Chittagong University of Engineering and Technology

Department of Electrical and Electronic Engineering

Project Title: Simplified model of a Small-scale Microgrid

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Objectives of this project

- Improve energy efficiency.
- Integrate renewable energy effectively.
- Enhance grid resilience and reliability.
- Optimize control and management.
- Ensure economic viability.
- Enable seamless integration with the main grid.
- Design scalable and adaptable systems.
- Minimize environmental impact.

Introduction to small-scale microgrid

Energy Storage Systems: Battery storage and other energy storage technologies play a critical role in small-scale microgrids. They allow surplus energy generated during peak production periods to be stored for later use, enhancing grid stability, providing backup power, and enabling better integration of intermittent renewable sources.

Control Systems: Advanced control and management systems are essential for small-scale microgrids to operate seamlessly. These systems monitor energy demand and supply in real time, optimizing the allocation of energy resources and maintaining grid stability.

Smart Grid Technologies: Small-scale microgrids often leverage smart grid technologies such as advanced meters, sensors, and communication systems. These technologies facilitate real-time data exchange, grid monitoring, and demand-response mechanisms, enabling more efficient energy use and load management.

Islanding Capability: One of the defining features of small-scale microgrids is their ability to operate autonomously in "island mode" during grid outages. This ensures that critical facilities like hospitals, emergency centers, and essential services can maintain power supply even when the central grid experiences disruptions.

Resilience and Reliability: Small-scale microgrids enhance energy security by reducing reliance on centralized power sources. Their ability to operate independently during grid failures makes them a valuable asset in disaster-prone areas or locations with unreliable grid infrastructure.

Energy Efficiency: By utilizing localized energy resources and optimizing distribution, small-scale microgrids can achieve higher energy efficiency levels compared to traditional grids, which experience transmission losses over long distances.

Economic Savings: Small-scale microgrids can lead to reduced energy costs by incorporating cost-effective renewable resources, lowering transmission fees, and implementing demand-side management strategies.

Environmental Sustainability: The integration of renewable energy sources in small-scale microgrids contributes to greenhouse gas emissions reduction and overall environmental sustainability.

Community Empowerment: Small-scale microgrids can empower communities, giving them greater control over their energy production, consumption, and pricing. This fosters a sense of ownership and involvement in sustainable energy practices.

In conclusion, small-scale microgrids represent a transformative approach to energy distribution and management. By combining decentralized energy resources, smart technologies, and localized control, these microgrids offer enhanced resilience, improved efficiency, and a pathway towards a more sustainable and adaptable energy future.

General Background Information

A microgrid is a local electrical grid with defined electrical boundaries, acting as a single and controllable entity. It is able to operate in grid-connected and islanded mode. A 'Stand-alone microgrid' or 'isolated microgrid' only operates off-the-grid and cannot be connected to a wider electric power system.Here’s the general background of microgrid :

Early Grid Systems : The Manhattan Pearl Street Station, Thomas Edison's first power plant built in 1882, is where microgrids got their start. Since the centralized grid had not yet been constructed, it essentially served as a microgrid. Edison's business had put 58 DC microgrids in place by 1886. However, due to a number of factors, such as the early adoption of an alternating current (AC) electric grid, the prohibitive cost of grid equipment, and the general monopolistic structural model that formed in the electric power business, further development of microgrids slowed for decades. However, new developments in technology and law have brought microgrids back into use.

Emergence of Microgrids (1970s to 1990s) : The concept of microgrids began to gain attention as a response to growing concerns about energy resilience and sustainability. Early experiments and research focused on creating smaller, localized energy systems that could operate independently or in coordination with the main grid. These microgrids often utilized renewable energy sources such as solar panels, wind turbines, or small-scale generators.

Islanding Capability (Late 1990s to early 2000s): One significant development during this period was the introduction of islanding capability in microgrids. Microgrids equipped with islanding technology could disconnect from the main grid during power outages or emergencies. Islanding capability allowed microgrids to operate autonomously, providing a continuous power supply to critical loads within their boundaries.

Energy Storage Integration (2000s to present): Energy storage systems, particularly batteries, became an essential component of microgrids. The integration of energy storage addressed the intermittent nature of renewable energy sources and allowed for stable and reliable power supply during periods of low or variable energy generation. Energy storage systems also facilitated the integration of intermittent renewable sources, reducing dependence on the main grid and fossil fuels.

