Study on Renewable Distributed Generation, Power Controller and Islanding Management in Hybrid Microgrid System

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Abstract

This paper presents the latest trends and challenges in renewable based distributed power generation, control, and islanding management in hybrid microgrid system (HMS). With evolution of distributed generation (DG), the power conversion, transmission and distribution losses have been reduced significantly in electrical system. Further, the reliability and security of the power system network have also been enhanced with reduced carbon emission to the environment. It is witnessed in recent years that the development and implementation of emerging DC grid system with the counterpart. In this paper, we have suggested and discussed the hybrid microgrid architecture with the combination of DC as well as existing AC microgrid. Further, different sources of DG are discussed and classified for HMS. The state of art for both AC and DC bus voltages in the HMS is presented. HMS has both AC and DC natured sources and load, therefore, the power electronic converters play crucial role to enhance the performance of the HMS. Thus, selection methodology and design parameters of power converter have been extensively analyzed and addressed in the paper. The comprehensive

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review of various islanding detection techniques are addressed as per IEEE 1547–2003 standards. Finally, the implementation challenges of islanding detection in HMS are presented and summarized in the paper.

Keywords: Distributed generation system, hybrid system, microgrid, renewable energy, smart grid.

Nomenclature

ΔP	:	Active power balance in the network.
P_L	:	Active power at load.
P_{IG}	:	Active power at the inverter.
ΔQ	:	Reactive power balance in the network.
Q_L	:	Reactive power at load.
Q_{IG}	:	Reactive power at the inverter.
R_{in}	:	Input resistance
R_o	:	Output resistance
R_L	:	Load resistance
D	:	Duty cycle

1 Introduction

Energy is one of the fundamental to quality of lives and key ingredients in all sectors of modern economics. There is a huge demand of energy to fulfill the different needs of life which require uninterrupted and abundant energy resources. In coming days, energy demand will shoot up to 60% in developing countries like India. Growing electricity demand will remain the biggest carter of energy needs, and electrical energy will account for 40% of global energy by 2040. Keeping pace with energy demand growth; would require an exceptional level of investment and research. It has also made the country to become more dependent on fossil fuel such as coal, oil, and gas, whose rising price and potential shortage have raised uncertainties about the security of energy supply in future. The dependency on fossil fuels will directly affect the growth of the national economy of any country at the same time increasing use will also causes environmental problems. Hence, there is a primary need to use sources of energy which are easily available, renewable, suitable for the environment, and economic benefits. The renewable resources like solar, wind, tidal and micro-turbines provide clean and free energy but have their own challenges such as reliability of supply, difficulty in bulk generation, substantial capital cost, and large tracts of land requirement [1]. The solution to the challenges mentioned above is a tradeoff between conventional and renewable sources of energy, which will be economical, stable and reliable supply system [2].

The use of renewable resources has led to a paradigm shift in the way of electrical power is generated, transmitted and consumed. Technological advancement and regulatory changes in power system have resulted in the emergence of a smaller generating system like micro-turbine, wind energy conversion system (WECS) and PV solar system; have opened up new opportunities for the generation at site, which is termed as distributed generation system (DGS) [2–6]. DGS have the advantage of reducing power losses in the network by supplying the load demand locally. Further, it improves voltage profile, reliability, productivity, and security for critical loads. It also helps in load management, peak load shaving, flexibility in installation reduction in emission, and effective energy pricing. DGS have come up as a promising solution to meet the growing energy demand. In the initial stage of development, DGS were primarily used as back up source and standalone power supply. With technological advancement, the role of DGS has changed from backup to primary energy supply by synchronizing to the grid power supply. This particular change in the role of DGS has led the concept of the microgrid. A microgrid can be defined as a scaled version of existing centralized grid connected system with their local control strategy for coordination control [7]. A microgrid is one of the most effective and efficient ways of integrating renewable energy resources into the utility grid. It helps in overcoming the adverse effect of the renewable energy resources, enhances the performance, reliability of the power supply and the efficiency of the power system. Because of the presence of, both DC nature of some power sources, load, storage system, and the existing old AC power system, there is a need for a system which can incorporate all the parameters of AC and DC microgrid into one platform which is termed as a hybrid microgrid system (HMS). The HMS has AC as well as DC generation, transmission, and distribution and also has the features of both old existing AC system as well as DC system. The system can be considered as an impending generation, transmission, and distribution system. Instead of having the overall AC or DC microgrid concept in which unnecessary power conversions from DC to AC or vice-versa takes place causing power loss. Hence, the concept of HMS is proposed where renewable resources and load both are AC or DC in nature [8, 9].

In an HMS, AC loads are supplied by AC renewable resources and DC loads along with storage elements are connected to DC sources. The overall system is synchronized to the central existing grid having conventional resources with bidirectional flow of energy. The HMS will reduce the power conversion, transmission and distribution losses and has also increased the reliability of the system [10–12]. There are certain cases in which the central grid is not able to power the system/utility whereas distributed generator continues to power the utility which can be dangerous to utility workers and is referred as islanding. So, it is important for distributed generation to detect such islanding and immediately halt the power generation and is called as anti-islanding. According to IEEE 1547–2003 standard, when the islanding will be detected, DGS has to be disconnected within a time frame of 2 seconds [13]. Sometimes, distributed generator are disconnected from the grid and forced to power the local utility and is called as intentional islanding. The intentional islanding is mainly done as a backup power system for generators that usually sells their surplus power to the grid [14]. Islanding can help in enhancing the reliability and security of power supply and also have economic benefits [15]. The islanding transition is an important aspect which involves different types of the control strategy, power management, and protection scheme [16, 17].

For the smooth and reliable operation of HMS, there are three critical aspects, which can be classified as control strategy, power management and protection scheme [18–20]. It is very important that a microgrid operation is stable and power quality is maintained at point of common coupling. Moreover the power flow control and intelligent coordination between internal systems is desirable. The control is simple in case of a DC microgrid as compared to an AC or HMS. For safe and reliable operation of any microgrid topology a well-equipped and functional protection scheme is instrumental. The principal aim of a protection scheme is to detect the fault and prevent it from spread further by isolating it within the desired (minimum) time frame. Further, the challenge lies in extinguishing the arc in DC system which happens obviously in AC system [21, 22].

In this paper, a novel HMS architecture has been suggested for better reliable and economical operation in Section 2. Detailed study on various DGS technologies, interfacing converters and coupling converters is presented in Sections 3 and 4 respectively. In Sections 5 and 6 detailed reviews on islanding transition and islanding detection is presented.

