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Design and Control Issues of Microgrids : A Survey

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Abstract – *Microgrids are promising and innovative grid structures that exploit their benefits to penetrate electric power systems worldwide. The rapid deployment of microgrids globally sheds light on many challenges faced in its effective design, control, implementation, and operation. Some of the major issues include islanding detection, harmonics, stability, optimal power flow regulation and protection coordination. Over the past five years, many researchers have attempted to tackle some of these issues. This paper aims at reviewing and summarizing some of the issues revolving around the design and control of microgrids, to provide a comprehensive analysis of the solutions proposed and a consolidated discussion of the research done in these areas.*

Key Words: Microgrids, design criteria, optimal configuration, control.

1. INTRODUCTION

The electric grid is an elaborate energy system that facilitates the transportation of electricity from the generation sites to consumption. According to the International Energy Agency (IEA), the global energy-related carbon emissions as of 2021 were at 36.3 billion tons which is 60% greater than what it was at the beginning of the industrial revolution [1]. Our awareness of the detrimental environmental impact of the energy industry has improved over time. Many countries around the world have pledged to reduce global energy-related carbon footprints to net-zero by 2050. Renewable sources of energy like solar energy, wind energy, battery storage systems, microgrids, and hybrid power plants are gaining high traction as they can contribute to mitigating energy-related carbon footprint while at the same time providing sustainable energy. Microgrids can be used to power small townships, businesses, and institutions autonomously.

According to the United States Department of Energy (DOE), microgrids can be defined as, "… a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid that can connect and disconnect from the grid to operate in both grid-connected and islanded fashions…" [2]

The International Council on Large Electric Systems (CIGRE) defines microgrids as, "… electricity distribution systems containing loads and DERs that can be operated in a controlled and coordinated manner either when connected to the main power network or while islanded…" [3]

Both these definitions emphasize three basic building blocks for microgrids:

a. DERs and consumer loads as controllable entities
b. Precisely demarcated electrical boundaries
c. A master control that can govern the DERs, loads, and utility grid connection.

The fundamental design considerations required to build a stable and reliable microgrid include [4-7]:

a. Suitable choice of microgrid size and technologies
b. Appropriate sizing, and positioning of DERs for integration
c. Well defined energy dispatch algorithms for self-reliance
d. Robust communication protocols and control strategies
e. Active/ Reactive power balance and Voltage/ Current regulation.

These considerations pose various design and control issues. The design and control of microgrids will be discussed in detail in Section 2 and 3 respectively. Section 4 will address the design and control issues faced by the microgrids and the research done to address them.

2. DESIGN OF MICROGRIDS

Despite its many benefits, PV and wind energy standalone systems are unable to fully supply local demand due to the unpredictable, intermittent and seasonal nature of their energy source, namely, solar radiation and wind. Hence, it is critical to state and solve the optimal design of microgrid systems. This includes the ideal selection, design and sizing of the microgrids' energy conversion sources (ECS) and energy storage sources (ESS) to improve factors such as cost and reliability while at the same time ensuring adequate energy supply to the loads [10]. The IEEE Standard 1547 for interconnecting distributed resources with electrical power systems [11], IEEE 2030 Smart Grid Series [12] and IEC TS 62257 Recommendations for Small renewable Energy and Hybrid Systems for Rural Electrification [13] was created to address a dearth of knowledge about microgrid deployment and is useful to microgrid designers and operators.

Since the scale of microgrid system is much smaller than that of a typically large interconnected power system, the nature of the stability and dynamic performance of a microgrid is very different from that of a conventional power system.

Furthermore, compared to the conventional utility grid, microgrid feeders are relatively short and run at medium voltage levels, resulting in lower reactance to resistance ratio [8]. As a result, microgrids' dynamic performance and inherent mathematical relationships between voltages, angles, active and reactive power flows differ from traditional grids [9].

Figure 1 shows the basic flowchart of the design approach of a microgrid. The process starts with the selection of ECS and ESS and proposing one or more probable solutions. These solutions are configured and the control and management strategies optimized followed by the design evaluation. Once all the design requirements are met and the design is found to be the best choice, the microgrid design is finalized, otherwise, the design is sent back to the drawing board and a redesign is proposed. [10]

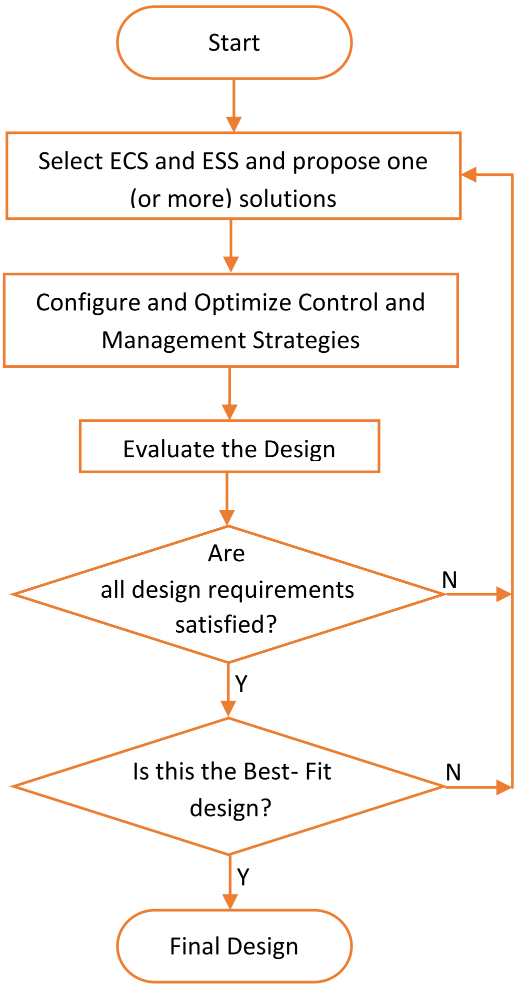

Fig -1: Basic Flowchart of the Design Approach of a microgrid

The primary step of ECS and ESS selection includes the statistical analysis of energy potential and meteorological data.

