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Review Article

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Electric Power Grid Modernization and Energy Management Roadmap

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Abstract

Generation, transmission, and distribution have been an integral part of the conventional power sector, interconnected over long distance through a diverse network of wire known as the electric grid. The grid has been an incredibly important and complex system, signifying the modern era's most remarkable engineering feats. With the evolution of cost-effective energy storage devices and the new green distributed energy resources concept of microgrid and smart grid has come into action and gained immense popularity. The aim of designing and developing a decentralized grid mainly focuses on operating autonomously, strengthening grid resilience. Moreover, it proves fantastic in mitigating grid disturbances with faster system response and recovery rate; it has been characterized by dual operative nature, which includes both grid-connected or island mode. Smart grid is a concept which upgrades the conventional electrical power grid by adopting automatic control devices; implement smart communications technologies, analyzing real-time data, applying the software-based solution for continuous, efficient, and cost-effective power transmission and distribution. In this paper, the authors have made an effort to undergo potential case studies and present a brief investigative report on the Indian Power Sector transition to techno-economic viability and strategic management to relinquish a specific outcome.

Keywords: Energy; Distributed generation; Management; Grid; Network; Renewable; Sustainability

Introduction

Imagining a world without electricity, and that too in the 21st century, is like a dark night as it has become an important aspect of our livelihood with numerous notable contributions for upliftment against socio-economic barriers. In present times the electric grid has been the only linker between genco, Transco, and discom. With technological modernization and the evolution of state-of-the-art technologies, scientists and researchers are capable of developing localized, sustainable grids using sophisticated equipment or machinery. Traditional grid very often undergoes stress and unwanted faults, mostly due to large dependence and diverse load demand nature with inferior technical accessories and affects power quality. Since the industrial revolution, it has been a challenge to connect every corner of the world with electricity. The adaption of an energy-efficient microgrid model with a deliberate roadmap allows wide scope and endless opportunities to connect even with the remotest rural areas with greater energy security and virtuous governance. In the conventional method of transmission and distribution of electrical energy, we normally transmit high voltage electricity from the electrical power generation plant to the substations. After that, we step down the voltage level using a step-down transformer for distributing the electrical energy to the end-users. In the last few years, there has been a blast of uses of renewable energy sources in the generation of electrical energy; for that, we need a smart electrical distribution system for efficient and uninterrupted electricity supply. As society and the economy are growing, energy resources are reducing, and the environment becomes more polluted; therefore, we need to ensure a clean energy supply. Smart Grid is the concept that gives a solution to the above problems. The way a smart grid is constructed increases the adaptability of clean energy in the power grid, provides a secure, efficient, and economic power supply.

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Literature Survey

To support scientific planning, innovation and penetration of smart microgrids in the replacement of conventional electric grid are challenging and full of opportunities that allow the harnessing of natural renewable resources than exploiting fossil fuels. The field is relatively new, thus demanding the research community's involvement to provide strategic scope using new technologies for strengthening grid synchronization, performance, and connectivity. A comprehensive framework for integrating modern edge technologies facilitates the convergence of acutely needed standards and implementation of necessary analytical capabilities. Authors have undergone a vast spectrum of research directories to investigate and highlight the critical factors regarding a smart microgrid and justification for the necessary revolution in the Indian power sector. Scope, challenges, probable solution, possibilities, future prospective, the specific outcome has been discussed. P. Kalkal et al., in 2017 has presented a detailed review of the grid ecosystem and formulated significant elemental differences in the smart microgrid with the present-day grid [1]. In 2015 G. Tang et al. [2] has analysed topology and critical devices for DC grid facilities and accord a positive strategy to overcome multi nature fault [3]. Y. Wan et al. has worked on testing the feasibility of cybersecurity in modern-day power system, i.e., smart grid, in 2014 and proposed an integrated cyber-physical simulation environment. D. Wu et al. [4] 2012 conducted a real-time harmonics assessment to understand the transient pattern for an online vehicle-to-grid system. Apart from this, IT architectures for techno-commercial progress have been detected for remote monitoring, automatic fault diagnosis, and control operations [5-8]. In their previous work [9-10], authors attempted to optimized operational effectiveness in solar-powered and waste-to-energy conversion plant for better adaptableness. Moreover, the author has closely studied the fundamentals of smart microgrids and numerous faults associated with it, & troubleshooting them remotely. Harmonic assessment base power quality analysis and its impact over grid have been reflected in work.

