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A Novel Method of Islanding Detection in a Distributed Power Generation System Integrated with Photovoltaic-Array

***Abstract**. Distributed generation (DG) systems have been widely applied in power systems and will also be the dominant part of future power systems. This type of generation system has features that are distinctive among non-renewable huge capacity fossil and nuclear power generation systems. These types of distributed generation are comparatively very small and most of them are constructed for the application of non-conventional energy such as hydraulic power or wind power in the generation of electricity. And, whenever this type of DG system are functioned in parallel together with main utility power systems, then particularly the power quality problem become more significant with reverse power flow. Reliability, frequency deviation, harmonics, and voltage deviation of the power system are the main power quality problems. Also, a critical, and major problem of power quality is an islanding protection. To resolve islanding problems, the detectors of islanding conditions are used to find an islanded situation and allow the circuit breaker to trip. These circuit breakers are available in between the distributed generation and the power system. This Paper presents a novel concept of the detection of islanding by the support of Slip Mode Frequency Shift (SMFS) technique for the defense of distributed generator fed systems from the Islanding conditions which has been tested and verified by the help of the proposed Simulink diagram on Matlab-2021a platform.*

***Streszczenie.** Systemy generacji rozproszonej (DG) są szeroko stosowane w systemach elektroenergetycznych i będą również dominującą częścią przyszłych systemów elektroenergetycznych. Ten typ ma cechy charakterystyczne dla nieodnawialnych systemów wytwarzania energii z paliw kopalnych i jądrowych o dużej mocy. Różne rodzaje generacji rozproszonej są porównywalnie małej mocy i większość z nich jest konstruowana do wykorzystywania energii niekonwencjonalnej, takiej jak energia hydrauliczna lub energia wiatru do wytwarzania energii elektrycznej. I kiedy ten typ systemu DG działa równolegle z głównymi systemami zasilania, to szczególnie problemy z jakością zasilania stają się bardziej znaczące przy odwróconym przepływie mocy. Niezawodność, odchylenie częstotliwości, harmoniczne i odchylenie napięcia systemu elektroenergetycznego to główne problemy dotyczące jakości energii. Ponadto krytycznym i głównym problemem jakości energii jest ochrona wysp. Aby rozwiązać problemy związane z wyspą, detektory warunków wyspowych są wykorzystywane do wykrycia szczególnej sytuacji na wyspie i umożliwienia przerwania obwodu. Wyłączniki są dostępne pomiędzy generacją rozproszoną a systemem elektroenergetycznym. Niniejsza praca przedstawia nowatorską koncepcję wykrywania zjawisk wyspowych przy pomocy techniki przesunięcia trybu poślizgu częstotliwości (SMFS) do ochrony systemów zasilanych z generatorów rozproszonych przed warunkami wyspowymi. Pomysł został przetestowany i zweryfikowany za pomocą proponowanego diagramu Simulinka na platformie Matlab-2021a. (**Nowatorska metoda wykrywania wysp w rozproszonym systemie wytwarzania energii zintegrowanym z matrycą fotowoltaiczną**)*

Keywords: Circuit breaker, distributed generations (DG), MATLAB-2021, non-detection zone (NDZ), PV- array, Slip mode frequency shift (SMFS), total harmonic distortion (THD).
Słowa kluczowe: Wyłącznik, generacje rozproszone (DG), MATLAB-2021, strefa niewykrywalna (NDZ), PV-ray, przesunięcie częstotliwości w trybie poślizgu (SMFS), całkowite zniekształcenia harmoniczne (THD).

1. Introduction

The situation in which a DG system continues to supply electricity even when power coming from an external power grid is no longer available. Whenever any distributed generation system having few loads is instantly disconnected from the main utility power system, the DG is still supplying the power to the loads and, but these are rare situations, prevails an islanding condition of the power system. These island conditions should be eliminated due to the protection causes of maintenance people and the improvement of power quality in the distribution lines [1]. The condition, when a part of the utility system is energized by one or many more distributed generation resources and that part of the utility power system is isolated electrically from the remaining part of the utility power system, is known as an islanding condition. Optimal islanding detection systems will function under all system situations with very high security and dependability. Unfortunately, getting a system with a absolute zero NDZ for all conditions and that has the lowest power quality erosion is very tough. With each islanding detection method, there are some factors, that can influence the sensitivity and quality of the system. The main objective of this paper has been to find an islanding detection technique that can work well in a zero-power flow situation and other operating situations with a very low cost of integration. The condition of loading for which the method of islanding detection could not operate at the time, then that zone is called the non-detection zone (NDZ). This zone is mainly used to estimate anti-islanding detection techniques [2]. Fig. 1 illustrates the non-detection zone of a power system.

