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Review of Investigation on Distributed Control of Islanded Micro Grid

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***Abstract*—** In the hierarchical control of an islanded microgrid, secondary control could be centralized or distributed. The former control strategy has several disadvantages, such as single point of failure at the level of the central controller as well as high investment of communication infrastructure. In this paper three-layer architecture of distributed control. The agent layer is a multi-agent system in which each agent is in charge of a distributed generation unit. Due to communication network constraints, agents are connected only to nearby neighbors. However, by using consensus algorithms the agents can discover the required global information and compute new references for the control layer. In this paper, a review of distributed control approaches for power quality improvement is presented which encompasses harmonic compensation, loss mitigation and optimum power sharing in multi-source-load distributed power network.

***Keywords:* -** Distributed Control, Real-time Simulation, Micro-grid

I. INTRODUCTION

A well-known fact is that, in micro grids several renewable changes required in order to reduce the carbon footprint and to offer autonomous energy provision as well as resilience in disaster relief. In general, a MG consists of a cluster of distributed generators (DGs), loads, energy storage systems and other equipment, which can operate in islanded mode or grid-connected, and can seamlessly transfer between these two modes [1]. A hierarchical structure comprised of primary, secondary and tertiary control is typically used to control MG. The primary control, typically droop-based, is designed to stabilize frequency and voltage by using only local measurements. It is necessary to have a fast response time in this control level in order to keep frequency and voltage near the nominal values. The secondary control, implemented in either centralized or distributed fashion, is responsible for the restoration of the frequency and voltage by compensating the deviations caused by the primary control. At the top level, tertiary control manages the power flow to the main grid and optimizes certain economic or operational aspects.

The comparison between centralized and distributed control has been properly discussed in [2]. Figure 1 illustrates the main differences between the two control approaches. The distinct feature of the distributed approach is that the information involved in the control algorithm is not global, but adjacent for any given unit. Also, the length of the communication links is often shorter, which offers better and more reliable latency. Moreover, the risk of overall system failure can be reduced, because the system does not depend on a sole central controller.

