Microgrid Energy Management System

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APPENDIX – II

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Further, I certify that the work is based on the investigation made, data collected and analysed
by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial
fulfilment for the award of degree of MBA.

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APPENDIX – IV

Table of Contents

Acknowledgment	2
Table of Contents	4
List of Tables and Illustrations	5
List of Figures	6
Executive Summary / Abstract	7
Chapters	9
Glossary of Terms – Acronyms	28
Bibliography	29
Appendix	30

APPENDIX – V

List of Tables and Illustrations

Table no.	Description	Page no.
1	Power Generation System Storage Issues	12
2	Renewable Energy Scenario in India	15
3	Renewable energy sources (RES)	17
4	Year wise RES & Non-RES generation	17
5	Sources wise breakup of Renewable energy	18
6	Sources of Microgrid Finance	21

APPENDIX – VI

List of Figures

Sr. no.	List of Figures	Page no.
1	Microgrid Components	10
2	Power Generation System Storage Issue	13
3	Renewable Energy Scenario in India	16
4	Electricity Generation	17
5	Renewable energy sources (RES)	17
6	Sources wise breakup of Renewable energy	17
7	Identified economic issues relevant to Microgrid	18
8	Different Scales of Microgrid	19
9	Energy Management system of Microgrid	19
10	Centralised EMS operation	20
11	Sources of Microgrid Finance	23

APPENDIX – VII

Abstract

Evolutionary changes in the regulatory and operational climate of traditional electric utilities and the emergence of smaller generating systems such as microturbines have opened new opportunities for on-site power generation by electricity users. In this context, distributed energy resources (DER) - small power generators typically located at users' sites where the energy (both electric and thermal) they generate is used have emerged as a promising option to meet growing customer needs for electric power with an emphasis on reliability and power quality. The portfolio of distributed energy resources includes generators, energy storage, load control, and for certain classes of systems, advanced power electronic interfaces between the generators and the bulk power provider. This paper proposes that the significant potential of smaller distributed energy resources to meet customers' and utilities' needs, can be best captured by organizing these resources into Microgrids.

Microgrid concept assumes an aggregation of loads and micro sources operating as a single system providing both power and heat. The majority of the micro sources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the Microgrid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security. The Microgrid would most likely exist on a small, dense group of contiguous geographic sites that exchange electrical energy through a low voltage (e.g., 480 V) network and heat through exchange of working fluids.

APPENDIX – VIII

List of Contents

Chapter No	Description	Page No
1	Introduction	9
1.1	Overview	9
1.2	Background	9
1.3	Purpose of the Study	11
1.4	Introduction to Microgrid	12
1.5	Need for the research	13
2	Microgrid Research	15
2.1	Future Directions on Microgrid Research	15
2.2	Indian Renewable Energy Scenario and Status of Microgrids	16
3	Research design, methodology and plan	19
3.1	Research on Microgrid EMS	19
3.2	Microgrid EMS Methods	20
3.3	How Would a Microgrid Help My City	20
3.4	Role of Local Government	21
3.5	Involvement	22
3.6	Ownership of Microgrid	22
3.7	Financial Feasibility of Microgrids	23
3.8	Legal Considerations of Microgrid	24
4	Key Study Findings & Analysis	26
5	Conclusion and Scope for Future Work	27
	Glossary of Terms – Acronyms	28
	Bibliography	29
	Appendix	30

CHAPTER 1

1.1 OVERVIEW

Renewable energy resources are currently being deployed on a large scale to meet the requirements of increased energy demand, mitigate the environmental pollutants, and achieve socio-economic benefits for sustainable development. The integration of such distributed energy sources into utility grid paves the way for microgrids. The microgrid concept is introduced to have a self-sustained system consisting of distributed energy resources that can operate in an islanded mode during grid failures. In microgrid, an energy management system is essential for optimal use of these distributed energy resources in intelligent, secure, reliable, and coordinated ways. Therefore, this dissertation presents a comparative and critical analysis on decision making strategies and their solution methods for microgrid energy management systems.

A microgrid is defined as an aggregation of electrical loads and generation. The generators in the microgrid may be microturbines, fuel cells, reciprocating engines, or any of a number of alternate power sources. A microgrid may take the form of shopping center, industrial park or college campus. To the utility, a microgrid is an electrical load that can be controlled in magnitude. The load could be constant, or the load could increase at night when electricity is cheaper, or the load could be held at zero during times of system stress.

The microgrid utilizes waste heat from the generators to improve overall efficiency. The purpose of the Energy Management System (EMS) is to make decisions regarding the best use of the generators for producing electric power and heat. These decisions will be based upon the heat requirements of the local equipment, the weather, the price of electric power, the cost of fuel and many other considerations. The EMS will dispatch the generators and provide an overview of the Combined Heat and Power (CHP) system. There are several commercially available Energy Management Systems that hold promise for the control and management of microgrid operation. Although no fully developed EMS exists today, manufacturers are already introducing into the market innovative products that can serve as building blocks to a highly versatile EMS.

