A Review on Challenges and Techniques for Secondary Control of Microgrid

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Abstract. Environmental concern, limited availability of fossil fuel and economic aspects have resulted in increasing interest in microgrid technology comprising of various renewable energy based distributed generators such as PV, wind, fuel cell and biomass. Microgrid provides various advantages such as higher combined heat and power efficiency, high reliability and lesser carbon emission and also reduction in technical losses. However, microgrid operation and control is associated with various challenges such as power quality issues, bidirectional power flow, voltage and frequency variations, coordinated operation of multiple distributed generators, stability, power management and economic operation. In this paper, a brief discussion on these challenges is presented. A classification of various control principles on the basis of their controller function, connection with grid and response time is also presented. The paper classifies and compares microgrid hierarchical control into three levels, i.e. primary, secondary and tertiary control. Also, a detailed discussion on various schemes of secondary centralized, decentralized and distributed control has been presented. Finally, an attempt has been made to identify research gaps in various control strategies.

Keywords: Consensus based technique, decomposition based technique, distributed generators, droop control, gossip based techniques, microgrid, multi agent system, model predictive control, Master slave control, MGCC, non-model based control, optimal dispatch.

1. Introduction

In recent years, microgrid has emerged as a viable solution to various problems like, environmental change due to high greenhouse gas (CO₂) emission, depleting fossil fuel reserves, economical consideration and electrification of remote areas where connectivity with grid is not feasible [1]. A definition of microgrid according to United State department of energy is given as follows [2] -

“Microgrid as a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both connected or island-mode.”

Therefore a Microgrid, on the basis of this definition, can be described as a group of-

1. Distributed generators (e.g. PV, wind, fuel cell, biomass, microturbine),
2. Energy storage devices (e.g. battery, supercapacitors, flywheel),
3. Power electronic interface, e.g. converters and control devices,
4. Load (e.g. electric vehicle, residential, local load, liner load, non-linear load),

which constitute a single and controllable power supply system and connected to the distribution grid through STS, i.e. static transfer switch at the point of common coupling (PCC) [3], figure 1, shows basic layout of microgrid network.
A microgrid is basically a small scale low voltage supply network, if connected to main grid, can be seen as a single aggregate load or source. Although, microgrid can be considered as a miniature grid, there are various parameters which differentiate microgrid from main grid. A comparison between microgrid and conventional grid based on different parameters has been presented in table 1.

![Figure 1. Basic layout of microgrid](image)

Table 1. Comparison between conventional grid and microgrid.

| Parameters                        | Conventional Grid                         | Microgrid                                      |
|-----------------------------------|-------------------------------------------|------------------------------------------------|
| Mode of control[4]                | Centralized only                          | Centralized, decentralized and distributed     |
| Mode of operation[4]              | Grid connected only                       | Grid connected and islanded mode both         |
| Global parameter for control strategy[5] | Frequency(change of frequency through their P/f droop control) | Dc link voltage (difference between dc side power and ac side power which is visible in the dc-link voltage of unit) |
| Connection of DG’s[5]             | Directly coupled to electrical network    | DG’s use power electronic interfaces         |
| Share of renewable and volatile energy sources[5] | Less                                      | High                                           |
| Rotating inertia[5]               | High rotating inertia of synchronous generators (present) | Low inertia                                   |
| Grid frequency[5]                 | Grid frequency is directly coupled with the rotational speed | Rotational speed of generator is not directly coupled with grid frequency |
| Greenhouse gas (CO₂)emission[6]   | Increases                                 | Reduces                                       |
| Reliability[6]                    | Low                                       | High                                          |
| Power quality[6]                  | Low                                       | High                                          |
| Combined heat and power efficiency[6] | Low                                      | High                                          |
| Power loss[6]                     | More                                      | Less (because microgrid can decrease the transmission and distribution line power flow) |
| costs for additional power[6]     | Increases                                 | Reduces (microgrid can alleviate the power flow on transmission and distribution lines) |
| Cost of installation in rural and remote location[6] | High because of installation of new lines | Low                                           |
| Voltage level                     | High                                      | Low                                           |
| Mode of communication             | One way communication                     | Two way communication                         |
| Efficiency[6]                     | Low                                       | High                                          |
| Size of power sources             | Big                                       | Small                                         |
| Capacity of power source generation[7] | High                                      | Small (typically less than 100Kw)             |
| Flexibility[6]                    | Less flexible                             | More flexible because of use of small power generation |
Microgrid can be classified into two categories viz. ac and dc microgrid. Since mostly conventional grids are ac in nature so ac microgrids nowadays are being more focused because of their flexibility to operate in connection with grid and also due to their economical and simple structure [8]. Microgrid offers several advantages however they also introduce several major challenges related to operation, control and protection of system. In microgrid we can classify control approach on the basis of various objectives for example on basis of their controller function, connection with grid and response time. With reference to the architecture of a power system’s control there are mainly three control approaches namely centralized, decentralized and distributed [9].

