those to which it is touchy. Burden exchanging and jitter, which can prompt flaw identification and make limit choice troublesome. This technique can't recognize whether the recurrence change is brought about by island changes or burden changes.

- **Rate of change of frequency over power (ROCOFOP)**

This technique depends on the estimation of the worth of =f = ∂PL, a record to decide if the microgrid is worked in an island state, where PL is the heap power. This strategy has higher unwavering quality, a lower imperfection location proportion, and its NDZ is lower than ROCOF. It can distinguish the island all the more viably when the force confound between the DG and the heap is little. The location season of this strategy is approx. 100 ms. Compared to ROCOF, this strategy could be utilized in a more extensive scope of circumstances and can adequately distinguish islanding in microgrids with little force unevenness.

B) active strategies

- **Active frequency drift (AFD)**

This method is based on slightly distorting the current waveform injected into PCC by the inverter. When connected to the grid, the voltage and frequency of PCC will not change owing to the stability of main grid, and the frequency of the inverter's output current will not change after a phase-locked loop, either. When a grid disconnection occurs, because of distortion of the injected current waveform, the zero crossing of the voltage occurs sooner than expected, thus giving rise to a phase error between the voltage and the inverter's output current. It makes the inverter to drift frequency of output current to eliminate the phase error. The voltage response of this current frequency drift causes an earlier zero crossing than expected again, making the inverter's output current to drift its frequency until the voltage frequency measured in PCC exceeds the threshold of OUF and then the islanding is detected [12]. The major parameter describing the distortion of the inverter's injected current is the chopping fraction, which is defined in [25,26], as the following equation

$$cF = \frac{2t_Z}{T_{vutil}}$$

where tz is the dead time and T_{vutil} is the period of voltage.

The strengths of AFD are that it is easy to implement and has a small NDZ, and particularly, there is no NDZ in resistance load with the detection time within 2 s [11]. The weakness is that in multiple inverters case, the method may fail to detect islanding because of inverters in different deviations of frequency bias. With the injected current distorting more heavily, the power quality of inverters output will degrade more quickly. Load parameters play a great role to the effectiveness of the method. If the load is not resistance, the detection time and the NDZ will increase with higher value of Q. Therefore, AFD is the best for the islanding detection of microgrid which is just made up of resistive loads and without multiple inverters.

- **Frequency jump (FJ)**

FJ is a modification of AFD, which also inserts dead zones into current waveform, but not into each cycle, for example, one dead zone in every 3 cycles, instead. When the microgrid is connected to main grid, the waveform of voltage in PCC, which is imposed by the grid despite inverter's current is distorted, is not distorted. When disconnected from main grid, islanding can be detected by a variation in voltage frequency [7,8,11]. FJ is very effective in detecting microgrid without multiple inverters in parallel; the disadvantage is that, like AFD, the detecting effectiveness will be reduced when multiple inverters are in parallel.

- **Active frequency drift with positive feedback (AFDPF)**

To overcome the weakness of AFD in multiple inverters and reduce NDZ, AFDPF utilizes a positive feedback to increase chopping fraction to accelerate frequency deviation, detecting islanding more effectively.

$$Cf_{k-1} + f(\Delta\Delta\omega k)$$

where cf k and Cf_{k-1} are the chopping fractions of the kth and k-1th cycles, respectively. Where ωk is the frequency of the kth cycle, , F is usually a linear function. The value of cf in AFDPF can be positive or negative. No matter if frequency drift is upward or downward, this method can reinforce the frequency drift instead of counteracting it, overcoming the impact of the load parameters [26]. The performance has been improved compared to AFD, greatly reducing the NDZ. Its disadvantages are that it affects the power quality slightly, and still has NDZ for loads with high quality factor.