1.2 BACKGROUND

This section introduces the backgrounds of the research in the dissertation on Microgrid energy management system. The rapid development of renewable energy techniques has prompted microgrids to change towards more intelligent and more efficient entities. Microgrid is defined as a cluster of distributed generation units and energy storages and is able to supply power to local users in a decentralized manner There are strong incentives to utilize distributed generations (DGs) for reducing greenhouse gases, improving power system efficiency as well as its reliability, competitive energy policies and postponement of transmission and distribution system upgrading. In fact, DGs are composed of renewable units such as wind turbines (WTs), photovoltaic (PV), fuel cells (FCs), biomass along with non-renewable ones such as micro-turbines (MTs), gas engines (GEs), diesel generators (DiGs), etc. DGs eliminate the need for the transmission system by being installed near the customers. Integration and control of DGs along with storage devices and flexible loads can constitute a low voltage distribution network, called a microgrid, which can be operated in isolated or grid-connected mode. The generic concept of a microgrid is shown in Figure 1.

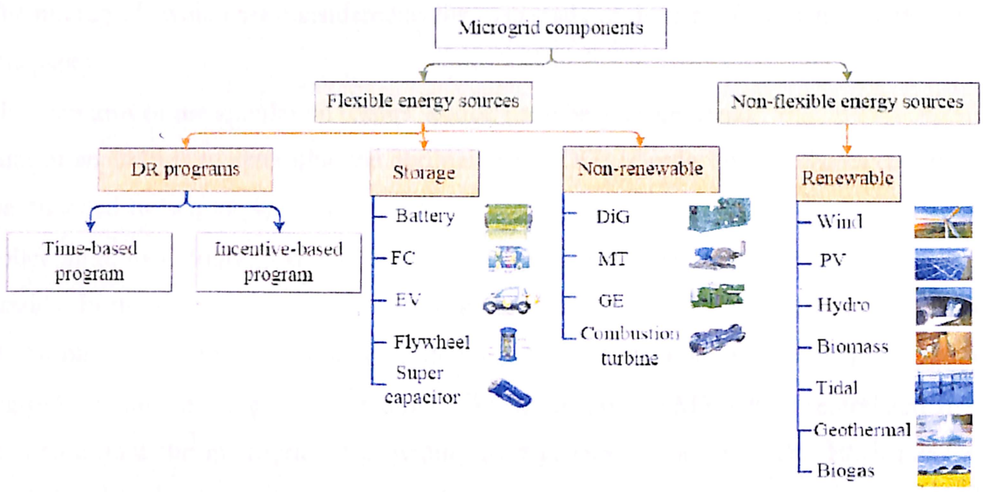


Figure 1. Microgrid components.

Microgrids often face difficulties in supplying demand due to the lack of sufficient energy generation sources. This obstacle is caused by intermittent nature of loads and renewable energy sources. As a result, an energy management system (EMS) is necessary to tackle this problem.

EMS for a microgrid represent relatively new and popular topics that attracted lots of attention, recently.

Components of microgrid

- Distributed generation
- Loads
- Energy storage systems
- Static disconnect switch
- Controller
- Mode switching device
- Point of common coupling

The contributions of this desertion are:

- Microgrid EMSs have been classified into four categories based on the kind of the reserve system being used including non-renewable energy sources, energy storage system (ESS), demand-side management (DSM) and hybrid.
- Energy management modelling studies have been reviewed in terms of uncertainty modelling techniques, objective functions (OFs), constraints, and optimization techniques.
- The microgrids which are considered as the case study of different EMS papers have been reviewed in this paper.
- The scenarios of the simulation results section have been categorized.

The aim of an EMS is to determine the optimal use of DGs in order to feed the electrical loads. An EMS can be operated in two modes, namely centralized and decentralize. In the centralized mode, the central controller aims to optimize the microgrid power exchanged based on the market prices and security constraints. In the decentralized mode, DGs and controllable loads have more degree of freedom. As a result, the microgrid components are considered to be intelligent and try to maximize the revenue of the microgrid by communicating with each other. The initial duty of EMS in both centralized and decentralized mode is to ensure the microgrid of providing load-generation balance. The EMS fail in matching the generation and load, whenever the total load is higher than the maximum capacity of DGs and no other additional actions are taken. A solution for this drawback is to trade power with the utility or other micro-sources, however, this solution leads to an increment of pollution, costs and the need to solve a more complex unit commitment problem as a result of the additional units. Various supporting systems such as DiGs, ESSs and DSM are employed to overcome the supply-demand mismatch of a microgrids. This paper provides the literature review of microgrid EMSs by classifying the existing articles into four categories as follows:

(1) Non-renewable based EMS

(2) ESS-based EMS

(3) DSM-based EMS

(4) Hybrid systems-based EMS

1.3 PURPOSE OF THE STUDY

A microgrid is characterized by the integration of distributed energy resources and controllable loads in a power distribution network. Such integration introduces new, unique challenges to microgrid management that have never been exposed to traditional power systems. To accommodate these challenges, it is necessary to redesign a conventional Energy Management System (EMS) so that it can cope with intrinsic characteristics of microgrids. While many projects have shown excellent research outcomes, they have either tackled portions of the characteristics or validated their EMSs only via simulations. This paper proposes a Microgrid Platform (MP), an advanced EMS for efficient microgrid operations. Design the MP by taking into consideration (i) all the functional requirements of a microgrid EMS (i.e., optimization, forecast, human-machine interface, and data analysis) and (ii) engineering challenges (i.e., interoperability, extensibility, and flexibility). We then conduct experiments to verify the feasibility of the MP design in real-world settings. Our testbeds and experiments demonstrate that the MP is able to communicate with various energy devices and to perform an energy management task efficiently.

