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A brief review on Management and Control Strategies for Micro-grid

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Abstract:

The demand for high-quality electricity and growing electricity consumption caused by increasing electrification of daily life causes and the rising number of important loads. This high demand for electricity has caused the need for innovation and sustainable power production schemes. The current power system is therefore, challenged with the need for quality, reliable and sustainable power production. Micro-grids (MGs) have been developed as a building block for the future smart grid system. The main issues for the control and operation of MG include integration for technologies and energy management schemes. This paper presents an overview of the most obvious control challenges of MG operating, control and energy management strategies of MGs. It covers a brief explanation of the fundamental principles of the proposed strategies. Finally, this paper considers a comparison of the strengths and weaknesses associated with control and management strategies on literature.

Keywords— **Microgrid; Control; Energy management; Smart grid**

1. Introduction

The increased in distributed generation (DG) installation, most importantly those based on renewable energy sources, in recent years, is expected to address the concerns on greenhouse gas emission energy stability, energy security etc. The wind and photovoltaic (PV) power generation and the fastest growing DG technologies among various kinds of renewable energy based DGs [1]. Since the mid-1990s, wind power installation has been growing by 25% per year. By 2011, China has the highest wind power capacity with more than 60GW [2]. A similar trend was followed by PV installation, but with an even faster growth rate around 48% each year in recent years, making it the fastest growing energy micro-sources in the world. As of 2011, PV installation has reached around 78GW with the Germany as the leader [3]. In addition, the need for alternative energy sources such as fuel cells and microturbines have been increasingly used in recent years for power generation. Fuel cells produce electrical power directly from chemical energy contained in a fuel, which can be hydrogen, natural gas, methanol, gasoline etc. These power generations are inherently modular in nature, and their capacity added easily as loads grow. On the other hand, microturbines originally designed for aircraft applications [4].

The microgrid concept has the potential to solve major problems arising from large penetration of distributed generation in distribution systems. A small-scale system is located near the consumer is called the Micro-grid (MG) system. The inter-connection of small generation to low voltage distribution systems can be termed as microgrid. Micro-grid operate with and without connecting to the main power network. The various energy resources in MG are PV, wind, diesel generation, small capacity hydro units, Biogas plants, fuel cells etc. For electrification of areas mainly rural areas when there is no possible access to grid electricity due to poor access of remote areas to technical skills. The micro-grid designed such that there is ease of installation, commissioning, operation and maintenances. The microgrid helps in reducing the expenditure by reducing network congestion, line issues, and line cost and thereby having higher energy efficiency.

One attractive feature of MG on the capability of working in both grid- connected and islanded operation modes. Fig 1 shows a configuration of micro-grid [5]. In case of power system contingency occurring such as outage, voltage sag or frequency variation, which causes failure of the upstream distribution network, a micro grid, can be disconnected from the main microgrid and work in an islanded mode and supporting the local distribution energy resources (DERs) and energy storage systems (ESSs). This feature ensures supply reliability and power quality of its internal customers. Moreover, a micro-grid is able to provide surplus generated power to external customers by involving in the distribution, reconfiguration process when faults occurring in upstream of the network [6]. However, appropriate coordination of internal components is essential for an MG to gain such functionality, in this sense, proper control and energy management techniques are necessary to achieve above objectives. This paper tries to review control methods of micro grid such as master-slave, peer-to-peer, hierarchical and multi-agent control systems. In addition, for proper operation of a micro grid, energy management strategies are important to regulate the output power of DG as well as the voltage and frequency of the MG systems [7],[8], [9]. We, therefore, reviewed different types of energy management schemes including communication-based and communication-less strategy.