Present Energy Scenario

Energy is one of the major ingredients for the economic development

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of any nation, and it becomes critically important energy is one of the primary ingredients for any nation's economic development, and it becomes critically important for developing countries such as India. The energy sector's present scenario can be assessed under several parameters, which include commercial energy pricing, conservation, production, end demand, reforms, etc. In-country like India, almost 50 percent of energy is dominated by fossil fuels as India has one of the largest coal reserves. Recent high energy demands have led to the forceful adaption of clean, renewable energy for prosperous development. Analyst describes that increased energy demand has a unique indication on the health of Gross Domestic Product (GDP) Figure 1.

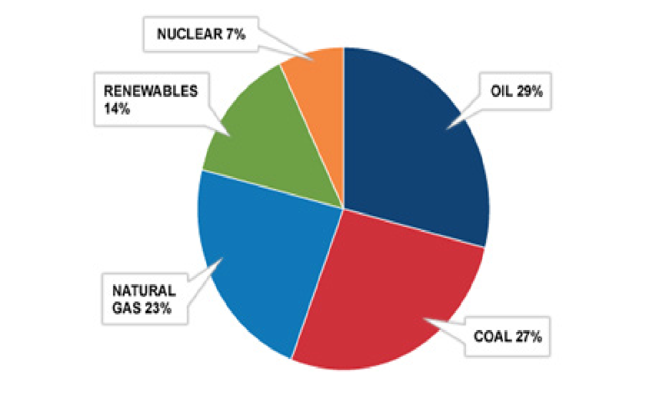

Figure 1: Global energy share 2020.

In this context, energy demand over GDP (Figure 2) indicates the scope of a country's industrial and agricultural growth. It has a strong influence on multiple social indexes that represent the essential quality of living. Underneath are two different graphics which show the percentage of energy share for diverse resources across the globe and Indian subcontinent [11-12].

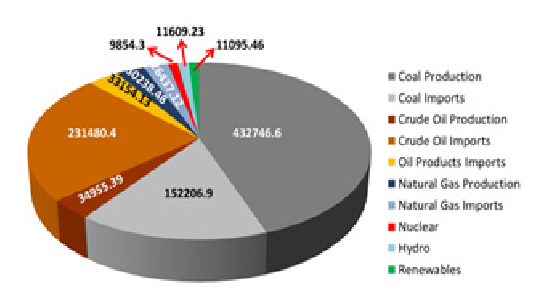

Figure 2: India energy share 2020.

Classification of Electric Grid

The microgrid can be often be classified into substantial sub-categories with respect to capacity, nature, configuration, location, DRs Demand and future context Table 1.

Microgrid

Microgrids could be the best-suited option to fight an alarming worldwide energy crisis. Competent to deliver superior quality, reliable energy supply to critical loads, which enables grid transformations. Microgrids prove beneficial in minimizing transmission losses and also result in substantial saving and Promote community energy independence. To emphasize and promote the growing need for smart microgrids, a comparison table has been prepared, highlighting its superior characteristics over the traditional grid. The conceptualization of microgrid (Table 2) has been a small-scale power supply network to provide affordable electricity to the small community by enabling decentralized power generation for local loads by reinforcing Distributed Generations (DGs), which has received much attention because it reduces the burden from the conventional power systems with an eco-friendly sustainable approach and looks promising from future aspects. To better understand, some of the prominent characteristic's properties of microgrids have been identified & listed as follows:

Table 1: Classification of electric grid.

Capacity	Future microgrid	Type of distributed resources	Location	Configuration	Functional demand	Nature
Simple	Blockchain MGs	Traditional generation	Institutional	Grid connected	Simple	DC
Corporate	Networked MGs	Non-Traditional generation	Community	Remote off grid i.e., Island	Multi DGs	AC
Independent	Autonomous MGs	Cutting-edge Technology Driven generation	Military		Utility	Hybrid
Feeder area	Desalination MGs		Commercial and Industrial (C and I)			
Substation area						

- Stability
- Autonomy
- Flexibility
- Scalability
- Efficiency
- Security
- Economy
- Compatibility
- Interoperability
- Auto-troubleshooting

Table 2: Traditional vs. smart-micro grid.