In centralized control, a central controller i.e. MGCC collects data information and determines controlling actions for all units. This control requires huge communication between all the units and the central controller. Due to large geographical area it is not feasible to have fully centralized control because it requires considerable amount of communication and so it is not a cost effective solution. While in decentralized control, every individual unit is controlled by its own local controller and due to that reason it receives only local information such as frequency and voltage value. In comparison with the centralized method where, global information is required for making decision for the overall system, the decentralized control does not need local controller to exchange whole information with other local or central controller; however some local controller can exchange information with the neighbour control unit and hence, communication requirement is significantly reduced. But with small communication, fully decentralized control is also not possible because the operation of various units in the system is highly dependent on each other and can cause the system to become unstable or operate non-optimally. Hence a compromise between these two controls can be obtained by introducing a third approach called distributed control scheme, consisting of some degree of centralization along with some degree of decentralization property. In distributed method of control, each unit uses local information such as frequency and voltage, provided by its neighbours. In this method, local units exchange information through two-way communication link and thus can achieve global optimization same as centralized method. This distributed method can preserve unit’s privacy because a lot of important information is not shared globally [9]. On the basis of connection with main grid, microgrid has two modes of operation viz. grid connected mode and islanded mode.

Islanding of microgrid can be due to planned reasons like for maintenance schedules or can be due to unplanned action like faults in system. Comparison between two modes has been presented in table 2 [8], [10].

The paper also presents categorization of secondary control on the basis of MGCC position into centralized, decentralized and distributed control. The objective of this paper is to provide a comprehensive survey on strategies applied for secondary control (i.e. for centralized, decentralized and distributed secondary control) such as model predictive control, optimal dispatch, multi agent based control, droop control, and gossip based techniques, in microgrid along with challenges associated to it. The paper is organized as follows: Section II presents key challenges associated with microgrid. Section III elaborates control of microgrid. Hierarchical control structure of microgrid on the basis of various objectives has been discussed. A comparison between primary, secondary & tertiary control has also been presented. Section IV presents a discussion on secondary control. Centralized, decentralized and distributed secondary control along with controlling techniques associated with them have also been discussed and analysed.

| Table 2. Comparison between grid connected mode and islanded mode of operation in microgrid. |
|---------------------------------|--------------------------------------------------|--------------------------------------------------|
| Parameters                     | Grid connected mode                              | Islanded mode                                   |
| Connection with main grid      | Microgrid is connected to main grid through STS, i.e. static transfer switch at the point of common coupling (PCC) | Microgrid is not connected to utility grid and works independently. |
### 1.1. Challenges in microgrid operation

- Although microgrid offers a spectrum of advantages, its implementation is associated with multiple challenges. These challenges are discussed as follows:
  - Bidirectional power flow- The distribution feeder was designed to flow power in one direction. But because of invention of microgrid which includes distributed generators of low capacity cause power to flow in both direction which can lead to complexity in protection coordination, undesirable power flow pattern [11].
  - Power quality issues in ac/dc microgrid- Harmonics, voltage and frequency variation in ac microgrid and issues like inrush current, circulating current, dc bus faults that are related to dc microgrid are some major challenges in microgrid operation [12].
  - Low inertia- Microgrid shows low inertia since it mainly contains power electronic interfaced distributed generators which can improve the system dynamic performance. But when microgrid works in islanded mode then this low inertia can cause high rate of frequency deviation, if proper controlling measures is not taken [11].
  - Islanded mode of operation- Due to faults or voltage drop, operation of microgrid changes from grid connected to island mode. In that situation, power flow and voltage &frequency control become a challenge for reliable and efficient operation of microgrid. Also overload and low power quality issues become prevalent in islanded operating mode [3], [11].
  - Coordinated control of Multiple DGs- Microgrid consists of multiple distributed generators having different characteristics of their operation and control. Therefore proper coordination control of these DG’s is also a matter of great concern [13].
  - Energy storage options- Microgrid having multiple distributed generators mainly consists of renewable sources which are very intermittent in nature and hence for continuation of power supply it requires efficient energy storage systems. Also it stabilizes load and generation imbalance and helps in safe and reliable operation of microgrid [14].
  - Economical and reliable operation- Economical operation of microgrid along with constant value of voltage and frequency is a major challenge.
  - Technology and cybersecurity challenges- Availability of low cost technology for safe, reliable operation along with need of proper control and technology for integration of renewable sources is a key challenge [11]. Need for speedy and accurate computational devices and communication system is again a challenge for reliable microgrid operation [10].
  - Regulatory barriers- Even nowadays most regulatory officials are still not familiar with microgrid concept and also uncertain about how the policies related to microgrid should be develop. Also some regulatory authority prohibits communities from making infrastructure development [15].

