Islanding Operation of DG Integrated Distribution System: A Survey

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Abstract : The increasing demand of modern grids with good reliability leads to implementation of Distributed Generators in distribution networks. DGs may be renewable or non renewable energy based systems. These DGs operate either in grid connected mode or islanding mode. This paper is a review on Islanding mode of operation. Formation of islands may be advantageous or hazardous according to the real time operating conditions of distribution system. The paper is a survey of both the cases in islanding mode of operation. Also a comparison of all Anti-Islanding techniques is given on different parameters in tabular form

***IndexTerms* - Distributed Generation, Unintentional islanding, Anti islanding techniques, Intentional islanding.**

I. INTRODUCTION

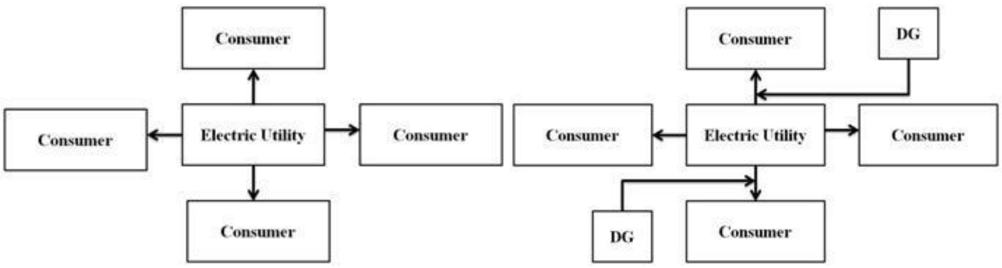
The quality of electric supply to the consumer is majorly affected by the continuity of supply. We can't consider central power systems very reliable as power is transmitted from long distances through transmission lines .Transmission faults, like breaking of line due to a tree fall, may lead to back to back failure of system equipments, [5]. Reliability of power system can either be measured in terms of continuation or in terms of net interruption in supply at consumers' end. Using components in parallel, alternative feeders to restore supply, application of more reliable components, backup protection, better maintenance, additional protection devices are some of the traditional methods of improving reliability.

Techniques like Renewable Energy, Distributed Generation, Electric Vehicle, micro-grid, energy storage, automation in protection devices and demand response are developed in order to improve system reliability. These techniques can further broaden the ways to get more reliable distribution systems. For example let us suppose an occurrence of fault in a part of system, then the energy storage system can continue the supply minimizing the time of interruption. If the load demand is more, then a cluster of conventional and renewable energy systems can supply power sufficiently. Demand response disconnects or shifts the critical load and reduce the load under fault condition. Due to the reduction in load the DG can restore the power supply in both islanded mode and grid connected mode of operation, [1].Therefore we can have immediate solutions for most of the contingent problems.

All these technologies have their specific impacts on reliability of distribution system. These impacts can properly be addressed to make better planning decisions.

Implementation of distributed generators near consumers' end is one of the most effective techniques to increase the efficiency of electrical system. Installed distributed generation capacity decentralizes the system and makes the power flow bidirectional and can be used to improve reliability of distribution system. Other than utility reliability, benefits like improved power quality, reduction in losses, voltage support etc can also be achieved. Although for achieving these benefits DG reliability and compatibility with utility are first and foremost, which is not so often easy because of the following prominent reasons-

- DG may not be owned by the utility i.e., there may be some other private players in electricity market.
- And DG may consist of different energy sources (wind, solar etc) which should be desirably synchronized with central system.



(a) Traditional distribution system (b) Modern distribution system

Fig.1 Block diagram representation of traditional and modern distribution system

DG sources are typically classified as synchronous or inverter based systems. For instance, small gas-fired machines used as backup units are classified as synchronous generators, while renewable energy sources like wind and solar are classified as inverter-based units,[4].

1.1 MODES OF OPERATION-

DGs on distribution network used for reliability improvement generally operate on two modes, they are –Grid connected mode and Islanded mode.

The grid connected refers to the areas of the network equipped with Normally Open Points (NOPs) that have limited capacity to transfer power from adjacent feeders. The Islanded mode refers to the areas isolated from the primary substation under fault conditions; in this case the DG units located within the isolated areas are used to provide energy that is not supplied by the primary substation, [1].