Wind speed and direction are difficult to forecast and model. Wind energy potential is assessed and estimated using a variety of methods. They differ in terms of complexity, data requirements, depth of analysis, and precision. Due to its low uncertainty and large number of parameters, the Weibull probability function distribution (PFD) is the most widely utilized technique [14]. The power of the wind P, which flows with a velocity v through an area A and has a density ρ, is a cubic function of the wind speed in theory, as stated in Eqn. 1.

$$P = \frac{1}{2}\rho A v^3 \ (in\ W) \tag{1}$$

Eqn. 2. Shows the wind power density (WPD), which is defined as the wind power divided by the area.

$$WPD = \frac{1}{2}\rho v^3 \ (in\ W/m^2) \tag{2}$$

By checking solar radiation maps supplied by local or international authorities, or, more specifically, by measuring global radiation in situ or using satellite photos, it is feasible to assess the solar energy potential [15]. At ground level, components of radiation can be distinguished into direct, diffused, and albedo radiation. Direct radiation which is received from the sun in a straight line without atmospheric diffusion is the most important component. The total radiation at ground level, known as base radiation, can be approximately 1000 W/sq.m under ideal conditions, such as cloudless days and maximum solar exposition.

The peak sun hours (PSH) describe the daily solar energy potential. These are defined as the number of hours required to obtain the radiated energy using a constant base radiation, as shown in Eqn. 3.

$$PSH = \frac{1}{R_B}\sum_{i}^{24} R_i \tag{3}$$

where the base radiation is R_b and the radiation measured at hour i is R_i. It is possible to establish whether the available solar irradiation is sufficient for the installation of PV panels and other solar appliances based on the values of yearly average PSH. It is regarded that a day with 3 PSH is suitable for PV generation [16].

PV arrays, wind turbines, diesel generators, batteries and fuel cells are all examples of energy sources that can be used in microgrids. The study of these sources sizing, implementation, local control and energy management in the microgrid requires modelling and simulation. Mathematical models, electric single line diagrams, experimental data, and computer based models are also being considered for these energy sources. The most appropriate model is chosen based on the accuracy of the solution as well as its computing cost.

Following this, design optimization is carried out using factors such as reliability, cost, environmental effect, and social acceptability[10]. This is done by optimization algorithms like multi-objective genetic algorithms. Artificial intelligence algorithms are frequently employed, according to trends observed in literature [17].

3. CONTROL OF MICROGRIDS

Microgrid control structure's main objectives include [18]:

a. Voltage and Frequency regulation in both islanded and grid connected modes.
b. Proper coordination between DERs and appropriate load sharing
c. Resynchronization of the microgrid with the main grid
d. Control of the flow of power between the microgrid and the main utility grid and
e. Optimization of microgrid operating cost.

Since multilayer hierarchical control is a viable solution for microgrid operability challenges and constraints, it has become a fundamental framework for distributed generation systems. Primary, secondary, and tertiary control layers are prevalent in hierarchical control as shown in Figure 2. Each control layer has a separate control aim and a different response time. This allows the layers' dynamics to be decoupled and their distinct designs to be facilitated [18].

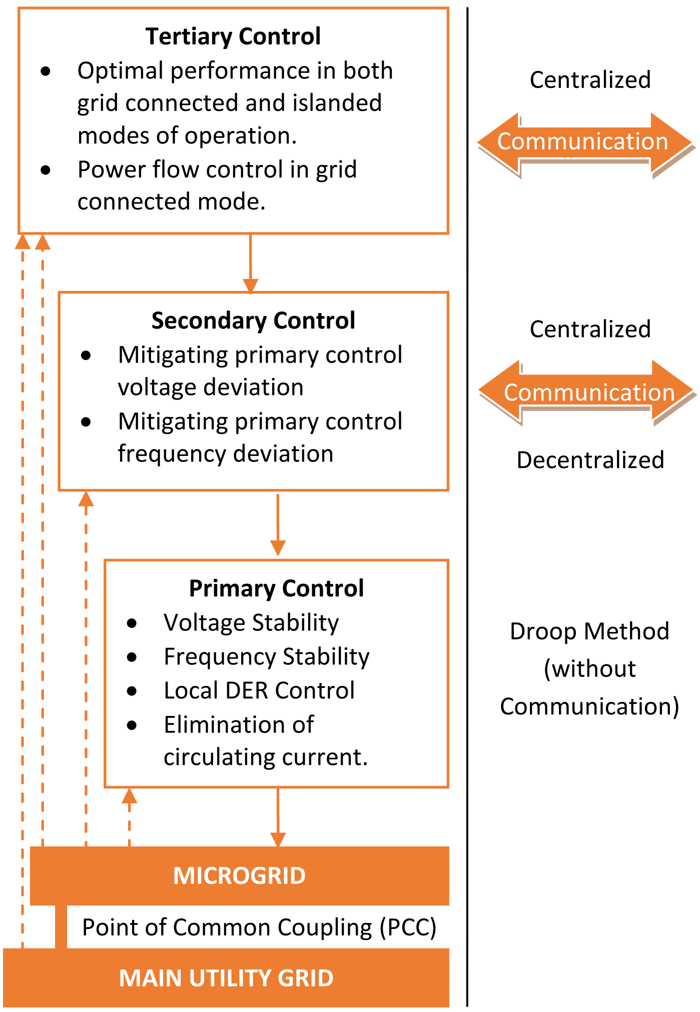

Fig -2: Control Layer approach for Hierarchical Control of Microgrids

In both grid connected and islanded mode of operation, hierarchical control can be implemented by creating layers with distinct control purposes. Since the operative property of each mode of operation are different, distinct control objectives have been proposed for each layer, in literature, particularly those allocated to secondary and tertiary layers [19].

