ON AUTOMATED MICROGRID CONTROL SYSTEMS

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ABSTRACT

With the development and evolution of modern power system, new challenges appear. This is more apparent in distribution systems. Microgrid technology has the potential to be an integrated solution that can meet these challenges. The control system is the backbone for the microgrid's reliable and economic operation. This paper introduces a perspective on automated control systems applied in a microgrid. In addition, a microgrid automation project – Microgrid 0 automated control system in Singapore, is introduced as an example. The proposed automated control system was designed and implemented to reduce local diesel generator's rotation speed variations caused by intermittent renewable generation.

INTRODUCTION

With the quality of life improving for most, the need to protect the environment is becoming more important and the demand for clean energy is increasing [1]. Many countries have set themselves goals on renewable energy development. This will significantly reduce the greenhouse gas emission mainly caused by fossil fuel burning. But high penetration of renewable generation integrating may bring serious problems to current power networks, which may threaten the safety and reliability of power supply. Besides that, humans have been dedicated to electrification for over 140 years, but there are still nearly 1.3 billion people (almost one-fifth of the world's population), most of them in developing Asia and Africa, who have no access to electricity [2].
Development of new power networks or rewiring existing power network in large-scale is costly, therefore energy grid operators need to rethink and find innovative solutions to enable the use of new technologies to avoid or defer system reinforcement.
Microgrids are believed to be one of several optimal solutions to these issues [3]. It represents entities (consumers, generators, operators) to provide a set of services in a coordinated manner. Its services range from optimizing the energy utilization, improving energy efficiency, providing ancillary services to the main grid, aggregating customers for market participations, improving reliability and so on [4]. It is also believed that this has huge potential in applications such as rural electrification, island systems, hospitals, army bases, commercial buildings etc. Currently, America, Europe, China, and Japan are engaged in microgrid development.
A typical microgrid schematic representation is shown in Figure 1. It is an integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate connected to the

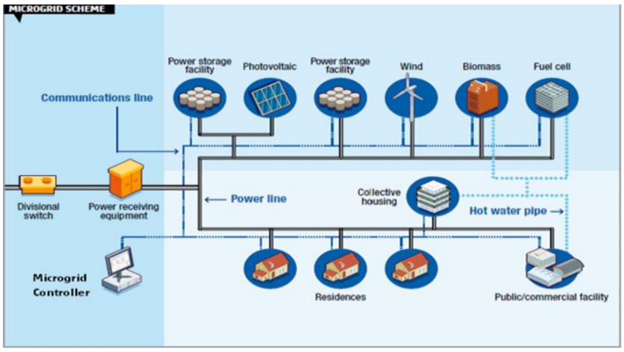

Figure 1. Schematic of a typical microgrid

grid or in an islanded mode.
The application and objectives of microgrids can be different. They are normally classified in three segments: public, private and stand-alone microgrids.

- Public microgrids – The usual objective of microgrid technology in this class is to increase the reliability and Renewable Energy Sources integration; for example, municipalities, cities and public campus microgrids. Public microgrids are usually grid-connected.

- Private microgrids – The objective of microgrid technology in this class is to ensure surety and energy efficiency, in defense microgrids, university campus microgrids and commercial and industrial microgrids. Private microgrids are normally grid-connected but also have the capability of operating in islanded mode.

- Remote microgrids – This class of microgrids is intended for islands and in developing countries with no available main grid or where the connection costs/impacts to the existing main grid are high.

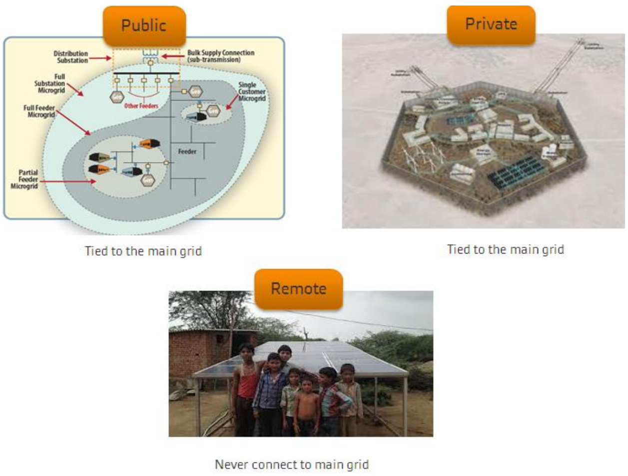

Figure 2. Microgrid segments

A control system responsible for microgrid's reliable and economic operation is critical to the overall solution. Since the objectives of individual microgrids may be different, the control/operation system should be designed for their specific purpose.

