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A review on microgrid central controller

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ABSTRACT

The microgrid central controller has most important role for satisfactory automated operation and control of microgrid while working in grid connected and islanded modes. The central controller has several features for proper coordination of distributed energy resources as per their power generation capacity to serve the critical and non-critical loads. It also initiates the protection techniques at the time of occurrence of severe short circuit fault at the grid end or in microgrid thus ensuring stability and reliability. This paper presents a comprehensive literature review on microgrid central controller. The evolution and advancement of microgrid central controller technology is explored and presented in a compact form. The classification of microgrid central controllers is proposed based on the outcomes found in the process of review. The role of central controller in the domains of microgrid protection, stability and power quality are also explored and summarized. This literature review may be considered as an initial platform for research work on microgrid central controller.
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Contents

1. Introduction

The electric power system is the most vast and complex managed by power system community. As the demand is increasing and the conventional energy sources gradually become exhausted, we have alternative option of renewable energy sources to sustain the growth of power generation in future. Fossil fuel

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based power generation causing several unwanted emissions are threatening our environment, so our aim is to develop low carbon power generation technologies to cater the future power demands. Global warming and changing climate conditions are the alarming problems which must be tackled through introduction of microgrid which is developing to generate electricity with less pollution and low transmission losses [1].

A microgrid can be defined as a low-voltage distribution system to which small modular generation systems are to be connected. It consists of small generation systems and electrical loads through a low-voltage distribution network. In microgrid, small renewable energy sources are installed and that can fulfill the load demand. The microgrid can be installed in a village or a small town [2]. The integration of distributed generators based on renewable energy resources (RER) and microsources like photovoltaic system, wind turbine, microturbine using CHP system, fuel cell and batteries with storage facilities etc. has initiated more recent concept of microgrid which is considered as a cluster of interconnected distributed generators (DGs), loads and intermediate storage units that co-operate with each other to be collectively treated by the utility grid as a controllable load or generator towards an evolutionary power solution for scarcity of fossil fuel in near future. The integration of microgrid with RER is evolving as an emerging power scenario for electric power generation, transmission and distribution. In this prospective, IEEE-P1547-2003 is a benchmark model for interconnecting DERs with Conventional Electric Power System [3,4]. All these different types of renewable energy sources must be properly coordinated by the deployment of microgrid central controller (MGCC) to extract adequate amount of energy from each of them.

The main objectives of this review are to explore the evolution of microgrid central controller on the basis of need, implementation, development, classification, power quality, stability and protection of microgrid system. The requirements and implementation of MGCC in microgrid is discussed in Section 2. The evolution and advancement of MGCC are reviewed and presented in Section 3. Based on the review on MGCC technology, its classification is proposed in Section 4. The Section 5 presents role of MGCC in the areas of maintaining power quality, protection and stability of microgrid systems. The role of MGCC in grid situation for sustainability and renewable energy needs have been discussed in Section 6 and the conclusions are given in Section 7.

2. Microgrid central controller: it's requirements and implementation

A microgrid central controller controls the load in the microgrid by properly managing the energy balance in the system. It compares the total generation with the load demand in microgrid and some non-critical loads is shaded if load demand becomes higher than the generation. MGCC regulates the voltage and frequency to maintain system stability [5]. The schematic diagram of a typical microgrid is shown below in Fig. 1 and the coordination of microgrid central controller with distributed energy resources, grid, critical and non-critical loads etc. are shown in Fig. 2.

To supply various loads in microgrid, the different energy resources are integrated with the main grid. So for proper coordination of the energy sources there are a need of controller in microgrid for satisfactory operation. Microgrid central controller monitors the power generated by DGs and matchup with the demand to maintain balance in the system. Microgrid central controller is needed to detect the power quality at PCC and so that it can decide whether to disconnect grid i.e. to initiate islanding mode operation of microgrid. Resynchronization is done by central controller once the grid is restored by properly matching the voltage and frequency with that on the grid side. So there is need for microgrid central controller for resynchronization purposes and islanding decisions as reported in [5].

2.1. Cost benefit offered by microgrid central controller

Microgrid central controller reduces the operational cost of microgrid for customers. Since it fulfills the demand of the microgrid by using its own energy resources, it reduces the network congestion at the time of peak demand when energy prices are high in open market. The cost benefit which may be achieved through MGCC based microgrid operation is briefly illustrated below on the basis of research presented in reference [6].

The centralized microgrid control offered by the MGCC is comprised of the following three levels of control.