1.4 INTRODUCTION TO MICROGRID

The microgrid is a miniature power supply load and an independent control system to provide local power and heat. This concept provides a new model to describe the microgrid operation; microgrid can be seen in the power unit in a controlled, it can respond in seconds to meet the needs of the external transmission and distribution networks; on the user, the microgrid to meet their specific needs: increase local reliability, reduce feeder loss, to maintain local voltage, through the use of waste heat to provide higher efficiency, the voltage drop to ensure uninterrupted power supply.

Microgrid technology can effectively integrate the advantages of distributed generation, and also provide a new technical way for large scale application of grid-connected generation of new energy and renewable energy. Microgrid can not only enhance the efficiency of energy cascade utilization, but also be used as an effective complementary of power grid and improve the reliability of power supply and power quality.

The microgrid Energy Management System is gradually becoming a research focus along with the continuous development of microgrid technology. Energy management in microgrids is defined as an information and control system that provides the necessary functionality, which ensures that both the generation and distribution systems supply energy at minimal operational costs

A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. Enables local power generation for local loads. Comprises of various small power generating sources that makes it highly flexible and efficient. It is connected to both the local generating units and utility grid thus preventing power outages. Excess power can be sold to the utility grid. Size of the Microgrid may range from housing estate to municipal regions.

Key Attributes of Microgrid

- Grouping of interconnected loads and distributed energy resources
- Can operate in island mode or grid connected if desired
- Acts as a single controllable entity to the grid

The Need of Microgrid

- Microgrid could be the answer to our energy crisis
- Transmission losses gets highly reduced

- Microgrid results in substantial savings and cuts emissions without major changes to lifestyles.
- Provide high quality and reliable energy supply to critical loads

Conventional grid Vs. Microgrid

- Efficiency of conventional grid is very low as compared to Microgrid
- Large amount of energy in the form of heat is wasted in conventional grid
- Power sources in case of Microgrid are small and located in close proximity to load.

Power Generation System	Storage issues
Resources, devices, machine, electrical control	• Medium size and micro-turbines • Permanent magnet and doubly fed induction generators • Efficient inverters • Self-excited induction generators • Asynchronous or synchronous generators • Induction machine and DC machine based storage system such as flywheels
Advanced electrical design of devices and components	• Dynamic design of wind turbines • Bio-fuel based turbines • PV Solar cell system with high insulation system and sun tracking system to get maximum power • Minimum losses smooth output of wind farms
Types of loads	• Dynamic modeling of loads • Adoptive and frequency/voltage dependent characteristics of loads • Real time load shedding planning • Adoptive load management • SCADA based control
Energy management methods	• Both systems adoptable either centralized vs. decentralized control system. • Impedance matching to control reactive power and minimizing losses • Efficient protection methods • Implementation of hybrid sources to control fault current levels in the micro-grid • Smooth coordination with other micro-grid with the conventional grid • Intelligent Interface system • Operate in both modes grid connected or Islanding and detection methodologies • Low-voltage controlling system

1.5 NEED FOR THE RESEARCH

The demand for electricity worldwide is growing at a much faster rate and it is projected around 2.7 % growth per annum (Micro grids). The biggest challenge of any utility company is to provide clean and adequate power with convenient form to the consumer, as it has a direct bearing on the living standards as well as alleviating poverty and ensure energy security. The ever-increasing demand of electricity has to be met with higher volume of generation mostly from fossil fuel based conventional power plants. The energy customers are increasingly interested in improving their energy efficiency and reducing their energy costs, while the utility companies are consistently worried about increasing or simply maintaining good quality of power and their reliability while meeting new clean and green energy mandates and other standards. International organizations, Governments and non-government agencies are driving clean energy adoption, in the interests of climate change mitigation, energy security, and other environmental goals.

Microgrid is an interconnection of distributed energy resources mostly of renewable based power sources such as wind, solar photovoltaic (SPV), micro turbines, fuel cells and biofuels integrated with energy storage devices. However, the definition and explanation for Microgrid generally varies and is viewed in different perspectives while implementing distributed generation. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. In India the Microgrid projects are initiated as a part of the smart grid project and many researches are going on (in academic and research organization) in the field of design, modelling and development of Microgrid systems. The implementation of any microgrid system involves i) analysis of consumer site and estimation load demand, ii) selection of sources, iii) assessment of source variability, iv) optimization of power sources, v) modelling of MG system, vi) development of metering infrastructure.

Objectives

In microgrid, energy storage is able to perform multiple functions, such as ensuring power quality, including frequency and voltage regulation, smoothing the output of renewable energy sources, providing backup power for the system and playing crucial role in cost optimization. To identify and overcome the technical barriers that impede adoption of the new paradigm of distributed energy resources represented by microgrids. To analyse new energy management models that take into account the interaction between microgrids and distribution lines.

Microgrid Advantages

- A major advantage of a Microgrid, is its ability, during a utility grid disturbance, to separate and isolate itself from the utility seamlessly with little or no disruption to the loads within the Microgrid.
- In peak load periods it prevents utility grid failure by reducing the load on the grid
- Significant environmental benefits made possible by the use of low or zero emission generators.
- The use of both electricity and heat permitted by the close proximity of the generator to the user, thereby increasing the overall energy efficiency.
- Microgrid can act to mitigate the electricity costs to its users by generating some or all of its electricity needs.