2 Architecture of HMS

In this paper, the hybrid system refers to an HMS which contains both AC and DC microgrid. Voltage level in a microgrid is always a tradeoff between safety, cost and efficiency. The AC bus voltage is kept as 230V (single phase) and 415V (three phase) in HMS. However, the DC bus voltage may vary according to the application i.e. 400V DC is used in data center. Since the voltage level is high, accurate grounding and protection is a requisite. Apart from 400V DC 325V, 230V, 120V, and 48V DC are also used as bus voltage [23–25]. 48V DC bus voltage is preferred for residential application considering the safety and efficiency factor. However, 400V is preferred for commercial application. The structure of HMS depends on the connection of DGS and loads which are connected to the system and the configurations of AC or DC buses. In DC microgrid, various DGS and storage devices are connected to a DC bus with the help of interfacing converters. In AC microgrid, DGS and storage devices are connected to a common AC bus through interfacing converters. Further, both buses are connected to utility grid using suitable interfacing devices. In HMS, AC and DC buses are interlinked to each other by using suitable coupling converters, as shown in Figure 1. Under normal operating condition, the loads connected to AC/DC buses are supplied by DGS which are connected to respective buses. In case of surplus power generation, the storage element is charged and the power is supplied to the grid. In case of power imbalance, coupling converter allows bidirectional flow of power, and storage maintains the stability of the system. The various DGS which are considered in this hybrid system are solar PV, the WECS, fuel cells, microturbine, and reciprocating engine.

3 DGS Technologies

A small-scale conventional or non-conventional generation unit located near the load is called as distributed generation[5, 26, 27]. As per the perspectives of different engineering association and organizations, the standards of DGS are described as follows.

- Electric power research institute defines distributed generation from a few kW to 25 MW.
- Gas research institute defines distributed generation between 25kW to 50 MW.
- Cardell defines distributed generation between 500 kW and 1 MW.

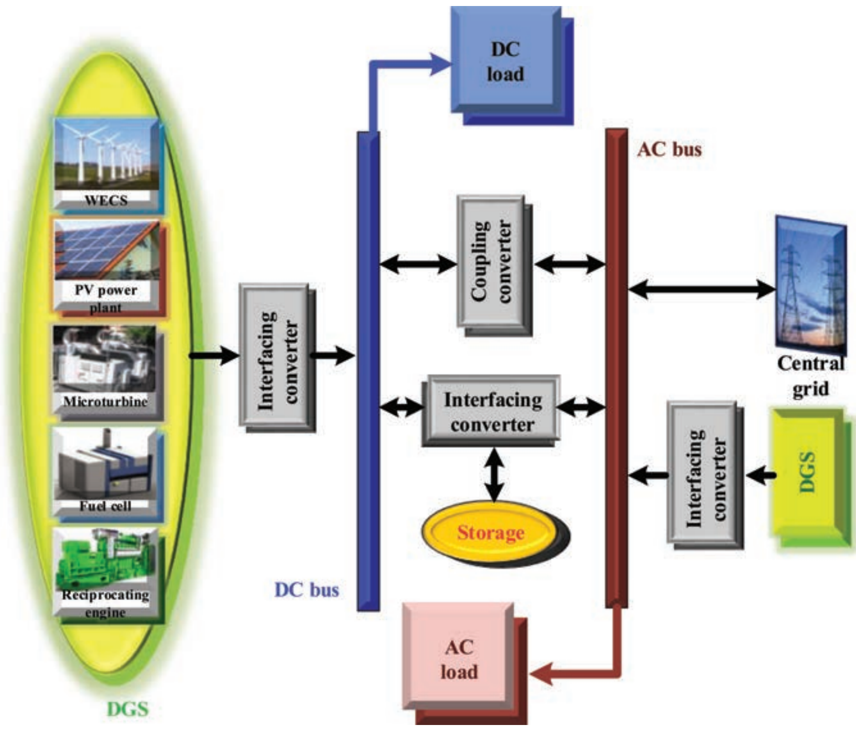


Figure 1 Architecture of hybrid microgrid system.

- Preston and Rastler define distributed generation from few kW to 100 MW.
- The international conference on the large high voltage electric system (CIGRE) defines distributed generation below 100 MW.

Distributed generation has a significant number of technologies which can be classified as given in Figure 2.

4 Power Converters in HMS

Renewable resources (RR) generate power at different pattern than required by the load. They are intermittent in nature; output depends upon the environmental condition and varies with varying loads. Hence, an interfacing unit is required between the load and the source which makes it compatible [28]. Different power converters involved in the renewable power generation are DC-DC converters, DC-AC converters, and AC-DC converters.

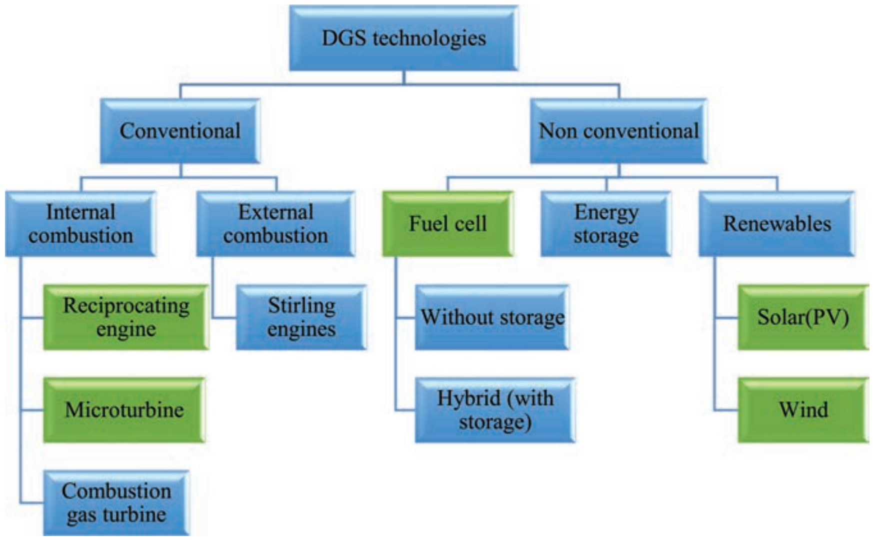


Figure 2 Classification of DGS technologies.

Power converters perform the following tasks in renewable power generation [29]:

a) Interfacing unit: It provides the power from the source to load at desired voltage, frequency, whether DC or AC.
b) Buffer unit: It provides robust output to the load by rejecting input and output variations.
c) Impedance matching: It matches the equivalent source impedance with the load to extract a maximum power.
d) Integration: Integrate many RR with load simultaneously.
e) Synchronization: Synchronizing the output power of the RR to the grid.