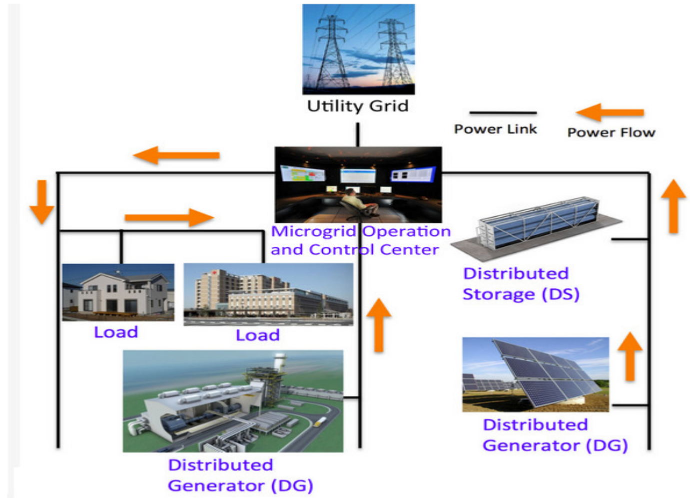

Figure 1:- Micro-grid configuration overview [5]

2 Operation and Control of Micro-grid

Micro grid contains various renewable DGs such as PV arrays and wind turbine. It known that energy source is difficult to be predicted. Power flow between MG and main grid needs to be controlled in grid-connected mode to ensure a seamless transition and MG should have the ability to survive after disconnecting with the main grid. Moreover, renewable energy resources have stochastic generation, behaviour and therefore, proper control technique are necessary to fulfil above objectives. The objectives of MG control are as follows controlling DG power and reactive power flow to main grid or load hinder the request of main grid in grid connected mode, dynamic load sharing a load suddenly increase or decrease in islanded mode, provide power quality, ability to keep the stability of network under transient period or disturbance occurs [10]. Finally, seamless transition from grid connected mode to islanded mode in case of intentional oor unintentional disconnection with the main grid.

Control methods of micro-grid can be divided into two parts i.e. grid-connected and islanded mode control technique. There are mainly 3 categories of DGs, which are grid-forming, grid-feeding and grid-supporting [11], [12]. Grid forming units are controlling voltage and frequency of main grid while connecting to the host grid [13]. Grid-following controls are employed when micro-grid is connected to the main grid and active and reactive power of grid-feeding unit are regulated according to requirement from micro-grid central controller and in the islanded mode grid-feeding units adjusts real power (P) and reactive power (Q) by given PQ characteristics [13]. One control method for grid-supporting units are utilized droop control to regulate frequency and voltage according to given power and reactive power set point. The most attractive feature of micro-grid is that it can work independently without connecting to the main grid. When upstream distribution system experiences outage, frequency fluctuation, voltage sag and swell or commanded by dispatcher to shed downstream network, micro-grid can then disconnect from the main grid and continue independently. Therefore, proper control methods are needed to maintain the system and continue to operate in the islanded mode. Control methods of micro-grid are categorized in following classes based on the different roles that DG plays to maintain balance power and keep the stability of micro-grid.

2.1 Master-slave control

While micro-grid is connected to the main grid, all micro-grid sources including the master converter follow grid voltage and frequency as references [14]. A power-frequency droop is used in this mode to adjust power for each DG.When micro-grid switches from grid-connected to islanded mode, one micro-source will behave as master controller under voltage mode control meanwhile providing voltage and frequency reference to other micro-sources, which are working under current control mode [14]. In this way, loads are automatically re-distributed among master DG and other DGs. Micro-grid central controller works as a master controller [15], when adjusts the set points for DGs when frequency and voltage violate defined settings. However, master-controlling DG is considered fully loaded to handle disturbance of the micro-grid, because a failure of master controller lead to whole system shutdown [14]. Fig.2 shows the control method for a master-slave converter topology that two DC sources connect to an AC micro-grid through a full bridge inverter and LCL filters. The master converter is under the voltage control mode and providing voltage as well as current references to the slave converter has two controller loops with an outer control loop as the current controller and an inner control loop as the voltage controller. Master-slave control can be implemented in both centralized and distributed structure. Centralized control requires fast communication links determine the controller dynamic response.