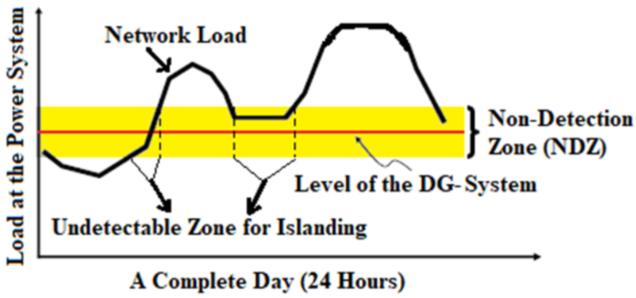

Fig. 1. Non-detection zone in a profile of the daily load

The islanding of distributed generations may be coincidental or intentional. Coincidental islanding can happen due to some normal fault or due to other uncertainties or climate issues such as heavy storms, heavy rain, etc. and intentional islanding can occur due to some scheduled maintenance at the utility grid. Fig.2 shows the general architecture of an islanding detection technique. In recent decades, the installation of distributed generators into low voltage buses near the consumers of electricity has been developed. Some novels confront the protection engineers, which are very different from various substantially radially based protection technologies. So, the classic protection configurations should reconsider like again closures unstable monitoring, protection zones of Impedance relay alongside the unwanted islanding detection of the DG system.

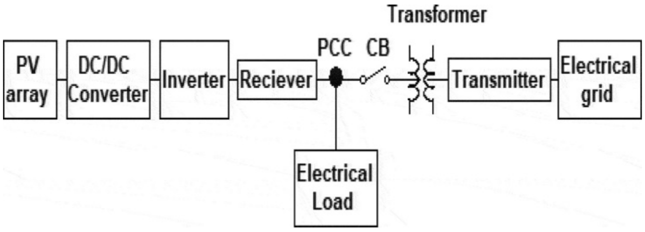

Fig. 2. The General Architecture of Islanding Detection Technique [3]

There are several methods for the protection of the power system from the islanding condition has been proposed yet. Islanding detection techniques are of two types: active and passive detection methods [4]. The passive islanding detection systems have over/under frequency and under/over voltage relays. This work is especially focused on the passive methods that have been proposed for DG systems. Fig.3 shows the type of islanding that occurs in the power system.

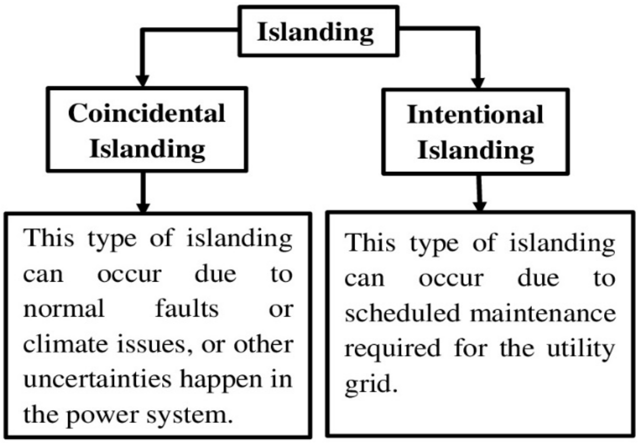

Fig. 3. Types of islanding in power systems

2. Previous Work

In recent decades, various research has been carried out for the detection of islanding in the DG systems towards getting the highest quality of power. S. H. Lee et al. [5] propose a methodology of passive islanding detection by zero NDZ property analysis by considering an inverter switching frequency of the DG system. This detection technique does not cause any bad impacts on the issues mentioned earlier because it obstructs the application of essential changes such as harmonic and reactive power fluctuations, which are needed in the detection methods of active islanding. W. K. A. Najy et al. [6] present a novel detection technique of passive islanding for DG systems having grid-connected inverters. An algorithm of statical signal processing known as evaluation of parameters of the signal via techniques of rotational invariance is utilized to extract novel features from quantifications of the frequency and voltage at the PCC (point of common coupling) as indicators of islanding. The rate of accuracy for this methodology towards differentiating non-islanding and islanding events is very high which means approximate 100%. H. Laaksonen [7] presents an algorithm of local passive detection techniques for the protection of DG systems. This novel algorithm estimates total harmonic distortion and voltage unbalance from every phase and can detect selectively and fast situations of islanding in an optimal balance of power without NDZ together with the utilization of the information available for fault detection and new verification logic of islanding. This technique provides better performance, high-speed detection, and reliability. Cassius R. et al. [8] present an analysis of effects caused by automatic reclosing of out-of-phase in DG systems integrated with the grid. Here, two cases are discussed: in the first method, it is assumed that the DG system cannot detect islanding and work with a controlled current during the reclosing; in the second case, the DG system can detect islanding, if the reclosing happens when the DG system is working with voltage control. The algorithm of synchronization and structure of control has been presented in this article. D. D. Reigosa et al. [9] explains the utilization of distortions of voltage in pulse width modulation source of voltage inverters caused by the switching of inverters for islanding detection. Here harmonics order is used for the detection of islanding, however, harmonics are a bad phenomenon that can reduce the quality of power. Passive islanding detection technique has been applied in this research article. D. Mlakić et al. [10] present a novel technique of the detection of islanding with the help of the Gibbs phenomenon-based hybrid technique in distribution networks having low voltage based on the integration of passive and active techniques of the rate of change of frequency at a given instant and estimation of fixed total harmonic distortion. This method exploits the occurrence of the Gibbs phenomenon at the insertion of sinusoidal functions. This paper shows that the proposed technique performs precise and fast detection of islanding in both high-power and low-power low-voltage microgrids with significant improvement in power quality. B. K. Choudhury et al. [11] proposed a new scheme of passive islanding detection techniques based on the collective summation of the superimposed impedance for DC microgrids. Here, current and voltage samples are gathered at distributed generations terminals to estimate a DC microgrids response to the condition of islanding. The collective summation of superimposed impedance and superimposed impedance is evaluated, and fluctuations in the collective summation of superimposed impedance are estimated to detect the phenomenon of islanding. This technique is more effective and takes less time to perform detection of islanding in the system.