Desired features of the power converters as an added stage between the source and load are:

a) It should not degrade the efficiency of the energy extraction from the RR.
   i) A minimum number of switch counts to have minimum switching losses and conduction losses.
   ii) Less number of power conversion stages to interface the RR and load.
b) Presence of power converter should not make the response of the system sluggish rather.

i) It should improve the settling time of the system to reach the steady state after any sudden disturbance to the system.
ii) The system should not have undershoots or overshoots in the output during the transient response.

c) The power converter should not inject much harmonics at the source or load side.
d) It should have continuous ripple free input and output currents for easy sensing to implement the maximum power point tracking (MPPT).
e) It should not degrade the stability of the overall system.
f) The control should be simple, robust and easy to implement.

4.1 DC-DC Converters

A DC-DC converter is a switched mode power converter (SMPC) consisting of semiconductor devices like MOSFET that operate either in ON or OFF states which results in low (ideally zero) on state conduction losses. Hence, SMPC have higher energy conversion efficiency. The high switching frequency operation of DC-DC converter facilitates the reduction in the size of transformer, filter components such as inductor and capacitor. Thus, high frequency operation increases the energy density of the DC-DC converter based switched mode power supplies. The conventional DC-DC converter cannot provide the high voltage gain for the sake of constraints like losses associated with the inductors, capacitor, and diode, the risk of pulse modulator saturation, efficiency degradation, and electromagnetic interference. Therefore, different topologies have been suggested in the literature using a transformer to achieve the desired voltage gain to ensure reliable grid-connected operation of renewable resources. The problems associated with those topologies are increased in magnetic, electrostatic components, switches, control complexity because of increased switches and increment in cost and size with transformer based converters. To avoid the problems raised due to the isolated DC-DC converter, the cascaded DC-DC converters are proposed. But, cascaded DC-DC converters are having more number of switches. So, to reduce the number of active switches in the cascaded DC-DC converter, a single active switch based converters are derived such as quadratic converter (QBC), cubic, and n-converters.

4.1.1 Classification of DC-DC converters

The power converters have been fed variable DC as input and provide regulated DC at the output. It will be used to interface RR with DC nature of sources

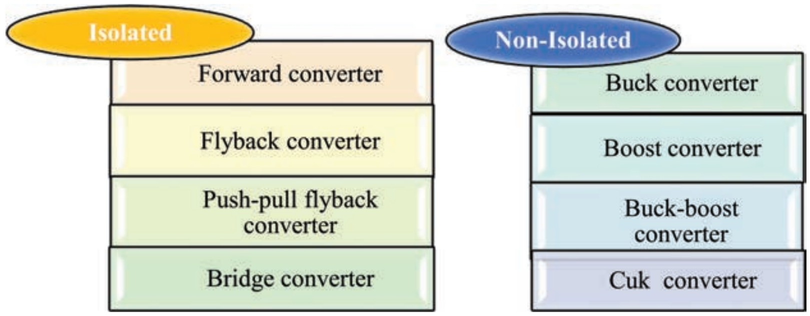


Figure 3 DC-DC converter classification in terms of isolation.

like PV system, fuel cell, and microturbines to DC load or DC link [30]. DC-DC converters could be classified based on the number of inputs/outputs as single input single output converters or multiple input multiple output (MIMO) converters [31]. Also, on the basis of isolation perspective to the load from source, it is classified as isolated converters and non-isolated converters. Different topologies based on isolation are shown in Figure 3.

4.1.2 Multi-port converters (MPC) configuration

Since, RR is intermittent in nature, for reliable and smooth supply to the load is provided by employing battery bank in the system. The battery bank is the bulkiest and expensive part in terms of smaller lifespan and frequent regular maintenance requirements which will increase the already high capital investment of RR installation. Further, battery management system has also to be incorporated which will again increase the cost. The more promising approach is using, MPC for further reduction in cost of the system [32]. It takes input from different resources to supply the load continuously and optimizes the energy extraction from renewable and reduces the operating cost with reduced carbon emissions. Thus, it results in simplified circuit topology with central control and implementation at less cost and reduced size [33, 34]. Different MPC topologies based on the coupling element are shown in Figure 4.

4.1.3 Selection of power converters topology

Depending on the type of RR, nature of load, and function performed by the converter, the converter topology has to be selected from the existing converter topologies [35]. The features of the various DC-DC converters are tabulated in Table 1. According to maximum power transfer theorem, maximum and

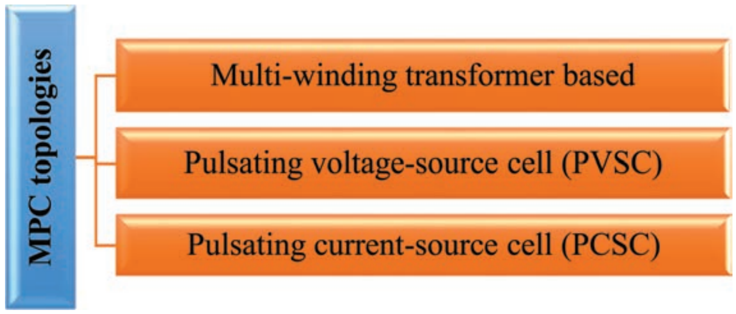


Figure 4 Different MPC topologies based on coupling element.

Table 1 Performance characteristics comparison of DC-DC converter

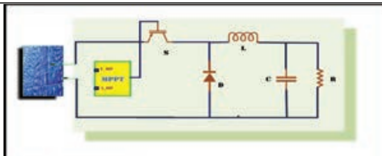
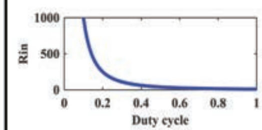
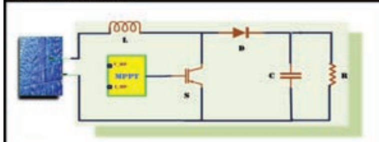
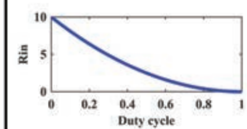
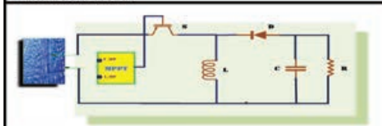
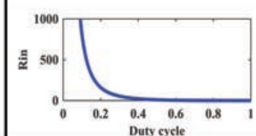
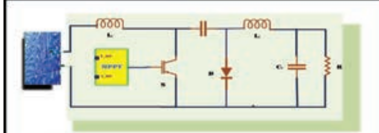
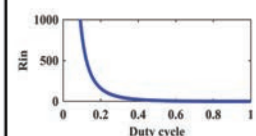
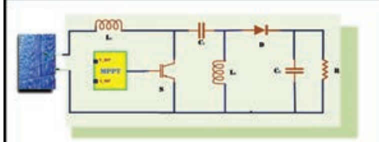
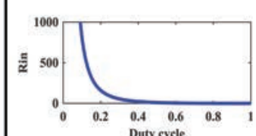
Feature	Buck Converter	Boost Converter	Buck-Boost Converter	Cuk Converter	Sepic Converter
Input current	Pulsed	Continuous	Pulsed	Continuous	Continuous
Output current	Continuous	Pulsed	Pulsed	Continuous	Continuous
Output voltage magnitude as compared with input voltage	Lesser	Higher	Lesser or greater	Lesser or greater	Lesser or greater
Output voltage polarity	Same	Same	Reverse	Reverse	Same

