ANALYSIS OF CONTROL STRATEGIES FOR POWER QUALITY ENHANCEMENT IN MICRO-GRID

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ABSTRACT

This paper presents a review of the control strategies of micro-gird for improving the power quality. Flexible and scalable control techniques are required for microgrids that contain a significant number of distributed energy resources, smaller energy storage systems, and electric vehicles. In order to regulate and coordinate distributed energy resources, energy storage systems, and electrical cars in a microgrid, this paper will discuss the most recent centralized, decentralized, multi-agent, model predictive, cooperative, and competitive control methodologies. This study provides an overview of the many approaches that have been utilized to control the voltage, frequency, and power quality of standalone hybrid microgrids powered by solar photo-voltaics, wind energy, and batteries and also discusses microgrid control methods based on the internet of things.

Keywords: *Isolated Microgrid (IM), Solar Photo Voltaic (PV) System, Wind Generation System (WGS), Battery-Storage System, Decentralized Production (DP), Distributed Energy Resources (DERs), Power Management System (PMS).*

INTRODUCTION

Any physical action in the world, either by man or by nature is triggered by the flow of energy in some form. Energy has always been vital to human society. As a result of rising living standards, energy usage increased (Khan, 2006). A network of electrical components is utilized to generate, transmit, and use electricity in an electric power system. The utility circuit, which supplies electricity to residential and commercial applications over a large area, is an illustration of a power system network. The producers that produce energy, the transmission system that transfers power off the production centres to the consumer centres, and the supply chain that feeds power to surrounding homes and companies make up the electrical network (Electric Power System, n.d.). In general, it is agreeable that an electrical power system is a complicated project requiring four key elements-

a. Energy Production

b. Energy Transfer

c. Energy Dispersion

d. Energy Demand (Laughton & Say, 2013).

Each of these four electrical system components has its own set of problems-few of them are listed ahead such as- (i) far off placement of power production units which often require large area due to which the biodiversity and human residents suffer, (ii) transfer of the power generated add on to the problems of the power system via transmission losses,(iii) the volume of renewable resources is expanding, (iv)power outages are prevalent, (v)electro-mobility, (vi) reshaping the grid, (vii) cyber-threats are a real possibility, (viii) terrorist strikes are a hazard,(ix) voltage stability in dispersion network, (x) demand has been on the rise since first discovery of electricity and will continue to increase thus coping with the demand has been huge concern, etc. (Stompf, 2020).

The technology used to create power is under massive strain due to major changes occurring to supply-side as well as demand-side. Big synchronous machines are being phased out in favour of milder units and stochastic energy sources on the side of supply and transition towards the rapidly expanding application of electronic converters in buildings, industrial units, and consumer's gadgets on demand-side. Additionally, the transition from analogue to digital communications and control systems is making headway. During this time, the network is forced to operate in ways and settings for which it was not intended. This and many other factors all together are pushing the network under ever more stress, therefore, this calls for greater flexibility, agility, and capacity to effectively improve power system operations at time scales extreme for human oversight. Significant improvements in the power system are needed to accommodate the changes and ensure the reliability of the system. (Department of Energy, 2015).

The underlying precepts in transition of power system include restructuring of the electricity system, greener energy solutions that would benefit health of the public while also battling anthropogenic global warming, facilitating power system reform, markets, tariffs, and rates should be harmonized. The smart microgrids along with alternative energies are also a crucial facet of utility system change. Finance and acquisition innovation is critical to speeding transition; there should be optimization of the link between power systems and other energy systems. Further, the development of skills and ability is crucial in 21st-century power grids, accumulation of power, redistribution of energy, increased energy independence, intelligent grid, block-chain, microgrids, etc. (Power System Challenge: Synthesis Report for the 7th Clean Energy Ministerial, 2016), (Stompf, 2020).

Undoubtedly, push towards the transition of power system from conventional to smart one is being carried out yet; the concerns arisen from incorporation of renewables, power electronic equipment has another set of challenges and are depicted in Figure 1.

The various number of combinations of renewable energy resources are progressively being established to overcome the world-wide climate alterations (Kuhn et al., 2016). Therefore, innovative approaches such as Distributed Energy Resources (DERs), Microgrids (MGs), Active Production Scheduling (APS), and Energy Storage Systems (ESS) have emerged as feasible answers to the aforesaid concerns over recent times.