### 1.2. Control of microgrid

Main purpose of any control technique used in microgrid is to maintain the voltage and frequency of microgrid constant. Other than this, microgrid control has some more objectives which are specified as follows:

- Addition of extra distributed generators or energy storing devices into already present system, without altering the existing device
- The microgrid is capable of choosing operating point autonomously
- Voltage and frequency should be maintained constant
- Active and reactive power can be controlled independently
- During connection and disconnection of microgrid from the main grid due to system imbalance.

Several control techniques are used for microgrid control. A systematic classification of various control techniques is presented in figure 2 [10], [16].

With reference to the power systems control architecture, control techniques can be classified into centralized, decentralized and distributed control. In centralized control, MGCC (microgrid central controller) determines controlling actions for all units. However, large amount of communication requirement between MGCC i.e. microgrid central controller and remaining all units is the main drawback of this scheme. In decentralized control each unit is controlled by its local controller and only receives local neighbouring information. The third control i.e. distributed control have some level of centralization as well as some level of decentralization and hence uses less communication line as compared to centralized and larger communication line when compared to decentralized one. A settlement between these three controls is obtained by hierarchical control scheme consisting of three levels, i.e. primary, secondary and tertiary control [11]. figure 3, shows a hierarchical control structure of microgrid [17]. The control of output of parallel inverters in distributed generation systems is based on three control loops: (1) inner control loop, i.e., voltage and current control loop (2) Intermediate control loop, i.e., virtual impedance loop (3) The outer loop, i.e., active and reactive power calculation loop The primary control level introduces droops in the output voltage amplitude E and frequency W of inverter using droop method as given in equation (1) and (2) as-

\[ W = W_0 - K_w (P - P_0) \]
\[ V = V_0 - K_v (Q - Q_0) \]

Where, \( K_w \) and \( K_v \) are the droop coefficients for frequency and voltage amplitude respectively and thus provides reference for inner voltage and current loops. Figure 4, shows frequency vs. output power and output voltage vs. reactive power characteristics. In this figure \( W_{ref} \) and \( V_{ref} \) are the value of angular frequency at no load and amplitude of output voltage at no load respectively.

By this regulation, although, the primary control attains required power sharing but also cause the frequency and voltage amplitude to deviated from their mean value. In order to compensate this deviation, secondary control is used which, sensed the voltage amplitude and frequency of microgrid, processes it through compensator and sends to all units, and achieves the required compensation.
Also the secondary control manages the synchronization of microgrid with the main grid. After secondary control action, for controlling and managing the flow of power between microgrid and main grid, tertiary control is used. In this control, the power is re-distributed among distributed energy resources in best possible economic way and this redistribution of power can be accomplished by regulating set points of individual distributed resource units, and this adjustment of set points can be done on the basis of their marginal cost functions comparison. The point, at which each distributed energy resources have equal marginal cost, is called an optimum economic operating point [17], [18]. In this way hierarchical control of microgrid can be obtained. Table. 3, shows a brief comparison between primary, secondary and tertiary control.
Figure 3. Hierarchical control structure of microgrid

(a) Frequency v/s Active Power    (b) Voltage v/s Reactive power

Figure 4. Frequency and Voltage Droop Characteristics

Table 3. Comparison between primary, secondary and tertiary control of microgrid.

