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Distributed Active and Reactive Power Control With Smart Microgrid Demonstration

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ABSTRACT

Energy is one of the leading contributors to the economic development of any country. Energy plays a vital role for developing countries like India because it has to serve its large population [1]. Establishing a large power grid serving billions of people requires a significant investment. The world's growing population has created a lot of problems that exist today. The most important issue of all is global warming caused by the abundance of greenhouse gases present in the atmosphere. Many of these greenhouse gases such as CO2 are produced from power plants all over the world burning fossil fuel. To reduce these emissions out into the atmosphere alternative sources of energy must be used. In the last two decades, both solar and wind energy have become an alternative to conventional energy resources [2]. These alternative energy resources are non-polluting, abundant, and renewable. In recent years, thanks to the advance in technology, better manufacturing processes have decreased their capital costs thus making them more attractive. This has led to the outburst of the distributed generators (DGs) and Smart Grid concepts [3]. The United States of America is among one of the leading countries in the world and as such, they invest lots of money and resources in the renewable energy sources [4]. Figure-1 shows Uzbekistan maps of the solar; (this illustration is provided by the Energy Sector Management Assistance Program (ESMAP)).

KEYWORDS: *Advantages Of Microgrid, Smart Microgrid, Smart Meter, Grid Tie Inverter, Computer Controllable Loads, Microgrid Test-Layout.*

The other factors that motivate concepts such as Microgrid and Smart Grid are improving the reliability of the power system. With the conventional centralized power system, any disturbance can cause the complete failure of the grid (not all disturbances cause complete grid failure but there is a possibility) [5]. For instance, the blackouts that occurred happened in the Central Asian nations of Kazakhstan, Uzbekistan and Kyrgyzstan in 2022 [6] (Figure-2) caused millions of homes to loose electricity for several hours.

The world's power delivery system consists of a large number of substations, transmission lines, and distributions lines, which are not designed to withstand or quickly recover from outages. The number and duration of power outages in the Central Asia or Uzbekistan continue to rise, driven primarily by weatherrelated incidents such as natural disasters Hurricanes and Earthquakes. The average outage duration in Uzbekistan is around 200 minutes and is rising annually.

Figure-1. Photovoltaic Solar Resources of Uzbekistan

Figure-2. Central Asia Map Kazakhstan, Uzbekistan and Kyrgyzstan

Microgrid

The concept of a Microgrid can be considered to be a collection of various loads and distributed generation on the distribution segment of the grid. Microgrid [9] offers a viable solution during a sudden power outage. During power outages or emergencies, the part of the grid which is unaffected can detach itself from the utilities and coordinate the generator in the area and power the grid. Rather than having backup generators turned on throughout the restoration period. The illustrative construction and operation of the Microgrid [10] is shown in Figure-2. there are numerous advantages of Microgrid beyond the backup generators,

- It encourages the installation of non-conventional energy resources such as the wind, solar and biogas.
- Electrical energy stored in the battery and the Hybrid Electric Vehicles. The Microgrid can sense critical loads in case of power outage, it reroutes power to critical areas as possible given any situation. When there is a power outage occurs in the Microgrid and it self-heals at any given situation. Microgrid comprises four key properties [11] as follows:
- The Electricity Generation is local and distributed through the installation of rooftop solar panels at home, windmills and solar farms.
- The loads are distributed and local.

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- During power outage or system failure the Microgrid has the ability to self-heal and automatically detach itself from the main grid until the system is brought back to the normal stage.
- Utilities in the Microgrid can work together for the better performance.