Microgrid Disadvantages

- Voltage, frequency and power quality are three main parameters that must be considered and controlled to acceptable standards whilst the power and energy balance is maintained.
- Electrical energy needs to be stored in battery banks this requiring more space and maintenance
- Resynchronization with the utility grid is difficult.
- Microgrid protection is one of the important challenges facing the implementation of microgrids.
- Issues such as standby charges and net metering may pose obstacles for Microgrid.
- Interconnection standards needs to be developed to ensure consistency.

CHAPTER 2

2.1 FUTURE DIRECTIONS ON MICROGRID RESEARCH

- To investigate full scale development, filed demonstration, experimental performance evaluation of frequency and voltage control methods under various operation modes.
- Transition between grid connected and islanded modes on interaction phenomena between distribution generation and high penetration of distributed generation.
- Transformation of Microgrid system today into the intelligent, robust energy delivery system in the future by providing significant reliability and security benefits.

Challenges

Microgrids, and the integration of DER units in general, introduce a number of operational challenges that need to be addressed in the design of control and protection systems, in order to ensure that the present levels of reliability are not significantly affected, and the potential benefits of Distributed Generation (DG) units are fully harnessed. Some of these challenges arise from assumptions typically applied to conventional distribution systems that are no longer valid, while others are the result of stability issues formerly observed only at a transmission system level. The most relevant challenges in microgrid protection and control include:

- **Bidirectional power flows:** The presence of distributed generation (DG) units in the network at low voltage levels can cause reverse power flows that may lead to complications in protection coordination, undesirable power flow patterns, fault current distribution, and voltage control.
- **Stability issues:** Interactions between control system of DG units may create local oscillations, requiring a thorough small-disturbance stability analysis. Moreover, transition activities between the grid-connected and islanding (stand-alone) modes of operation in a microgrid can create transient instability. Recent studies have shown that direct-current (DC) microgrid interface can result in a significantly simpler control structure, more energy efficient distribution and higher current carrying capacity for the same line ratings.
- **Modelling:** Many characteristics of traditional schemes such as the prevalence of three-phase balanced conditions, primarily inductive transmission lines, and constant-power loads, do not necessarily hold true for microgrids, and consequently, models need to be revised.
- **Low inertia:** Microgrids exhibit a low-inertia characteristic that makes them different to bulk power systems, where a large number of synchronous generators ensures a relatively large inertia. Especially if there is a significant proportion of power electronic-interfaced DG units in the microgrid, this phenomenon is more evident. The low inertia in the system can lead to severe frequency deviations in island mode operation if a proper control mechanism is not implemented. Synchronous generators run

at the same frequency as the grid, thus providing a natural damping effect on sudden frequency variations. Synchronverters are inverters which mimic synchronous generator to provide frequency control. Other options include controlling battery energy storage or a flywheel to balance the frequency.

- **Uncertainty:** The operation of microgrids involves addressing much uncertainty, which is something the economical and reliable operation of microgrids relies on. Load profile and the weather are two of these uncertainties that make this coordination more challenging in isolated microgrids, where the critical demand-supply balance and typically higher component failure rates require solving a strongly coupled problem over an extended time horizon. This uncertainty is higher than those in bulk power systems, due to the reduced number of loads and highly correlated variations of available energy resources (the averaging effect is much more limited).

2.2 INDIAN RENEWABLE ENERGY SCENARIO AND STATUS OF MICROGRIDS

In the past several years India has seen significant growth in renewable energy generation. Fig. 1 shows installation of various energy resources as in the year 2009 and projected installed capacity in the year 2032. The growth in this renewable energy installation is a combined effect of regional energy development agencies, ministry of new and renewable energy (MNRE), and private sector participation. Supportive government policies are also driving renewable energy installation. The planning commission of India has published integrated energy policy report (IEPR) which highlights the need to maximally develop domestic supply options and diversify energy sources for sustainable energy availability. According to IEPR, total renewable energy may account for 11-13% of India's energy mix by the year 2032. It also suggests that the distributed nature of renewable energy sources can provide many socio-economic benefits for the country. Reference presents various issues and feasible solutions associated with large scale deployment of the renewable energy technologies in India. Grid Interactive Energy sources developed so far in India are Solar, Wind, Small Hydro and Bio Energy. It is estimated that bio-power may play a key role in the next couple of decades due to the availability of abundant bio-fuel of different forms in India.

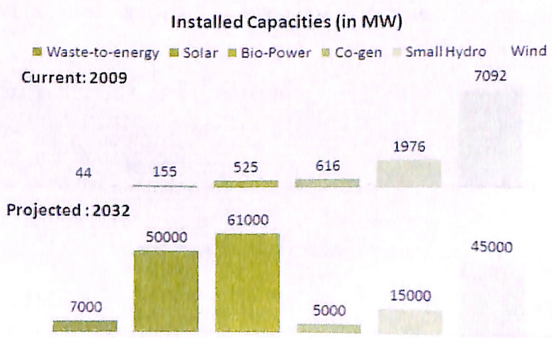


Fig. 1. Renewable energy scenario in India

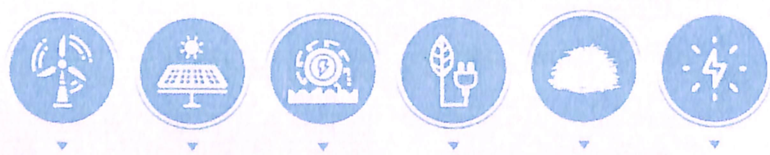
Electricity Generation (Conventional and Renewable Sources) :