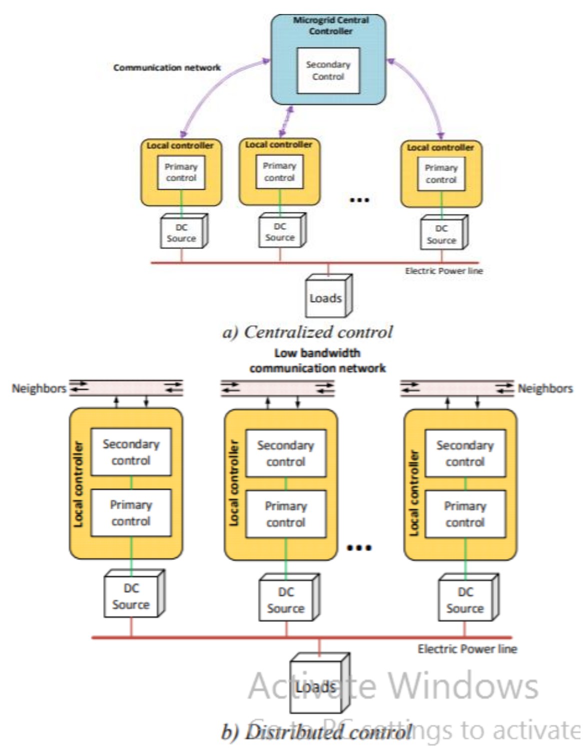

Figure 1: Control strategies in microgrid

In islanded mode, MG operation is more sensitive to frequency disturbance compared to the grid-connected case due to the lack of inertia in the system, the intermittency of renewable generators and varying demand of loads. DG controllers need to be properly coordinated to satisfy the demand requirement and maintain a stable frequency. In this paper, a distributed control structure is proposed for implementing the frequency control of an islanded MG. This is achieved by sharing the active power demand among multiple inverter-based DGs. In order to provide a distributed control, the multi-agent system approach is proposed. The given control architecture includes three layers: the device layer, the control layer and the agent layer. An experimental setup consisting of a real-time simulation model running on OPAL-RT and a real TCP/IP communication network are established in order to validate the operation of the proposed control strategy. The device layer and control layer are considered part of the physical process and are running on the real-time simulator, meanwhile the agent layer is created by a set of ARM-processors connected between them via TCP/IP. The multi-agent system (MAS) is an innovative technology that has been recently used in a wide range of applications in power systems. The agent based distributed control is also presented in [3]. However, in these works, the inter-agent transmission latency which plays an important role in distributed control is neglected or simulated as a deterministic time. In this paper, a communication network with real and variable latencies is considered in the process of validating the proposed distributed control method. Each agent in our system is connected only to nearby neighbors due to communication constraints. Thus the consensus algorithm is implemented in order to get the global information, specifically the value of frequency deviations.

II. MICROGRID STRUCTURE

Microgrid solar PV, batteries and wind generation system become very attractive solution in particular for stand-alone applications. Combining the two sources of solar and wind can provide better reliability and their hybrid system becomes more economical to run since the weakness of one system can be complemented by the strength of the other one. The integration of hybrid solar and wind power systems into the grid can further help in improving the overall economy and reliability of renewable power generation to supply its load. Similarly, the integration of hybrid solar and wind power in a stand-alone system can reduce the size of energy storage needed to supply continuous power. Solar electricity generation systems use either photovoltaics or concentrated solar power. The focus in this paper will be on the photovoltaics type. Detailed descriptions of the different technologies, physics and basics of PV can be found in many textbooks and papers such as [4-7]. Kurtz [8] pointed out that ten years ago the concentrator cell was only ~30% efficient compared with more than 40% today with the potential to approach 50% in the coming years. Si cells have efficiencies of 26% and multi-junction III-V-compound cells have efficiencies above 45% (48% in the laboratory) as pointed out in reference [4]. PV modules produce outputs that are determined mainly by the level of incident radiation. As the light intensity increases, photocurrent will be increased and the open-circuit voltage will be reduced. The efficiency of any photovoltaic cell decreases with the increasing temperature which is non-uniformly distributed across the cell [5]. The solar output power can be smoothed by the distribution of solar power in different geographical areas. Electricity from solar PV and concentrated solar power plants is significantly expensive and requires significant drop in cost or change in policies by either subsidizing or forcing the use of these technologies to be able to achieve significant market penetration [6]. Global wind report (2012) indicated that the annual market grew by around 10% to reach around 45 GW and the cumulative market growth was almost 19%. Detailed descriptions of the wind energy can be found. Wind turbines (WTs) are classified into two types: horizontal-axis WT (HAWT) and vertical-axis WT (VAWT). The highest achievable extraction of power by a WT is 59% of the total theoretical wind power. Hybrid solar-wind systems can be classified into two types: grid connected and stand-alone. Literature reviews for hybrid grid connected and stand-alone solar PV and wind energies were conducted worldwide by many researchers who have presented various challenges and proposed several possible solutions. Due to the nature of hybrid solar PV and wind energies, optimization techniques can play a good role in utilizing them efficiently. Graphic construction methods, linear programming [7], and probabilistic approach [8] are few examples of optimization techniques that have been developed for techno-economically optimum hybrid renewable energy system for both types.