Traditional grid	Smart-micro grid
Large in size	Small and modular
Centralized generation	Decentralized generation
One-way energy communication / transfer	Single and two-way energy communication/transfer

Hierarchical structure	Network type structure
Manual restoration	Self-healing and auto-regulating
Limited control	Modern pervasive control
No choice is provided to customer or end user	Infrastructure can be shared to a wide range of customer
Few sensors are employed	Equipped with sensors throughout
Technology used mainly electro-mechanical type	Information technology enabled digital system
Not efficient	Effectively efficient
Significant losses due to Tand D	Relatively less losses due to Tand D

Strategic Roadmap

Technological innovation and cutting energy technologies have made it possible to move towards the best alternative grid infrastructure, thus empowering and shaping a new nation of the next generation. In this context, the World Bank has introduced the Clean Technology Fund (CTF) to encourage microgrid-based distributed energy generation. India has been a critical player in the global race to achieve sustainable goals by taking several game-changing initiatives, among which proposal for a whole new concept of 'one sun One world one grid' with an ambitious vision to connect all microgrid network clusters through a centralized network and also witnesses formation of International Solar Alliance (ISA) as a founding member. Green energy corridor and Solar Transfiguration of India (SRISTI) are one of India's ambitious projects to enhance grid connectivity infrastructure. The evolution of intelligent power electronic devices and communication mechanization has considerably reduced the energy domain gap. The government has made an extraordinary effort in setting up of Ministry of new and Renewable Energy (MNRE) as a National Nodal Agency, the formation of Non-banking financial institution, i.e., Indian Renewable Energy Development Agency (IREDA) for providing monetary assistance in installation of captive microgrid model-based generation by individuals, farms, or industry and establishes several world-class RandD institutions with high-tech laboratories to uphold the quality benchmark.

A variety of concerns need to be resolved in order to enforce a microgrid as a consumer product. A microgrid cannot function politically because the local utility did not see the value of eliminating and restoring the macro grid. It may take longer for microgrids to become predominant power supply agents. In comparison, entities also own wires and communication components. Utilities' approval is required to pass power via the macro grid. Besides, utility operators take on the microgrid as their rival and have begun investing in better macro grid stability. Besides, current grid codes must be modified to enable microgrid consideration. Localized electricity is beneficial from the user/energy/environment viewpoint, but service providers politically do not see it this way. The sector's condition undergoes a revolution and an essential assessment before specific problems are discussed and decisions are taken. Nowadays, utilities slowly adopt emerging technologies, but microgrids would not be economically feasible until they release ownership and equipment access. However, further study is needed to address some crucial challenges and provide funding and motivation for micro-grids from manufacturers to local and federal governments. State-of-the-art infrastructure, cutting-edge technologies, and the out of box innovation could prove beneficial in succeeding the traditional grid with all new smart microgrids.

The power sector is witnessing many technical obstacles, including growing electricity prices, energy efficiency, reliability, ageing facilities, widespread electrification, environmental dynamics, and so on. There may be systematic challenges to be overcome by producing low voltage Distributed Generation (DGs) at both origins and loads. The development of global micro-grid capability has been significantly increased since 2011 and is expected to exceed the complete deployed capacity by 2022 with more than 15GW. The industry has a potential of more than 5 billion dollars and is likely to cross over 27 billion dollars in market size for dealers by 2022. Campus/institutional microgrids are currently the highest by use and are projected to develop an 18.83% year-on-year (CAGR) compound growth rate between 2012 and 2022. Military, defense, and industrial microgrids could have comparable installed power by 2022. Off-grid microgrids aim to expand for the next 5-6 years at the fastest CAGR, whereas hybrid markets are projected to grow at their highest between 2012 and 2022 CAGR. For a fully developed microgrid, a more extended payback period is expected. Until microgrids begin to play an important role in cities, many study opportunities remain.