Smart Grid Technologies (2000s to present): The integration of smart grid technologies brought advanced monitoring, control, and communication systems to microgrids. These technologies enabled efficient energy management, load balancing, and demand response within microgrids. Real-time optimization and data-driven decision-making became possible, leading to improved energy efficiency and grid stability.

Technical difficulties

The technical difficulties of a small-scale microgrid are mentioned below:

Distributed Energy Resources (DERs): Microgrids typically incorporate various types of distributed energy resources, such as solar photovoltaic (PV) panels, wind turbines, small-scale generators, energy storage systems (batteries), and sometimes combined heat and power (CHP) units. Understanding how these resources operate and interact is crucial.

Power Electronics: Power electronics play a vital role in microgrids by managing the flow of electricity between different sources and loads. Components like inverters and converters enable the conversion of DC (direct current) to AC (alternating current) and vice versa, as well as voltage and frequency control.

Energy Management System (EMS): An EMS is the central control system of a microgrid, responsible for optimizing the operation of distributed energy resources. It monitors and manages power generation, load demand, and storage, ensuring efficient and reliable operation while considering factors like grid stability, demand response, and energy market integration.

Islanding and Grid-Connected Modes: Understanding the transition between islanded mode (operating independently) and grid-connected mode is important. Switching between these modes requires automated control mechanisms to ensure a seamless transition and maintain system stability.

Protection and Control: Microgrids require robust protection and control systems to safeguard against faults, voltage fluctuations, and other issues. This includes protective relays, fault detection algorithms, and islanding detection mechanisms to isolate the microgrid during grid outages or disturbances.

Microgrid Architecture: Familiarity with different microgrid architectures is helpful, such as radial, mesh, or hierarchical structures. Each design has its own advantages and considerations regarding reliability, fault tolerance, and scalability.

Energy Storage Systems: Energy storage is a critical component of microgrids, providing backup power, smoothing intermittent renewable energy generation, and improving overall grid stability. Understanding different storage technologies, like lithium-ion batteries, flow batteries, or flywheels, is beneficial.

Resilience and Microgrid Operation: Microgrids are often designed with resilience in mind, allowing them to operate autonomously during grid outages or emergencies.

A description of the knowledge gap that microgrids were designed to fill:

Microgrids are localized power systems that can operate independently or in conjunction with the main power grid. They provide reliable, sustainable, and affordable electricity to communities and businesses. However, microgrids face several challenges that need to be addressed for their successful implementation and operation. Some of these challenges include:

Load management: Microgrids must be able to manage the load on the system and ensure that energy demand is balanced with supply. This requires sophisticated energy management systems that can predict and manage load fluctuations.

Energy storage: Microgrids often rely on energy storage systems to provide backup power and balance energy supply and demand. However, managing energy storage systems can be challenging, as they require careful monitoring and maintenance to ensure their effectiveness.

Energy dispatch: Microgrids often rely on multiple sources of energy, including renewable energy sources such as solar and wind power, as well as conventional sources such as diesel generators. Managing the dispatch of these energy sources to meet the needs of the system can be complex.

Grid connection: Microgrids must be able to connect to the main power grid and manage the flow of energy between the microgrid and the grid. This requires careful coordination to ensure the safety and stability of the system.

Cybersecurity: Microgrids are vulnerable to cyberattacks, which can disrupt their operation and compromise the security of the system. Ensuring the cybersecurity of microgrids requires robust cybersecurity measures, including firewalls, intrusion detection systems, and regular security audits.

Operating modes of Microgrid

A microgrid is a localized group of interconnected energy resources and loads that can operate independently or in conjunction with the main power grid. It can function in different operating modes to optimize energy generation, distribution, and consumption based on various conditions and requirements. The primary operating modes of a microgrid are:

Grid-Connected Mode: In this mode, the microgrid is connected to the main power grid. It can draw electricity from the grid when its own generation falls short or supply excess power back to the grid when its generation exceeds local demand. The grid serves as a backup and ensures a continuous power supply. In this mode, the microgrid may also participate in demand response programs, where it can adjust its energy consumption based on grid signals to support grid stability and reduce peak demand.

Islanded Mode: Islanding is the mode where the microgrid operates independently from the main grid, creating its own self-sustaining electrical network. This can occur during grid outages or intentionally, such as during planned maintenance or to support critical loads during emergencies. The microgrid relies solely on its local generation sources, such as renewable energy systems (solar, wind, etc.), energy storage (batteries), and backup generators.