2. UNINTENTIONAL ISLANDING

When a part of distribution system is isolated from utility due to the operation of any upstream breaker, fuse or any static switching in condition of fault but the local distributed generators continues the supply to the isolated area, then this is called Islanding operation in distribution system. When the distributed generators get self excited and bear the load of isolated area then the area is termed as island.

Islanding of any section is not so desirable as it can be harmful to the distribution equipments and the workers as well. Islanding leads to safety and power quality problems in distribution system.

For example, if an island develops on a feeder during standard reclosing operations, the islanded DG unit will quickly drift out of phase with utility system during the "dead period". Then when a reclose occurs, the utility will connect out of phase with the island if reclose blocking into an energized circuit is not provided at the breaker control. This can cause damage to utility equipment, the DG unit supporting the island, and customer loads,[2].

Islanding may happen due to any transmission fault, equipment malfunctioning, substation failure or any similar reasons. And if islanding operation in system is not detected by utility protection system and corrective actions are not immediately initiated, then an unintentional power supply may occur. This may also result in failure of automatic reclosing, this condition give rise to need of manual reclosing which results in long discontinuity of power supply. To avoid such problems anti-islanding techniques have been developed and are under continues research programs. Accurate and immediate detection and protection from islanding is necessary in DG integrated distribution system.

3. ANTI-ISLANDING TECHNIQUES-

To avoid undesirable islanding anti islanding techniques have been developed which are classified under as following -

(i) Passive techniques
(ii) Active techniques
(iii) Remote techniques
(iv) Machine learning techniques,[4].

3.1 Passive Techniques for anti-islanding –

Variation in system parameters like voltage, current and frequency on the DG side at the point of common coupling is monitored to detect islanding. The passive techniques can be further classified as time domain and frequency domain,[4].

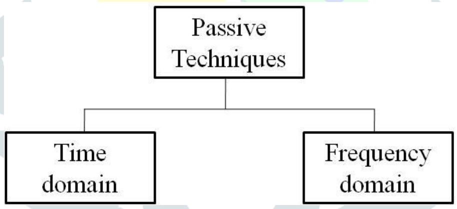


Fig.2 Classification of passive techniques of islanding detection

3.1.1 Time Domain –

Time domain AI techniques are divided into four categories on the basis of the parameter detected.

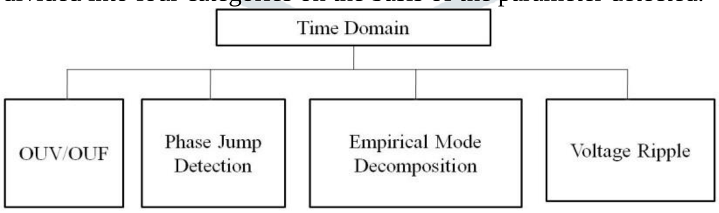


Fig.3 Classification of time domain passive AI techniques

OUV/OUF (over under voltage/over under frequency) techniques are most commonly used as they are not very complex and easily embedded in all PV inverters and the protective relays connected in protection system of DG, [6],[7].

These techniques continuously monitor the voltage and frequency at the point of common coupling if they cross the predefined threshold values, the protection system isolates the DG from the distribution system and turns it off. It is the oldest islanding detection method, hence it is simple but the reaction time is unpredictable and variable also its Non Detection Zone (NDZ) is large.

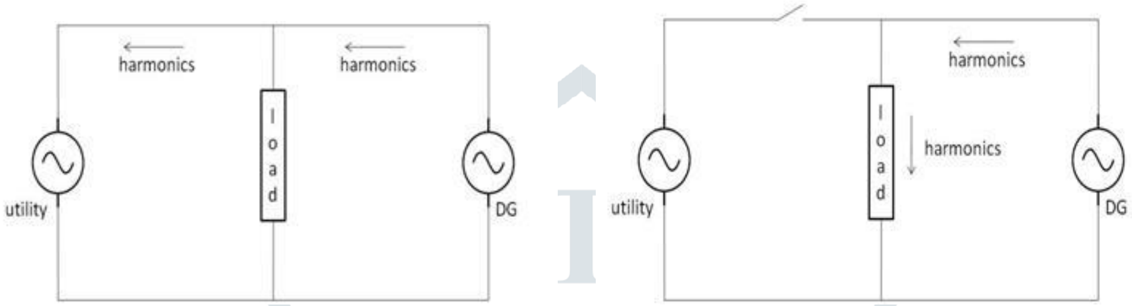
However for further improvements to overcome the limitation of large NDZ a method has been suggested in [8], in which P-V and P-Q characteristics of controlled constant current inverter is compared. In this method the islanding detection associated with interface control performances was applied in parallel to OUV/OUF as an additional parameter.