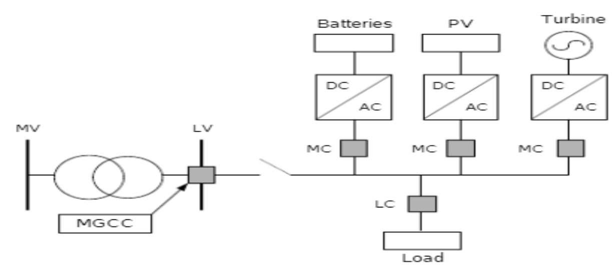

Figure 2: Micro Grid Control Architecture

III. CONTROL OF MICROGRID

In micro-grid system, due to various micro-power types, it is difficult to control them in coordinating to establish a stable voltage and frequency. Now the control strategy commonly used is divided into master-slave station control, the droop control and control based on multi-agent technology, etc. The typical droop control based on P-f and Q-V characteristics improved in Reference avoids the switch of control strategies and achieves the smooth transition when operating modes change. Reference [9] adopts an integrated control strategy that integrates master-slave control with peer-to-peer control to control the operation mode transition between grid-connected operation mode and islanding operation mode of micro-grid. Reference [10] considers decentralization of the distributed generation units and loads in the micro-grid and concentrating on generation types and models of the storage devices, using different control strategies in controller design for the distributed generation units. When the regular grid breaks down or the power quality cannot meet the requirements, micro-grids will disconnect with regular grids and forms into islanding operation.

In the micro-grid system, the master-slave control is that one or several micro-power control all of micro-power according to V/f control. Except the main control source, other micro-powers often adopt P-Q control, the constant power control. The main control source which adopts V/f control supplies reference of voltage and frequency to other micro-powers [1]. The process of master-slave control method goes as follows [2]:

1) When islanding is detected, or the grid disconnects from the distribution network into the islanding operation mode, micro-grid control will switches to the master-slave mode, by adjusting the various micro-power output to reach the balance of power.

2) When the micro-grid loads change, firstly the main power adjusts output current automatically according to the load change. At the same time system detects and calculates the power variation to adjust their output power; when other powers' output power increase, the output of the main power will automatically reduce accordingly to ensure that the main power always has enough capacity to adjust the change of instantaneous power.

3) When the grid lacks for active power or reactive power, system can only rely on the main unit to adjust. When the loads increase, according to the load characteristics, system will reduce voltage appropriately.

Peer-to-peer control

Peer-to-peer control is that all of the DGs have equal status in the control in the system of micro-grid. There is no hierarchy among the controllers. Each DG is on the control according to signals at the point where system voltage and frequency access.

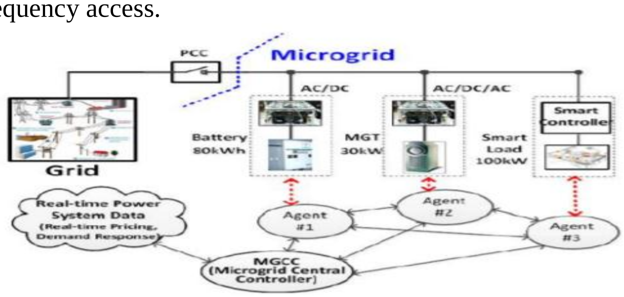

Figure 3: Configuration of Micro-Grid

Only peer-to-peer control can make the micro-grid plug-and-play. In general, in the control strategy DGs are allowed to control by using only local information, namely control does not depend on communication [8]. In peer-to-peer control mode, when the micro-grid runs in islanding mode, each DG used droop control strategy will be involved in the regulation of the voltage and frequency in the micro-grid [9].

IV. MANAGEMENT OF MICROGRIDS

Microgrids are relatively weaker to endure disturbances, especially when it operates in the islanding mode. The safety could be exposed with higher risk. And thereby effective operation control and optimal energy management need to be researched.

A. Supervisory and Control Architecture For the sake of friendly integration with the main grid, the normal operation of microgrids is carried out by cooperation of three level supervisory and control systems as follows [11]:

i. Distribution level: distribution network operator (DNO) and market operator (MO);
ii. Microgrid level: microgrid central controller (MCC);
iii. Unit level: local controllers (LCs). DNO/MO are used to achieve dispatch functions at the distribution level.

MCC is the interface between the microgrid and the main grid. It communicates with both DNO/MO and LCs. LCs are developed for distributed energy resources and controllable loads. They could also be used to regulate voltage and frequency. According to the different modes of decision making, the supervisory and control systems are divided into centralized microgrid control and decentralized microgrid control.