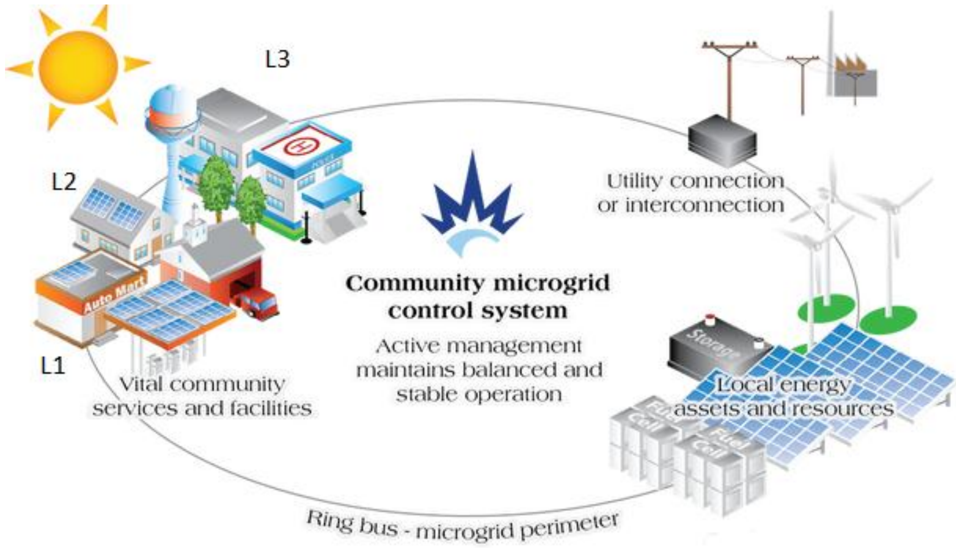

Figure-3. Microgrid background

Smart Grid The modern power system made up of a network of very long transmission lines, substation, transformers and more that deliver power from the power plants to the home. The DOE definition of the Smart Grid is defined as a "A smarter grid applies technologies, tools, and techniques available now to bring knowledge to power–knowledge capable of making the grid work far more efficiently." The Green American Design Group notes that the main advantages of the smarter electric grid are as follows:

- Smart grid updates existing power infrastructure which increases the reliability and safety of the existing grid.
- Easy to maintain, service and decreases power outage.
- Encourage more renewable energy generation across the system.
- Reduces the pollution by promoting renewable energy.
- Introducing advancements and efficiencies yet to be envisioned. (GADG).

The electric power industry is set to bring out a revolution from a more decentralized, producer controlled network to the one that is less centralized and more consumer-interactive. The move to completely change the grid is going to create a revolution in the history of the power sector. With minimal human interaction, the amount of energy is going to be saved is tremendous.

Microgrid Test-Layout setup

Reactive power is present everywhere in the modern electrical system that demands careful compensation. One of the modern approaches to the reactive power compensation is to use locally advanced inverters coupled to the grid/battery for the local reactive power compensation. A Microgrid setup with distributed energy resources is built in collaboration with new Instruments. This chapter deals with the Hardware section, consists of various evaluation modules used in building the test Microgrid setup and how the communication between the evaluation modules has been established. The evaluation modules discussed later in the chapter are smart meter, grid tie inverter and computer controllable loads. The other topics discussed in the chapters are communication between the smart meter and the communication between the grid tie inverter and the smart meter. Microgrid Description The system shown in Figure-3 comprises of three load location i.e. The loads in the Microgrid consist of both the constant impedance loads and variable impedance loads. In the current setup, load 2 is an adjustable AC load bank, either inductive or capacitive. The loads in the Microgrid vary arbitrarily, the requirement for the active and reactive power also varies. The main objective is to minimize the amount of reactive power supplied from the main grid. The main approach is to use distributed inverters, with aid of multiple local communication channels, for reactive power compensation of the Microgrid in a real-time, distributed, and cooperative manner. The schematic diagram of the Microgrid setup is shown in Figure-4.