optimum energy from RR is extracted by impedence matching. Thus, DC-DC converter is used as interfacing device between the load and the RR to match the impedence. The DC-DC converter equivalent resistance versus duty cycle characteristics are also presented in Table 2 for MPPT algorithm for any renewable energy system [36, 37].

4.2 DC-AC Converters

The DC-AC converter (or inverter) converts DC input voltage to AC voltage at the output while keeping up the international standards, such as IEEE-519 and IEC-1000-3-2 [38, 39]. The inverters make RR with DC output compatible to AC load in a standalone system or synchronize with the supply in grid connected system. In general, conversion takes place in two power stages i.e. pre-regulator and inverter as shown in Figure 5. Pre-regulator stage consists

Table 2 Equivalent resistances of various power electronic DC-DC converters

Converter Topology	R_{in} Vs D Characteristics	Equivalent R_L at Input of Converter
 **Buck converter**		$R_{in} = \frac{R_o}{D^2}$
 **Boost converter**		$R_{in} = (1-D)^2 R_o$
 **Buck-boost converter**		$R_{in} = \frac{(1-D)^2 R_o}{D^2}$
 **Cuk converter**		$R_{in} = \frac{(1-D)^2 R_o}{D^2}$
 **Sepic converter**		$R_{in} = \frac{(1-D)^2 R_o}{D^2}$

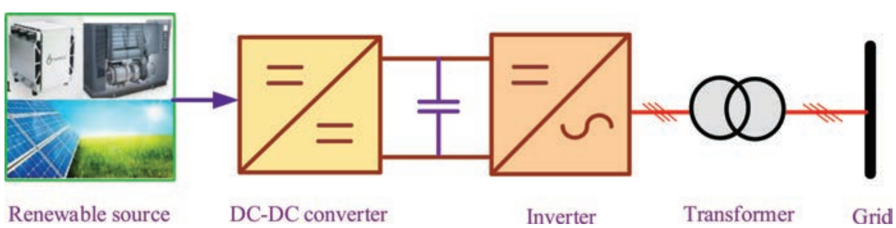


Figure 5 Power converter architecture for injecting renewable energy to the grid.

of DC-DC converter that performs the task of MPPT for RR [40]. As the power converters have semiconductor switches and filtering elements such as inductor and capacitor which are lossy and non-linear in nature. Thus, it poses hindrance in achieving high system efficiency and designing the control system.

4.2.1 Classification of DC-AC converters

Based on the power rating, the inverters are mainly classified as a central inverter, string inverter, and micro-inverters or module integrated inverter (MIC) [40, 41] as shown in Figures 6 and 7. String inverters have been used in the residential and commercial application. Power rating of string inverters could be easily extended by parallel operation of the inverters. MIC offers the plug and play facility which optimizes the energy extraction from the RR but it has the issues that still need to be resolved are cost, reliability, and stability [42].

4.2.2 Design parameters challenges

a) Power density: It is the indicator of compactness of the inverter. For MIC, the goal is to achieve 1 W/cm^3 [43].
b) Efficiency: High efficiency of the power converter is important to extract maximum energy from the renewable resources. The following factors are affecting the efficiency of the system:
    i) Leakage current: In PV inverters, leakage current is an important factor to consider for static efficiency. Leakage current issue is addressed by providing galvanic isolation to the PV arrays

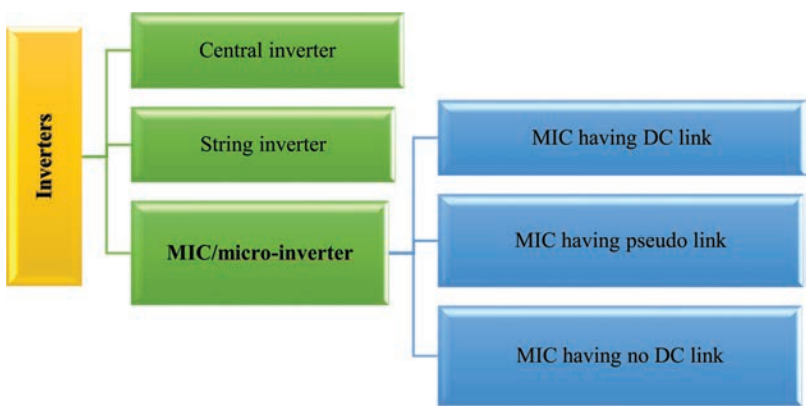


Figure 6 Classification of inverters based on power rating.