Operation and Energy Management

There are many differences between traditional power systems and microgrids in operational modes, policies of power market and energy, types and penetration of distributed energy systems, and restrictions about characteristics of loads and power quality. As a result, it is necessary to investigate reasonable dispatching and management strategies to guarantee the security, stability, reliability and operation in an efficient and economic manner, which involve the randomness of actual production, the uncertainty of power flow, the operation diversity of the microgrid, the power market, and new energy policies. The research of integration and control are relevant to all distributed energy systems, one or more microgrids and the main grid. Market policies will play an important role, when microgrids operate in the grid-connected mode. One is that a microgrid could input power from but not output to the main grid, while demand of loads is satisfied by inner distributed energy systems to the best of their abilities. The other is that a microgrid could exchange power with the main grid freely, what is more, distributed energy systems and demand-side management are allowed to participate in the bidding processes. The strategies could integrate local thermoelectric demand, weather conditions, pricing, fuel consumption, power quality requirements, wholesale/retail service demands, demand side management requirements, and the level of congestion to make decisions [9].

These depend on new network and distributed control theories, computing and evaluating methods so as to support microgrids for reliable, effective and flexible operation. Because of the increasing variety and scale of distributed resources, and the introduction of microgrid technology, a new energy management system (EMS) must be considered for distributed energy systems and microgrids. A new generation of EMS involving a variety of power advanced applications is being developed in order to implement operation and energy management of a microgrid. It is expected to carry out real-time energy management and dispatching on the basis of a hardware platform. C. Ancillary Services The most exciting aspect of microgrid control is the ability to provide ancillary services. As for this aspect, one of opinions is that a microgrid could just operate as a controlled load but will provide power toward the main grid in no case; another is that a microgrid could provide power to the main grid and participate in the power market. In fact, even if a microgrid doesn't provide power to the main grid, it can still provide an important service for the main grid. The control of loads is very important to the main grid in a heavy-burden condition. Some kind of ancillary services are listed, made definitions and explained in detail in literature, mainly including: regulation and load following, reactive supply and voltage control, supply of reserves in long-term or short-term, system blackstart, network stability etc [10].

Micro-Grid system

The concept of micro-grid was proposed by Consortium of Electric Reliability Technology Solutions (CERTS) as a system consisting micro-power resources which can provide electric as well as heat power to the distributed loads. Power electronic devices perform energy conversion and storage, with desired modulation and control. Micro-grid has the capability to operate as a singly controlled element or simultaneously with the main or utility grid, to meet power demand and quality for end utilization. In United States, CERTS's micro-grid concept presents a systematic overview of its architecture, design, control, and operation in regulating, managing and providing power. The specific architecture varies with different types of load, communication and control and monitoring technologies. However, a lot of structural variants are based on the distributed nature of the supply network and have high efficiency and reliability [11].

"European Commission Project Micro-grids defines micro-grid as a system that uses power electronic devices for energy regulation to provide users with cold, heat, and electricity; it takes the advantage of micro-power source from the primary energy, which can be divided into uncontrolled, partly controlled and fully controlled types". It can be concluded from this definition that European Union emphasizes on efficient control of micro-power. There are different types of micro-power sources used within a micro-grid system, typically small generation units with power ratings of < 100kW. Commonly used energy sources are photovoltaic cells, wind turbines, micro-turbines, fuel cells and energy storage devices are batteries, flywheels and super capacitors. These sources are interfaced with the loads and the main grid through power electronics interfaces at the user's side [2]. There are two distinct components of micro-gird control: 1) micro-grid configuration manager, for supervisory control and 2) power flow controller, for controlling DG units. Due to varying load demand, the power flow controller dynamically regulates active and reactive power based on local voltage and frequency information, and the DG units adjust their power output accordingly to maintain power balance and inertia. Information and communication technologies (ICT) at supervisory layer provide an additional degree of monitoring.

Distributed Control Techniques for Micro-grids

Micro-grid system has two operating modes: 1) grid-connected mode and 2) islanded mode. Reliability, efficiency, load management and power control are the key features of this type of power generation and supply network. Contrarily, large-scale use of DG units may lead to transients, voltage instability, power fluctuations, and harmonics. "All renewable energy sources are uncontrollable and unstable in nature which leads to output power fluctuations. When micro-grid is connected or disconnected from the main grid it causes the voltage profile to unbalance.