The advent of Microgrid into the power industry is a comforting approach to clarify the dilemmas, and has many deployable benefits over previous grid, including (i) increased network stability, (ii) improved quality by preventing loss during transmission and distribution, (iii) reduced rising temperatures and pollution by implementing technology with low carbon uptake, and (iv) steady supply of electrical power, (v) provides small power infrastructure and fosters generation strengthening, thus improving overall system performance and stability of electricity, (vi) plug and play potential of transitioning either to on-grid or self-governing operational mode, and (vii) offers possible replacement in form of source, when the utility grid fails (Choudhury, 2020). The key differences between the classic bulk energy grid and the microgrid has been summarized and presented (Singh et al., 2019).

Therefore, in this paper, the review on various types of methods that have been used to regulate voltage, frequency and power quality of stand-alone hybrid Solar Photo-voltaic, Wind and Battery based Microgrid system and is divided in some sections-Part II provides the insight of the Microgrid itself, and shows the stand-alone hybrid Photo-voltaic, Wind and

Fig. 1. Reservations pertaining to electricity network (Lopes et al., 2020).

Battery-Storage Microgrid system along with their literature surveys and Part III concludes the paper by suggesting future scope.

MICROGRID SUMMARY AND LITERATURE SURVEY

Definition

Microgrids be defined as- aggregation of micro-sources or distributed energy resources (like Wind, Solar, etc.) along with storage units and loads that portrays itself to the power networks as a unified entity capable of responding to control signals from a centralized location. The theory of a flexible, yet manageable link between the microgrid and the larger power supply is the core of the microgrid concept. This interface electrically divides the two sides effectively while still connecting them inexpensively. The definition of microgrid is suggested in (Mukund Kumar Choudhary, 2021; R.H.Lasseter, 2002; Sabpayakom & Sirisumrannukul, 2016). The basic structural layout of a microgrid is displayed in Fig. 2.

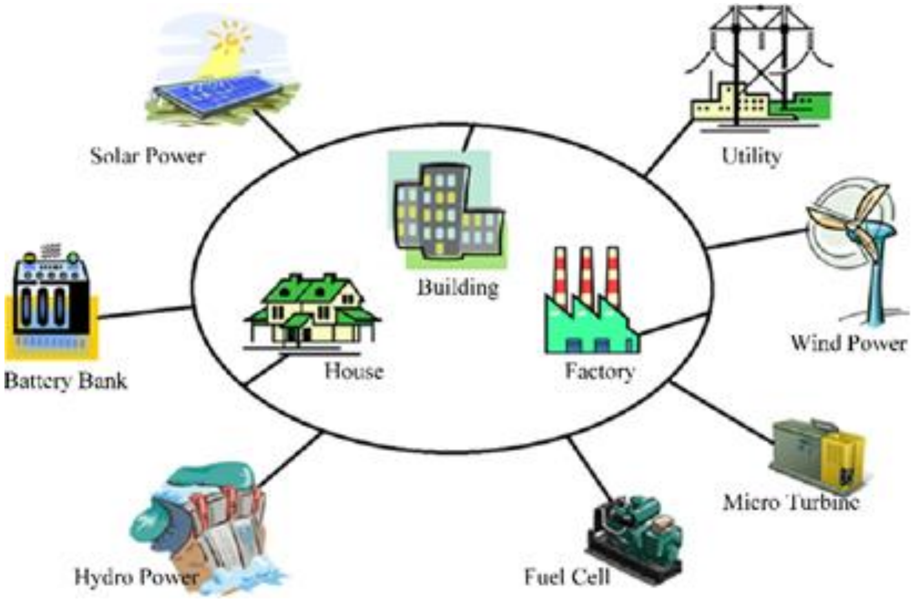

Fig. 2. Layout of Microgrid (Kuo & Lu, 2013).

Classification of Microgrid

Microgrids are classed into three forms- AC, DC, or Hybrid (AC and Dc both) (Dagar et al., 2021), (Sarma & Jayalakshmi, 2016) and based on connection with utility; on-grid and off-grid (Kumar et al., 2021) as shown in Fig. 3. Every class of microgrid has its own pros and cons and utilization of particular type of microgrid is determined according to the requirements of the users.

Self-Sufficient Standalone Microgrid Components

Until 2021, the solar and wind energy combined accounted for 88 percent of all net renewable resources' generation capacity. In this paper, the self-sufficient microgrid comprises of reusable resources like photo-voltaic and wind systems along with energy storage system and power electronics interface system ("Renewable Energy Capacity Highlights," 2021).