(1) Local microsource controller (MC) and load controller.
(2) Microgrid system central controller (MGCC).
(3) Distribution management system.

Apparently saying, inclusion of MGCC may increase initial cost, but the following discussion is relevant to justify how the cost does reduce in long term usage [6]. MGCC can maximize

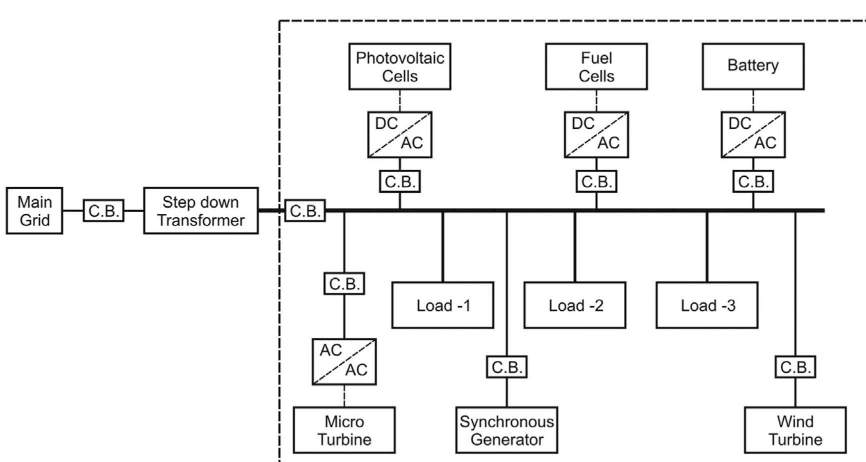

Fig. 1. Schematic diagram of a typical microgrid.

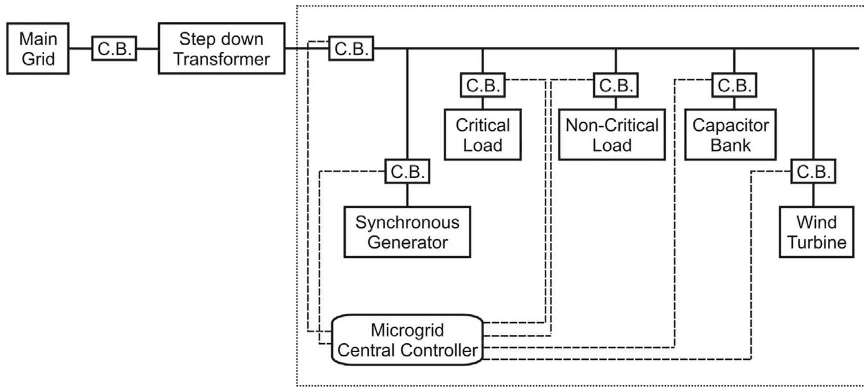

Fig. 2. Block diagram of a microgrid model with MGCC.

Table 1
MGCC techniques under different modes of operation for AC/DC microgrid.

Mode	AC Microgrid	DC Microgrid	Cost benefits due to addition of MGCC
Grid-connected	Provides control methods: prediction, security, power flow.	Controls the power demand and voltage variation under changed conditions and loads.	Consumers can avail cost benefit for the long run on the basis of power control and power system security.
	Maintains synchronized operation.	Scheduling, load profile and demand side management.	Better synchronized operation and proper scheduling will reduce the operational cost.
Islanded	Active and reactive power flow control, voltage profile, frequency control with the help of energy storage system.	Controls and maintain power flow and load voltage during any disturbance.	Power quality will attract the consumer to buy power from microgrid in long run.
	Maintain reliability of power supply and interconnects the microgrid with utility grid after clearance of fault.	Stabilizes the generated voltage.	MGCC will improve reliability.

microgrids value by optimizing its operation on the basis of information on market price of electricity, gas, grid security etc. to decide the amount of power the microgrid may draw from the distribution system. MGCC sends the predefined control signals to the microsource controller and load controller. Microgrid operation is optimized by MGCC as per open market price; the bids received by the DG sources and forecasted loads. On the other hand, consumers within microgrid might bid for their load supply for the next hour or might bid to curtail their loads. Inclusion of MGCC unit may increase the initial cost of investment of a microgrid system. Therefore, it will be beneficial to present the initial cost estimates and how the effective cost does reduce in long term uses of MGCC based microgrid as given below.