All India Generation From Renewables				(All Figures are in MU)	
Sl.No.	Source-Wise All India Generation from Renewables	For the Month of		Cummulative for the period	
		Apr-2020	Apr-2019	Apr-20 to Apr-20	Apr-19 to Apr-19
1	Wind	3448.94	3707.28	3448.94	3707.28
2	Solar	5338.90	4181.23	5338.90	4181.23
3	Biomass	265.10	235.01	265.10	235.01
4	Bagasse	917.86	1201.29	917.86	1201.29
5	Small Hydro	629.84	518.13	629.84	518.13
6	Others	33.18	38.77	33.18	38.77
	Total :	**10633.82**	**9881.70**	**10633.82**	**9881.70**

Renewable energy sources (RES) includes Wind, Small Hydro Projects, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power & Solar Power.

Year	Non RES Generation (MU)	Generation from RES (MU)	Total Generation (MU)	Year-wise growth for renewable energy (%)	Contribution of renewables in total generation (in %)
2014-15	10,48,673	61,719	11,10,392	-	5.56
2015-16	11,07,822	65,781	11,73,603	6.58	5.61
2016-17	11,60,141	81,548	12,41,689	23.97	6.57
2017-18	12,06,306	1,01,839	13,08,145	24.88	7.78
2018-19	12,49,337	1,26,759	13,76,096	24.47	9.21

Sources wise breakup of Renewable energy:



Source of energy	Wind	Solar	Small hydro	Biomass	Bagasse	Others
Cumulative generation (MU)	62,036	39, 268	8,702	2,763	13,562	425
Percentage (%)	48.94	30.98	6.87	2.18	10.7	0.34

Total Cumulative Generation (MU) → 1,26,759

DGs/DERs are considered as the building blocks for the existence of a sustainable Microgrid. Economics of Microgrids are mainly dependent on the regulatory and the economic frameworks of DGs/DERs in the respective countries. The issues of Microgrid economics can be broadly classified as shown in Fig. 2.

MicroGrid Economics

- Main Issues
  - Optimal technology investment
    - Optimal mix of renewables
  - Utilization of some unique aspects
    - Local control of power quality and reliability
    - Societal perspective
  - Relationship with distribution system
- Emerging Issues
  - Joint optimization of demand and Supply
  - Joint optimization of heat and electric supply
  - Focus on quality & reliability
  - Metering arrangements
  - Connection charges
  - Tariff mechanisms

Fig. 2. Identified economic issues relevant to MicroGrids

Summary

- Microgrid gives impetus to the use of renewable sources of energy
- Reliability is achieved due to decentralization of supply.
- In an event of power grid failure Microgrid is one of the best alternatives.

CHAPTER 3

3.1 RESEARCH ON MICROGRID EMS

Due to intermittence of RES, researchers started focusing on EMS strategies. Extensive research has developed an EMS for different MG scales ranging from small-scale (single home) to large-scale Microgrid (cities) as depicted in Fig.3.

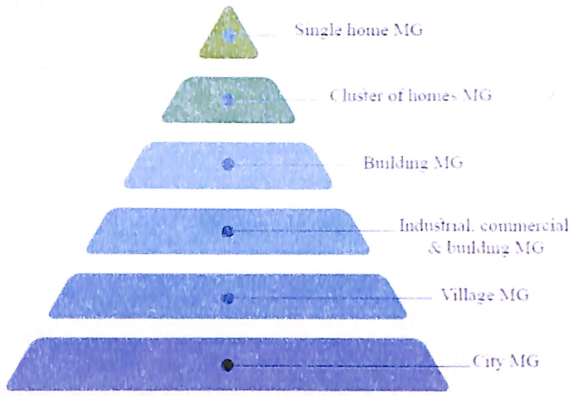


Fig3 : Different scales of MG

Research has focused on modelling and studying the feasibility of MG components, optimum scheduling of DGs, forecasting environmental data (wind speed, solar irradiance and water speed), forecasting consumption profile, EMS based optimization algorithms, for the purposes of getting economic benefits with less impact on the environment. Fig.4 outlines the main MG structure and components related to EMS.