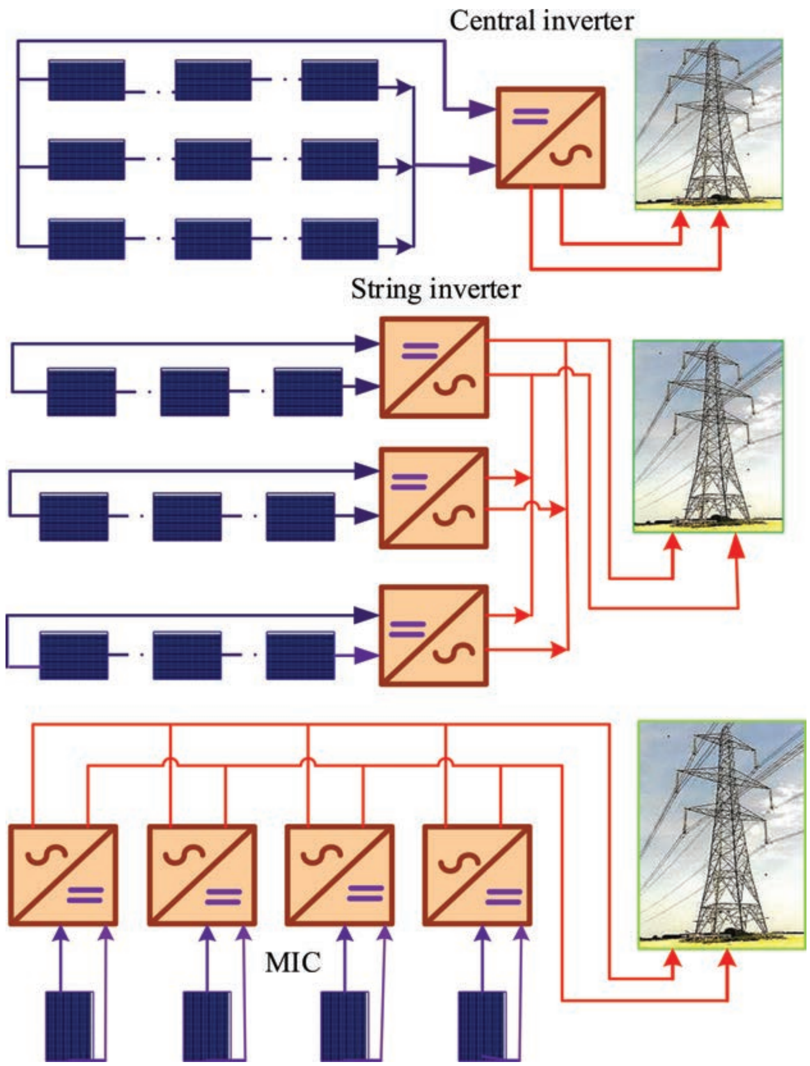


Figure 7 Central inverter, string inverter and MIC.

synchronized to the grid by using line frequency or high frequency transformer [44]. However, this penalizes the system efficiency in terms of lossy magnetic components. This led to the development of transformerless topologies to make the system more efficient.

ii) Switching losses: In a commercial inverter, almost two third of the total losses occurred in the semiconductor devices and magnetic components [45]. The switching devices made with silicon material are not efficient as they suffer from issues such as tail current in high voltage IGBTs, and reverse recovery current in high voltage diodes. The following solutions have been suggested in literature to make the switching of the devices efficient.

  - Multilevel switching techniques: To deal with the shortcomings in inverters like low breakdown voltage, high switching loss, injection of harmonic currents into the grid has led to the development of multilevel converters. The Figure 8 shows the basic classification of multilevel inverters [46].
  - Silicon Carbide (SiC) based semiconductor devices: The switching devices have been manufactured from SiC which can withstand high junction temperature and reverse recovery voltage. These devices also have the low conduction losses [32]. Hence, inverters with SiC devices have very efficient switching characteristics.

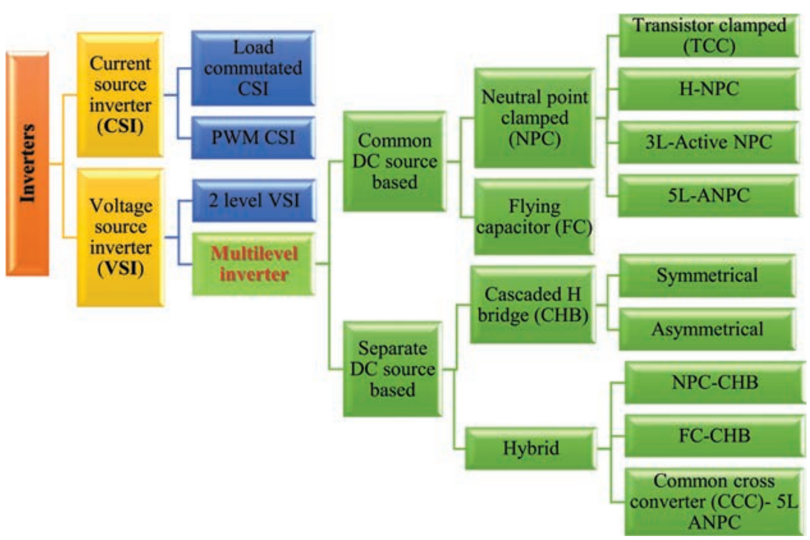


Figure 8 Classification of multilevel converters configuration.

- ○ High operating frequency: High-frequency operation results in reduction of the size and cost of the core in magnetic components with the usage of materials like ferrite. Further, operating frequency is a crucial factor in determining the system efficiency and reliability. However, for any converter design, efficiency is given as the highest priority which may cause higher system cost. Hence, the trade-off between efficiency and cost is a significant challenge [48].

c) Reliability: Inverters are the most vulnerable component in the system. The two indices, i.e., mean time between failures (MTBF) and mean time to first failure (MTFF) are employed to define the reliability of the inverters. Currently, an inverter is said to be reliable if MTBF and MTFF are 10 and 5 respectively [49].

d) Energy optimization: Since, RR are intermittent in nature, some external sources or energy storage system such as batteries are integrated into the system as shown in Figure 9. This structure facilitates and stabilizes the bidirectional power flow between the HMS and the central grid. However, efficiency of this structure relies on the technological advancement of the batteries, which directly affects the size, the cost and the reliability of inverters. It has also led the research of three or multi-port inverters [50].

For HMS, the research should be oriented towards developing the inverters having the smart features as tabulated in Table 3.

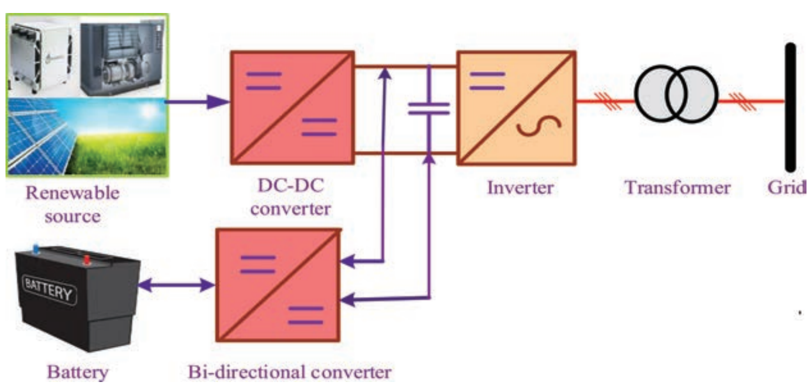


Figure 9 Renewable resource energy extraction system with battery storage.