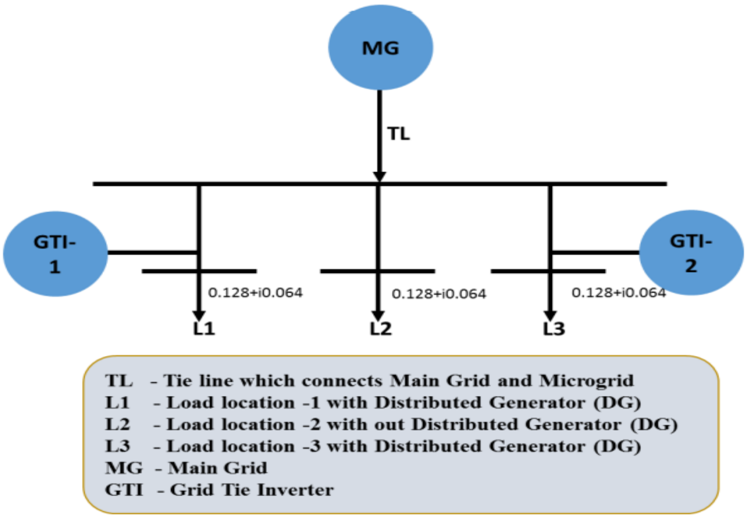

Figure-4. Schematic Diagram of the Microgrid Setup

Smart Meter Energy meter is a type of equipment used to measure amount of electrical energy consumed by the device or the unit. Power is defined as the product of voltage and current. Energy is the power integrated over time and is measured in kilowatt-hours(kWh). There are two types of energy meters: electromechanical meters and electronic meters. The electromechanical meter operates on the principle that disc rotates at a rate directly proportional to the power consumption and by counting the number of rotations the disc made the power consumed is calculated. The reading of the electromechanical meter is done manually. The electronic meter makes use of the digital signal processors (DSP) and microcontrollers for the metering purpose and is extremely accurate for the measurement reading and display it on the LCD screen. The smart meter shown in Figure-3 has special features such as NILM (Non-Intrusive Load Monitoring. Each and every device has its own voltage and current signature. NILM is a process by examining the changes in the voltage and current signature of the power system and what type of device or units is turned on. The main objective of using the smart meter in this system is to measure the real time AC power values. The smart meter is used to calculate the following parameters and it can be calculated in real time such as real power, reactive power, apparent power, RMS voltage, RMS current, frequency and power factor. These smart meters can be easily interfaced with the PCs. The smart meter used to build this test bed is Instrument's EVM430F6736 and the smart meter is shown in Figure-5.

Figure-5. Smart Meter

Communication between the Smart Meters An interesting feature about the smart meter is that they can talk to each other, with other entities in the system and to customers through the interactive Graphical User Interface (GUI). The smart meter can communicate with other smart devices and technologies through wired or wireless communication. The wireless communication can be done in two ways HAN (home area network) and WAN (wide area network). The HAN is a secure network similar to the wireless systems in your home internet connection. It allows the smart meter to communicate with the other meters in your home such as gas meter, water meter, personal computer, and in-home displays. The WAN is a type of mobile network that is used to send and receive data. It allows the smart meter to send and receive data and also to communicate securely outside the home using the mobile network. Once the data is collected in the smart meter, it transfers the data back to the energy supplier for billing and other purposes. The wired communication can be done through Ethernet cables or USB cables connected to the computer. In a larger system the communication between the smart meters are achieved through the data concentrators. Data concentrators are the combination of the hardware and the software module that connects a large number of the smart meters to one destination and then the data values are transferred to the utilities for various functions such as billing, real-time pricing, etc.

Both the wired and wireless communication has been implemented in the Microgrid test bed. The wired communication for the Microgrid testbed has been implemented using the RS232- USB cable, the RS232 pin is attached to the smart meter and the USB part of the pin is attached to the computer. In the computer each USB pin act as a serial COM port, and each smart meter is assigned to a particular COM port such as COM9. The smart meter sends in the data pack to the COM port and a program is written in order to fetch data pack from the COM port and convert it to the real time values. The data pack consists of lot of information such as size of data pack, voltage, current, active, reactive, apparent power values and identification number for each smart meters. The big disadvantage of this method is the assigning of the COM port to the smart meters and its overcome by the wireless communication.