The other most commonly used time domain technique is voltage phase jump detection method (PJD). PJD method monitors the sudden change in phase difference between terminal voltage of inverter and the output current, [9]. DG system is synchronized with distribution system at unity power factor but when islanding occurs there is a sudden change or jump in phase, protection system of DG detects this change and turns the DG off to prevent islanding. This method can be used in multiple inverters without affecting the power quality of inverters, [10].This method is easy to implement but choosing threshold value is again a challenge. Although the NDZ is smaller than OUV/OUF method but when the DG power generation is equal to power demand of local load, the islanding is not detected. Hence, PJD is not suitable for detection of islanding of all operating conditions,[11].

Other two passive methods for islanding detection are proposed in [12] ;Empirical mode decomposition and [13];Voltage ripple method. The empirical mode decomposition method is also called shifting process. When the grid is disconnected and islanding takes place, then PCC voltage is affected and its components are considerably changed. On the other hand different modes of signals on different time scales can be extracted by using Empirical Mode Decomposition (EMD). Non linear signals are decomposed into its components by EMD technique. Hence, the basic concept of this method is to extract PCC voltage components and detect the changes in these components in order to detect islanding. Voltage ripple method of islanding detection monitors the converter-induced ripple in the PCC voltage amplitude. There is no NDZ in this method also the computation is easier and economical than frequency domain techniques.

3.1.2 Frequency Domain-

Frequency domain techniques monitor the harmonic content of the current and voltage signals at point of common coupling, [6]. Normally grid is connected to the system and harmonics are absorbed by low impedance grid but when islanding occurs the harmonics travel to the load and are detected by protection system to disconnect DG from system as illustrated in fig.4.



(a) (b)

Fig.4 Flow of harmonics in (a) Normal mode of operation and (b) during islanded mode of operation

The frequency domain passive AI techniques are classified in fig.5

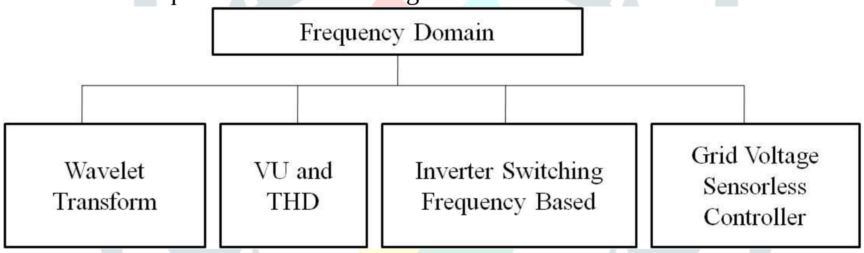


Fig.5 Classification of frequency domain passive AI techniques

Wavelet transformation method processes signals to estimate the frequency components of signals whose frequency components are time variant, [14]. Wavelet transform provides an efficient mathematical tool to analyze frequency components of signals. Low frequency components with high frequency resolution and high frequency components with high time resolutions of signal can be analyzed with wavelets. Useful information are extracted from current and voltage signals to calculate islanding detection parameters.

Islanding is also detected by Total Harmonic Distortion (THD) in DG inverter output current or the voltage on PCC. However, THD techniques can lead to false detection due to the possibility that non linear loads can increase the harmonics in system and if those harmonics detected they may lead to undesirable tripping if DG. To overcome this limitation of THD techniques Voltage unbalance was introduced, [15],[16]. Inverter switching frequency based techniques monitors the high switching frequencies of inverter, [17]. This method has no NDZ and it eliminate the false tripping due to non linear load present in system. It also remains unaffected by other DGs connected with the system.

3.2 **Active Techniques for anti-islanding –**

In passive frequency domain AI techniques we have seen that when the system is grid connected the harmonic distortions are absorbed by low impedance grid but when the grid is disconnected and islanding occurs these harmonics can be detected on PCC to detect and prevent islanding. In Active techniques these distortions the inserted in the inverter output current waveform. These distortions trigger the protection switches when islanding is detected. Active techniques are classified as following in [4].