The primary control layer's principal duties are as follows:

a. To ensure voltage and frequency stability. Due to the disparity between the power generated and consumed, the microgrid might lose its voltage and frequency stability after islanding.

b. To provide local DER control and to effectively perform active and reactive power distribution between them,

c. To eliminate circulating currents that can create over current phenomena in power electronic devices.

The microgrids primary control modes are usually implemented using active load sharing, droop characteristics or virtual synchronous generator techniques [18,19].

Even under steady state conditions, the primary control layer can induce frequency and voltage deviations. Although the ESS can accommodate for this variation, due to their limited energy capacities, they are unable to deliver the power required for load frequency regulation in the long run. As a centralized controller, the secondary control mitigates the error caused by the primary control layer by restoring the microgrids voltage and frequency. This layer is designed to have a slower dynamic response compared to the primary layer, which explains the primary and secondary control loops' decoupled dynamics and simplifies their individual design.

The last and slowest control layer is the tertiary control layer. It examines the economic issues in the optimal operation of the microgrid and handles the power flow between the microgrids and the main utility grid. This power flow is adjusted by regulating the amplitude and frequency of the ECS voltage. The microgrid's active and reactive powers P and Q are measured first. These values are then compared against the reference values P_{ref} and Q_{ref}, to obtain frequency and voltage reference ω_{ref} and V_{ref}.

$$\omega_{ref} = K_{pp}(P_{ref} - P) + K_{ip}\int (P_{ref} - P).dt \quad \textbf{(4)}$$

$$V_{ref} = K_{pq}(Q_{ref} - Q) + K_{iq}\int (Q_{ref} - Q).dt \quad \textbf{(5)}$$

where K_{pp}, K_{ip}, K_{pq} and K_{iq} are the controller parameter.

4. DESIGN AND CONTROL ISSUES

A. Islanding Detection and Non-Detection Zones

The transition from grid connected mode to islanded mode of operation and vice versa are considered as the most sensitive stages of the microgrid. In grid connected mode, the DERs are expected to share active and reactive power to the consumers based on their capacities. However, in islanded mode, the ECS and ESS are needed to adjust the voltage and frequency at the microgrids PCC. The system inrush current may create a large deviation in system frequency and voltage when starting a microgrid in islanded mode. It may cause the generator protection to trip offline during start up. During the shift from grid connected to islanded mode of operation, several transients will be created, necessitating extra control to achieve a smooth transition from grid power control mode (P/Q) to voltage-frequency (V/f) island mode. After a smooth transition, the microgrid must continue to feed the loads to satisfy demand as usual and must return to steady state operation. To do this, the first step that need to be taken is islanding detection. The different classifications of islanding detection techniques (IDT) are shown below in Figure 3 [21].

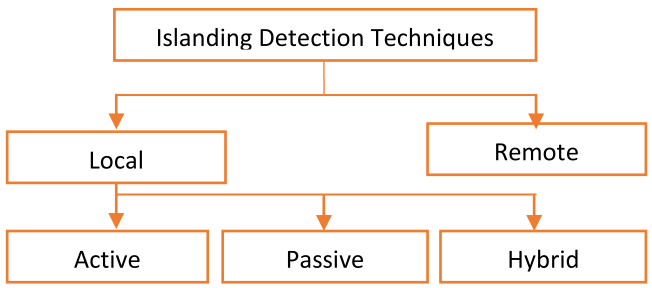

Fig -3: Types of Islanding Detection Techniques

IDTs can be classified as local or remote techniques. The local techniques monitor grid parameters like voltage and frequency and make decisions based on preset thresholds. Remote techniques complete the islanding detection by communicating with the power grid using SCADA, Power line communication etc. The majority of IDTs rely on monitoring and identifying anomalies in magnitudes of frequency, voltage, power and current. The main utility grid, however, experiences voltage and frequency fluctuations under normal operations, and grid standards mandate that local generators remain connected if the deviation from the nominal values do not exceed the preset thresholds and ramps. This means that the IDTs will fail to detect islanding if variation does not exceed the grid code criteria, which is referred to as the non-detection zone (NDZ).

Dr. S.K. Rao et al. [20] had proposed the use of a robust synchronous reference frame phase lock loop (SRF-PLL) to obtain smooth transition through robust islanding detection. A simple microgrid consisting of a PV array connected in parallel to a battery source and connected to 2 loads was considered. Initially, the microgrid is assumed to be connected to the utility grid. During this time the battery is considered to be in a state of charging. The microgrid identifies the islanding using the SRF-PLL detection mechanism and is isolated at the PCC using a static transfer switch. The V/f controller manages the discharge condition of the ESS by employing the droop control method. It was observed that the SRF-PLL methodology was effective in managing the internal control and primary droop control loops and ensuring system stability after islanding.