Table 3 The control functions features and benefits associated with smart inverter [51]

Smart Features	Control Functions	Benefits
Plug-and-play	• Standardized communication protocols • Non-formation cooperative controller (distributed frequency control, parallel processing) • Communication graph (at cyber layer)	• Scalability • Interoperability • Resilience • Reliability
Self-awareness	• Fault diagnostics (detection, isolation and classification) • Prognostics & health management (condition monitoring and device lifetime estimation) • Self-expression with communication (alarm, status)	• Operational reliability • Lifetime prediction • Enabling fail safe or maintenance action • Avoiding catastrophic accident in safety-critical system
Adaptability	• Grid parameter estimation (frequency, impedance). • Frequency-adaptive grid synchronization • Distributed anti-islanding detection and adaptive mode transfer • Real-time optimization • Fault tolerance (modular and redundant structure, fault current control, fault ride-through) • Current source/voltage source flexibility	• Achieve Lyapunov stability under uncertainties and wide operating range • Tracking and grid synchronization under non-linear grid conditions like distortions, unbalance, frequency drifts, and phase angle jumps • Proper selection of operation mode of inverter and decoupling of active and reactive power
Autonomy	• Active/reactive power flow control • Grid forming	• Seamless power transfer Dynamic grid forming and feeding • Power quality enhancement
Cooperativeness	• Dynamic grid feeding Dynamic grid supporting • Active/reactive power and harmonic current sharing • Sub- or super-harmonic damping Ramp rate control • Soft start • Coordinated harmonics compensation • Coordinated unbalance compensation	Self-organization and robustness to dynamic uncertainties. • Optimal voltage regulation in active power distribution system. • Plug and play operation in micro-grids Fault tolerance and scalability.

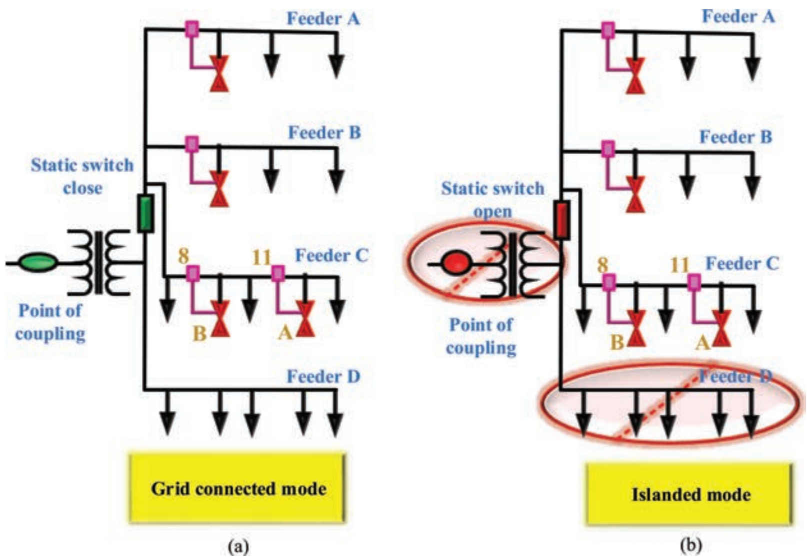


Figure 10 Islanding transition (a) Grid connected mode (b) Islanded mode.

5 Islanding Transition

A hybrid system can operate in two modes, it can be grid connected or islanded mode (off grid). In grid-connected mode, the system is coupled to the utility grid i.e. it can either receive or inject power into the grid as shown in Figure 10(a). In islanded mode, the system is disconnected from the main grid as shown in Figure 10(b). The islanding can be unintentional or intentional. The islanding operation has a certain issues such as safety and stability whereas it also has some economic and security benefits. Unintentional islanding can be caused by power quality issues and any fault in the system. An unintentional islanding has to be detected, and DGS has to be disconnected from grid within a time frame of 2 seconds as per IEEE 1547–2003 standard. The faster and accurate islanding detection is the key to safety and stability of any such system [52].

6 Islanding Detection

The basic principle behind the islanding detection is continuous monitoring of DGS and their system parameters. Then, based on the change in the parameter, islanding situation is predicted [53]. Islanding detection can be broadly classified into three categories namely remote, local and artificial

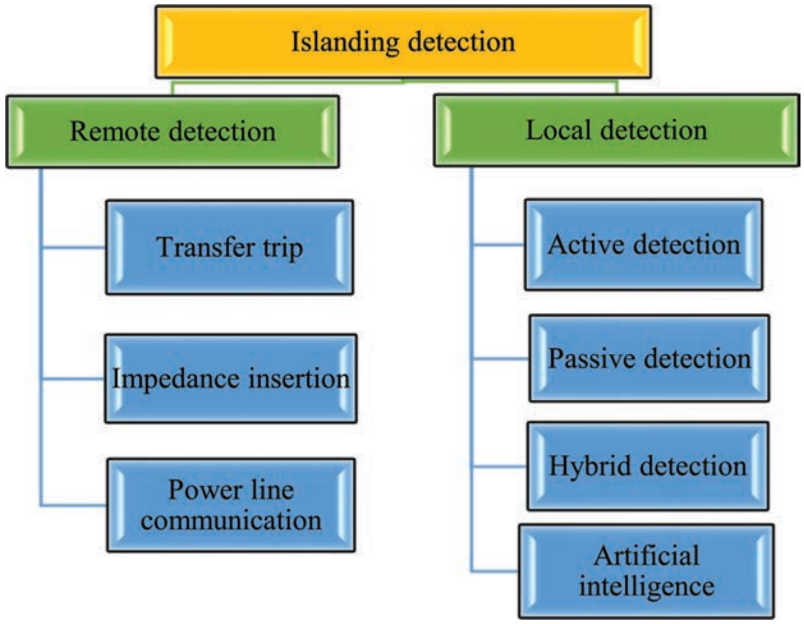


Figure 11 Classification of islanding detection.

intelligent techniques, further local can be subdivided into active, passive and hybrid techniques as shown in Figure 11. Islanding detection scheme is chosen by considering the characteristics of DGS into account. One of the issue with local detection technique is that each scheme has defined operating region under which some region where islanding cannot be detected is called as no detection zone (NDZ) [54].

6.1 Remote Islanding Detection Technique

Remote islanding scheme is based on telecommunication between the utilities and DGS. The techniques have better reliability, expensive to implement as compared to local detection technique [55].