Grid-Forming Mode: Grid-forming mode is when the microgrid operates in islanded mode and assumes the role of a primary grid source. In this mode, the microgrid's control system manages the voltage and frequency levels, enabling it to establish stable power generation and supply within the microgrid boundaries. This mode is especially important for situations where multiple microgrids need to work together or if the main grid is not available.

Grid-Parallel Mode: In this mode, the microgrid operates in conjunction with the main grid but with a higher degree of autonomy. It can optimize its energy generation and consumption based on local conditions and priorities, while still being connected to the grid for additional support. This mode allows the microgrid to prioritize renewable energy sources and manage its own energy resources more efficiently.

Emergency Mode: Emergency mode is activated during critical situations, such as natural disasters or grid failures. In this mode, the microgrid focuses on supplying power to essential loads like hospitals, emergency services, and critical infrastructure. Non-essential loads may be temporarily disconnected to conserve energy and ensure the availability of power for crucial services.

The selection of operating mode depends on factors such as energy availability, grid reliability, environmental goals, economic considerations, and regulatory policies. Microgrid control systems play a crucial role in seamlessly transitioning between these modes, ensuring optimal operation, and maintaining stability and reliability in both grid-connected and islanded scenarios. The flexibility of microgrids to switch between these modes enhances energy resilience, supports renewable energy integration, and contributes to a more sustainable and reliable energy future.

Methodology

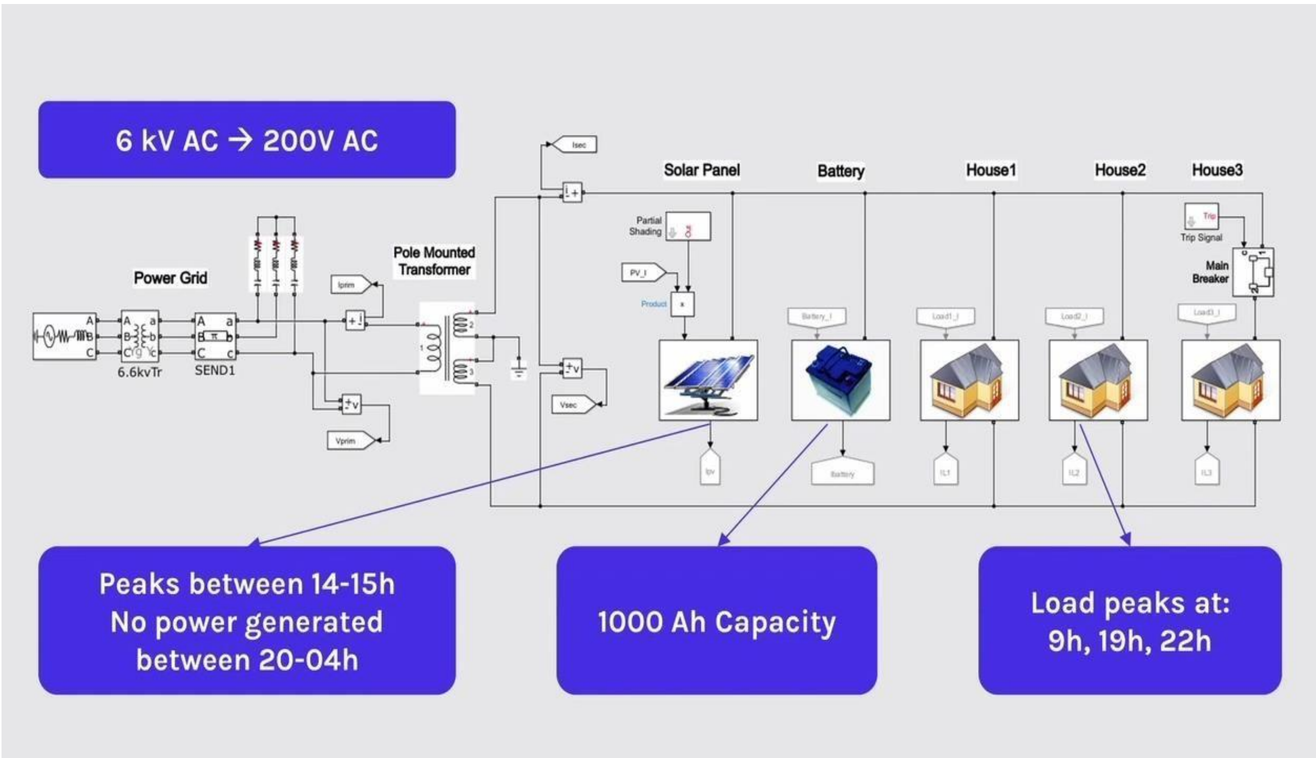

Figure 1 : simplified model of a small-scale microgrid

This example shows the behavior of a simplified model of a small-scale micro grid during 24 hours on a typical day. The model uses Phasor solution provided by Specialized Power Systems in order to accelerate simulation speed.