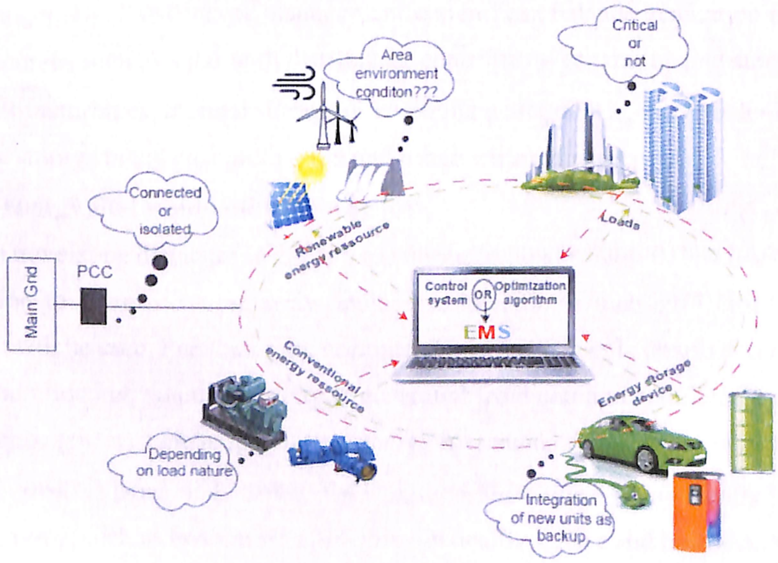
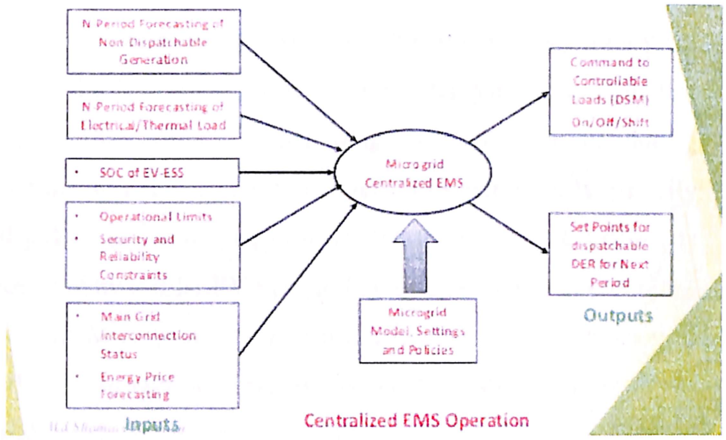


Fig4: Energy management system of Microgrid

3.2 MICROGRID EMS METHODS

- Genetic Algorithms (GA)
- Particle Swarm Optimization (PSO)
- Model Predictive Control (MPC)
- Ant colony optimization (ACO)
- Potential function-based control
- Voltage unbalance compensator technique
- Multi-agent (MAS) concept
- Gossip based technique
- Distributed cooperative control



3.3 HOW WOULD A MICROGRID HELP MY CITY

Microgrids can provide several benefits to the environment, utility operators, and customers. These benefits are particularly important to cities, which strive to create safe, liveable communities with thriving economies.

Microgrids can reduce greenhouse gas emissions in two ways:

1. **Offering the opportunity to deploy more zero-emission electricity sources.**

The microgrid manager (e.g. local energy management system) can balance generation from intermittent renewable power sources such as solar with distributed, controllable generation and storage (e.g., natural gas-fuelled combustion turbines, thermal storage or emerging generation sources such as fuel cells). They can also use energy storage to balance production and usage within the microgrid.

2. **Making use of energy that would otherwise be lost.**

When power has to travel long distances (e.g. from a centralized power station), line losses occur, requiring additional generation to ensure that far away demand is met. Since microgrid electricity is generated adjacent to where it will be used, line losses are minimized and less power is required to meet an equivalent level of demand. Additionally, when electricity is generated from certain centralized power sources (e.g., fossil fuels and nuclear power) a great deal of heat energy is created, and typically released unused into the atmosphere. When power is generated close to the end users, it becomes economically feasible to use this heat energy productively, such as heating water or space in nearby homes and businesses. Thus, less fuel is combusted overall, resulting in lower greenhouse gas emissions.

When sited strategically within the electricity system, microgrids can help to lower electricity prices and reduce peak power requirements by reducing or managing electricity demand and alleviating grid congestion. In this manner, microgrids may support system reliability, improve system efficiency, and help delay or avoid investment in new electric capacity.

In addition, microgrids can enhance grid resilience to more extreme weather. When Hurricane Sandy cut off power to millions of homes and businesses in the Northeast, a few areas mostly parts of universities kept the lights on using their own power generation systems. Sustaining electricity service during widespread natural disasters is one reason for the growing interest in microgrids particularly for city governments tasked with maintaining critical public services. The city of Charlotte, North Carolina, is exploring a public safety campus microgrid powered by a solar PV system (an arrangement that combines climate change mitigation and resilience benefits). Microgrids such as this can also help the microgrid recover from a system outage, either indirectly, by sustaining services needed by restoration crews, or directly, by helping to re-energize the microgrid.

For cities on the edge of the microgrid, microgrids can ensure power reliability. For example, in Borrego Springs, California, a mixed-ownership microgrid is providing clean, reliable, and resilient power cost effectively to a hard-to-serve, isolated community.

3.4 ROLE OF LOCAL GOVERNMENT

Local governments can play a critical role in supporting microgrid technologies. Developers respond to market signals, and local policy can create clarity and communicate priority levels for microgrid developers. In addition, local governments can engage stakeholders around market needs and opportunities, and even set the tone as a microgrid customer.

Set the policy environment:

- Assist would-be developers in determining limits on their potential customer base, e.g. examine franchise agreements that give exclusive rights to the incumbent utility.
- Waive permitting fees and/or expedite the permitting process.
- Grant zoning incentives to projects that include microgrid features such as energy storage, renewable generation, or intelligent energy management.
- Ensure zoning codes and homeowners association covenants do not inhibit on-site energy storage and renewable energy generation.
- Require or encourage developers to consider microgrid technologies in permit applications.

Support project development:

- Engage anchor institutions (like hospitals and universities) and developers on community energy use, public purposes, and customers the microgrids might serve.
- Identify locations ripe for economic development, or local energy systems that could be expanded.
- Provide information about underground infrastructure to interested developers during project conception.