6.1.1 Transfer trip scheme

In transfer trip scheme as shown in Figure 12, the position of circuit breakers and reclosers switch is continuously monitored i.e. any disconnection in the system network will initiate the algorithm which determines the islanded area. Then, the controlled trip signal is send to the DGS connected in the area to disconnect it from the grid. Supervisory control and data acquisition system

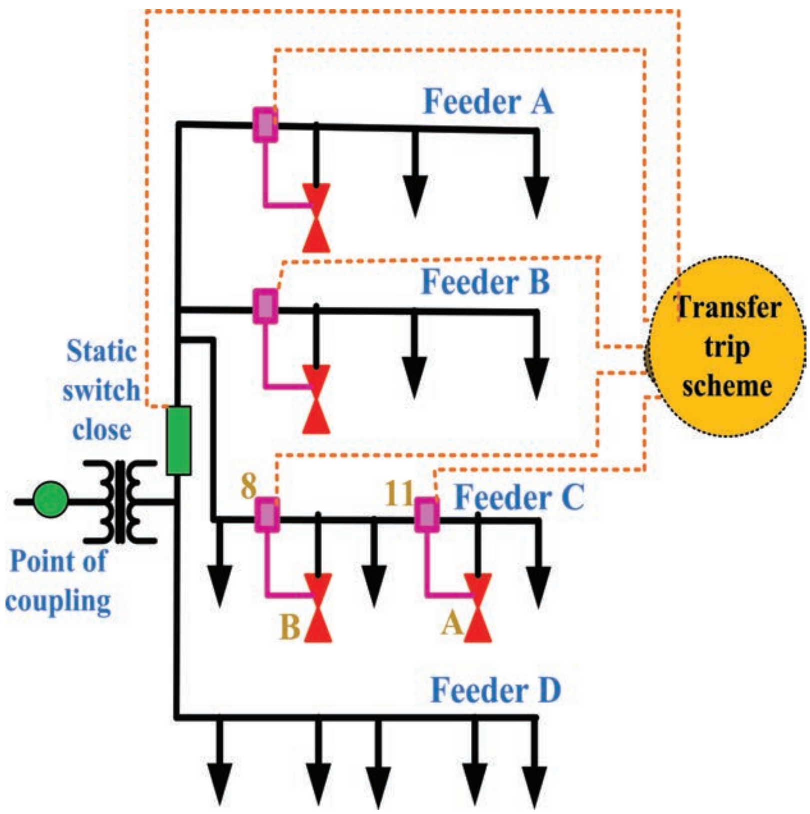


Figure 12 Transfer trip scheme.

(SCADA) is used for monitoring and operation. The interaction between utility and DGS is the key to precise and accurate operation of the system in transfer trip scheme. The number of the circuit breaker to be monitored in the scheme is large which increases the complexity of the system. Further, the requirement of accurate and precise interaction between utility and DGS increases the cost of the system.

6.1.2 Power line communication scheme

In the power line communication scheme as shown in Figure 13, transmitter or signal generator is installed at the transmission line and continuously send signals to the receiver which is placed at distribution feeder using the same power line as a medium. If the receiver placed at DGS end, it does not receive any signal (due to the operation of circuit breaker installed

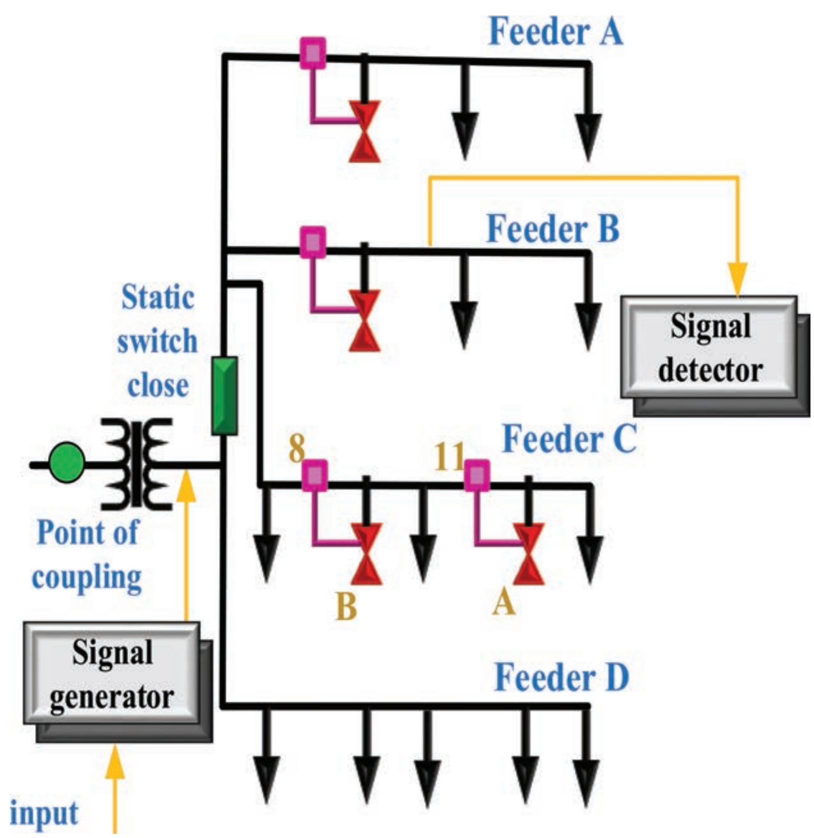


Figure 13 Power line communication scheme.

between the transmission line and DGS), DGS assume it to be an islanded condition and disconnect it from the locally connected load. The use of single transmitter reduces the deployment cost and increase the system reliability. Any interference to the transmitted signal will lead to maloperation. Further, the signal generator needs a transformer installation for its operation which will again increase the overall cost of installation [56].

6.2 Local Detection Scheme

The local detection technique is based on system parameter such as voltage, harmonic distortion, current, and frequency which are available at DGS site. Additional sensors and components are not required for obtaining system parameter since these parameters are already available for DGS control part.

Further, local detection scheme is classified as active, passive and hybrid detection scheme, as given in this section [57].

6.2.1 Passive detection

Voltages and currents are the measures for islanded detection in passive detection scheme. When these parameters exceed the threshold of normal operation, detection occurs. The detection techniques are based on under-voltage or over-voltage, under-frequency or over-frequency protection and also taking the DGS characteristics into consideration [57]. The various passive local detection schemes are as following.

a) Synchronous generators based passive scheme/Frequency based technique:
   Frequency based protection scheme are mostly used for islanding detection in the system comprising of synchronous generators. Frequency based relays are mainly classified as three types.
   i. Frequency relay: Frequency relay measures the terminal voltage and consequently estimate the frequency of the system. The protection system will be triggered, if the measured frequency is beyond the threshold value.
   ii. The rate of change of frequency relay (ROCOF): For islanding detection, ROCOF relay is based on the rate of change of frequency within a measurement frame. When the rate of change of frequency exceeds the threshold time duration, DGS will trip. Comparison of rate of change of frequency (COROCOF) is a new type of relay which is mentioned above.
   iii. Voltage surge relay (VSR): Voltage surge relay compares the phases of the measured and reference voltage. If the difference exceeds the threshold value DGS will be tripped.