3. Proposed Methodology

During some loading situations, a very less amount of power differences between the power of the load and the power of the inverter provides through the potential, during the frequency and voltage for the defined point of common coupling must be in between the typical point of operation starting and the point of an instant where islanding happens. In this situation, the corresponding protective relays are not able to find islanding. Then in this instance, another form of the detection of islanding technique must obtain the assurance that the inverter is not connected from the main utility grid in a period of the universal required time frame, and this is 150 MS (milliseconds) defined on the standard of IEEE.

Every grid-connected inverter has a few kinds of passive islanding, and each inverter contains under/over voltage relays and, under/over frequency relays. Whenever islanding occurs, then inverters are the only source for distributing power toward the given load [12]. Thus, the given frequency and voltage for the point of common coupling (PCC) may be replaced. This is because the active and reactive power does not match the localized load capacity of power utilization and the inverter capacity of output power production; these are shown in Eq. (1) and (2) [13].

$$P_L = \frac{V_p^2}{R} \quad (1)$$

(2) $Q_L = V_p^2 * \left(\frac{1}{2*\pi*f*L} - 2*\pi*f*C\right)$

where P_L is localized load power, V_p is the voltage and f is the frequency at the point of common coupling, Q_L is the reactive power of the load, R is the resistance of the load line, L is the inductance of the line, and C is the capacitance value of the system.

Detection of SMFS islanding technique is the unique and best suitable method which utilizes positive feedback towards the islanding finding, and it also applies positive feedback towards the inverter phase angle. SMFS islanding detection is implemented through the phase-locked loop (PLL) execution. If we acknowledge that there is no short message service (SMS) inside the main control panel of Inverter. The voltage and current phase angle are managed to be zero in every situation. During that situation, if the islanded part frequency is disturbed downward, then an adverse phase error could be observed by the phase-locked loop. Thus, the PLL may decrease the frequency of the system to bring the voltage and current output in the same phase. Now suppose the output current of the inverter and the phase angle is successful from the properties of the SMFS islanding detection phase angle [14]. Also, if the islanded part frequency is increasing, then the SMFS islanding detection characteristics create a positive error of the phase to the phase-locked loop, and the PLL frequency also increased. Whenever the frequency of the system increases, then the phase error will also increase, bringing the PLL into the condition of the further impression of the frequency value. Thus, the PLL control works in a bad direction towards the correction of the errors. This situation will remain available until the output current phase angle of the inverter and phase angle of the local load become the same. Thus, the output current of the Inverter will be explained by Eq. (3) [15].

(3) $I_{o/p} = I * \sin(2\pi * f * t + \theta_{smfs})$

where $I_{o/p}$ is the output current of the inverter, I am the current of the system, f is the frequency at PCC, t is the time and θ_{smfs} Phase angle for the SMFS method.

The inverter current phase angle is managed to get a sinusoidal function for the PCC voltage frequency deviation from the usual operating frequency for any utility power system. SMFS islanding detection phase angle properties will be illustrated by Eq. (4) [15],

(4) $\theta_{smfs} = \theta_{max} * \sin\left(\frac{\pi}{2} * \frac{f - f_u}{f_{max}}\right)$

where θ_{smfs} is the angle of SMFS islanding detection characteristic, θ_{max} (in degrees) is the highest phase shift angle, f_{max} (in Hz) is the value of frequency at the θ_{max}, f (in Hz) is the system's main functioning frequency, and f_u is main utility grid frequency which is the typical functioning frequency of 60 Hz.

Whenever the main utility system has an Inverter, the voltage of the point of common coupling has the rigid frequency, this frequency gives an absolute zero phase angle in the case of inverter operations, although when the islanding happens, the actual frequency of the point of common coupling fluctuates either in upward or in downward, depending on upon the disturbance direction. Also, the stable state of the frequency value may be explained as the frequency when the phase angle of the local load and the phase angle of the inverter are equal as given in Eq. (5) and (6) [16].

(5) $\theta_{load} + \theta_{smfs} = 0$

(6) $\theta_{load} = -\tan^{-1}\left(R * \left(2\pi * f * C - \frac{1}{2\pi*f*L}\right)\right)$

where, C is the capacitance of load, θ_{load} is the phase load angle, R is the load resistance, θ_{smfs} is the phase angle for the SMFS method, f is the main system frequency and L is the inductance of load.