The smart grid refers to an advanced information infrastructure that enables efficient energy optimization, storage, production, transmission, and distribution of electrical energy. Emerging engineering tools that will shape the grid over the next decade are as follows:

- Block chain
- Database Management System (DBMS)
- Big Data analytics
- Cloud Computing
- Artificial Intelligence (AI)
- Internet of Technology (IOT)
- Programmable Logic Control (PLC)
- New Generation Communication Technology
- Salient features and contemporary challenges

Micro-Grid enablers clean and flexible generation-share of renewable energy sources to increase and move towards sustainability. It has now been essential to highlight some of the smart microgrid's salient embryonic features to have a clear understanding for the student, academician, industry personnel, and finally, policymakers.

- Active distribution network
- Sensors- smart meters, PMUs
- Local, closed power network
- Operates as a controllable unit
- Physically separable from the grid
- Market and regulatory framework
- Wide secure communication network
- Grid-connected or island operation mode
- Advanced Metering Infrastructure (AMI)
- Allows Flexible Transmission - FACTS
- Analytics-wide area monitoring and control
- HTLS Lines, Multi-Circuit, Compact Tower
- Automation of Substation, Digital Substation
- SCADA/EMS, synchro phasor-based auto

Although, microgrid has several features, unfortunately, specific challenges primarily affect its growth, which includes intermittent generation, dependent on weather, need accurate forecasting, power balancing, complex voltage and frequency control as many of these sources do not have reactive power generation and sudden generation loss can lead to immediate system instability. Apart from this, an effort has been made to list some other dormant challenges.

- Dealing with intermittent generation
- Adaptive protection and stability issues
- Inverter design for DC-AC conversion
- Controllers for Regulation of power flow
- Minimizing harmonics in DC microgrids
- Info. security and privacy-compromising
- Reliability of tech with Economic aspects
- Optimal siting and sizing of storage devices
- Customers' acceptance of RES deployment
- Topological imbalance leads to a change in opt

Microgrid Power Management System Prototype

A small prototype of the microgrid, (Table 3) an energy management system, has been designed for demonstration and explanation purposes. The figure below consists of many sophisticated components that result in better power regulation and stability at the load end Figure 3.

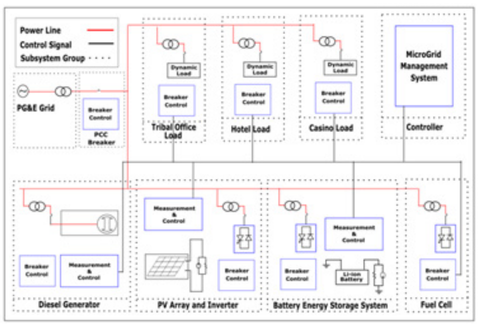

Figure 3: Single line diagram of BLR power system model in RTDS.

Table 3: DERs.

Source	Rating
BESS	500 kW/ 1 MWh
Diesel generator	1000 kW
PV	30 kW *14=420 kW

Smart grid

In the modern world, due to renewable energy sources, consumers can now contribute to energy supply, so as per the demand, we need a bidirectional power grid system that can ensure two-way communication between suppliers and consumers. Smart grid can ensure two-way communication and uses computer processing, advanced control for automation. Phasor Measurement Units (PMUs) used to ensure and assess grid stability, advance digital meters, PLC, SCADA, etc. are used to get real-time data, accurate measurements and automatic outage reporting, Microprocessor based relay used to sense and recover from faults, automatic feeder switches are used to re-route the power line when any problem arises in a line to ensure continuous power supply.

"The smart grid is the electricity delivery system, from the point of generation to the point of consumption, integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits." US Dept of Energy. In today's world, electricity is vastly spreading in different areas, like Electric Vehicles (EVs), which are a huge load for the network in upcoming years. So, the electricity demand is rapidly increasing all over the world. Looking at the data, we can imagine how the electricity demand is increasing every year, and in the year 2020, the installed capacity of electricity is 370106 MW [4]. So, with this huge power, there will be problems like overload, short circuits, and other faults in the network. For these, we need a well-planned smart grid Figure 4 system that can transfer and distribute electricity