It was observed by H.Mohamad et al [22], that a hybrid IDT combining the passive rate of change of frequency over active power technique (df/dP) and the active PQ load insertion technique was able to prove the successful and precise detection of islanding. The test system consisted of a synchronous distributed generator connected to a 7-bus system. 4 different cases including loss of mains with both small and large power mismatches, fault conditions and consumer load manipulation were observed. It was concluded that the proposed hybrid technique was able to effectively identify islanding and non-islanding events. Furthermore, the NDZ size was reduced which allowed for accurate detection of islanding.

A.M.Nayak et al. [23] developed a novel anti-islanding defense mechanism that could eliminate the disadvantages of active and passive IDTs. The technique was developed on the basis of Islanding Detection Signal and Voltage Unbalance Factor (VUF). The test system consisted of a DER connected to a load which is connected to the utility point. It was observed that by examining the VUF at the PCC, against thresholds had resulted in a fool-proof method against false and inadvertent islanding. Since the signal was conveyed over the power line, this mechanism could be used in any DG system regardless of the telecommunication infrastructure.

V. Nougain et al. [24] proposed a hybrid IDT for islanding detection that is quick, secure and reliable. On a UL1741 test configuration, the rate of change of frequency (ROCOF) over reactive power was used as the passive IDT, allowing the active IDT to inject d-axis disturbance current to analyze the d-axis voltage component at the PCC.

The research conducted by Z. Li et al. [25] provided an active frequency drift IDT for grid connected PV system with positive feedback from the absolute value of voltage frequency. When compared to the conventional AFD method, this technique produced 4% less harmonic distortions and 0.02sec decrease in islanding detection time. When compared against the conventional AFD method, this technique was able to increase the detection speed, power quality and lower the NDZ.

From the above literature it can be concluded that traditional islanding methods like the passive IDT, have limitations in the form of huge non-detection zones, whilst active IDTs have disastrous consequences on the power quality. To address these issues, hybrid IDTs were able to aid in the precise diagnosis of islanding condition. However, most of the research analysis is performed on very small single DER systems.

B. Stability Issues

Currently, microgrid stability research is mostly focused on the mathematical models of microgrid stability analysis, microgrid stability analysis methodologies and microgrid stability improvement techniques, among other things. Small signal stability analysis and transient stability simulation analysis receive a lot of attention.

Depending on the mode of operation of the microgrid, its stability can be classified as grid connected stability issues or islanded stability issues as shown in Figure 4 [26].

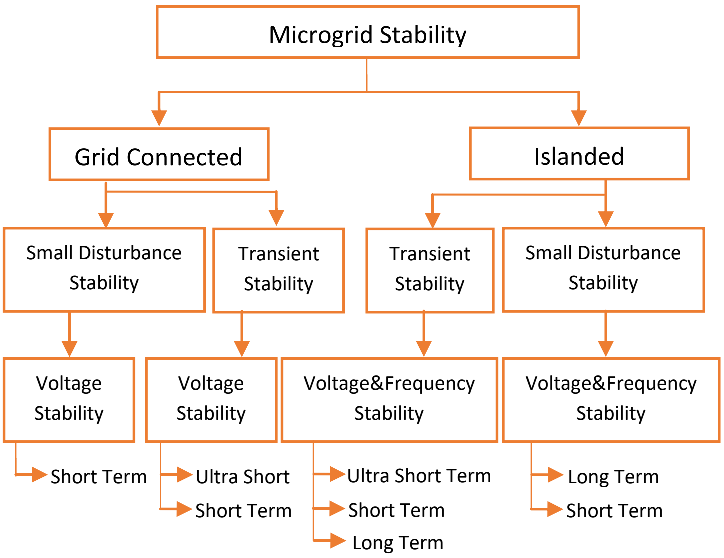

Fig -4: Classification of Microgrid Stability

The droop control and small disturbance stability analysis methodologies used in UPS systems are applied in microgrids as well. The small disturbance stability is investigated using a linearized network of DERs, DER controllers and loads. When the microgrid operates in different operating points, the Eigen value can be calculated using the linearized model. The relationships between the Eigen values and state variables can be explored and the most valuable state variable for a given Eigen value can be identified which aids in improving the microgrid small disturbance stability [26]. Figure 5 shows the research domain on small disturbance stability.

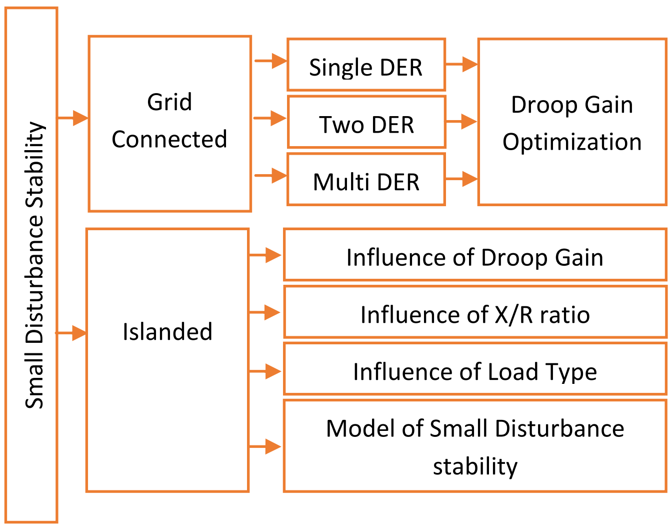

Fig -5: Research on Microgrid Small Disturbance Stability

Optimal control gains and improved microgrid performance can be acquired using microgrid small disturbance stability analysis. However, one of the most critical concerns for a microgrid is maintaining stability after severe disturbances such as short circuit faults and operational mode switching. As a result, a growing number of studies have recently focused on dynamic behaviors and transient stability of microgrids. Figure 6 summarizes the present "state of the art" of microgrid transient stability.