- **Sandia frequency shift (SFS)**

As an extension of AFD, a positive feedback is applied for the frequency of inverter's voltage, whose chopping fraction is [12,25,27]

$$cf^{`} = cf_0 + k(f_{pcc} - f_{grid})$$

where cf 0 is the chopping factor with no deviation in frequency, K is the accelerating gain, f PCC is the voltage frequency in PCC, and f grid is the frequency of the grid. When connected to main grid, the method attempts to change the voltage frequency of PCC but it is prevented by main grid. When disconnected from main grid, the chopping fraction increases with the increase off PCC. Therefore, the frequency of the inverter also increases, and all these processes will continue to reinforce the frequency shift to detect the islanding effectively. The detection time of SFS is within 0.5 s, and it even can detect islanding in 7 cycles [17]. This method, compared with another active methods, has the smallest NDZ. In addition, SFS is very effective to compromise the detecting efficiency, power quality as well as the impact on system transient response.

- **Sandia voltage shift (SVS)**

Sandia voltage shift is similar to SFS in principle. By applying a positive feedback to the amplitude of voltage in PCC, the inverter changes its current output and power output. When connected to main grid, the amplitude of voltage is not affected by power change, whereas without the support of main grid, power output changes can accelerate the voltage drift to detect islanding [13,17,27]. SVS is easy to implement, and it has the same efficiency as the SFS method which is based on positive feedback. The primary weakness of SVS is that it slightly degrades power quality. Secondly, because of changing the inverter's output power, it affects the maximum power point tracking algorithm of the inverter, reducing the inverter's operation efficiency [12,13].

- **Sliding mode frequency shift (SMS)**

SMS utilizes positive feedback to change the voltage phase of PCC, monitoring frequency deviation to detect islanding. In SMS, the current–voltage phase angle of the inverter is set as [9,20,28]

$$\theta = \theta_m \sin \frac{\pi f^{k-1} - f_n}{2\, f_m - f_n}$$

where θm is the maximum phase angle at the frequency f m, f n is the rated frequency, and f^{k-1} is the frequency of previous cycle. When the microgrid operates normally, its power factor operates with main grid. The phase angle between the inverter current and the PCC voltage is controlled to be zero or very close to it. When disconnected from main grid, the phase angle of load and the frequency will vary along with the SMS curve, and thus islanding can be detected if frequency variation exceeds the threshold. The detection time of this method is about 0.4 s [9]. Advantages of SMS are that it is easy to implement and has smaller NDZ than general active methods. Moreover, SMS is highly effective in multipleinverter systems. Disadvantages of the method are that it reduces the grid power quality and has certain impacts on system transient stability.

- **Variation of active and reactive power**

This method varies the output power injected by inverter and monitors the variation in voltage amplitude and frequency to detect islanding. For example, when a microgrid is islanding, the active power of DG will flow into the load. To balance the active power between DG and the load, the voltage variation must satisfy [27]:

$$P_{DG} = P_{LOAD} = \frac{V^2}{R}$$

Islanding can be detected when the voltage exceeds the threshold of OUV. In a similar way, the disturbance of reactive power will affect the variation in frequency, and islanding can be detected by measuring whether the frequency exceeds the threshold or not [13]. The detection time of this method is between 0.3 s and 0.75 s, and its advantages are that it is easy to implement, and has a small NDZ with less investment [25]. The greatest weakness is that it will lead to erroneous detect when multiple inverters are parallel at the same PCC. The method continuously varies power output of inverters, affecting the grid power quality and transient stability greatly. Variation of active and reactive power is generally applied in islanding detection for microgrid without multiple inverter

VI. CONCLUSION

This paper mainly discusses in detail about islanding condition, the detection methods that exist, their classification and details about a few islanding techniques. The methods can be broadly divided into active, passive, hybrid, involving communication and using artificial intelligence techniques.. Each method has been discussed with necessary examples. In part IV. Emphasis is put on discussing about the application of neural networks and fuzzy logic for getting better performance of islanding detection. Every method has its own feature, advantage and disadvantage. While choosing a particular detection method, one has to do a comparative analysis in terms of his own requirement. Faster detection may be achieved with the help of advanced methods but again those methods come at a heavy cost and may not be practically implementable due to its increased complexity. Therefore one has to do a compromise between cost and efficiency

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