| Parameters          | Primary control                                           | Secondary control                                      | Tertiary control                                    |
|---------------------|-----------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------|
| Mode of Operation   | Decentralized (i.e. implemented locally at each DG’s)     | Centralized (i.e. by considering all DG’s)             | Centralized (i.e. by considering all DG’s and microgrids) |
| Objective of control| Voltage and frequency stability                            | Microgrid voltage, frequency, active power and reactive power control | Control of power flow between grid and microgrid      |
|                     | Mitigation of circulating current among DG’s              | Provides compensation for deviation in frequency and voltage value caused by primary control | Provides economical operation of microgrid in both islanded and grid connected mode |
|                     | Proper sharing of active and reactive power among DG’s    | Provides synchronization of microgrid with the utility grid | Set point of microgrid inverter can be adjusted by tertiary control |
|                     |                                                           |                                                        |                                                     |
Parameters | Primary control | Secondary control | Tertiary control
--- | --- | --- | ---
Use of communication scheme [20] | Absent | Present | Present
Time constant [20] | Low | Higher than primary control | Higher than primary and secondary control
Speed of operation [20] | High | Slower than primary control | Slower than primary and secondary control
Bandwidth of control levels [20] | Not applicable (because there is no use of communication scheme) | Low | Lowest
Control method used [11], [19] | Droop control, Q-V method, etc. | Multi-agent based, droop control, gossip based technique, potential function based optimization technique. | Gossiping algorithm based control, model predictive control.

1.3. Secondary control of microgrid

While achieving power sharing, the primary control leads to some steady state deviation in voltage and frequency. So to restore these deviated values of voltage and frequency to a nominal value, secondary control is used. Also secondary control is used in synchronizing microgrid with main grid and to find optimal unit commitment of DG’s. Secondary control response is slower than primary control and can be classified into three category i.e. Centralized, decentralized and distributed control. A brief of these three control methods is as follows-

1.3.1. Centralized control

In this method of control, MGCC (microgrid central control) plays main role in managing power flow between different microsources and the main grid. This MGCC provides reference value for primary control. Hence after gathering data and performing required calculations, it determines control action for all its units. Main disadvantage of this control method is huge dependency on communication between MGCC and the units to be controlled. Another drawback is huge dependency on MGCC which means if there any fault occurs in central control, the entire microgrid will be disturbed. Figure 5. shows a basic diagram of centralized control. Some control mechanism used for centralized control is as follows [21]-

![Figure 5. Basic structure of centralized control of microgrid](image)

1.3.1.1. Model predictive control. MPC is able to predict next control sequence along with control action, for example, variation in output of renewable energy sources, change in load demand [22]. It is a discrete time control strategy and used for controlling large power plants.
1.3.1.2. **Optimal dispatch.** This approach is used for small size microgrid where less number of microsources is present. In this control, an offline calculation is being performed, which is a cost effective approach. This approach firstly analyses the possible operational states of various DG’s and then calculate the optimal dispatching of each unit. This approach firstly analyses the possible operational states of various DG’s and then calculate the optimal dispatching of each unit. Main drawback of this approach is that for consideration of all possible faults or problems, the number of possibilities will result in complex situation [11].

1.3.1.3. **Non-model based control.** Sometimes conventional model base control does not provide adequate control to promote plug-and-play operation. Also if any unexpected changes occur in the system topology, then there is possibility that they may pose an additional problem related to effective and faster mitigation of transient. Therefore, the non-model based control method such as neural network and fuzzy logic can be adopted in order to achieve desired control and adaptiveness. Advantage of these methods is that, they are quick to handle the system changes and do not require detailed modelling [23].

1.3.2. **Decentralized control**

In this control method, various individual local controllers do control their respective controlling unit [7] i.e. in this control the secondary control is being transferred to beside each primary control [24]. In this scheme local controllers do not exchange whole information with other local or central controller; however some local controller can exchange information with the central controller and hence, communication requirement is significantly reduced. Advantage of decentralized control is the capability to safeguard the privacy of units by segregating their private information. Also this control scheme provides scalability and improves reliability and stability of microgrid in both mode, i.e. grid connected and islanded mode [14]. Drawback of this control is that it will not able to reach at global optimization. Figure 6, shows basic diagram of decentralized control [21]. Techniques used for decentralized control is as follows –

![Figure 6. Basic structure of decentralized control of microgrid](image)

1.3.2.1. **Droop control.** This control scheme is identical to primary voltage and frequency control of microgrid which does not require any communication with other units, because in this control there is linear relationship between active power & frequency similarly between reactive power and output voltage. This linear relationship can be described by equation no. (1)&(2). Fig. 4 shows frequency vs. output power and output voltage vs. reactive power characteristics.