(1) The MGCC could work effectively to manipulate the power generation and consumption of load supplied by microgrid based on the current status of DERs combination. The MGCC could offer power with lower price than the original incentive recommended by the grid operator; hence the remaining money could be shared by microgrid entities or used for microgrid maintenance cost [7].
(2) The MGCC based microgrid system has shown the savings up to 21.56% for a daily operation during high price periods [8].
(3) Importance of MGCC based on control strategies [9] shown in Table 1. Based on the observations in Table 1, the authors' views have been included in 4th column of the table.
(4) For an annual operation and maintenance cost of 2% of the total investment, the complete cost could be pay-back over a period of 20 years of the project [10].

3. The evolution and advancement of microgrid central controller technology

The initial stage of development of the operation of microgrid central controller is suggested in the following manner:

3.1. Improvement of energy balance, efficiency estimates and other features of microgrid based on MGCC

In [11], automated load management technique is proposed for energy balance in microgrid in which microgrid central controller isolates the loads during peak-load hours to reduce demand on the system. Energy balance is necessary for the safe operation of microgrid. Otherwise voltage fluctuation may cause harm to the whole system. So to overcome this problem, automated load management can be used which includes peak-load reduction and control energy provision by the demand side of the system for online energy management. Instead of shedding the entire region, smart automated demand system can selectively switch off the loads on priority basis. This system includes MGCC that isolates the loads from the grid in order to reduce overall load demand on the system for maintaining energy balance during peak-load hours. As the system is fully automated, it is easy to setup with minimum human interaction and involves minimal maintenance and operational cost. An admittance-compensated-quasi-proportional resonant controller is proposed in [12] to provide energy balance estimate while power is being exchanged between the battery storage system and the ac utility grid through a bidirectional ac-to-dc converter as the interface system. The state-of-charge of a battery energy storage system (ESS) is an indicator of the estimated stored energy in the storage system. The controller proposed in reference [13] demonstrated that it can mitigate the mismatch of an energy amount series connected storage cells, supportive reactive power flow and seamless energy transfer.

In [14], the network based control of multiple DGs is adopted by an active synchronizing control scheme. This technique provides the reliable connection of main/utility grid with the microgrid. A reliable synchronization is achieved by using microgrid pilot-plant.

Microgrid Voltage Controller (MGVC) is implemented in [15], to improve the voltage profile of microgrid while operating in grid-connected and island-mode. The improved results are shown with the addition of MGVC. In [5], An MGCC is implemented to work in various modes of operation, such as, grid-connected, islanded and transition from grid connected to island mode and vice-versa. An MGCC monitors the loads to ensure stability of the system. In [16] A Central controller is designed for stable operation of microgrid. To adjust the voltage and frequency a droop control scheme is provided by connecting inverters in parallel.

Automated load management is proposed to minimize the energy imbalance issue as presented in [11]. A self-configuring approach for demand side control is proposed in which MGCC controls the load and isolates them to reduce load demand on the system for maintaining energy balance. The system is fully automated with minimum costs and maintenance. Wireless sensor network approach is used to maintain communication between MGCC and loads. Self-organization, low power consumption and low cost are the main features. In addition, this approach provides stability to microgrid. [6] proposes MGCC which uses optimization technique for the operation of microgrid. The controller optimized the total generation of DGs and exchange of power with the main/utility grid. Demand-side bidding options are considered for controllable loads which lead to reduced energy prices for customers.

[14] proposes an active synchronizing control system which uses the DG to adjust the voltage and frequency of microgrid. A reliable synchronization can be achieved with this method under the condition of the fluctuating output and rapid load change. The author proposed the microgrid pilot plant to verify the behavior of microgrid. [17] discusses a microgrid operation control which works on local-level distributed generation and system-level distributed generation control for stable operation. In local-level DG control in microgrid, inverter based DG-units are used due for faster dynamics and it can quickly switch between grid-connected and islanded mode. In system-level operation control, Distribution Management System (DMS) is used. MGCC as the main interface between DMS and microgrid detects the blackouts and controls the blackout procedure. An MGCC is proposed in [15] for the improvement of voltage profile in microgrid and avoid any voltage tripping. The grid-connected and islanded-mode are considered for simulation. To evaluate the performance of controller, a 22-bus microgrid test system is used, which include different types of DGs.