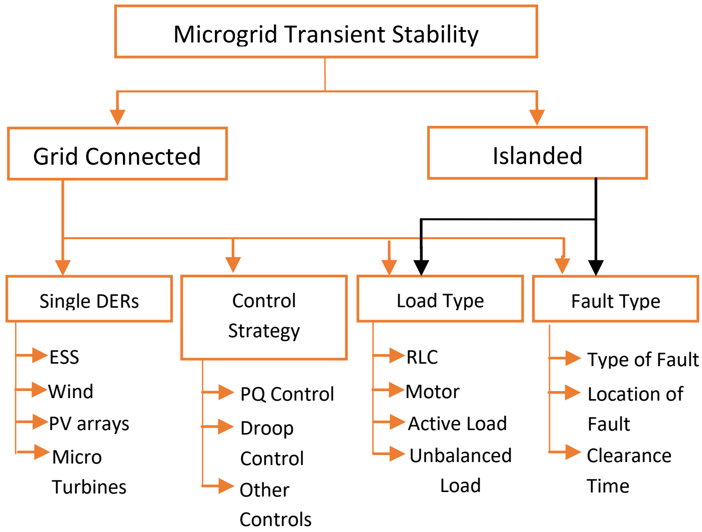

Fig -6: Microgrid Transient Stability Issues

K. Zuo et al [27], used Eigen value based analysis to examine the stability performance of a droop free controlled islanded microgrid. A modified Eigen value analysis method was proposed to show that all effective system Eigen values under the symmetric communication network were located in the left half plane which implied that the droop free controlled microgrid was asymptotically stable. Next the asymmetric communication network was studied under a homogenized electrical network and the analytical Eigen values were inferred. Stability margin analysis and vulnerability analysis were used to examine the stability of the designs. The numerical case studies demonstrated that the asymmetric cycle design outperformed the symmetric cycle design in terms of overall convergence speed and stability against droop free controller communication failure.

Dongao Island hosts a medium voltage microgrid. Since it is not connected to the main utility grid, it is difficult to manage and regulate the system frequency. Z. Zhao et al [28] proposed a hierarchical control technique to maintain the frequency stability. The proposed architecture divided the frequency of the system into 3 zones: stable zone, precautionary zone and emergency zone. Within the precautionary and emergency zones, the microgrid central controller implements dynamic stability control to deal with short term disturbances. Meanwhile the microgrid energy management system in the stable zone performs steady state stability control to tackle the peak and valleys of the DERs on a long term scale.

In literature, most authors propose the use of algorithms to perform stability assessments for microgrids. It can be observed that the effectiveness of the algorithm depends on the accuracy of determining the threshold values and the stability margin factors.

C. Harmonic Distortion

The predominance of small capacity customer DERs is expanding. They provide a variety of benefits to the utility grid they are linked to, including lower power losses and cost, improved power quality, and increased power supply dependability and security. As the cost of installing PV arrays continue to fall, more and more consumers benefit from it. DC-AC conversions, which are common in PV systems can however inject harmonic currents into the network that are above the acceptable limits. Severe harmonic distortions can cause transformers to overheat and harm sensitive electronic components. When a large number of PVs are integrated into the network, the study of harmonic distortion is critical. [30]

Y. Guan et al. [32], focused on suppression the feed-in harmonic grid current in a grid connected microgrid. An autonomous Current Sharing Controller (ACSC) based harmonic current suppression control strategy coupled with a current compensation loop was proposed. It was observed that for selected harmonic frequencies, the setup could efficiently minimize the system equivalent output admittance. As a result, the total harmonic distortion caused by the harmonic grid current was reduced to 2.97%.

K.P. Kumar and team [33] designed a single-phase bridgeless single end primary inductor converter (SEPIC) capable of operating in both step up and step down modes. The SEPIC converter regulates the output voltage of the PV array to ensure stable and efficient operation. It was observed that by using this arrangement, the total harmonic distortion caused by the PV array can be decreased to 3.44%.

Optimization Techniques like Particle swarm optimization (PSO) algorithms were employed by many researchers like R. Keypour et al. [34]. The study introduced a central controller to minimize voltage harmonics in islanded microgrids. The PSO algorithm generates the optimal amplitude of voltage in the central controller and adds it to the voltage reference generated by the droop controller. It can be concluded that the proposed strategy was able to minimize the total harmonic distortion to 2.4%.

The interface voltage source inverters govern the voltage and frequency of the microgrids operating in islanded mode. As a result, when subject to unbalanced and non-linear loads, the power quality can worsen. To reduce voltage harmonic distortions, T. T. Thai et al [35] proposed the combination of virtual oscillator control and proportional resonate control. The study employed a modified nested loop proportional resonant controller with the fundamental frequency unit in the outer loop and harmonic frequency units in the inner loop. It was proved that the system was able to reduce the total harmonic distortion to 4.37%.

Studies by M. Ahmed et al. [36] suggest appropriate placement of Battery Energy Storage Systems (BESS) to help reduce the total harmonic distortion. Two positioning architectures – clustered and shared – were compared. On comparing the two, it was established that the clustered placement of BESS units resulted in a lower harmonic distortion.