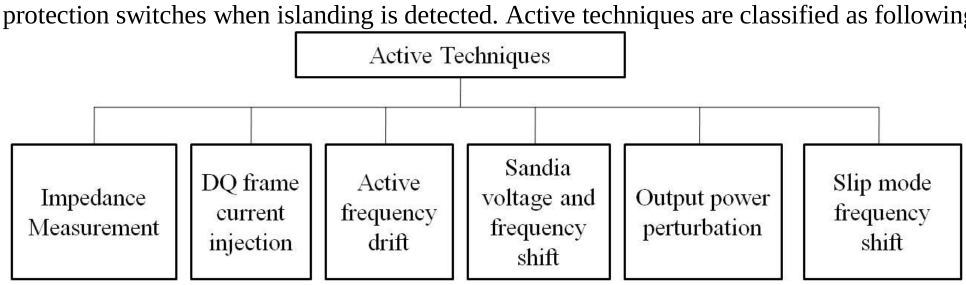


Fig.6 Topologies of active AI techniques

Generally impedance in grid connected mode is lower due to presence of low impedance grid in parallel to load. Impedance measurement techniques add new frequency components in the output current of inverter and determine the impedance. Hence different techniques to measure impedance and islanding detection through it have been proposed in [18 - 23].

DQ frame current injection techniques inject current in dq frame. DQ0 transformation is a tensor that rotates the reference frame of a three element vector to simplify the analysis. In electrical practices DQ frame is often used to rotate the reference frames of three phase ac waveforms such that they become dc signals. After computing a simplified analysis inverse transform is taken to obtain actual three phase ac results. In this technique dq components can independently control active and reactive power, which is an important advantage of this technique. In [24] the d-axis current and q-axis current injections at certain frequencies have been investigated. However, grid connected mode of operation remains unaffected by such current injections. But in islanded mode of operation, the d-axis current injection results in an additional component, which is very small and system dependent, and q-axis current injection deviates the frequency. Since this method was not applicable for Q>3 [4], modifications were made and a new index called Average Frequency Deviation Value (AFDVAG) was proposed in [25] and so one can refer for detailed information.

Active frequency drift technique forces the variations in inverter output and accelerates the frequency of inverter output current using positive feedback, [10, 26]. This method is easy to implement in microcontroller-based inverters given that all inverters must have identical AFD otherwise in multiple inverter case it would fail to detect islanding, [27].

Sandia voltage and frequency shift are the two methods applied to detect islanding. The principle of SVS is to apply positive feedback to the amplitude of voltage. SVS is very effective method however, this may cause very little effect on system transient response and power quality. In [28] addition of disturbance current through voltage source control was proposed to detect islanding more effectively. This method was faster and had a smaller NDZ. In [29] negative sequence current injection was proposed to obtain faster islanding detection. SFS have small NDZ and also not very difficult to implement. It is used in combination with SVS is considered to be very effective. The drawback of this method is power quality and system stability.

Slip mode frequency shift applies positive feedback to the phase of voltage at point of common coupling. This method is easy to implements because a slight modification of required component is involved in it. SMS is more effective than other active techniques and has a very small NDZ. The other common problems (power quality and transient response problem; common in all three positive feedback techniques) were improved in [30].

3.3 Remote AI techniques-

Remote AI techniques are mainly based on communication between central power-system, DG source and monitoring system. Remote AI techniques detect islanding from utility and takes corrective actions. Classification of remote islanding techniques is illustrated in Fig. 7

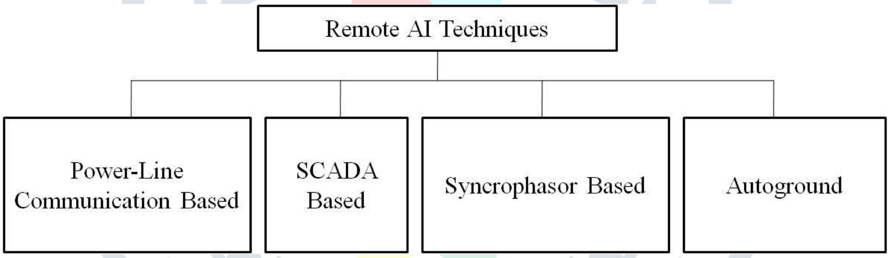


Fig.7 Classification of Remote AI techniques

In power line carrier communication techniques the encoded signals are sent via power line from the remote located utility. These signals confirms the grid connected with the system and if this connection is lost, it detects the islanding. The transmitters on utility side and receivers on DG side are installed, which makes this method too expensive to be used for small systems. However this method is very reliable. The design and implementation of this method can be referred from [31] and [32].