According to the graph shown in Fig. 4, the point of the steady state is at the cross-section of the curve of the islanding detection phase shift response curve of the power system. The cross-sectional place may be unstable or stable. Also, whenever the cross-section point is not stable, it goes either downward or upward according to the direction of disturbance and gets settled at a novel steady functioning point. If the end steady functioning point is in between the permitted frequency range, this is between 49.5 Hz and 50.5 Hz, then the SMFS islanding detection is unable to find the islanding, and then the inverter shall continuously transfer power towards the islanded section of the DG grid [17]. Thus, the regular SMFS islanding detection has been enhanced to confirm the certainty that islanding should find for any conditions of loading. Advance SMFS islanding detection has almost zero non-detection zones, hence with the variation of the value of parameters of SMFS islanding detection depending upon the value of the impedance of the local load, detection of islanding must be sure for every situation of loading.

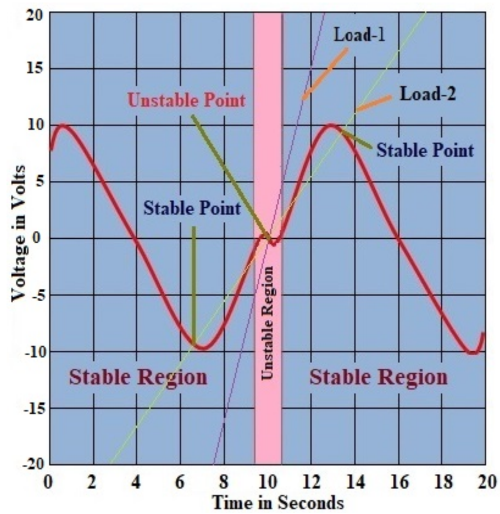

Fig. 4. Phase-shift islanding characteristic graph

During the starting period of the DG connected Inverter, when the inverter is at the primary level, then that time is the required time gap before linking the given inverter in the main grid of utility, in that period the local load impedance value must be evaluated. The procedure of the impedance of local load estimation must be repeated at a certain time interval after joining the Inverter from the main Grid. The procedure is done in this way when the shutdown of a given Inverter occurs periodically, which finishes only in a very fewer cycles. So, it's probable to find the load impedance of a given local load near the stage of a harmonic frequency created with the help of inserting the harmonic current through the Photo-Voltaic inverter at the place of PCC [18]. After that, we compute the response of voltage.

The flow chart in Fig. 5 shows the complete islanding detection process step by step. The initial step is the estimation of the algorithm of SMFS islanding detection with the help of formulation of the parameters $f_{max,}$ and θ_{max}. Now in the second part of the given algorithm, the connected load phase response slope will be estimated. Eq. (7), (8), and (9) represent how to find the connected load line slope near the elemental frequency according to [19].

(7) $$Q_f = \frac{R}{2\pi f_0 L} = 2\pi f_0 RC$$

(8) $$\theta_{Load} = -\tan^{-1}[R*(2\pi fC - \frac{1}{2\pi fL})] = -tan^{-1}\left(Q_f*(\frac{f_0}{f} - \frac{f}{f_0})\right)$$

(9) $$m_{load} = \frac{d\theta_{Load}}{df} = \frac{-Q_f(-\frac{f_0}{f^2} - \frac{1}{f_0})}{1+Q_f^2(\frac{f_0}{f} - \frac{f}{f_0})^2}\Bigg|_{f=f_0} = \frac{2Q_f}{f_0}$$

where Q_f is the quality factor of the system, f_0 is the elemental frequency, θ_{Load} is the phase load angle, m_{load} is the slope of the load line, and f is the frequency of the system.

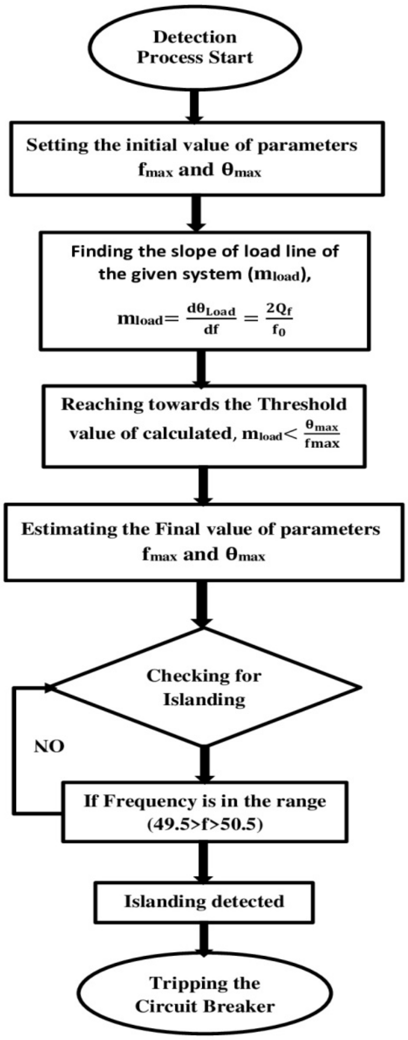

Fig. 5. Flow chart of the islanding detection process

The Quality factor (Q_f) can be estimated [19] with the help of harmonic inductance in the eq. (10).

(10) $$Q_f = 2\pi f_0 * R * C = R * X_c = R * h * X_h$$

where Q_f is the quality factor, h is the harmonics, X_h is the harmonics inductance, and X_c is the capacitive reactance.