The wireless communication of the smart meter is implemented using the RF wire cars from the Anaren RF. Each smart meter is attached to the RF card which acts as a transceiver; transmit the data packet from the smart meter. They have a common receiver, which receives the signal and transmits to the utilities for other functions. The receiver is a USB device with the RF receiver in it. The USB is attached to the computer which act as an USB serial COM port, then the program can be used to read the incoming data packs and then the smart meter identification number in the data pack is used to identify which particular smart meter these data corresponds to. Irrespective of the large number of the smart meter, there will be only one receiver attached to the computer which receives all the data packs.

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Grid-tie Inverter

The grid tie inverter shown in Figure-6 is a power inverter that converts direct current (DC) electricity into an alternating current(AC). This allows synchronizing to interface with a utility line. The main application of the grid tie inverter is converting the power produced by the solar and windmill into an alternating power for tying it in with the grid. Today's grid tie inverter is more advanced, as they can monitor the solar output, track the maximum power and operate at that point, compensates reactive power, monitor the grid and islanding operation. These inverters are active as long as sun/wind is available, if the sun is out or the wind is not blowing the inverters becomes idle. The best way to increase the effective use of grid tie inverters is to operate them as VAR compensators to generate reactive power whenever possible. The GTI inverter used in the Microgrid setup build-up is donated by the new technologies and the grid tie inverter is shown in Figure-6 and the graphical user interface of the grid tie inverter is shown in Figure-7.

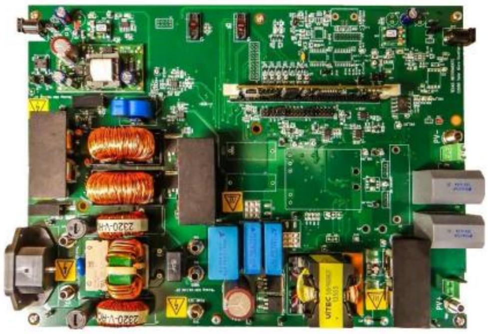

Figure-6. Grid Tie Inverter

Computer Controllable Loads

The three load locations i.e. load location 1, load location 2 and load location 3 consists of loads that can be varied from a computer. The load location-1 and load location 2 consists of constant impedance loads0. In the current setup, the load location 2 is an adjustable AC load bank both with an inductive load bank as shown in Figure-7 and capacitive load back as shown in Figure-8. The loads in the Microgrid test bed are computer controllable. The loads can be turned on and off also can be controlled from the graphical user interface using the buttons on the screens. The computer sends a signal to the microcontroller unit that controls the relay which is used to turn on and off the load loads.

Figure-7. Inductive Load

Figure-8. Capacitive Load

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Development of Graphical User Interface

The screen-shot of the graphical user interface (GUI) that has been developed using the processing software has shown in Figure-8 for your reference. In Figure-8, the “SMART METERS -I, II, and III” display the voltage, current, active, reactive and apparent power values of the smart meters in real time. The “Conventional grid” picture in the middle of Figure 8 picturizes the controls implemented in the Microgrid test bed. The buttons “INVERTER ON” and “INVERTER OFF” will send command signals to turn on and off signals to the respective inverter. The buttons below the control algorithms are used to write the algorithms in the pictures. The power produced by the respective grid tie inverters are also shown in the GUI. The buttons in the bottom of the GUI is used to control the inductive and capacitive loads from the GUI by sending signals to the GUI. The objective of the GUI is to give an easy interface for the people to work on the test bed and virtually see the results in the computer.

Development of Smart Microgrid test-layout

This is an experimental setup for communication and control for the Smart Grid. Figure-9 shows a high-level setup of the Energy Grid with Distributed Energy Resources (DER) to form a micro-grid. The system is made up of three different loads (Load 1, Load 2 and Load 3) at locations marked Location 1, Location 2 and Location 3. These are variable inductive and capacitive loadunits that can be changed intermittently. In the current setup, Load 2 is an adjustable AC load bank, either inductive or capacitive; Load 1 and Load 3 are constant impedance loads. These loads in the Microgrid vary arbitrarily and the quantity of active and reactive power fluctuates. The primary objective is to minimize the amount of reactive power supplied from the main grid. The approach is to use distributed inverters with the aid of multiple local communication channels for reactive power compensation of the micro-grid real-time in a distributed and cooperative manner. The test bed is flexible and we can add ‘n’ number of load locations and the distributed measurements can be obtained with ease. When load changes, reactive power is supplied distributive by the inverters, and uniform voltage is achieved. Demand responses so inverters (together with their simulated storage devices) can maintain active power dispatch from the main grid. In the islanding operation, frequency regulation is ensured collectively by inverters.