SCADA or Supervisory Control and Data Acquisition is a monitoring and controlling computer system. Voltage sensors are mounted on DG side of system if they detect voltage even after disconnection, the alarms are activated and corrective actions are taken in order to prevent islanding. This technique is very reliable and accurate but not used for small DG system due to expensive communication infrastructure.

Synchro-phasor or Phasor Measurment Unit sends a many synchronized current and voltage phasors to the utility every second. Two methods have been suggested for utilization of this data for control and protection; i.e. the Angle difference method and the Acceleration-Slip method. The angle difference method monitors the difference between the value of local and remote voltage angle, when islanding occurs this difference exceeds the threshold value for a period of time. The acceleration is first order derivative of this difference and slip is second order derivative of this difference. During islanded mode of operation the absolute values of acceleration and slip tend to rise higher otherwise they are very small in grid connected operation. On this principle Acceleration-slip method works. Another method was proposed in [34] in which an algorithm blocking logic was included to prevent nuisance trips. This method was a combination of angle difference method and acceleration-slip method.

Autoground prevents islanding by 3-phase short circuit at DG side to shut it down. A autoground switch is used to short circuit the three phase lines, this switch is coordinated with utility breaker. This technique is economical and protects the system in less than two cycles, [35]. Although this is applicable for only single DG source, but in future this may be modified for multiple DG implementation.

3.4 Machine Learning Based AI Techniques-

These techniques are based on algorithms that are trained to detect islanding operation by several parameters at PCC. Classification of these techniques is illustrated in Fig.8, [4].

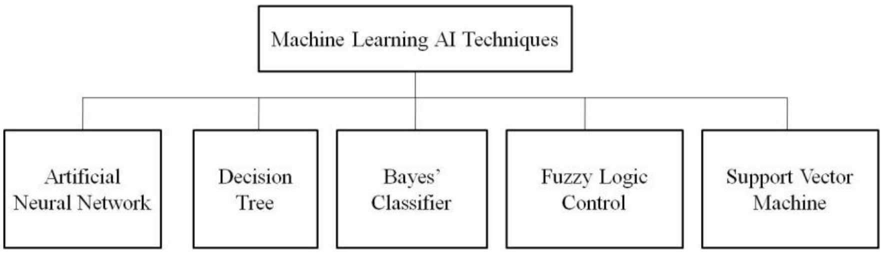


Fig.8 Topologies of Machine Learning AI Techniques

Artificial neural network method based on neuro-wavelet for multiple DG system was proposed in [36]. This method locally measures the voltage on DG side and hence can be categorized in passive techniques. The method has no negative effect on power quality and gives highly accurate results, also applicable for high loads. Another method also have been proposed in [37], in this method a modal signal is synthesized using the three phase current at DG terminal during disturbances. This modal signal is used to train an artificial neural network, by which the islanding is detected.

Another machine learning method based on decision tree was proposed in [38]. This method utilized the decision tree classifier for identification and classification of islanding detection by different parameters. The complex decision making is simplified with this classifier and easily interpretable decisions can be made, [39]. The limitation found in this classifier was threshold was dependent on the splitting criterion of respective decision tree. This criterion is about 83.3% accurate. Later a DWT was used in a combination with decision tree classifier which gave better results and accuracy around 98% and confidence level 95% with a response time less than two cycles. For detailed study one can refer [38-42].

A method proposed in [43] based on Bayes classifier. In this method quantitative data of fundamental difference in transient responses of mode of operation were obtained by using ESPRIT, which is a powerful statistical method for signal processing. The parameters were obtained from PCC voltage and frequency waveforms which were further fed to Bayes classifier, which have the capability of continues data handling in form of three discritization methods. Out of which two discritization methods (EFD and PKID) gave virtually error free classification as results.