Fig.6 shows that the values of parameters are adjusting there in the graph from curve 1 to curve 3 and finally at a point, getting fixed which is after than f_m, such as for Qf=1.5, 2.5, 3.5, ……, Value of θ_m are enhancing and Value of f_m are declining from curve 1 to curve 3.

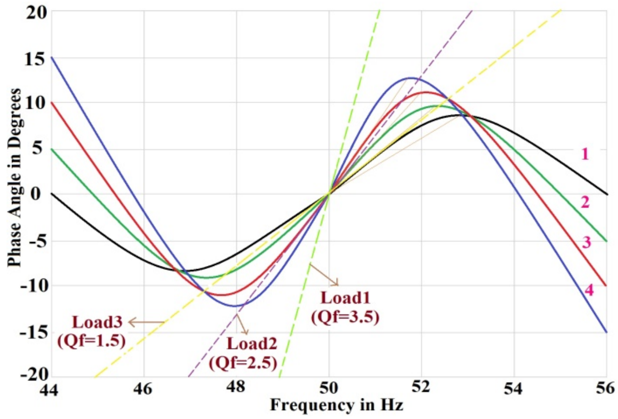

Fig. 6. Graphical representation of an algorithm for SMFS islanding detection technique

The fourth step in the SMFS islanding detection flowchart is to find whether the convergence point is either stable or not stable depending upon the DG system frequency; if it is not falling in the defined range from 49.5 to 50.5 Hz, then the system will have islanding problems. The actual value of θ_{max}/f_{max} is applied here as an estimation toward the slope value of the phase response detection curve of the SMFS islanding near the elemental frequency. Whenever the value of θ_{max}/f_{max} will be more than the slope of the load line near the elemental frequency, it means that the starting cross-section point will not be a fixed point. The point will slip towards another edge of the curve. And get a fix at near a point and that point is just ahead of f_{max}, as shown in Fig. 6. Thus, in this situation, whenever islanding generates, the last steady point of frequency will deviate from the defined range of frequency for the operation of the power system. Hence, the values of f_{max} and θ_{max} are fixed as optimal or final values for the perimeters of the detection characteristics of the island SMFS. But, in another case, if the actual value of θ_{max}/f_{max} is less concerning from the slope of the load line near the elemental frequency, the position of the cross-section must be a point of stability in the defined limit of frequency operation, but this will not be useful for us, as different loads are given in Fig. 6. Therefore, in this situation, the defined algorithm will get the estimated slope with the help of the decrement in the value of f_{max} by the amount of Δf_{max} and increase the value of θ_{max} by the amount of $\Delta\ \theta_{max}$ and check the situation once again. The appropriate values of f_{max} and θ_{max} get to variate until the situation when a, not a stable point becomes the truth. In the next step, the given values of fmax and θ_{max} are fixed as optimal or final state values for the parameters of the SMFS islanding detection characteristics. The performance of this algorithm to fix the character of the parameters is shown graphically with the help of Fig. 5. After fixing the end values of the given f_{max} and θ_{max}, then the inverter is almost ready to attach to the DG system. It is already defined that; the net local load value might be changeable whenever the Inverter application is in the distribution systems. Thus, repeated calibration of the islanding detection parameters of characteristic is necessary to confirm that the NDZ for this complete procedure is forever almost zero and that the islanded part can be found in the given time defined already. The output value that came from the calculated impedance can be implemented in the algorithm for the calibration of the parameters.

4. Block Diagram of the Proposed Model

Using various types of relays to locate islanding in the DG system is not an ideal methodology, and it has several drawbacks which are still available in addition to the other problems. To remove these issues, different types of new and modern detection techniques and simulation approaches have been implemented. The proposed model of the islanding detection technique can be well represented according to the block diagram as shown in Fig. 7. This block diagram shows the complete step-by-step process for detection of islanding in a typical DG- system. This model is well designed to detect islanding in the DG system with higher accuracy and less time for the protection of the DG system. The proposed block diagram is representative of the Simulink diagram. The major parts of the Simulink diagram are PV array, transformer, utility grid, 3-level of bridge inverter, RL filter, 3-phase circuit breaker, SMFS islanding detector, MPPT, 3 phase RLC load, and the utility grid. A Simulink function which is defined in the Simulink model, that one is established between PCC and inverter for the detection of islanding in the proposed model

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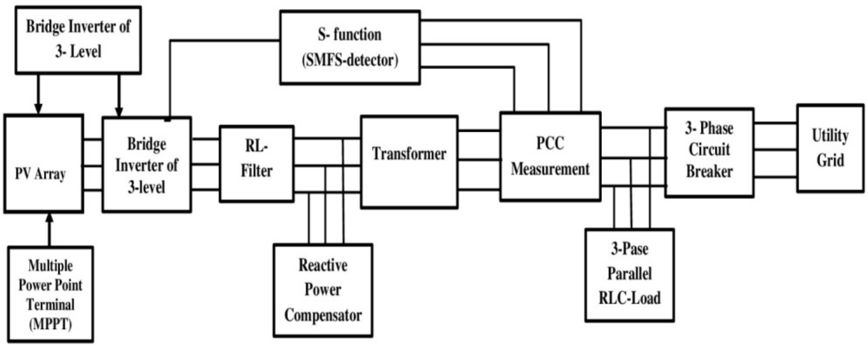