MICROGRID CONTROL SYSTEM

System Architecture

The representative microgrid control system architecture, is shown in Figure 3.

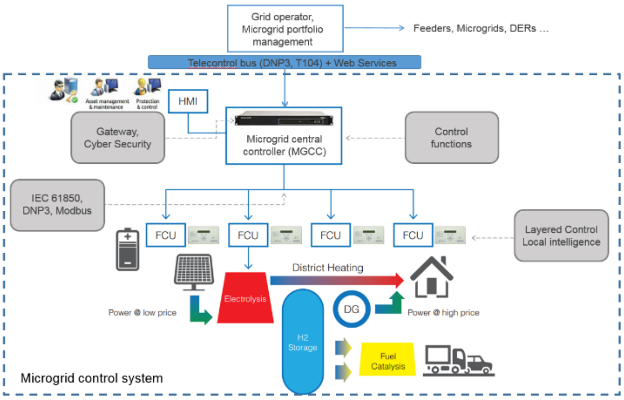

Figure 3. Microgird control system architecture

The microgrid control system is composed by the microgrid central controller (MGCC) and field control units (FCUs). The MGCC is the brain, which manages energy/power production and consumption autonomously or based on higher level control commands (e.g. command from network operators). In addition, it also enables the integration of field devices, real time data concentration, and unification of microgrid data from a wide range of field devices. The MGCC also provides human machine interface (HMI) service for local microgrid management, as well as interfaces with microgrid cloud applications form remote management.

The field control units (FCU) are linked directly with local components. They can work as actuators to drive the network components to track the set-points determined by MGCC or they can run local intelligent control if the system is operating in local control (decentralised control) mode. In addition, the FCUs can monitor and measure local information in real time and send it back to the MGCC.

Digital Platform

Information and communication technologies (ICTs) play an important role in power systems. Advanced network prediction, monitoring, management, control and protection etc. all rely on sophisticated ICTs systems.

Two key components of the Microgrid's ICT solution are the MGCC and FTU and the digital platforms on which they are implemented. The MGCC digital platform should have the following capabilities:

- powerful computing capability to run complex algorithms in relatively short times;
- Multi-protocol support so that it has wide compatibility to integrate with multi-vendor substation devices;
- Reinforced cyber security services to guarantee information security, integrity, and confidentiality;
- online condition monitoring functionality to help operators know the network status in real time.

The FCU platform should have the following capabilities:

- provide both analogue and digital I/O ports to interface with network components;
- have powerful data processing and communication capability.

Control Schemes

The microgrid normally operates in a centralized or a decentralized mode. This section states some characteristic of both control schemes.

Centralised Control

In centralised control mode, the operation of the whole system is scheduled, commanded and regulated by the MGCC. The FCUs are responsible for collecting the local components' date and sending them to the MGCC. The FCUs also enable the local components to track the set-points or status determined by MGCC. The properties of centralised control are summarised below [5-6]:

- Elements in the Microgrid operate normally with common goals.
- The ownership of distributed energy resources (DERs) and loads isn't diverse.
- The devices can accept and follow the central controller's command.
- The number of DERs and loads is generally limited.
- It has a fast communication system and a set of sensors.
- It searches for the optimum or near optimal solution to the common goal.

Decentralised Control

The core idea of decentralised control is that an autonomous control process is assumed by each controllable component and each controllable component does not have full system vision. Initially, decentralise-controlled components (such as capacity bank) only respond to local events. There is no communication and coordination among them. Then multi-agent system concept was proposed as an enhanced decentralised method which also includes coordination algorithms and communication between the agents and the organization of the whole system. In this scheme, the MGCC may only operate as an information hub rather than a central controller. The FCUs control local devices based on local intelligence and may have the same coordination rules. The characteristics of decentralised control are listed below:

- The microgrid operates in a market environment and requires competitive actions from the DERs and loads.
- Local DER owners may be diverse and have their own objectives.
- Each device's controller has certain degree of independence and intelligence.
- The number of DERs and loads are normally high.
- Dedicated communication system may not exist.