Fuzzy logics are also helpful in islanding detection. Islanding detection using FL was proposed in [44, 45]. In [44] voltage frequency derivative and active power derivative were measured for Fuzzy Logic. The detection is based on multi criterion algorithm. In [45] a DT initialized fuzzy rule base classifier is used for detection of islanding. A crisp algorithm of decision tree is developed as classification model using DT. Fuzzy MFs are developed from DT classification boundaries The simplification and reduction of these fuzzy MFs are performed on similarities measures. This method provided 100% islanding detection and considered to be easy and accurate for development of real time relay application in large distribution networks.

In [46] an advance machine learning technique was used to detect islanding with the help of support vector machine. At first stage of this method the useful data is extracted from voltage and current signals by autoregressive signal modeling method. Then support vector machine classifier based machine learning technique is used to predict islanding condition from calculated input data. Machine learning classifier is a developed by Vapnik efficiently generalizes the parameters. It is based on SRM (Structural Risk Minimization), and makes good prediction for small data sets. The SVM classifier aims to produce data model in training phase. In testing phase, these data models predict the class level.

Table 1 is a comparison of all the anti-islanding techniques.

Table 1 Comparison of AI techniques-

Technique Name	**Type of techniq ue**	**NDZ**	**Impleme-ntation**	**Implem-entation cost**	**Time of operation**	**Effect on power quality**	**Reliability**	**Effect of connection of multiple DGs**
OUV/OUF	Passive	Large	Easy	Low	Unpredict-able	No effect	Low	none
THD	Passive	Large	Easy (but threshold selection in difficult)	Low	Small	No effect	Low	None
PJD/VU	Passive	Large	Difficult	Low	Small	No effect	Low	None
Impedance measurement	Active	Small (large for Q loads)	Easy	Low	Large	Degrades	High	Synchronizatio n issues
SMS	Active	Small (large for Q loads)	Not so difficult	Low	Large	Degrades	High	Synchronizatio n issues
AFD	Active	Small (large for Q loads)	Easy	Low	Large	Degrades	High	Synchronizatio n issues

SFS	Active	Small (large for Q loads) but less than other active techniques	Difficult	Medium	Medium	Degrades	High	Synchronization issues
SVS	Active	Small	Medium		Small	Harmonic distortions	High	
Machine Learning techniques		Small		Low	Variable	No effects	High	None
Auto-ground	Remote	None	Difficult	Very high	Very small	None	Very high	Increased cost
SCADA	Remote	None	Difficult	Very high	Very small	None	Very high	Increased cost
Synchrophasor based detection	Remote	None		Very high	Very small	None	Very high	Increased cost

4. INTENTIONAL ISLANDING

These were the methods in practice for prevention of undesirable islanding. But when there is no intentional power cut from utility i.e.; a power cut is caused due to fault at transmission side or generation end then it is necessary to island the load (partially or fully). As stated before islanding makes the power flow bidirectional and stands for many benefits. But to acquire those benefits the system must be well coordinated, both technically and non technically (coordination of central utility and DGs). When islanding occurs, the utility losses its control from the system and new control systems take over, which depends on the islanding method agreed by utility and integrated DGs. The limitations like good communication techniques, appropriate control and protection are yet to be overcome in order to permit intentional islanding in practice. There are several indices that affect reliability of intentionally islanded system; actuation of protective devices, generation and load models, adequacy assessment of load and generation, etc.

Table 2 and 3 are the voltage and frequency limits derived from international standards a secure, reliable and efficient power supply to the consumers that are part of the formed island.

Table 2. Respond of interconnection system during abnormal voltage

Voltage range (% of base voltage)	Clearing time
V < 50	0.16 s.
50 ≤ V < 88	2.00 s.
110 < V< 120	1.00 s.
120 ≤ V	0.16.

Table 3. Respond of interconnection system during abnormal frequencies

DR size	Frequency range (Hz)	Clearing time
≤ 30 kW	>60.5	0.16
	<59.3	0.16
>30 kW	>60.5	0.16
	<{59.8 – 57.0} (adjustable set point)	Adjustable 0.16 to 300
	<57.0	0.16

DGs should cease to energize the parts of the network supplied by them during certain clearing times prescribed by IEEE 1547-2003 standards in table 2 and 3. If these abnormal situations can be avoided by properly implementing the protection system, then islanding operations can be successfully implemented.

The most important states to be planned very efficiently for successful implementation of islanding operation are – the transition from grid connected mode to islanding mode and the operation of islanded part when it is disconnected from the central utility.