Fig. 7. Block Diagram of the Proposed Model

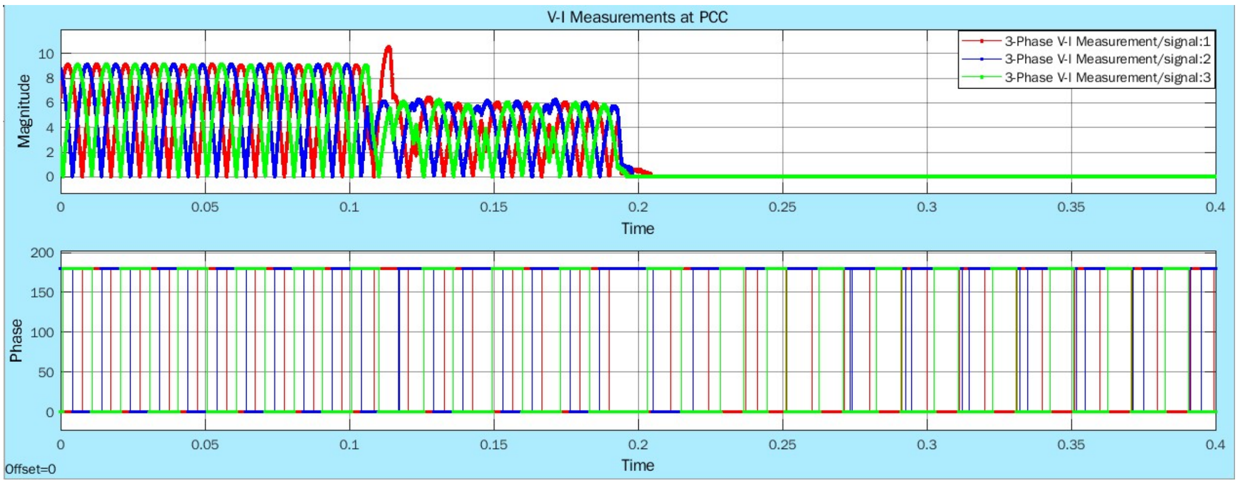

Fig.8. Measurement of V-I Characteristics at PCC

5. Result and Discussion

There are various types of islanding detection methodology have been discovered from the perspective that islanding performance should be neutralized. However, various novel techniques of autonomous distribution generation systems are also being implemented in the layout. Novel technologies are implemented such as controlling the power flow and stabilizing the control of output power by using power electronics equipment, a loop-type distribution system rather than radial, and a hybrid system having power electronics equipment, combined with a control and protection system, and collective information commute between resources and the customers. In such a type of novel system, the common boundary between the power distribution system and distributed resources will be exceptionally better and output controllability will be also better, and thus the result, power quality for the given distribution system must be well improved. Fig.8 demonstrates the V-I characteristics of the system at PCC.

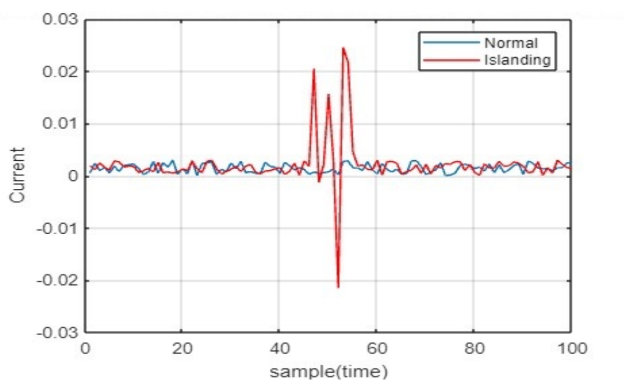

Fig. 9. Comparison between the sequence current for islanding and normal condition

The output that came from this model shows the distortion in frequency wave for a while as shown in Fig. 9, which means the islanding was detected properly by the proposed model.

An algorithm for spontaneous fixing, the variables of the SMFS islanding detection, is introduced. It has been proved that in this process of islanding detection the NDZ of the usual method of SMFS Islanding detection has been overcome, and the PV- inverter might find islanded part in any type of loading situation. This proposed islanding detection algorithm has been experimentally authenticated using the Simulink platform. The SMFS islanding detection method has been implemented in this research paper to remove the NDZ of the distributed generations. In this process of islanding detection, the variable of SMFS islanding detection change is dependent on the impedance value of the local load. The values of each parameter are calibrated periodically by calculating the impedance of the local load. Local load impedance can be calculated by injecting harmonic currents into PCC and measuring its voltage.