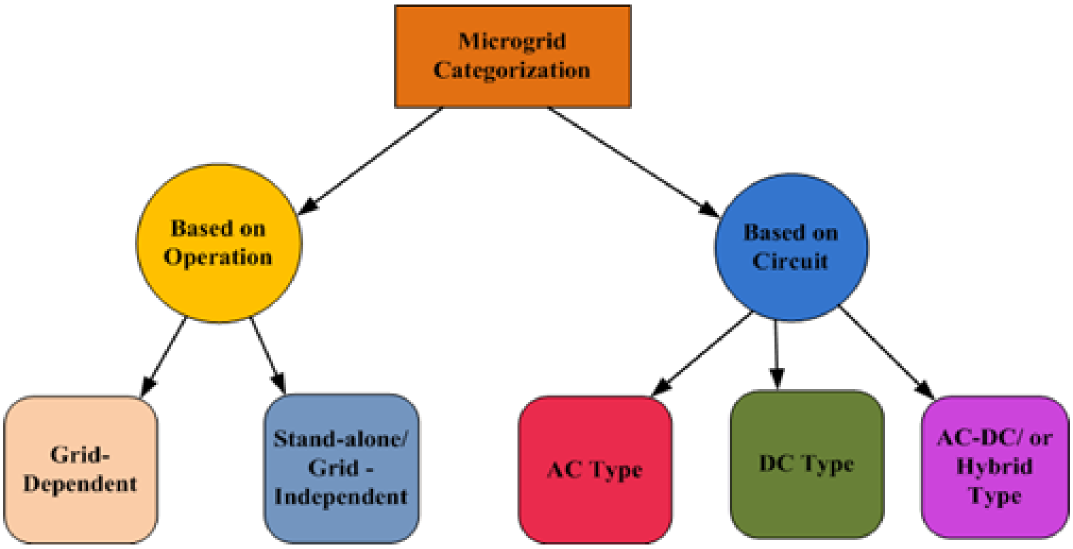

Fig. 3. Categorization of microgrid.

Photo-voltaic system: The sun has been worshipped as an existence-giver to our planet for many eras. However, industrialization time period gave us the knowledge of utilizing sunlight as source of power supply. Solar based technology has evolved at swift pace, thanks to the technological advancements, lower material costs and government backed policies for sustainable power generation. Photo-voltaic cells are the building blocks to utilize sunlight for power production. Solar cells in photo-voltaic systems turn sunlight into electricity. Currently, photo-voltaic technology both technically and commercially is mature and capable of generating and using solar energy to fulfill the ever-increasing needs. Several advancement are seen in the solar PV area as per the following literature (Gul et al., 2016; Tyagi et al., 2013). And numerous studies are being investigated to obtain Maximum Power Point Transfer (MPPT) of solar photo-voltaic which is discussed further in (Sarvi & Azadian, 2022).

Wind: Control mechanisms in wind power generation systems are governed by the form of generators used (induction and double-winding induction generators, synchronous and permanent-magnet synchronous machines etc.) (Cabana-Jiménez et al., 2022).

Energy storage system and Power electronic linkages: Storing electricity has always been crucial while dealing with either the traditional power generation or through non-conventional energy resources (wind, solar, etc.) which are known to be of intermittent nature therefore, power balance problems are frequent thus, battery-storages have pivotal role of providing back-ups while dealing with such energy sources. Several studies mention different varieties for the accumulation of energy (Krishan & Suhag, 2019), (Brahmendra Kumar & Palanisamy, 2021). A Power Management System (PMS) is requisite to correlate the functioning of Distributed Energy Resources (DERs) within in the MG for associated operation. In compliance with stated objectives, the PMS delivers baseline templates for the MG controllers (Luna et al., 2016).

The power electronics inter-linkage is apparently necessary when the DERs are in play. In this paper, the microgrid type is standalone and for such kind, power electronic converters are significant as presented in (Sarkar, 2021).

Control of Microgrid: Out of the major concerns as listed in Part I pertaining to the microgrids, this paper primarily deals with regulation of voltage and frequency, maintaining power balance and quality of power for the self-sufficient microgrids. Control of standalone microgrids is grouped into three (Ekanayake & Navaratne, 2020), (Sahoo et al., 2018)-

- Centralized control
- Decentralized control
- Distributed Control

Countless academic investigations are performed to manage different combination of renewable resources and energy storage devices based microgrids devices in order to overcome the problems. Summarizing few control strategies to overcome the issues presented in Table I.