- Suboptimal solutions to the Microgrid objective may be accepted.
- Allows for new DERs and loads to "plug and play".

Each control scheme has unique characteristic. There is no reference to justify which has more advantages. The control schemes are selected by considering many factors such as operational objectives, complexity of the microgrid, availability and capability of ICTs, business model and so on.

MICROGRID 0 CONTROL SYSTEM

Microgrid 0 (MG 0) is an autonomous electrical power system that supplies power to Semakau island in Singapore. In this project GE was responsible for developing a control system to reduce frequent generator rotation speed variations caused by renewable generation.

Project Objective

In an islanded microgrid, relative high penetration of intermittent renewable generation may result in imbalance of supply and demand. Such an imbalance may lead to system blackout. Consequently, generator needs to rebalance supply and demand in real time. But frequent variations in generator rotation speed can reduce its lifetime.
Electrical energy storage is a potential solution due to its fast response ability. Storage may be able to mitigate the supply and demand differences before the generator intervenes.
In this project, GE is delivering a control system in microgrid to reduce the diesel generator rotation speed variation resulting from intermittent renewable generation via controlling charging/discharging power of energy storage.

Proposed controller in MG 0

Network Topology
The MG 0 network single line diagram is shown in Figure 4. In this island network, two 400 V, 500 kW diesel generators are deployed. One of them feeds all the current load and the other is in cold-standby. The AC load is 400 kW during the day and 200 kW during the night. Two photovoltaic (PV) generation systems are installed and their total rated power reaches 400 kW. A 200 kW, 400 kWh li-ion battery storage is also installed on the site.

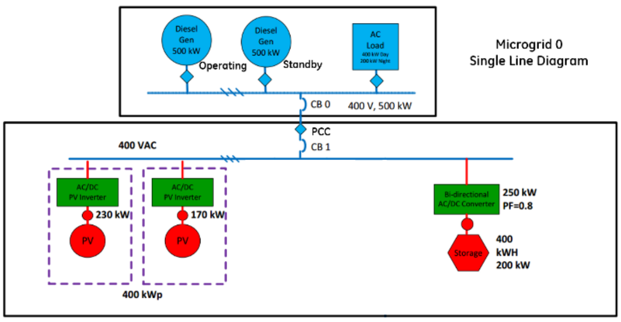

Figure 4. Microgird 0 single line diagram

Development of the Controller
As mentioned, high penetration of intermittent renewable generation may perturb the diesel generator's smooth operation. The proposed controller manages the energy storage's charging and discharging power to smooth the total power injection going through the point of common coupling (PCC).
The structure of the proposed control system is shown in Figure 5. There are two layers. Layer 1 is a field control/monitor unit (in this case a GE C264). The FCU is coupled with the network directly and measures the amount of PV power generation and sends the data to the MGCC directly. In this case the MGCC is implemented in GE's Digital Automation Platform (DAP) server. The control algorithms developed for the project are executed on this platform. The MGCC determines the energy storage operating power set point and sends it to the inverter of the energy storage via a fast communication channel.

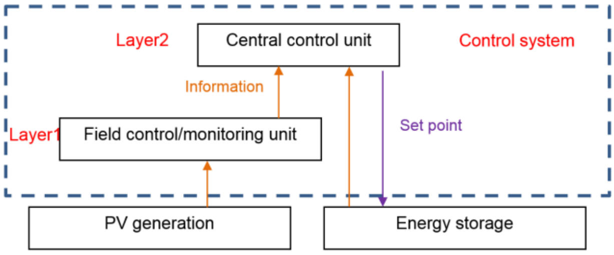

Figure 5. Proposed control system

In design phase, 4 control technologies were simulated and tested in a computer model. The test results shown in Figure 6 prove that the performance of proposed four techniques are all generally good. The network frequency (equivalent to rotation speed of diesel generator) turbulence is dramatically reduced from around 1.06 p.u. (max) to close to 1 p.u. once the control is being applied.