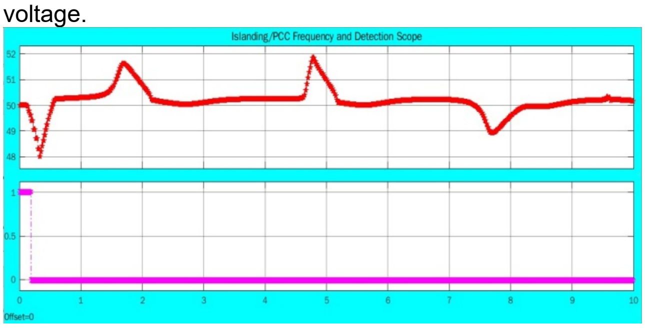

Fig. 10. Islanding/PCC frequency and detection scope1

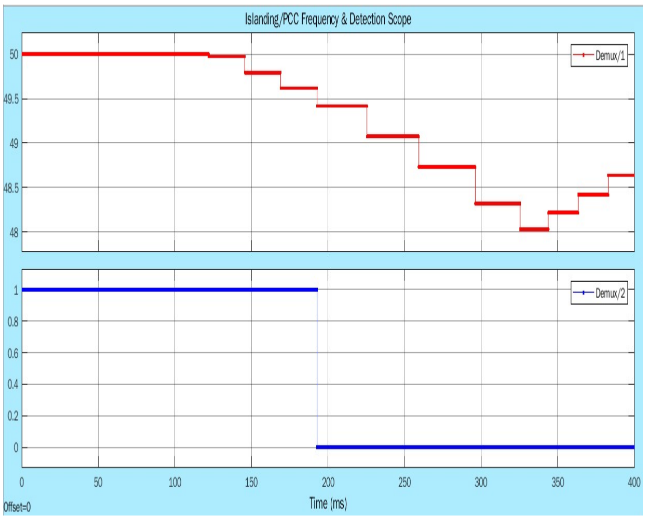

Fig. 11. Islanding/PCC frequency and detection scope 2

Figs.10 and 11 are the simulation scope from the proposed Simulink model. These figures are illustrating the output scope of the islanding detection and the frequency of the proposed system.

6. Future Research Prospective

There are already several techniques that have been discovered to encounter islanding in the power system, but the rate of accuracy of detection and timing to get accurate information are still a vital problem for researchers. Moreover, the idea of sequence components can be implemented for islanding detection, and the difference in angle between them can be considered for future research purposes. As well by employing a phasor measurement unit, and smart meters type smart grid components, we can detect islanded parts. The main advantage of this type of technique will be not required any other hardware or software unit for the detection of islanding. This will significantly bring lower the time of implementation and cost of making it economically and practically viable. Modern advanced digital signal processing methodologies such as Discrete Fractional Fourier Transform (DFrFT) integrated with learning algorithms can be employed in the future for the detection of islanding [20]. Current islanding detection models can be upgraded in the future for their better performance. Some significant issues have been not discussed yet for the islanding protections such as lower cost, lesser time, etc. in establishing the islanding detection model. Therefore, there are a lot of opportunities are available for the researchers to do their research on the protection of power systems from islanding conditions.

7. Conclusion

The accurate and fast process of the islanding detection phenomenon is one of the biggest challenges for technologists and engineers in recent power systems. Thus, the presented SMFS islanding detection methodology is introduced to get a better speed and higher accuracy detection technique. This Islanding detection technique was verified on a standard distributed generation system that DG contains multiple distributed resources and as well as with longer distribution circuits. The outcome of this technique specifies that this detection technique can detect islanding conditions with the highest degree of accuracy. It has also been found that this detection technique can be used to obtain the optimization value of the detection threshold of existing islanding detection methodologies. Fast and more appropriate islanding detection is one of the biggest challenges in recent power system operations with various generation systems that already have notable DG perforation because there are far fewer problems that could be solved with islanded conditions. Detection of islanding is also the main and important, as the operation of islanding of the DG system is discerned as a feasible future option to enhance the quality and reliability of the power supply. Furthermore, studies and research are required to achieve solutions to issues caused by instant load variation that might generate a wrong alarm in the process of islanding detection. The islanding caused by NDZ must be studied in detail furthermore. As NDZ is the important and main key index of performance for any process of islanding. The index of performance for the proposed methodologies is to be explained on an IEEE standard network of power distribution with various distributed generations interfaces.

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REFERENCES

[1] **"**Islanding**",** From Wikipedia, the free encyclopedia, March 22, 2022, available at https://en.wikipedia.org/wiki/Islanding (accessed on March 30, 2022).