Description of the Model:

The micro-grid is a single-phase AC network. Energy sources are an electricity network, a solar power generation system and a storage battery.

The storage battery is controlled by a battery controller. It absorbs surplus power when there is excess energy in the micro-network, and provides additional power if there is a power shortage in the micro-network. Three ordinary houses consume energy (maximum of 2.5 kW) as electric charges.

The micro-array is connected to the power network via a transformer mounted on a post which lowers the voltage of 6.6 kV to 200 V.

The solar power generation and storage battery are DC power sources that are converted to single-phase AC. The control strategy assumes that the microarray does not depend entirely on the power supplied by the power grid, and the power supplied by the solar power generation and storage are sufficient at all times.

- From 20h to 4h, the solar power generation is 0 W. It reaches the peak amount (5 kW) from 14h to 15h.
- As a typical load change in ordinary houses, the amount of electric power load reaches peak consumption at 9h (6,500 W), 19h, and 22h (7,500 W).
- From 0h to 12h and from 18h to 24h, battery control is performed by battery controller. The battery control performs tracking control of the current so that active power which flows into system power from the secondary side of the pole transformer is set to 0. Then, the active power of secondary side of the pole mounted transformer is always around zero.
- The storage battery supplies the insufficient current when the power of the micro-grid is insufficient and absorbs surplus current from the micro-grid when its power is surpasses the electric load.
- From 12h to 18h, battery control is not performed. SOC (State Of Charge) of the storage battery is fixed to a constant and does not change since charge or discharge of the storage
- battery are not performed by the battery controller. When there is a power shortage in the micro- grid, the system power supplies insufficient power. When there is a surplus power in the micro-grid, surplus power is returned to the system power.
- At 8h, electricity load No. 3 of an ordinary house is set to OFF for 10 sec by the breaker. A spike is observed in the active power on the secondary side of the pole transformer and the electric power of the storage battery.

Simulated result of the model:

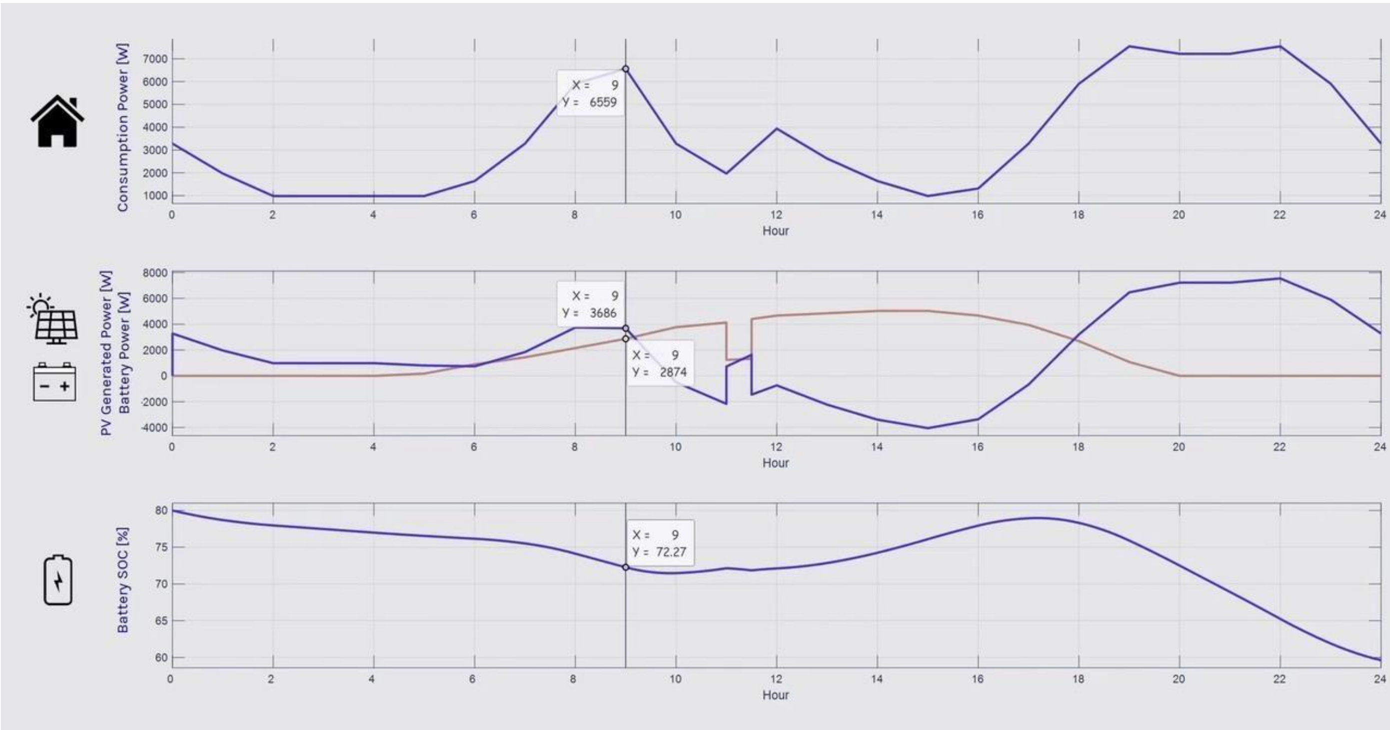

Figure 2 : Simulated result of the model

Peak shaving in Microgrid

Peak shaving is a strategy employed in microgrids to reduce electricity consumption during periods of high demand, known as "peak" periods. In peak shaving, a microgrid aims to lower its power consumption during these times in order to decrease the load on the main grid and potentially save on electricity costs. This is typically achieved by using a combination of energy storage, demand response, and load management techniques. Here's how peak shaving works within a microgrid:

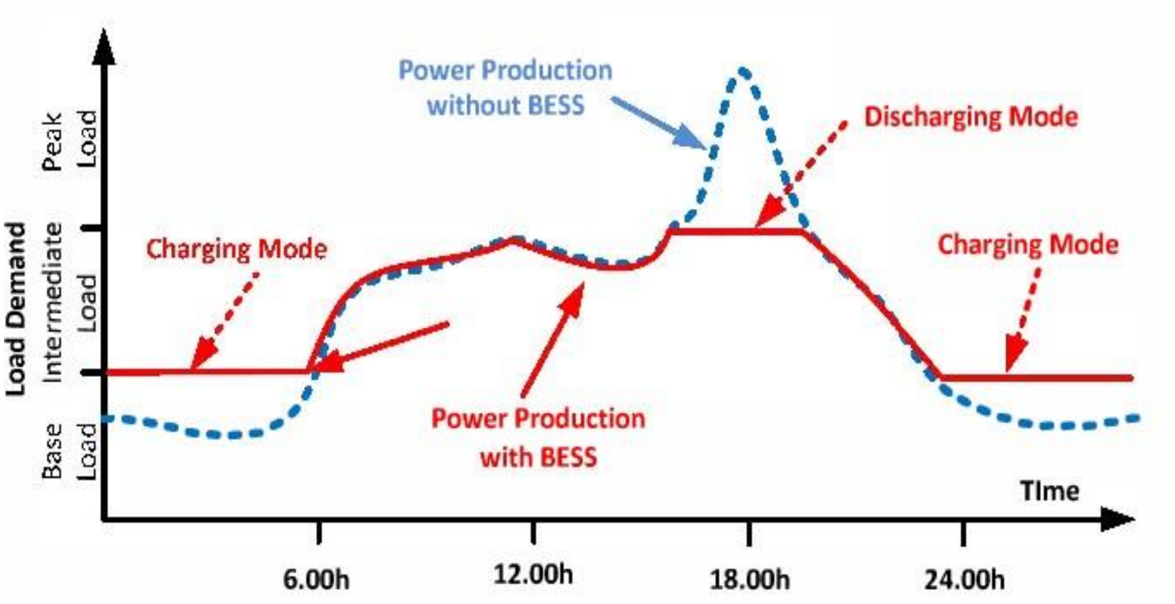

Figure 2 : Peak Shaving in Microgrid

Energy Storage: Microgrids often incorporate energy storage systems, such as batteries, to store excess energy generated during off-peak periods (when demand is low) and release it during peak periods (when demand is high). This helps in reducing the need to draw additional power from the main grid during peak times, thereby reducing the strain on the grid.