Participate in and develop projects:

- Establish district energy zones that provide municipal infrastructure that will allow future microgrid development.
- Pursue projects as an anchor customer or supporting partner. Acting as a first mover and demonstrating intent can pave the way for attracting private sector participants.

3.5 INVOLVEMENT

Microgrid developers must work with the finance community, advisors, partners, customers, regulatory agencies, government officials, and other stakeholders.

Developers/Owners: Builders or project managers of microgrids

Investors: Financial backers of projects

Advisors: Companies or individuals that provide technical design support, and/or help prepare and communicate the financial case for the project to investors

Partners: Companies that help to develop the project including utilities or government entities in the case of a public-private partnership

Customers: Consumers of the microgrid's power, thermal energy, and other services

Regulatory Agencies: Public utility commissions and their like

Government Officials: State and city officials

Other Stakeholders: Community representatives and others who might be affected by the microgrid development

3.6 OWNERSHIP OF MICROGRID

While each project is unique, here are three common ownership models:

Utility-owned microgrids can often be funded by including the capital cost in the utility's rate-base, provided the utility can demonstrate the need for and cost-effectiveness of the microgrid to its regulators.

These microgrids simply offer a different technological approach to delivery of traditional services by established service providers.

Privately-owned microgrids can be much more challenging. They may compete with electric service delivered through existing infrastructure and face legal and administrative challenges that limit their deployment.

Community-owned grids are often funded by government sources (state and federal) through bonds, tax credits, grants, loans, tax deductions, and credit enhancements. However, these microgrids face financing challenges even in states that have encouraged such projects.

Long-term public-private ownership microgrids are gaining popularity because they allow for flexible sharing of project risks and management. Mixed ownership microgrid projects were nearly non-existent in 2013 but were projected to make up 38 percent of the market in 2016.

3.7 FINANCIAL FEASIBILITY OF MICROGRIDS

A financial feasibility study can help quantify and reduce microgrid development risk. This standard industry practice includes calculating the project's start-up costs, identifying the sources of funding, and calculating the project's likely returns. Each project's starting point is likely to be unique. Existing electrical infrastructure or generation assets can help mitigate the cost of constructing the system. Buying electric generation equipment typically accounts for the largest share of the development and construction cost. Other costs to consider are infrastructure build-out and microgrid control systems. Development and construction costs can escalate depending on the location of the microgrid, its degree of sophistication, and whether the project is designed to be scalable.

TABLE 1: Sources of Microgrid Finance

PUBLIC FINANCE (FEDERAL, STATE AND MUNICIPAL)	PRIVATE FINANCE
• Tax-exempt bonds • Tax credits • Grants • Loans • Tax deductions • Credit enhancements • Clean Energy Banks • Commercial property assessed clean energy (PACE) • Resilience bonds • Power purchase agreements (PPAs)	• Equity financing • Debt financing, loans • Corporate bonds • Energy saving performance contracts (ESPCs)—Energy service companies (ESCOs) • Power purchase agreements (PPAs) • Third-party model

Microgrids generate revenue in several ways:

Providing metered electricity to consumers within the microgrid network. This provides a steady stream of income. Investors will consider the basis on which these sales are made, including the duration of their commitment as well as the creditworthiness of the customers.

Providing metered thermal energy. A microgrid can provide hot water, steam, or chilled water – offerings most electric utilities do not provide.

Ensuring reliable and resilient systems. A microgrid may attract a premium tariff from customers that require a higher level of service and have a low tolerance for disruptions. For example, a grocery store may be willing to pay a higher electricity price for a guaranteed uninterruptible power supply to keep valuable refrigerated and frozen food from perishing in the event of a grid outage. A data center or other service provider that cannot afford to be offline even for an instant might be willing to sign a contract for a premium service.

Generating Renewable Energy Credits. A microgrid may be eligible to generate renewable energy credits (RECs). While some owners will retire these RECs to assure their claim to "green" power, others may sell them, creating yet another revenue stream. Selling excess power back to the larger grid.

Providing microgrid services. Participating in demand response markets or providing frequency regulation services can provide another revenue stream.

This revenue will be offset by operating costs, including fuel, labour, security, and administrative costs, as any utility service provider will incur. Also, participation in markets to sell microgrid services (e.g., demand response, frequency regulation) has a cost, as the microgrid owner will need to become a market participant or contract with a marketer able to make the transactions. In addition, the microgrid owner may need to purchase power from the microgrid owner or the wholesale market. Like any business, meeting such obligations means the microgrid will have working capital requirements, which also need to be considered when arranging financing.

3.8 LEGAL CONSIDERATIONS OF MICROGRID

Microgrid investors will be concerned with the legal environment in which the project will operate, and should consider relevant statutes, regulations, market rules, local ordinances, tariffed rates, terms and conditions (including interconnection rules and fees and stand-by power charges), and even electrical codes. While risk related to future changes in law is unavoidable for any investment, the legal framework for microgrids is particularly undeveloped and contributes to greater risk. This risk is based on an expectation that the legal void will be filled soon, although the contours of new laws are unknown.

Microgrids confined to a single site and a single owner, such as within an industrial complex or a building, are generally the easiest type of project to assess. No state prohibits an entity from self-supplying its electrical needs, although the law may or may not be hospitable to such arrangements and may limit the use of leasing arrangements or other third-party services.