[2] H. H. Zeineldin, A. Saif, M. M. A. Salama, & A. F. Zobaa, “Three-dimensional Non-detection Zone for Assessing Anti-islanding Detection Schemes”, Electric Power Components and Systems, vol. 38, issue 6, pp. 621-636, April 2009, DOI: 10.1080/15325000903489645.
[3] Y. A. Elshrief, D. H. Helmi, S. A. Elhaleem, B. A. Abozalam, and A. D. Asham, “Fast and accurate islanding detection technique for microgrid connected to photovoltaic system”, Journal of Radiation Research and Applied Sciences, vol. 14, issue 1, pp. 210-221, Dec. 2021, doi: 10.1080/16878507.2021.1923913.
[4] Z. Mi, and F. Wang, "Power Equations and Non-Detection Zone of Passive Islanding Detection and Protection Method for Grid Connected Photovoltaic Generation System," 2009 Pacific-Asia Conference on Circuits, Communications and Systems, 2009, pp. 360-363, doi: 10.1109/PACCS.2009.167.
[5] S. -H. Lee, and J. -W. Park, "New Islanding Detection Method for Inverter-Based Distributed Generation Considering Its Switching Frequency," in IEEE Transactions on Industry Applications, vol. 46, no. 5, pp. 2089-2098, Sept.-Oct. 2010, doi: 10.1109/TIA.2010.2049727.
[6] W. K. A. Najy, H. H. Zeineldin, A. H. K. Alaboudy, and W. L. Woon, "A Bayesian Passive Islanding Detection Method for Inverter-Based Distributed Generation Using ESPRIT," in IEEE Transactions on Power Delivery, vol. 26, no. 4, pp. 2687-2696, Oct. 2011, doi: 10.1109/TPWRD.2011.2159403.
[7] H. Laaksonen, "Advanced Islanding Detection Functionality for Future Electricity Distribution Networks," in IEEE Transactions on Power Delivery, vol. 28, no. 4, pp. 2056-2064, Oct. 2013, doi: 10.1109/TPWRD.2013.2271317.
[8] C. R. de Aguiar, G. H. F. Fuzato, A. F. Q. Gonçalves, K. Ottoboni and R. Q. Machado, "Out-of-phase automatic reclosing in distributed generation systems with voltage source inverters," 2015 IEEE 13th Brazilian Power Electronics Conference and 1st Southern Power Electronics Conference (COBEP/SPEC), 2015, pp. 1-5, doi: 10.1109/COBEP.2015.7420212.
[9] D. D. Reigosa, F. Briz, C. Blanco Charro, and J. M. Guerrero, "Passive Islanding Detection Using Inverter Nonlinear Effects," in IEEE Transactions on Power Electronics, vol. 32, no. 11, pp. 8434-8445, Nov. 2017, doi: 10.1109/TPEL.2016.2646751.
[10] D. Mlakić, H. R. Baghaee and S. Nikolovski, "Gibbs Phenomenon-Based Hybrid Islanding Detection Strategy for VSC-Based Microgrids Using Frequency Shift, THD_{U}, and RMS_{U}," in IEEE Transactions on Smart Grid, vol. 10, no. 5, pp. 5479-5491, Sept. 2019, doi: 10.1109/TSG.2018.2883595.
[11] B. K. Choudhury, and P. Jena, "Superimposed Impedance-Based Passive Islanding Detection Scheme for DC Microgrids," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 1, pp. 469-483, Feb. 2022, doi: 10.1109/JESTPE.2021.3076459.
[12] R. Raj, and M. Praveen, “Survey of Islanding Detection Techniques for Grid-connected Photovoltaic Inverters”, International Journal of Computer Science and Network (IJCSN), Vol. 6, Issue 1, pp.14-23, Feb. 2017.
[13] G. Wang, F. Gao, J. Liu, Q. Li, and Y. Zhao, "Design consideration and performance analysis of a hybrid islanding detection method combining voltage unbalance/total harmonic distortion and bilateral reactive power variation," in CPSS Transactions on Power Electronics and Applications, vol. 5, no. 1, pp. 86-100, March 2020, doi: 10.24295/CPSSTPEA.2020.00008.
[14] Y. Gao and J. Ye, "Improved Slip Mode Frequency-Shift Islanding Detection Method," 2019 International Conference on Virtual Reality and Intelligent Systems (ICVRIS), 2019, pp. 152-155, doi: 10.1109/ICVRIS.2019.00045.
[15] A. F. Sapar, C. K. Gan, M. Shamshiri, and A. N. Ramani, “Performance Assessment of Slip Mode Frequency Shift (SMS) Islanding Detection Methods”, Applied Mechanics and Materials 699, pp. 546-551, November 2014.
[16] M. Pahlevani, S. Makhdoomi Kaviri, P. Jain and B. Mohammadpour, "Advanced slip mode frequency shift islanding detection method for single phase grid connected PV inverters," 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), 2016, pp. 378-385, doi: 10.1109/APEC.2016.7467900.
[17 Z. Ye, A. Kolwalkar, Y. Zhang, P. Du, and R. Walling, "Evaluation of anti-islanding schemes based on nondetection zone concept," IEEE 34th Annual Conference on Power Electronics Specialist, 2003. PESC '03., 2003, pp. 1735-1741 vol.4, doi: 10.1109/PESC.2003.1217718.
[18] S. Akhlaghi, A. Akhlaghi, and A. A. Ghadimi, "Performance analysis of the Slip mode frequency shift islanding detection method under different inverter interface control strategies," 2016 IEEE Power and Energy Conference at Illinois (PECI), 2016, pp. 1-7, doi: 10.1109/PECI.2016.7459250.
[19] Liu Hongpeng, Liu Guihua, Wang Wei, and Wu Hui, "Research on a novel islanding detection technique," Proceeding of the 11th World Congress on Intelligent Control and Automation, 2014, pp. 5448-5452, doi: 10.1109/WCICA.2014.7053645.
[20] S. Dutta, P. K. Sadhu, M. J. B. Reddy, and D. K. Mohanta, ”Shifting of research trends in islanding detection method-a comprehensive survey”, Protection and Control of Modern Power System 3, 2018, doi: 10.1186/s41601-017-0075-8.