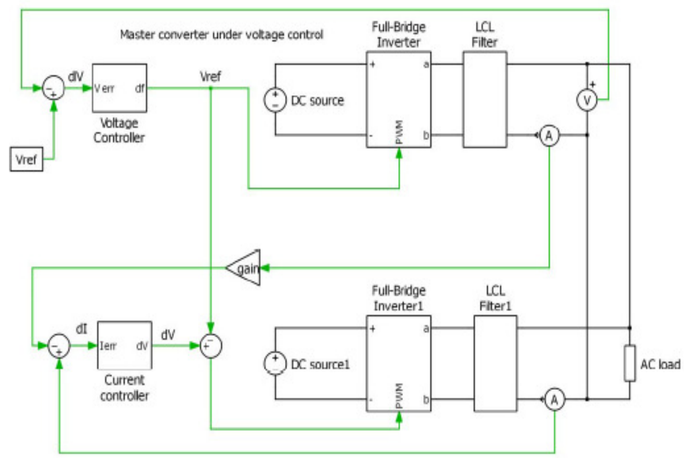

Figure 2:- Master-slave converter control method

2.2 Peer-to-peer control

Unlike master-slave control, all DGs performs a local control according to its own droop characteristics when micro-grid is working in the islanded mode. During a load transient, each of DGs will re-balance the load variation based on the droop characteristics and the system will automatically reach a new balancing point [16]. In this method, when one energy source is connected or disconnected from the system, the micro-grid will continuously operate without additional reconfiguration, thus, “plug and play” feature is achieved [15]. Droop control initially used in power system to manage load sharing between multiple generators, namely, primary frequency control. By adjusting real power, the frequency can be regulated and similarly voltage can be controlled by correspondingly adjusting reactive power.

2.3 Hierarchical control

As the name suggests, this control method contains three control levels, which are primary control, secondary control, and tertiary control. Primary control is on the converter control level, where P/Q droop method usually used to share active and reactive power between DGs [17]. Secondary control is used to compensate frequency and voltage deviations caused by primary control, also it ensures synchronization process with the main grid [17]. Tertiary control is the highest control level, which considers economy concerns and determines when to buy or sell power to or from the main grid. Furthermore, power flow between micro-grid and main grid also managed in this control level.

2.4 Multi-agent system control

Multi-agent (MAS) is an emerging technology that allows each micro-source or load represent as an agent and can exchange information with neighbour's agents to collaborate for a mutual objective [10]. MAS control can be actually being a decentralized control method. Each agent in the micro-grid is an autonomous entity to a certain extent that it can make decisions based on its status without external command. Compared with a traditional centralized control system such as SCADA system needs to process mass data such as measurements from RTUs, while MAS system has a small number of data to manipulate because an agent only need to care about own status and information from neighbouring agents [18]. Since any controller of DGs or energy storage or load can easily integrate with existing MAS controlled micro-grid by following the same rule, thus, a plug and play ability is realized.

3 Energy Management Schemes

For the sound operation of a micro-grid in both grid-connected mode and stand-alone mode, proper energy management strategies are very important. These energy management schemes determine output powers and/or voltages of each DG source, which then fed into the control system of interfacing converters as the control tracking references.

3.1 Communication-based energy management schemes

In the communication-based energy management schemes, the system information (current, voltage, power etc.) communicated in the micro-grid to determine operation point of each DG. These schemes take the full advantage of intelligence in the integration of the computing and communications technologies in order to determine the output powers of each DG. Considering the distances of power sources, the level of security, cost, and available technologies, the appropriate communication method is determined. The communication methods can be based on fibre-optics, microwave, infrared, power line carrier (PLC), and/or wireless radio networks (GSM and CDMA) [19]. In these schemes, combinations of Internet Protocol (IP) with existing industry protocols and standards are used to communicate over the grid.

In general, the communication-based energy management schemes can be divided into centralized and decentralized energy management schemes [10], [20]. These schemes explained as follow.

3.1.1 Centralized energy management scheme

This strategy is also known as supervisory energy management. In general, master-slave control and central mode strategies belongs to centralized energy management strategies. In this scheme, one centralized system or control center makes decisions and determines operation point of DGs. This control center receives all the measure signals of all energy units in micro-grid, and sets the operating points of DGs based on the objectives and constraints, which can be minimizing system operation and maintenance costs, environmental impact (carbon footprint), maximizing system deficiency, etc.[20], [10], [21]. These objective functions along with the constraints can be conflicting and sometimes solving these problems is difficult (if not impossible). After making decisions, the control signals sent to the DG local control systems. The DG local control mainly realized by controlling the DG's power electronics converters. Figure 3 shows block diagram of centralized energy management scheme, where the DG units include both the energy sources and DG-grid interfacing power electronics converter