It can be observed that researchers have been experimenting with ways to monitor and simulate real-world microgrids. Since inverters and non-linear loads are the two most common contributors of harmonic distortion, most studies concentrate on precise modelling of these components. Filters are designed and evaluated by researchers to address harmonic distortion. It can be noted that passive filters are less expensive than their active counterparts as they only include passive components. However, when harmonic distortion is severe and unpredictable, the functionality of passive filters are limited and fixed passive filters can only help reduce the harmonics of the default setting orders. As a result research has expanded to consider the implementation of active filters [31]. Unfortunately, most of these studies were primarily interested in the power electronics behind the filter design and inverter controls. It is critical to include precise inverter models in order to represent the actual microgrid systems. Besides the inverters, due to the penetration of DERs, meteorological data must also be incorporated in the harmonic study.

D. Optimal Power Flow Regulation

Microgrids address optimal power flow (OPF) with the goal of minimizing either power distribution losses or the cost of electricity drawn from the main utility and that provided by the ECSs while at the same time maintaining voltage regulation. Microgrids networks are intrinsically unbalanced. The presence of Single phase ECSs may also exacerbate this imbalance [37].

K.R. Naik et al [39], designed an adaptive energy management system (AEMS) for an off-grid hybrid DC microgrid subject to time-varying sources and load dynamics. The test system consists of PV arrays and hydro power plant as the ECSs which cause the power variations due to its intermittency. To compensate for such power dynamics, a hybrid energy storage system that includes batteries and super capacitor storages are introduced. Because of the intermittent dynamics of the PV system, the hybrid energy storage system may be forced into deep charging/discharging, resulting in power variations in the microgrid. The AEMS used an adjustable gate positioning system to regulate the charging and discharging of the BESS.

S.K. Jadhav in her research on OPF in a wind farm [38] employed the use of dynamic programming. The research focused on controlling the energy stored in the BESS to manage the energy of the microgrid. The test system consisted of a wind farm and BESS connected to a grid. The optimization algorithm regulated the active, reactive and battery power. In the time domain, the process utilized recursive dynamic programming, and in the network domain, it utilized a power flow solver. This programming is numerically efficient and offers good stored energy vs. time for each BESS.

Wagner et al's research [40] developed a day-ahead OPF of an existing microgrid operating in islanded mode. It was observed that most traditional techniques overlooked critical aspects of microgrid operation, such as storage system life cycle and the impact of renewable power generation stochastic nature. The research technique formulated a differential evolution algorithm to solve the OPF. It was reported that the design functioned efficiently as the energy resources were employed wisely.

For microgrids with DERs connected through a medium voltage distribution system, R. Jamalzadeh et al's [41] study presented a generalized bender decomposition based OPF algorithm. The algorithm investigated the multi-interval decisions using the entire unbalanced distribution network model. It was observed that in both grid connected and islanded modes of operation, the algorithm was successful in optimizing dispatch decisions.

It is observed that in the field of optimization and optimal power flow, intelligent algorithms are gaining high traction. They have inherent advantages, such as the ability to prevent entrapment in the optimization problem's local minimum and converge into a global solution. It can be recommended that parallel computational techniques be employed while tackling large scale networks.

E. Protection Coordination

Due to the growing use of DERs, microgrid protection coordination is an evolving research topic. Microgrid protection coordination in both islanded and grid-connected modes is regarded as a problem for microgrid operation. It can broadly be classified into two key factors. The first is the dynamic behavior of microgrids, which arise due to the intermittent nature of the DERs. The second is related to the microgrid's modes of operation, namely, grid connected or islanded [42].

S.A. Hosseini et al. [43] proposed a decentralized adaptive method for microgrid protection coordination. It stipulates that when a fault occurs, a group of agents in the vicinity of the fault location interact with one another to determine the optimum protective coordination method. Agents are placed in a number of groups with the members of each group interacting with each other, forming a protective layer. The optimal fault clearance plan is found by calculating the probability of correct operation of all recommended strategies and considering the least number of likely outages, taking into account the operational uncertainties of the relevant circuit breakers and communication links. This is accomplished by calculating the fault currents passing through the circuit breakers and the communication link latency. It was observed that this scheme works well to address single faults with considerable higher security, but when subject to simultaneous faults, the scheme functions only when there are no common agents between the protective layers.

H. Berder et al. [44] realized that one of the key protective devices for the microgrid is the directional overcurrent relays. However, they had noted that using the same protection settings for both primary and backup operations did not result in quick response time. It was concluded that the reliance on communication to maintain proper backup protection functioning was not a viable solution. They proposed a set of protective settings which were optimized for use in both modes of operation. For each relay, a protective setting consisted of two time dial settings and one pick up current setting. The proposal as verified on a modified section of the IEEE 30 bus test system and it was observed that the design solution reduced the total operating time since all protective duties were carried out in the forward direction and hence did not require relay communication.

O. Nunez-Mata [45] proposed a mechanism that worked by interleaving the actions of overcurrent and under-voltage protections. Both protection elements are to coordinate their internal time schedules with each other. The running times of the protective devices are maximized once the overcurrent element is established as the primary protection and under-voltage element as the backup protection. This technique was tested on an existing microgrid and the finding suggested that the proposed technique outperformed the existing microgrid protection mechanism in a timely and coordinated manner.

Proposal for new coordination approaches should be made and existing schemes should be enhanced. In case of over-current protection, techniques that take into account the different types of standard time-current curves, non-standard curves, current transformer relationships and polarization techniques need to be reviewed. Different microgrid topologies, types of installed generators and impedance fault should be considered while developing coordination approaches. When it comes to differential protection schemes, it is important to consider how current transformer saturation would affect coordination performance.