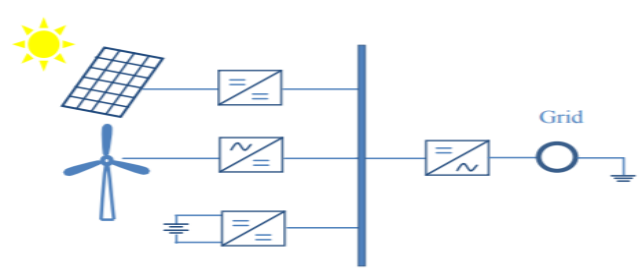

Figure 4: Grid-connected hybrid system at common DC bus

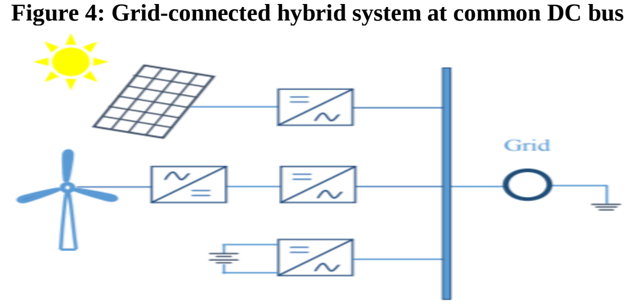

Figure 5: Grid-connected hybrid system at common AC bus

Optimization

As mentioned earlier, a combination of solar PV and wind sources improves overall energy output. However, energy storage system is required to have a continuous power supply and cover any deficiency in power generation from the renewable energy sources. The storage system can be battery banks, fuel cells, etc. with a more focus here on battery banks. Various optimization techniques have been reported which could be applied to reach a techno-economically optimum hybrid renewable energy system [16-19]. A comparison was made for many optimization techniques of hybrid systems in [18]. For remote areas which represent most of the standalone application for hybrid solar PV and wind systems, it is not always easy to find long-term weather data, such as solar radiation and wind speed that are used for sizing purposes. Hence, more artificial intelligence techniques such as fuzzy logic, genetic algorithms and artificial neural network are used for sizing standalone systems in comparison with traditional sizing method based on long-term weather data.

Wind Energy Systems

Wind energy has the biggest share in the renewable energy sector [1], [3]. Over the past 20 years, grid connected wind capacity has more than doubled and the cost of power generated from wind energy based systems has reduced to one-sixth of the corresponding value in the early 1980s [3]. The important features associated with a wind energy conversion system are:

- Available wind energy
- Type of wind turbine employed
- Type of electric generator and power electronic circuitry employed for interfacing with the grid.

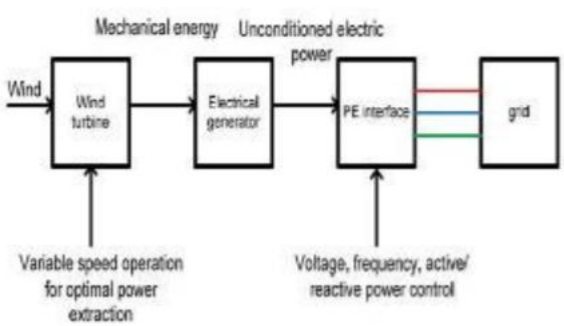

Figure 6: Variable speed wind energy conversion system

V. CONCLUSION

The concept of micro-grid has revolutionized the world of power systems with flexibility of power distribution from small to large scale. One of the major aspects for the development in this field is to avoid large power breakdowns as micro-grid can work in isolated mode if the primary supply fails. This can happen using the supervisory or distributed control of energy storage devices for the optimum utilization of energy resources. The analysis of power quality improvement strategies and advanced methods for micro-grid control has been presented. These strategies in all conditions ensure system efficiency, reliability, security and economics under different operating conditions for microgrids of distributed nature. The overall contribution of this research is to provide strong foundation for developing efficient and reliable distributed control techniques for smart and micro-grids.

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