An example of such supervisory energy management schemes is for micro-grids based on PV-Wind-Battery-FC (fuel cell) input power sources [22]. In this work, the measured micro-grid data sent to the central system, and the objective function in the central controller is to provide the load power with high reliability. The advantage of this centralized control scheme is that the central system receives all the data of the system, and then based on the available information the multi-objective energy management system can achieve global optimization. However, heavy computation burden is one of its main drawbacks. Another drawback of this system is the reliability concern as a failure in the communication system may cause overall shutdown in the system.

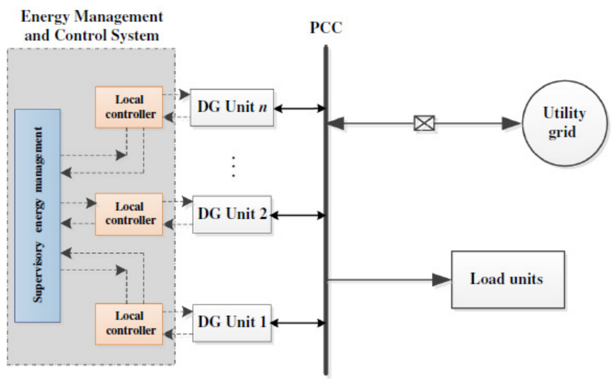

Figure 3:- Centralized Energy Management scheme

3.1.2 Decentralized energy management scheme

In decentralized energy management scheme, all the local controllers connected through a communication bus. This bus used to exchange data among DG's controllers. In this energy management system, each local control system knows the operation point of other converters. This information used to determine the DGs' operating points according to different optimization objectives [20], [10], [23]. In these systems, intelligent algorithm often used to find optimal operation point [23]. Figure 4 shows the block diagram of the decentralized energy management strategy.

This strategy has some advantages over centralized strategy. For example, it is easy to extend the control system to newly added energy sources with the plug-and-play feature. Moreover, computation requirement of each controller is reduced, and the redundancy and modularity of the system are improved [20], [10]. However, failure in the communication link can still cause the problem in the system (although unlike the supervisory control where a communication failure may collapse the system). In addition, potential complexity of its communication system is still a concern of this strategy.

Multi-agent system (MAS) can be the best example of decentralized energy management system [10]. In MAS, autonomous computational agents make decisions based on goals within an environment, and they communicate information about their goal achievement to other independent agents [24], [25]. These systems mainly used for large and complex micro-grids and artificial-intelligence-based methods such as neural network or fuzzy systems are improving the overall performance of the micro-grid [24], [25].

In addition to centralized and decentralized energy management schemes, a combination of these schemes will produce a hybrid centralized and decentralized scheme. In this hybrid strategy, DGs are divided into groups. In each group, the centralized scheme is used, which is responsible for local optimization within the group. Among different groups, decentralized energy management scheme utilized for global optimization. Such a hybrid strategy could be suitable for large systems with interconnected micro-grids, where centralized control of each micro-grid and decentralized coordination among micro-grids could improve reliability and resilience of the system. The recently proposed hierarchical energy management scheme considered as hybrid centralized and decentralized energy management scheme [17], [26].