3. CONCLUSION

Major research on critical issues faced in the design and control of microgrids is summarized in this paper. Microgrid characteristics have created a number of new issues in the field that did not exist in traditional utility networks. The technical literature has provided solutions to some of these issues. It is critical to emphasize that the current research serves as a solid foundation of additional research and innovation in this field. Combined efforts and information exchange amongst academia and industry on these initiatives will benefit the advancement of microgrid design, control and protection research.

REFERENCES

[1] IEA, "Global Energy Review: CO2 Emissions in 2021. Global emissions rebound sharply to highest ever level", France, March 2022.

[2] Department of Energy Office of Electricity Delivery and Energy Reliability, "Summary Report: 2012 DOE Microgrid Workshop," 2012.

[3] CIGRE, "Microgrids 1: Engineering, Economics & Experience, Working Group C6.22" 2015.

[4] T. Labeodan, K. Aduda, G. Boxem, W. Zeiler, "On the application of multi-agent systems in buildings for improved building operations, performance and smart grid interaction- A survey", Renewable and Sustainable Energy Reviews, pp.1405-1414, 2015.

[5] K. Tazi, F.M. Abbou, F. Abdi, "Multi-Agent system for Microgrids: design, optimization and performance", Artificial Intelligence Review, Springer, 2019.

[6] T. Logenthiran, D. Srinivasan, T.Z. Shun, "Multi-Agent System for Demand Side Management of Smart Grid" IEEE PEDS, Singapore, pp. 424-429, 2011.

[7] M.W.Khan, J. Wang, " The research on Multi-Agent system for microgrid control and optimization" Renewable and Sustainable Energy Reviews, pp. 1399-1411, 2017.

[8] C. Li, S.K. Chaudhary, M. Savaghebi, J.C. Vasquz, J.M. Guerrero, "Power flow analysis for low voltage ac and dc microgrids considering droop control and virtual impedance," IEEE Trans. Smart Grid , vol. 8, no. 6, pp. 2754-2764, March 2016.

[9] IEEE- PES Task Force on Microgrid Stability Definitions, Analysis and Modelling, "Microgrid Stability Definitions, Analysis and Examples", IEE Trans. Power Systems, April 2019.

[10] J.M. Rey, P.P. Vergara, J. Solano, G. Ordonez, " Design and Optimal Sizing of Microgrids. In: A. Zambroni de Souza, M. Castilla (eds) Microgrids Design and Implementation" Springer pp. 337-367, 2019.

[11] "IEEE Standard for Interconnecting Distributed Resources with Electrical Power Systems". IEEE Std. 1547-2003, pp. 1-28, 2003

[12] "IEEE Smart Grid Series of Standards". IEEE Std. 2030-2011, 2011.

[13] "IEC 62257: Recommendations for Small Renewable Energy and Hybrid Systems for Rural Electrification", 2008.

[14] G. Ordonez, G, Osma, P. Vergara, J. Rey, " Wind and Solar Energy Potential Assessment for Development of Renewable Energies Applications in Bucaramanga, Columbia", IOP Conference Series Materials Science and Engineering, 59, 12004, 2014.

[15] V. Khare, S. Nema, P. Baredar, "Solar-wind hybrid renewable energy system: A review", Renewable and Sustainable Energy Reviews 58, pp. 23-33, 2016.

[16] S. Ibrahim, I. Daut, Y. M. Irwan, M. Irwanto, N. Gomesh, Z. Farhana, "Linear Regression Model in Estimating Solar Radiation in Perlis", Energy Procedia, vol. 18, pp. 1402-1412, 2012.

[17] R. Luna-Rubio,M. Trejo-Perea, D. Vargas-Vazquez, G.J. Rios-Moreno, "Optimal sizing of renewable hybrids energy systems: A review of methodologies", Solar Energy 86(4), pp.1077-1088, 2012.

[18] A.Bidram, A. Davoudi, "Hierarchical Structure of Microgrids Control Systems", IEEE Transactions on Smart Grids 3(4), pp. 1963-1976, 2012.

[19] J.M. Rey, J. Torres-Martinez, M. Castilla, "Secondary Control for Islanded Microgrids. In: A. Zambroni de Souza, M. Castilla (eds) Microgrids Design and Implementation" Springer pp. 172-194, 2019.

[20] Dr. S.K. Rao. B.L. Raju, " Control and Stability of Microgrids during Grid to Island Mode" IJISRT, vol.5, issue 9, pp.1371- 1376, 2020.

[21] M. Suman, M.V. Kirthiga, "Chapter 17: Unintentional Islanding Detection In: Distributed Energy Resources in Microgrids: Integration, Challenges and Optimization" Academic Press, 2019.

[22] H.Mohamad, M. Muda, N.A. Salim, Z.M.Yasin and K. Naidu, "Islanding Detection based on Rate of Change of Frequency over Active Power and PQ Load Insertion for Synchronous Distributed Generation", 2022 IEEE International Conference in Power Engineering Application (ICPEA), pp. 1-6, 2022.

[23] A.M. Nayak, M.Mishra and B.B. Pati, "A Hybrid Islanding Detection Method Considering Voltage Unbalance Factor," 2020 IEEE International Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC), pp. 1-5, 2020.

[24] V.Nougain, S. Prakash and S. Mishra, "Hybrid Islanding Detection Methods backed on ROCOF over Reactive Power and d-axis Current Injection", 8th IEEE International conference on Power Electronics (IICPE), pp.1-4, 2018.

[25] Z. Li, X. Liu, X. Wang, and H. Wang, "Active Frequency Drift Islanding Detection Method with the Positive Feedback by Absolute Value of Voltage Frequency," Chinese Automation Congress (CAC) pp. 578-582, 2018.