3.2. Role of MGCC towards market participation

[18] reports the functions of MGCC for the participation of the microgrid in future real-markets. To reduce operational cost, the economic scheduling and forecasting function is developed for coordinated management of the micro-sources. The MGCC aims to satisfy the local energy demand using its local production. Because at the time of peak demand leading to high electricity prices, the MG relieves possible network congestion by partly or fully supplying its energy needs. From the end user point of view, the MGCC minimizes operational cost of the microgrid, taking into account market prices, demand and DG bids. End-users of the MG share the benefits of reduced operational costs. Therefore, in this case, MGCC is provided with the market prices for power, the power demand, probably as a result of short term load forecasting tool. [19] suggests a distributed secondary control approach to share reactive power between DGs by removing frequency and voltage errors. Also the failure of single unit will not lead to fail down of the whole system. To show the feasibility of distributed control, experimental results are presented. [16] employed a control strategy to switch the microgrid between grid-connected and islanded-mode. A droop control scheme is used to adjust the voltage and frequency by connecting inverters in parallel. In island mode voltage deviations control controller are eliminated by secondary loop to enhance the power quality of microgrid.

Several control techniques are presented in [20] for islanded operation of microgrid controlling the active and reactive powers for stable operation. The results are simulated which shows the transition of microgrid from grid-connected mode to islanded-mode. [21] proposed a real time simulator (RTS) to verify performance of demand and supply control in microgrid. The problem is simulated under both grid-connected and islanded-mode. RTS is used to verify the performance of Demand and Supply Controller (DSC).

4. Classification of MGCC

As per the literature survey on MGCC, it can be broadly classified in two types such as (i) A.C. microgrid central controller and (ii) D.C. microgrid central controller

4.1. A.C. MGCC (Alternating Current Microgrid Central Controller)

In AC grid, AC power sources and loads are connected. To enable the connection of renewable based power generating sources with the present AC system, AC microgrid has been developed in [22]. By connecting microgrid directly to the AC grid investment cost lowers and structure is simple but with less reliability and lack of flexibility, therefore an interface is needed as reported in [23].

Simulation work is carried out using Simulink model of microgrid which is well developed in [23], for study towards mitigation of harmonics in an AC microgrid. For more flexibility and reliability, a possible method is proposed in AC microgrid by using a back-to-back converter interface. The interface has strong voltage and current decoupling capability between the microgrid and the distribution grid in terms of various system disturbances shown in [24,25]. For maximum utilization of integration of RER in a distributed generation system, a high frequency AC microgrid is proposed. The successful implementation is done by using UPQC (Unified Power Quality Conditioner). The UPQC ensures the harmonic-free voltage. It also compensates for the harmonic-current and reactive power. The controller based on P–Q theory is used in [26]. The power flow between the main grid and microgrid cannot be controlled in grid-connected mode. If any fault occurs, cannot be isolated and power supply cannot be ensured and effects of harmonics occur in the microgrid system. So, a new scheme is developed to connect microgrid to the AC grid by a flexible interface device comprises of back-to-back VSC converter. It also controls the active power flowing between main grid and microgrid. Also it is helpful in reactive power compensation and keeping the microgrid voltage stable illustrated in [27].

To improve the power quality and reliability of the system, a flexible AC Distribution system is employed. In microgrid, for tracking of frequency and to extract the harmonic spectra of the grid voltage and the load currents, extended Kalman filter is employed in [27]. A droop control scheme is proposed to adjust the voltage and frequency by connecting inverters in parallel but this method has several drawbacks. Due to mismatch of line impedances, circulations will be generated between the inverters in islanded mode, when load or generation inside the microgrid changes. In grid-connected mode, the active output power of inverter is not regulated reported in [16]. A two cost-prioritized droop scheme is proposed for DGs in islanded microgrid having lower generation cost shown in [28]. A high-frequency generators having large-signal transient stability are introduced in [29].

4.2. D.C. MGCC (Direct Current Microgrid Central Controller)

In DC microgrid, DC power sources and loads are connected. The power supply connected with DC grid can be easily operated cooperatively, because they control only the DC grid voltage. The most of alternative energy sources as well as energy storage devices produce and store electrical energy in DC. Thus the design of DC microgrid is fundamental if the DC loads and microsources are to be easily integrated on the network. The system cost and losses are reduced. The DC system also eliminates the use of multiple converters which reduce the system efficiency. Skin effect is absent in DC system and no reactive power issues are less. Efficiency of DC is 10–22% more than AC system. In DC microgrid, voltage synchronization is easier and effect of phase imbalance is less as illustrated in [30,31].