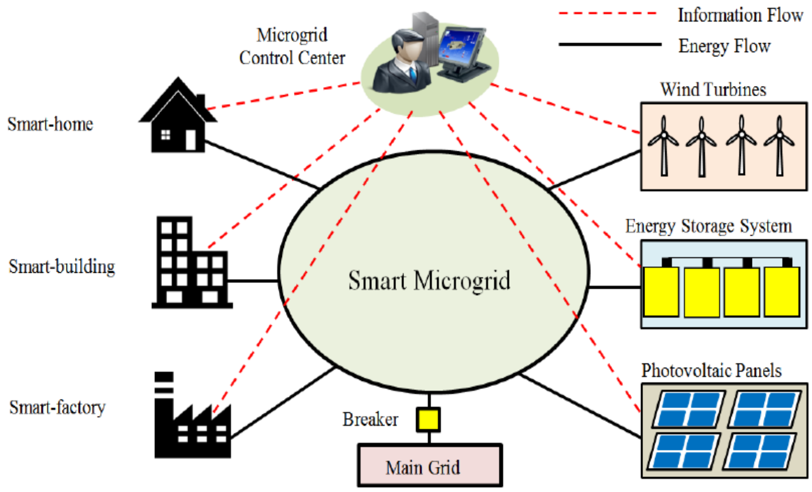

Figure-9. Main Grid Interfaced to a Microgrid with Distributed Energy Resources

When load changes, reactive power is supplied in a distributive fashion by the inverters to maintain a uniform voltage. By using the demand response mechanism along with their simulated storage devices, active power dispatch from the main grid can be maintained. In an islanding operation, frequency regulation is ensured collectively by inverters. The Microgrid test-layout is shown in Figure-10. The main functionality of the test bed is as follows

- Aggregate active power dispatch
- Reactive Power Compensation
- Multimode Communication
- Distributed optimization and control

Figure-11. Microgrid Test-Layout

The list of equipment's required to build the experimental setup is shown in the Table-1.

Table-1 List of Equipment's used to Build the Experimental Support

№	Part Number	Equipment Name	Quantity
1	MSP430F6779	Single Phase E-Meter	4
2	TMDSSOLARUNIVKIT	Grid Tie Inverter	2
3	MSP430F5529	Launch Pad	2
4	Relay Shield	Seed Studio	2
5	E3631 A	DC Power Supply	2
6	MODEL 8321	Inductive Load	1
7	MODEL 8331	Capacitive Load	1
8	300Watt	Resistive Load	1
9	300VA	AC Source	1
10	Connecting Wires		As Req.

Conclusion

The principles of reliable control and management, models, information measuring instruments and power supply monitoring module of developed and advanced renewable energy supply systems provide stable energy supply.

The review of this article work provides a good starting point for researchers, industrial people and academicians who are working on developing a prototype on smart grid and communication. It also provides detailed information how the smart meters can communicate with each and other evaluation modules available with the markets. It also shows how the distributed consensus algorithms that can be used effectively in the power system to achieve the desired objective.

This document also provides information how the distributed cooperative control and distributed cooperative optimization can be effectively used to organize and control the Distributed generators in the microgrid.

This report also gives a detailed implementation of hardware in the microgrid test-layout. The present setup of the microgrid includes communication between the smart meters using wired and wireless communication and multimode communication between the smart meter and the grid tie inverter. The future work on this test-layout includes demonstrating the islanding mode and physical cyber security on the microgrid.

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