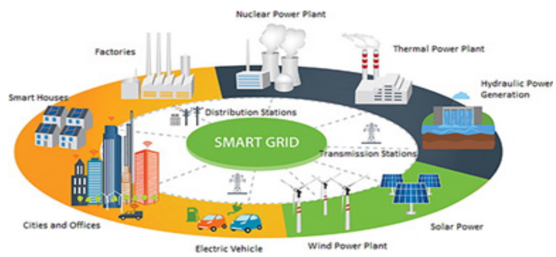

Figure 4: Basic smart grid architecture.

efficiently and economically. Apart from renewable power sources, conventional power generation is not environmentally friendly, so we need a smart grid system to reduce the power loss for the reduction of environmental pollution. As the uses of renewable sources increase, the consumer also becomes a source now, so two-way communication between the consumer and the grid is needed; here, the smart grid will provide all these kinds of features. Apart from these, a smart grid will give better security, efficiency enhancement, automation, etc. Due to the advancement in the power sector power system is transforming from centralized tropology to decentralized and distributed topology.

Operation/Management of Smart Grid

Management of smart grid is run by the continuous monitoring of the network then optimization of that collected data and taking decision-based on the optimization result automatically. Smart grid management is run by implementing the steps mentioned below [6]:

Smart metering: Monitoring and helps in two-way communication. Efficient management of conventional energy sources as well as renewable energy sources. Good management of power transmission and distribution between the main and the microgrid. Smart management for mobile electricity consumers e.g., EVs. In a smart grid management system, real-time monitoring of the network is ensured and sends to the respected governing body from where, as per the result and the conditions, the smart grid is mange efficiently and securely.

Due to the advancement of renewable energy sources, now a consumer can be a contributor to power network as per the result distributed decentralized energy network is growing rapidly, where we need to ensure the two-way communication between grid and the consumer. For good communication in the smart grid, we need to mention the parameters. By implementing the regulations and the protocols, a standard will achieve. Based on the IPv6 routing protocol for metering substructure used as a protocol in smart grid [7]. For secure and continuous data transmission, smart meter reading data should have data protection of the consumer as well as the governing body. If any kind of problem happens regarding data, then the smart grid should have the required software and the storage for retrieving that data. In the smart grid, various types of digital electronics devices are connected with the latest sensors and other security purpose devices to ensure efficient, secure, and reliable data transmission between the various connected systems Tables 4-6.

Table 4: List of loads.

Load	Rating in RTDS®(MW)	Nameplate rating (MVA)
Tribal office	0.012	0.075
Hotel	0.65	1
Casino	0.143	1
Air Conditioning (AC)	0.14	0.6

Table 5: AC load components.

AC load component	Rating in RTDS®(kW)	Nameplate rating (KVA)
3-phase motor compressors	100	450
Ventilation fans-three phase	76	150
Ventilation fans-single phase	40	30

Table 6: AC load rotation results.

Load name	Load status at t=0	Load status at t=1	Load status at t=2	Load status at t=3	Load status at t=4	Load status at t=5	Load (in kW)
Load 1	ON	ON	ON	ON	OFF	ON	37
Load 2	ON	ON	ON	OFF	ON	ON	37
Load 3	ON	ON	OFF	ON	ON	ON	37
Load 4	ON	OFF	ON	ON	ON	ON	37
Load 5	OFF	ON	ON	ON	ON	OFF	37
Total load (kW)	148	148	148	148	148	148	

Advanced Metering Infrastructure (AMI) is a system that collects, measures, and analyses energy usage by enabling data to communicate over a two-way communications network that connects with advanced meters "smart meters" and the utility's control systems [9]. Uses of AMI allow end-users to make informed, real-time choices about their energy usage.

Conclusion

With the increase of use of renewable and non-conventional energy resources, the Micro-grid system application is increasing day by day. To meet the ever-variable complex power demand, the micro-grid system's design and algorithmic operation need to be gradually updated. It has become essential to study such a system's quality issues and performance from the perspective of modern power system application. In this study, an attempt has been made to monitor various aspects of quality issues deeply, mainly in terms of harmonics and performance, to make the micro-grid system more robust, more flexible, and more reliable. Besides, driver and inhibitor are triggering parameters that regulate and partially influence the power sector, shown above. The driver and inhibitor have specific co-relation, which can be altered by a systematic approach, which endorses the novel smart microgrid installation. Future work would extend various performance assessments to determine behavioral physiognomies and validate captive microgrid infrastructure's characterization.

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