An autonomous-control method is proposed for DC-microgrid based distributed power generation system. A 10-kW DC microgrid system is designed to suppress the circulating current using only the DC-grid voltage. This shows the high reliability and flexibility of the system reported in [30]. To provide reliable supply to the loads, a new system is developed to control and operate DC microgrid. The different control and operation modes are discussed which shows the satisfactory performance of the DC microgrid operation in [32]. To regulate the grid voltage and to control the load sharing between different sources, a voltage droop control method using Proportional (P) and Proportional-Integral (PI) controller is adopted with DC microgrid. The P and PI controller show a good load sharing characteristics. A droop based controller is used for equal sharing of load among different sources in DC microgrid. The controller has high reliability and it lowers the cost. Steady state mathematical model is developed which is applicable to any interconnecting structure of load and sources. The effects of branch resistance and droop constants on the sensitivity of source currents are studied. To verify the results simulation is carried out in [31].

A DC microgrid could be applied for residential house. All houses have a cogeneration system such as gas engine and fuel cell and share the power among the houses by the DC distribution line. A laboratory scale DC microgrid is constructed to examine the fundamental characteristics of the system. The results show that the system is able to supply high quality power to the loads against a sudden load variation. Also short circuit occurrence on one load does not affect the power supply to the other loads reported by author in [33]. A low-voltage bipolar-type DC microgrid is proposed for high efficiency and high-quality power supply in which DC power is distributed through 3-wire lines, and it is converted to required ac or dc voltages by load-side converters. When blackout or voltage sag occurs in the utility grid, the dc microgrid can supply high-quality power stably, while inverters of DGs in ac microgrids should be tripped unless they have fault-ride-through capability. A DC microgrid for a residential complex is presented having Cogeneration system (CGS) like gas engine and fuel cell in each house and the power is shared among the houses with DC distribution line. By changing the number of CGS, total power can be controlled. The results shown in [34] proposes that the system can supply high quality power under several conditions.

To form an autonomous DC microgrid, several distributed generation have been merged together with a pair of batteries and loads. A double layer hierarchical control strategy was proposed for the co-ordination of multiple-batteries. The results show the performance of developed control in [35]. System stability is analyzed by using state-of-charge (SOC) based adaptive droop control method illustrated in [36]. A high speed differential protection schemes adopted in DC system for fast fault detection within microseconds proposed in [37]. Also a model is proposed to solve the problem of disturbances due to uncertain load changes in DC microgrid. The disturbance changes the parameters of microgrid. The proposed model is used to calculate the characteristics parameters of DC microgrid [38].

5. Role of MGCC to maintain power quality, protection and stability of microgrid

5.1. MGCC and power quality

Harmonic content, voltages unbalance and frequency regulation are major power quality related problem. Filters are introduced to eliminate the harmonics. Particle Swarm Optimization (PSO) algorithm based system is designed to regulate grid frequency and voltage flexible distributed generation are developed to control active and reactive power flow and for mitigation of voltage flicker and harmonics in [39]. In island-mode, as the main grid is disconnected, reactive power variation of the loads will lead to voltage fluctuation. To improve the power quality in island-mode, a combined system is constructed using SVC and SAPF (shunt active power filter). The microgrid is connected to main grid by inverter which leads to current harmonics. The combined system can compensate reactive power and mitigate the harmonic currents simultaneously and therefore the power quality is improved [40]. Also to improve power quality of microgrid in emergency condition, a microsource control algorithm and simulation using EMTP/RV is proposed. The microsource controller, proposed by simulation, is more efficient than existing microsource control method for voltage-sag compensation ability or local high quality power supply shown in [41]. The power problems such as total harmonic distortion (THD) and unbalanced voltages occur in microgrid due to non-linear and unbalanced loads. The control strategy is proposed to eliminate the non-linear and unbalanced loads based on d-q reference frame. To eliminate the unbalanced voltage disturbance a back-to-back converter is adopted in [42]. The power quality problems like voltage sags and unbalanced voltages are compensated by a 3-phase, 4-wire grid interfacing compensator. The compensator is used with each individual DG consists of two 4-leg inverter using shunt and series connection together to improve the power quality and current flowing between the microgrid and main grid illustrated in [43]. Also to improve the power quality in a microgrid, a dynamic voltage restorer (DVR) connected with the point of common coupling (PCC) and grid by a rectifier is proposed in [44].