Demand Response: Demand response involves adjusting the consumption of electricity in response to signals from the grid operator or energy market. During peak periods, when electricity prices might be higher due to high demand, a microgrid can temporarily reduce non-essential loads or adjust their operation to reduce overall power consumption. This helps in avoiding high-cost electricity during peak hours.

Load Management: Load management involves optimizing the usage of electrical appliances and equipment within the microgrid. By staggering the operation of energy-intensive devices or shifting their usage to off-peak hours, the microgrid can smooth out its demand curve and avoid sudden spikes in consumption during peak periods.

Overall, peak shaving is a valuable strategy within microgrid operations that not only benefits the microgrid itself but also supports the efficiency and stability of the broader energy system by reducing peak load on the main grid.

Future prospects of Microgrid in Bangladesh

Microgrids are small-scale, localized energy systems that can operate independently or in conjunction with the main grid. They have gained increasing attention worldwide due to their potential to enhance energy resilience, reduce energy costs, and integrate renewable energy sources. In the context of Bangladesh, a country that faces energy security challenges and aims to increase its renewable energy capacity, microgrids could play a significant role. Here are some future prospects for microgrids in Bangladesh:

Energy Access in Remote Areas: Bangladesh has many remote and off-grid areas where connecting to the centralized grid can be costly and challenging. Microgrids powered by solar, wind, or other renewable sources could provide a reliable and sustainable energy solution for these communities, improving their quality of life and fostering economic development.

Enhanced Energy Resilience: Bangladesh is susceptible to natural disasters, such as cyclones and floods. Microgrids equipped with energy storage systems and renewable energy sources could enhance energy resilience by providing a localized source of power during grid outages or disruptions caused by extreme weather events.

Integration of Renewable Energy: Microgrids can accelerate the integration of renewable energy sources into the energy mix of Bangladesh. As the cost of solar panels and battery storage continues to decrease, microgrids can be designed to maximize the utilization of solar energy during daylight hours and store excess energy for nighttime use.

Rural Electrification: Many rural areas in Bangladesh still lack access to reliable electricity. Microgrids could accelerate the electrification process by providing a decentralized energy solution that is quicker to implement compared to large-scale grid extensions.

Reduced Transmission Losses: Microgrids can reduce transmission losses associated with long-distance power transmission. By generating and consuming energy locally, these systems can minimize energy losses that typically occur when electricity is transported over long distances.

Community Empowerment: Microgrids can empower local communities by involving them in the management and maintenance of energy systems. This involvement can lead to a sense of ownership, skills development, and job creation at the local level.

Government Support and Policies: The Bangladesh government's commitment to increasing the share of renewable energy in its energy mix, as outlined in its Renewable Energy Policy, could provide a conducive environment for the growth of microgrids. Supportive policies, incentives, and regulatory frameworks could attract investments in microgrid projects.

Private Sector Investment: The private sector, including energy companies and investors, might see potential in investing in microgrid projects in Bangladesh. These projects could provide a reliable revenue stream while addressing energy access and sustainability challenges.

Technological Advancements: Ongoing advancements in microgrid technology, energy storage, and control systems could make microgrids more efficient, cost-effective, and adaptable to various local conditions.

Research and Development: Continued research and development efforts in microgrid design, optimization, and management could lead to innovative solutions tailored to the unique energy landscape of Bangladesh.

It's important to note that the successful implementation of microgrids in Bangladesh will require collaboration among government agencies, local communities, private sector entities, and international organizations. Challenges such as funding, regulatory hurdles, and technological integration will need to be addressed to realize the full potential of microgrids in our country.

Conclusion

Microgrids are becoming increasingly attractive to consumers and as such in the future, a great number of them will be installed at consumer's sites. In this situation, conventional distribution networks that accept distributed generation connections may face serious difficulty when its control and protection functions become more complicated. This incurs a burden to the network operation and some technical limitations will appear when a great number of distributed generations are installed. One way of overcoming such problems, a micro grid system is formed to provide reliable electricity and heat delivering services by connecting distributed generations and loads together within a small area. A microgrid is usually connected to an electrical distribution network in an autonomous way and employs various distributed generation technologies such as micro-turbine, fuel cell, photovoltaic system together with energy storage devices such as battery, condenser and flywheel. Micro grids can cause several technical problems in its operation and control when operated as autonomous systems.