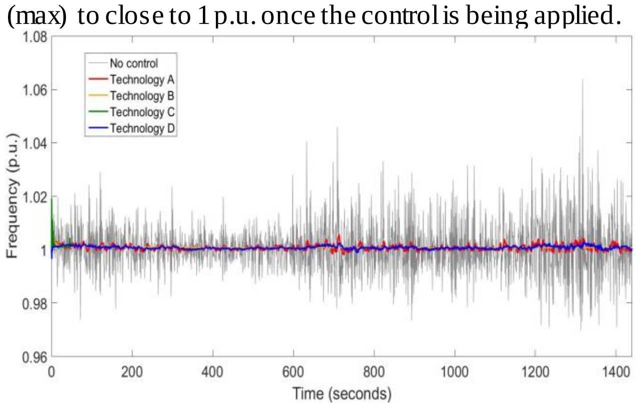

Figure 6. Computer based simulation result

The best technology was selected by considering computing time, complexity of implementation, impact of frequency deviation reduction, and impact on energy storage lifespan reduction.

Hardware in the Loop Test

Computer based off-line simulation could not simulate the controller's performance in real time environment, but hardware in the loop test can. The Simulink™ based network model was implemented and configured in Opal-RT™, a hardware in the loop simulator platform that can simulate the Microgrid 0 network profiles in real time. The simulated network status (e.g. active power, reactive power, voltage) was sent to the MGCC via fast communication protocol. In this test, DNP3.0 was applied. In a distributed architecture setting, IEC 61850 can be used between the MGCC and several FCUs; potentially using GOOSE when fast real time performance is required. The FCU was not included in this test because it is just a measuring device that does not have any logic operation function. In addition, the time consumption on FCU data measurement is very short. Once the MGCC got the required data, the energy storage operating set point was determined immediately and sent back to the simulation platform. The energy storage model in in the simulation platform would then track this set point. Consequently, the network state would be changed.

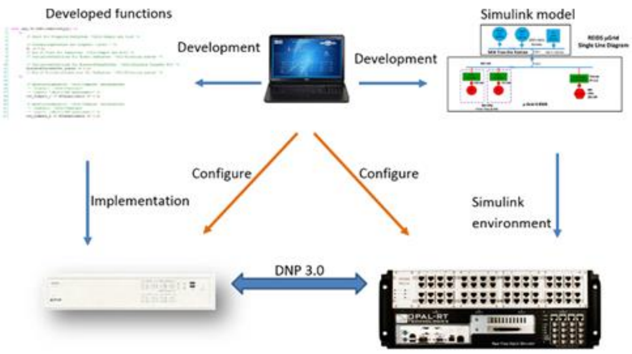

Figure 7. Hardware in the loop test rig

The real-time simulation result confirmed the reduction in frequency excursions that the diesel generator had to compensate when using the controller.

Human Machine Interface (HMI)

An intuitive and user friendly HMI was developed for this specific system. As shown in Figure 8, the topology of MG 0 was graphically implemented in the HMI. Customers can monitor the network status in real time. Meanwhile, the authorised operators can do network control remotely via wireless or telecommunication. In addition, network historical data can be stored in the data storage. The data can be reviewed and downloaded.

CONCLUSION

This paper introduces a perspective on automated control systems in microgrids. The characteristic of centralised and decentralised microgrid control schemes are described. Then, a microgrid automation commercial project – Microgrid 0 automated control system, is introduced in this paper. The proposed control system aims to reduce local diesel generator's rotation speed variation caused by intermittent renewable generation. The design and testing process of this controller is also stated.

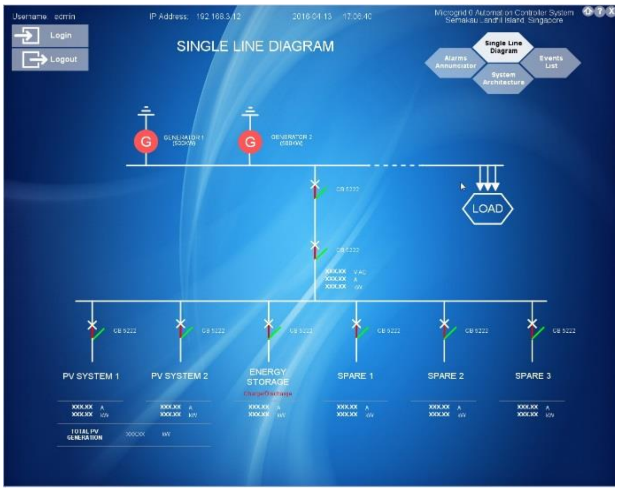

Figure 8. HMI of proposed control system

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