Microgrids that serve multiple customers, however, face challenges from a legal framework that fails to define the rights and obligations of the microgrid owner with respect to its customers and the microgrid operator. In addition, state franchise rights and rights-of-way laws granted to utilities may limit microgrid developers' access to customers. Connecticut was the first state to develop a legal definition of a microgrid to promote community microgrids for resilience in the wake of Hurricane Sandy. However, the Connecticut law is not designed to provide a complete framework for the development, connection, and integration of microgrids, including those that serve other purposes. Other states are even further behind in providing legal certainty. Addressing these legal barriers is essential to the wider deployment of microgrids.

CHAPTER 4

KEY STUDY FINDINGS

- An uptick in rural electrification projects
- An increase in the adoption of energy as a service model
- Asia Pacific has emerged as a leader in capacity with 9,935.4 MW – trailed by North America with 8,878.6 MW and the Middle East & Africa with 3,627.7 MW
- Remote microgrids and commercial and industrial represent nearly 70% of all microgrid capacity globally.

"One of the most notable trends from this update was the significant increase of remote systems in the Asia Pacific region, a key factor in the region's emergence as the global leader in both microgrid capacity and projects."

This research report outlines why microgrid which has only scratched the surface is likely to become huge in India market and it's perfect PPP model to achieve 100% household level access to electricity by 2024-2025. Microgrids utility will be beyond last-mile connectivity and will find its way into industrial captive power, commercial captive and even at the individual residence cluster level.

In an attempt to promote microgrids in India, the government issued a draft national policy on renewable energy-based mini- and microgrids. The policy proposes to set up at least 10,000 renewable micro-and mini-grid projects across the country, with 500 MW of generation capacity to be developed by private players by 2022 in order to cater to around 237 million people experiencing energy shortage.

Microgrids utilise various generation resources including diesel, solar photovoltaic (PV), micro-hydro and biomass gasification, and also employ hybrid technologies such as wind-diesel and PV-diesel. While diesel-based microgrids are the most commonly used globally, solar PV systems are also gaining popularity due to the reduced cost of PV modules and solar PV equipment. In India, solar microgrids with an aggregate capacity of 1,899 kWp have been installed so far in 63 villages with financial support (30 per cent of the project cost) from the Ministry of New and Renewable Energy (MNRE).

Thus, for a 10 kW direct current microgrid, the MNRE offers Rs 105 per watt, and for systems with a module capacity of 10-250 kW, it offers Rs 90 per watt. The systems come with a minimum warranty of five years in the rural and remote areas of the country. In India, key players in the microgrid market include Gram Power, Mera Gao Power, DESI Power, Omni grid Micropower Company and Gram Oorja Solutions. Most of these players deploy solar-based microgrids in combination with smart grid technologies in states such as Karnataka, Maharashtra, Uttar Pradesh and Bihar.

Currently, commercial investors are sceptical about investing in the microgrid market due to a perceived lack of visibility, market maturity, and scalability concerns. Given the increasing global focus on renewable energy generation and commitments to counter climate change, microgrids offer a range of benefits. There are challenges but the advantages outweigh these and the technology interventions, government support will pave way for economically sound microgrid based power distribution system which is self-sustainable, operates in tandem to the grid or on a completely independent grid basis.

CHAPTER 5

CONCLUSION

Microgrids can deliver benefits to the environment, the power system, and energy customers by enabling deployment of greater quantities of low-emission energy sources, creating opportunities for greater efficiencies, and ensuring system reliability. These benefits will be felt by the customers and their surrounding communities, which is a major reason microgrids are being considered. Although there is growing interest in related "smart city" investments, renewable energy, and resilience measures, greater awareness is needed about microgrids' potential and how they fit into the electricity grid of the future. Local governments can support increased awareness and decision-making by first understanding the variety of microgrid types and ownership models, as well as the emerging policy needs associated with microgrid technologies. While project developers and partners must navigate legal uncertainties and establish financing plans, municipalities have the unique capability to support the technology by creating development incentives, removing policy hurdles, and even pursuing their own microgrid projects.

FUTURE SCOPE

- In the near future when cost of Microgrid system will be affordable then Microgrids will become more popular and conventional grid will be replaced by Microgrid.
- Research are going such as to increase stability and reliability of the Microgrid for effective working.
- Smart Microgrids are the future of the grids since they provide concrete solutions to the problems faced by the old grid. They can be implemented in small areas as well as large ones such as cities.

GLOSSARY OF TERMS – ACRONYMS

DER	Distributed energy resources
RES	Renewable energy source
T&D	Transmission and distribution
DGs	Distributed generations
DISCOMs	Distribution Companies
FY	Financial Year
kWh	Kilowatt-hour
MW	Megawatt
PLF	Plant Load Factor
PPA	Power Purchase Agreement
PV	Photovoltaic Cell
RE	Renewable Energy
WTs	Wind turbines
FCs	Fuel cells
MTs	Micro-turbines
GEs	Gas engines
DiGs	Diesel generators
MP	Microgrid Platform
MNRE	Ministry of new and renewable energy
IEPR	Integrated energy policy report

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APPENDIX

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c. Microgrid news - India's Microgrid Market

d. Microgrid Projects- Microgrid Projects in India

e. CEA Report- Executive Summary on Power Sector

f. Tata Power in-house Magazine with Special edition on Renewal Energy