5.2. MGCC and protection

Protection is the major challenge in microgrid. Whenever fault occurs in microgrid, protection system should quickly isolate the microgrid from main grid to protect the microgrid. There are various protection issues related to microgrid. When distributed generation units are connected to grid, it changes the fault current level. Also relay operation is affected. The reverse power flow is main challenge for microgrid operation. The injection of 1-phase power into distribution grid affects the balance 3-phase currents; due to increase in unbalance current, stray current flows to earth and it should be limited. There are some possible solutions for protection issues like protection of inverter interfaced distributed generation units, differential protection scheme, balanced combination of different types of distributed generation units and adaptive microgrid protection system. Adaptive protection is the best solution as there is automatic readjustment of relay in both modes reported in [45–47]. MGCC is the main component of adaptive protection system. It is used to update relay settings. It will monitor the state of microgrid by polling all individual directional over current relays as presented in [47]. A differential scheme based on time–frequency transform is proposed for shunt and high-impedance faults for the protection of microgrid in [48]. A protection scheme is employed for a microgrid which detects the location of faults and then uses trip action in [49].

5.3. MGCC for stability of microgrid

Energy storage system, control strategies of the micro-sources and the energy storage system, types of load in the microgrid, location of the fault and inertia constant of the motors are the major factors which affect the stability of microgrid system. The simulation results obtained in [50] proves that under voltage load shedding on motors and control of the flywheel can improve the stability of microgrid. A small signal stability analysis of rectifier inverter fed induction motor drive is performed by neglecting the harmonics which has been carried out using Eigen value criterion. The result shows damping of the oscillatory modes proposed [51]. The dynamic model is presented in [52] with active load control to provide stability of microgrid. Active loads are modeled in nonlinear state-space linearized around an operating point. Due to unstable operation of inverter and to obtain steady-state voltage regulation, rectifier controller is designed by using conventional frequency domain analysis. A small-signal model of a microgrid is proposed to maintain stability of a microgrid shown in [53].

6. Role of MGCC in grid situation for sustainability and renewable energy needs

On behalf of the utility grid, the microgrid can be considered as a controlled cell of the power system [54]. Installation of unified controller can initiate switching between islanding and grid-connected modes without disrupting the critical loads connected to the multibus microgrid system [55]. In order to analyze the system stability, which gives rules to design the main control parameters, a small-signal analysis is to be performed in order to analyze the system stability of a flexible microgrid set both for grid-connected and islanded mode operation [56]. The sustainable development issues could be identified as – the integration of social, environmental and technical components (isolated microgrid) [57]. With the highly penetration of renewable sources in the grid, the MPPT condition could not be sustainable for long time [58]. With the advancement of DERs it could enhance the security and sustainability of the complete microgrid system [59]. It is also evident that the stability issues of dc microgrid connected with multiple distributed sources would have important role. The instantaneous constant power loads could create destabilizing effect into the microgrid which might develop voltage oscillation or collapse. So it could overcome by load shedding, using linear/non-linear controllers, filters or ESS. It was observed that a dc microgrid is better to realize the sustainable power based on integrated renewable sources as that of ac microgrid [60]. Power quality, protection schemes, secure operation, economic challenges, power management, communication and dynamic control are the most important issues connected to utility grid. The secure operation of a microgrid could be enhanced by the use of energy management system incorporation with communication protocol [59,61] and having problems of symmetrical, unsymmetrical and high impedance faults in grid connected mode and the differential scheme could overcome this instability factor with the confidence of reliability [62]. An interlink converter with the application of power management and control strategies could be implemented among all the possible DERs based on decentralized control scheme [63].

7. Conclusions

The paper shows the global research scenario of MGCC and the acceptability of microgrid as an emerging power scenario is justified. It is also found in few cases, such as reference [64], that the islanded microgrid with the facility of wind generator can work even in the absence of MGCC for reduction of generator cost in islanded mode based on the system operational constraint as per algorithm for choosing the optimal droop parameters. But in most of the microgrid applications, role of a central controller is essential to provide intelligence in the proposed microgrid system including cost saving approach. Even a probabilistic analytical approach for assessing the fuel saving benefit has been presented in [65]. Also as per the latest trend, optimized operation and control of microgrid is possible through a telecommunication infrastructure to exchange control signals between a distributed control layer and upper layer [66]. Finally, it is also revealed that an MGCC may work with high level intelligence if the same facilitated with human and equipment interface system [67]. A considerable number of literature reviews on microgrid central controller have been discussed in this paper. The evolution of MGCC technology has been studied through which classification of MGCC, based on DC and AC microgrid applications, are well justified. In this review work, the feasibility of a central controller for operation of microgrid is well defined. It reveals that, apart from generation and demand control, the MGCC plays important roles for maintenance of power quality, protection and stability of microgrid system.

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