4.1 Load sharing islanding method.

It is an islanding method in which all the DGs connected in an island are compelled to participate and share the load actively, this method of islanding is called load sharing method of islanding. For more information about load sharing one can refer [48-50]. Following fig.9 is a guide of IEEE standards for interconnection of DG into the system.

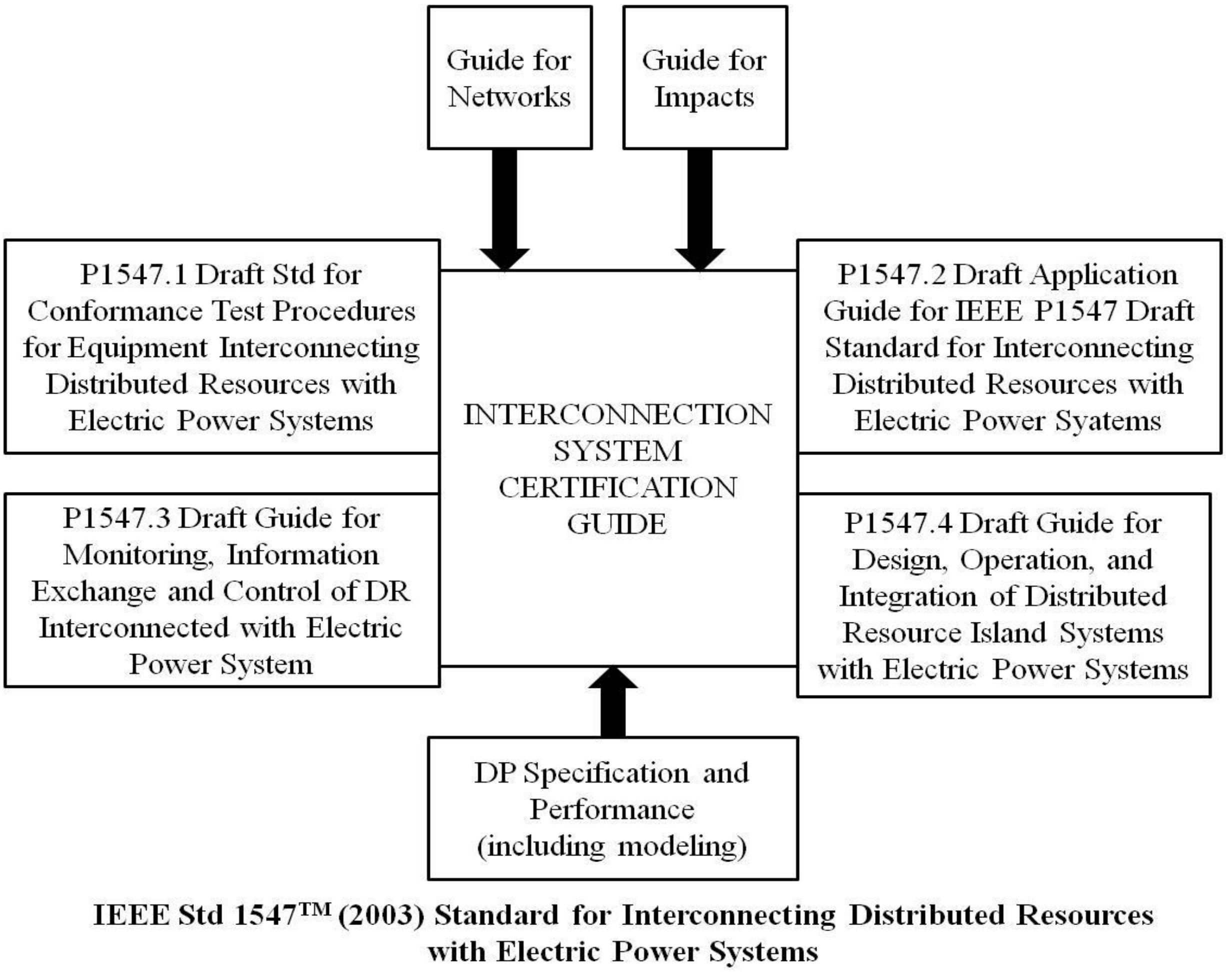


Fig.9 IEEE Std 1547^{TM} (2003) for interconnecting DGs with power systems

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