Table I: Some different Control Schemes for Microgrids

S.NO.	Reference	Control Schemes	Objectives Achieved
1.	K.W. Joung et al. (Joung et al., 2018)	Decoupled frequency and voltage controller.	Frequency and voltage control, Enhance the resilience.
2.	Simpson-Porco et al. (Simpson-Porco et al., 2015)	Distributed-Averaging Proportional Integral Controller (combination of decentralized proportional droop control and integral control with distributed averaging algorithms).	Regulation of Secondary frequency and voltage in microgrids.
3.	Shortobani et al. (Shotorbani et al., 2018)	Distributed Shortage Secondary Controller.	Power sharing, Voltage and frequency reestablishment, stabilizing State of Charge of energy storage device.
4.	B.N. Alhasnawi et al. (Alhasnawi et al., 2021)	Decentralized robust control strategy for multi-agent systems using consensus-based algorithm.	Voltage and frequency stabilization, real and reactive power sharing.
5.	M. Farrokhabadi, et al. (Farrokhabadi et al., 2017)	Proposed controller uses sensitivity of load voltage.	Frequency control process through voltage regulation.
6.	M. Ramezani and S. Li (Ramezani & Li, 2016)	Technique for regulating direct current vectors via droop method.	Voltage and Frequency stability of microgrid.
7.	Q. Guo et al. (Guo et al., 2017)	Event-triggered method used with multi-agent consensus algorithm.	Secondary voltage control, reduced usage of bandwidth.
8.	G. Lou et al. (Lou et al., 2017)	State estimation method along with cooperative	Secondary frequency and voltage control, improved

		scheme.	system reliability and scalability.
9.	B. De Nadai Nascimento et al. (De Nadai Nascimento et al., 2020)	Updating load-flow method in Jacobian matrix along with Levenberg–Marquardt approach.	Unified voltage and frequency control.
10.	W. Dong et al. (Dong et al., 2018)	Artificial Neural Network (ANN) algorithm conjoined with Droop control. Forward Accumulation Through Time (FATT) utilized to get value of Jacobian matrix.	Manage stable voltage, power sharing and handle load swings.

Benefits and Drawbacks: Microgrids potential benefits and applicability are provided in paper (Dagar et al., 2021), (Laaksonen & Kauhaniemi, 2008). Followed by the various challenges economical and technical has been highlighted in (Choudhury, 2020). The intricacy of the framework operation, management, and interactions will be greatly increased by dispersed generating units/loads and interplay among all hubs within a microgrid (Sabzehgar, 2017). As a result, several technological hurdles must to be overcome in order to assure the microgrid's safe, secure, dependable, optimized, efficient and cost-effective operation.

- Balancing of Quality and Flow of Power (Lavanya & Kumar, 2018; Natesan et al., 2014; Prabaakaran et al., 2013; Zahira et al., 2021),
- Regulating Voltage and Frequency (Arfeen et al., 2020; Dehkordi et al., 2017; Hu & Bhowmick, 2020; Rokrok et al., 2018),
- Management of Power (Bhargavi et al., 2021; Kaper & Choudhary, 2017; Rangu et al., 2020),
- Optimization methods (Fathima & Palanisamy, 2015; Salehi et al., 2022; Suchetha & Ramprabhakar, 2018),
- Stability (Mehta & Basak, 2021; Shuai et al., 2016),
- Dependability and Safety (Senarathna & Udayanga Hemapala, 2019),and
- Dynamic modelling (Schiffer et al., 2016; Sen & Kumar, 2018) are other few of the techniques and technologies offered by academic scholars and industry experts to address the challenges of microgrids.

CONCLUSION AND FUTURE SCOPE

As a result of the world's rapid transition to a digital power system, which adds new difficulties on account of previously existing ones, it is clear that microgrids are more important than ever. It is also necessary to conduct extensive research on microgrid and its components. In order to stabilize the operation of microgrids, more control mechanisms should be thoughtfully proposed along the lines of both established and novel ones. There has been significant scientific and commercial progress as a result of our search for new clean or greener alternatives to coal, oil, and gas. Such improvements would heavily rely on smart microgrid. Despite the fact that microgrids have been in operation for many years, their many components continue to advance. According to Forbes, future energy trends will mostly centre on storage, advancements in renewable technology, green hydrogen, internet of things, and artificial learning.

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