[26] Z. Shuai, Y. Sun, Z. John Shen, W. Tian, C. Tu, Y. Li, X. Yin, "Microgrid Stability: Classification and a review", Renewable and Sustainable Energy Reviews, vol. 58, pp. 167-179, 2016.

[27] K. Zuo and L. Wu, "Eigenvalue-based Stability Analysis for Droop-free Controlled Islanded Microgrid with Symmetric/Asymmetric Communication Network", in IEEE Transactions on Smart Grid, 2022.

[28] Z.Zhao, P. Yang, J.M. Guerrero, Z. Xu, and T.C. Green, "Multiple Time Scale Hierarchical Frequency Stability Control Strategy of Medium Voltage Isolated

Microgrids", in IEEE Transactions on Power Electronics , vol. 31, no.8, pp. 5974-5991, 2016.

[29] I. Lipuzhin, "Stability Issues for Modern Microgrids", 2020 International Ural Conference on Electrical Power Engineering (UralCon), pp. 339-343, 2020.

[30] M. Begovic, J. Zhang, D. Novosel and N. Cho, "Harmonic Distortion in Microgrids and Distributed Systems with Photovoltaic Generators", 48th Hawaii International Conference on System Sciences, pp. 2586-2594, 2015.

[31] Z. Liu, X. Xu, and E. Makram, "Harmonics assessment and mitigation: A case study on an unbalanced stand-alone microgrid integrated with PV", 2015 North America Power Symposium (NAPS) pp. 1-6, 2015.

[32] Y. Guan, W. Feng, J. Lu, J.M. Guerrero and J.C. Vasquez, "A Novel Grid Connected Harmonic Current Suppression Control for Autonomous Current Sharing Controller-Based AC Microgrids", IEEE Energy Conversion Congress and Exposition (ECCE), pp. 5899-5904, 2018.

[33] K.P. Kumar, R. Vanitha and S.S. Hemesh, "Reduction of harmonic distortion in microgrids and distribution systems with photovoltaic generators", International Conference on Computation of Power, Energy Information and Communication (ICCPEIC), pp. 768-772,2017.

[34] R. Keypour, B. Adineh, M.H. Khooban and F. Blaabjerg, "A New Population-Based Optimization Method for ONnline Minimization of Voltage Harmonics in Islanded Microgrids," IEEE Transactions on Circuits and System II: Express Briefs, vol. 67, no.6, pp.1084-1088, 2020.

[35] T.T. Thai, D. Raisz, A. Monti, F. Ponci, and A. Ahmadifar, " Voltage harmonic reduction using virtual oscillator based inverters in islanded microgrids", 18th International Conference on Harmonics and quality of Power (ICHQP), pp. 1-6, 2018.

[36] M. Ahmed, N.A Nahid-Al-Masood, and S.R. Deeba, "Impact of Integrating Battery Energy Storage Systems on Harmonic Distortion in an Industrial Microgrid" International Conference on Smart Grids and Energy Systems (SGES), pp. 712-717, 2020.

[37] E. Dall'Anese, H. Zhu, and G. B. Giannakis, "Distributed Optimal Power Flow for Smart Grids", IEEE Transactions on Smart Grid, vol. 4, no. 3, pp. 1464-1475, 2013.

[38] S.K. Jadhav, "Optimal Power Flow in Wind Farm Microgrid Using Dynamic Programming", International Conference on Emerging Trends and Innovations in Engineering and Technological Research (ICETIERTR), pp. 1-4, 2018.

[39] K.R. Naik, B. Rajpathak, A.Mitra, and M. Kolhe, "Adaptive Energy Management Strategy for Optimal Power Flow Control of Hybrid DC Microgrid", 5th International Conference on Smart and Sustainable Technologies (SpliTech), pp. 1-6, 2020.

[40] W.F.S. Souza, A.H.R. de Oliveira, L.F.M. Rodrigues, R. Kuiava, and G.V. Leandro, "Stochastic Optimal Power Flow Applied in Day-Ahead Planning of Isolated Microgrids," IEEE Power & Energy Society General Meeting (PESGM) , pp. 1-5, 2020.

[41] R. Jamalzadeh and M. Hong, "Microgrid Optimal Power Flow using the Generalized Benders Decomposition Approach", IEEE Transactions on Sustainable Energy,vol.10, no.4, pp.2050-2064, 2019.

[42] S.D. Saldarriaga-Zuluaga, J.M. Lopez-Lezama and N. Munoz-Galeano, "Protection Coordination in Microgrids: Current weaknesses, Available Solutions and Future Challenges" IEEE Latin America Transactions, vol. 18, no. 10, pp. 1715-1723, 2020.

[43] S.A. Hosseini, A. Nasiri and S.H.H. Sadeghi, "A Decentralized Adaptive Scheme for Protection Coordination of Microgrids Based on Team Working of Agentss", 7th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 1315-1320, 2018.

[44] H. Beder, B. Mohandes, M.S.E. Moursi, E.A. Badran and M.M.E. Saadawi, "A New Communication-Free Dual Setting Protection Coordination of Microgrid", IEEE Transactions on Power Delivery, vol. 36, no. 4, pp.2446-2458, 2021.

[45] O.Nunez-Mata, RPalma-Behnke, and P. Mendoza-Araya, "Robust Coordination of Overcurrent and Undervoltage Protection Devices for Microgrids," 38th IEEE Central America and Panama Convention (CONCAPAN XXXVIII) pp. 1-6, 2018.

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