b.) Other passive scheme
   i.) Active power output change
   ii.) Reactive power output change
   iii.) The rate of change of frequency over power (df/dP)

c.) Inverter based passive scheme
   i.) Under-voltage (UV), over-voltage (OV), under-frequency (UF), and over-frequency (OF) scheme: In inverter based system, power balance at point of common coupling is determined by:

$$\Delta P = P_{\mathrm{L}} - P_{IG} \tag{1}$$

$$\Delta Q = Q_L - Q_{\mathrm{IG}} \tag{2}$$

At ΔP and ΔQ = 0, the system is under normal operation. At ΔP $\neq$ 0, the voltage will deviate, and OV and UV schemes will work. At ΔQ $\neq$ 0, the frequency will deviate, and OF and UF schemes will work. The cost of this scheme is low whereas actuation of protection is variable at ΔP and ΔQ value near to zero. Further, it is hard to achieve the unity power factor in this scheme.

ii) The phase jump detection (PJD) scheme: In PJD scheme, the voltage and current at DGS terminal is monitored over a cycle when the utility is disconnected. When the voltage at DGS changes and current remain the same, the phase between voltage and current will change. When this phase change exceeds a threshold, DGS is disconnected from the grid. PJD scheme is easy to implement while it is a challenging task to define the threshold for detection.

iii) Harmonics detection scheme: In inverter based system, the total harmonics distortion (THD) is monitored at DGS terminals before and after the islanding. Under normal circumstances, THD is of low order, and power flow is towards low impedance network. However, during islanding, THD increases because of magnetic hysteresis, harmonic current will flow towards higher impedance part of the network, and other nonlinearities of the transformer, resulting in rise in harmonic current in PCC. The detection technique is efficient in this case, while determining the threshold is difficult.

6.2.2 Active detection

In this technique, disturbances enter into the system during islanding and transient condition. The magnitude and frequency of voltage, current and power changes because of the perturbation. At the same time, changes are negligible under normal or grid connected mode. The advantage of active detection is that islanding can be sensed under power balance which is not possible in passive detection scheme [58].

a) Impedance measurement scheme: Under normal operating condition, the impedance of the system is very low as seen by DGS. During islanding condition, the impedance becomes very large and leads to islanding detection. This technique is used for both synchronous and inverter based system.

b) Varying generator terminal voltage scheme: The change in reactive power is small with a change in system impedance when the system is coupled to the grid. During islanded mode, the change in reactive power is large with change in impedance. An automatic voltage regulator makes use of the change by introducing the change in voltage setting and monitors the variation in output for islanded detection. The change in frequency waveshape is much higher in islanded mode. This method is used only for islanding detection in synchronous generators.
c) Frequency and phase shift scheme: This technique is used in inverter based system. In this scheme, inverter phase, frequency and reactive power have controlled the inverter frequency, to shift rapidly for under-frequency/ over-frequency detection. This technique can be further classified as slip mode frequency shift, active frequency drift, and sandia frequency shift.
d) Voltage shift scheme: Positive feedback to current and active power regulation control loop causes the inverter terminal voltage to shift rapidly for under voltage or over voltage detection. This technique is used for inverter based system. Sandia voltage shift (SVS) is an application of this technique [59].

6.2.3 Hybrid detection technique

In hybrid detection, both active and passive local techniques are used in a sequential manner. Once the islanding is detected by passive technique, then active techniques are used for triggering. Islanding detection in hybrid technique is accurate, precise and has very small NDZ [60].

a) Positive feedback and voltage imbalance: In this islanding technique, positive feedback (an active technique) and voltage imbalance (a passive technique) is used to monitor three phase voltages to determine the voltage imbalance.
b) Voltage and reactive power shift: Voltage shift is the passive detection, and reactive power shift is an active detection technique being used.

6.2.4 Artificial intelligent technique based scheme

The detection of islanding must be accurate and quick. In this regard signal processing techniques were used to extract the hidden features of the measured signal for islanded detection. Further, artificial techniques, such as, artificial neural network, probabilistic neural network, fuzzy logic, etc. have used the extracted signal for classification of the islanding. Artificial intelligent techniques are faster as compared to other islanding detection techniques [61].

There are lots of detection techniques which are being illustrated in literature [59]. Each and every technique has its own advantages and constraints. No single technique will work satisfactorily for every system under different operating condition. So, it is necessary to summarize the key points of each technique for proper selection as presented in Table 4.

Table 4 Comparison of various islanding technique

S.No.	Detection Technique	Merits	Demerits	Example	Remarks
1.	Remote detection scheme	High reliability	Expensive for a small system.	Transfer trip, Impedance insertion, Power line communication	–
2.			Local detection scheme		
A.	Passive detection	Short response time, perturbation not required, accuracy depend on mismatch magnitude, low cost	Threshold setting is difficult, false tripping, island detection is difficult when mismatch is small, large NDZ	Frequency based, change of active power output, ROCOF, change of reactive power output, impedance measurement, ROCOF over power (df/dP), harmonics detection, UV, OV, UF, OF, PJD,	Detection depends on DGS characteristics
B.	Active detection	Small detection zone, Low cost	Response time is slow, the perturbation is required, less stable, and disturbance is introduced.	Varying generator terminal voltage scheme, frequency, and phase shift scheme, voltage shift scheme, impedance measurement	Detection depends on DGS technology and penetration level
C.	Hybrid detection	Very small NDZ, low cost	Detection time is more	Positive feedback and voltage imbalance, voltage and reactive power shift	
D.	Artificial intelligent technique	Very short response time, robost	Computational burden	ANN based, active power imbalance.	

7 Intentional Islanding

The distributed generators are disconnected from the grid and forced to power the local utility and is called as intentional islanding. This is mainly done as a backup power system for generators that usually sells their surplus power to the grid. However, during islanding, DGS are supposed to meet the power demand, i.e. there should be a balance between supply and demand and this can be achieved by controlling DGS as per grid condition. There are chances of conflict between grid code and DGS. Thus, an appropriate power management scheme and control technique is required to create the power balance. Islanding can help in enhancing the reliability and security of power supply and economic benefits [62].

8 Conclusion

This paper have addressed and classified the distributed generation technologies, power electronic controllers for conversion and islanding detection with associated issues for hybrid microgrid system (HMS). With the formulation of HMS, the overall losses in electrical network and components have been reduced along with the further enhancement in security and reliability. The challenging issues of HMS such as complexity in control, power quality and characteristic of converter and protection scheme have been addressed in the paper with system architecture. Selection of power converters as interfacing unit between source and load/ battery/grid was reported for minimizing the cost of the system. A critical review and analysis has been carried out for protection issue of microgrid and their solutions. Various islanding detections as well as merits/limitation of each scheme have also been presented extensively. The significance of the method presented in this manuscript will be useful for rural electrification.

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