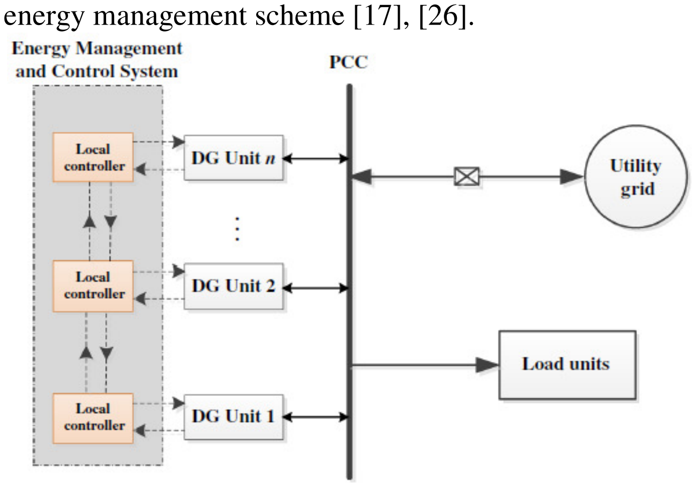

Figure 4:- Decentralized Energy Management scheme

3.2 Communication-less energy management schemes

The main idea of communication-less energy management strategy is that every DG unit must be able to operate independently when communication is too difficult or costly [1]. Figure 5 shows the block diagram of communication-less energy management strategy. In these methods, each energy source has its own local controller links with the other controllers.

Droop control method is probably the most popular strategy in communication-less energy management [9], [27]. This method emulates the behaviour of the synchronous generator where the voltage and frequency vary with the DG output real and reactive power. The droop control based on the assumption that the output impedance of DG is mainly inductive and it uses droop characteristics of the voltage amplitude and frequency of each DG to control its output. In other words, the virtual communication link here is the micro-grid voltage amplitude and frequency.

This strategy has obvious advantages: there is no communication requirement, so the control strategy is more reliable. In addition, the control system is expandable with true plug-and-play function. However, there are more potential issues. First, in this method, nonlinear loads are not considered and the nonlinear current sharing among DG units cannot be addressed directly. In addition, in low voltage micro-grid systems, high R/X line impedance ratio may lead to real and reactive power coupling and stability concerns[28]. In addition, the mismatched DG output can cause the power-sharing error. Recent work shave been done to improve droop control by adjusting the output voltage bandwidth, adding virtual impedance, or implementing the droop in virtual frames [28]. However, without a central control/ optimization algorithm, optimal operation of the micro-grid system is still difficult with the communication-less based control energy.

Other than the droop control method, if all DGs work at MPPT mode, it is not necessary for communication between DGs. As a result, this method could be considered as a communication-less energy management strategy. However, in such a system, energy storage devices are essential in stand-alone operation mode to provide the micro-grid voltage and frequency regulation.

Considering the drawbacks of communication-based and communication-less energy management schemes, a combination of the droop control with communication-based control could have both improved reliability and control performance and may be a good option for the future micro-grid systems. In such a combination strategy, with the help of communication-based energy management, the DG operation point in both grid-connected and stand-alone modes can be determined more accurately. Also with the droop control as the backbone, the communication requirement (such as speed and bandwidth) can be reduced and failure of the communication links will not cause a system collapse.

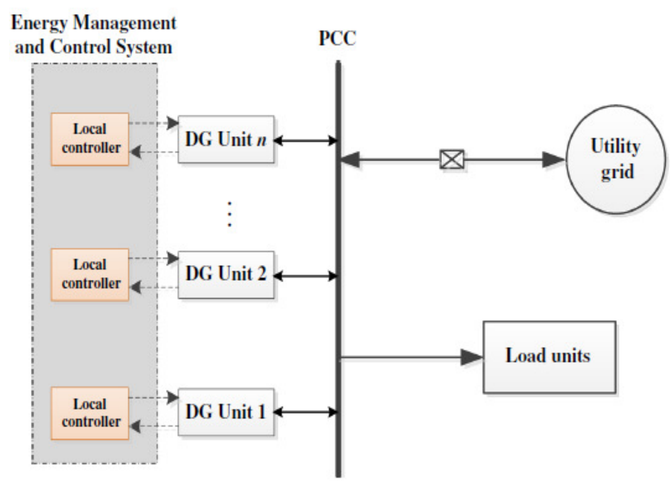

Figure 5: - Communication-less Energy Management Scheme

4 Conclusion

Micro-grid is becoming an important aspect of the future smart grid, which feature great control, flexibility, improved reliability, and better power quality. The important aspects of the MG are the control and energy management strategies of micro-grids. For the control of micro-grid, grid-connected mode control, master-slave control, peer-to-peer control, hierarchal control and multi-agent control strategies could be of adequate as reviewed in this paper. Also, for the energy management strategy, we reviewed a hybrid combination of communication-based and communication-less based energy management technologies which could be a good balance of system optimal operation, reliability, and resilience.

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