1.3.2.2. **Gossip based technique.** It can be considered as special case of multi agent based system (MAS). In this technique each DG unit requires measurement of its own voltage and current and also
some from its nearest neighbour but not all neighbours. This scheme requires discrete low bandwidth communication link. For maintaining the output voltage to near constant reference value, gossip communications required. This method provides better control [21], [25].

1.3.2.3. Master-slave control. In this control approach, there is one master controller and others act as slave controller, which works on the instructions provided by the master controller through communication link. In grid connected mode there is no need of frequency control and only PQ control is used in microgrid. And in islanded mode, the master controller maintains voltage and frequency of the system along with power balance. If master controller uses voltage-frequency control, then it can be divided into two types i.e. single master (having only one microsources of large capacity) control and multi master control. In multi master control, if a succeeding step master control microsource uses V/f control then the output of preceding step master control microsource uses P-Q control [8], [11], [26].

1.3.3. Distributed control
Distributed approach of secondary control have some degree of centralization (because each unit uses local information such as frequency and voltage, provided by its neighbours and exchange information through two-way communication link thus can achieve global optimization same as centralized method) [9] with some degree of decentralization, because the information obtained for controlling is not inclusive or global but, neighbouring for the specified unit and also has shorter communication link compared to the centralized one, which provides reliable delay [27]. Since, the dependency of entire microgrid system is not on a lone central controller; the risk of overall system failure is reduced [27]. This control technique provides great scalability, reliability and stability along with reduced communication cost. Figure 7, shows schematic diagram of distributed control [27].

Techniques used for distributed secondary control is as follows-

![Figure 7. Schematic diagram of distributed secondary control](image)

1.3.3.1. Multi agent system. In this technique each distributed energy resources units are controlled by local agents. For determination of system set points, these local agents communicate with neighbouring agent and exchange information with a central controller [11]. This technique is more flexible and having good computational efficiency.

1.3.3.2. Consensus based technique. Consensus based technique is used to converge the different DER units to a single value. Thus makes an average global consensus. This control technique requires sparse and simplified communication network, i.e. it achieves global consensus by using time varying communication between its neighbour units without need of any dedicated control unit. This control provides a flexible formulation of problem along with greater scalability [3].
1.3.3.3. Decomposition based techniques. Various decomposition based techniques have been proposed like, alternating direction method (ADM), predictor-corrector proximal multiplier method (PCPM) and auxiliary problem principle. All these techniques are based on decomposition of original optimization problem into various sub-problems or areas and then these sub-problems or areas are supposed to solve iteratively till the convergence of problem is not obtained. Also these areas can be defined by various methods like sensitivity factor and controllability of various buses, information availability [3].

1.3.3.4. Distributed model predictive control based techniques. This technique is a discrete time control technique in which control command for any system is obtained by cost function minimization. This cost function is linked with system performance over a specified future time period. Combination of deviation of system state and deviation from set points form a cost function, for MPC based technique. MPC is able to predict next control sequence along with control action. MPC can handle multivariable control problem and having ease of tuning [3].

2. Conclusion
With the increased penetration of renewable energy sources based distributed generators, the distribution network has become complex. Adequate control techniques thus become essential in order to maintain system performance. The concept of microgrid with its superior control structure has emerged as a viable solution to this problem. It is essential to realize the difference between Microgrid and conventional grid in order to come up with a suitable planning and control structure. Thus in this paper a systematic comparison of microgrid with conventional grid has been presented. Along with the development of microgrid, there are some challenges related to power quality, stability, reliability, safety, coordination and control. These challenges have been adequately discussed in this paper.

Due to complexity of system and the associated challenges proper control techniques are essential requirement for reliable and efficient operation of microgrid. This paper presents a classification of microgrid control techniques on the basis of various factors such as controller function, connection with grid and response time. A comparison between three control levels i.e. primary, secondary and tertiary control has also been presented in this paper. A discussion on sub-classification of secondary control into centralized, decentralized and distributed control and techniques related to them has also been presented here. Most of the techniques have adaptiveness and robustness as major problem. Hence, development of proper control technique and planning will lead to better operation of microgrid. This paper serves to form a background of research in the advancements in the area of secondary control of microgrid.

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