Basic Considerations for Integration of Microgrid Systems

Oliver Ibewuike Nwauka
Postgraduate School of Engineering Management,
Faculty of Engineering and Built Environment.
University of Johannesburg
onwauka@gmail.com

Arnesh Telukdarie
Postgraduate School of Engineering Management,
Faculty of Engineering and Built Environment.
University of Johannesburg
Arnesht@uj.ac.za

Johan Enslin
Postgraduate School of Engineering Management,
Faculty of Engineering and Built Environment.
University of Johannesburg
enslinuj@gmail.com

Abstract

Effective integration, optimization and management of energy sources, prompts careful selection of the intelligent systems to control and monitor the interaction and development of microgrids deployed for critical loads and for Cities. Due to the increasing energy demands and the stochastic nature of micro-sources, the need for reliable, sustainable, and cost-effective energy flow becomes mandatory both in the business case and technical.

To ensure the integration of distributed generations with responsive energy balance; higher power quality, protection, reliability, increased resiliency, sustainability, scalability and availability, there is need for correct real-time operations and coordination through the use of intelligent control interfaces, gateways, networks, data information techniques, and wireless communications devices, protocols and platforms.

This paper, therefore, reviews the rubrics of microgrid systems of intelligent for effective energy integration and balance of flow from generation to distribution of grids. This article as a recommendation for proper energy integration further proposes Control techniques and strategy that will assure responsive energy supply and demand through a microgrid System.

Keywords
Control, Energy, Intelligent, Microgrid System, Network.

1. Introduction

The increasing energy demand creates unexpected burden from generation, distribution and load consumption, which effect is the depletion and costs escalation of fossil fuels. This energy degradation prompted the development of microgrid systems that extended from the legacy grid of traditional (conventional) centralized generation control and grid '2.0' (smart grid) to a third-generation grid development called the future grid (grid 3.0). Microgrid uses same concepts in operation, deploying micro sources (wind, solar, fuel cells and other types of variable energy for a sustainable power flow. However, the variability of these micro-sources, clouded by randomness in generation, stability, and reliability of energy transition becomes a complex issue due to interoperability as evident in grid '1.0' and '2.0', which solution can only be resolved by use of advanced system intelligence controls, devices, gateways, platforms, Internet Protocols (IP), software components interfaces either in disconnected or grid-tied modes, but facilitated by internet. These group of dynamic grids called the Virtual microgrids based on horizon 2020 and vision report allows for efficient energy flow and control through sensors, actuators (devices), software management of the device (gateways) to data hosting (cloud), allowing for timing and synchronization to maintain the whole distributed updates.

Traditionally, as the operational mode shifts from grid connected to island mode, the system, should successfully manage and regulate both the frequency and voltage to safeguard the grid from blackout and brownout scenarios, in addition to satisfying the requirements of the system loads. These key technical constraints require a high integration of decentralized and intermittent renewable energy into the distribution grid. Facilitation is, therefore, necessary in the generation process, distribution, load consumption and the resynchronization process to create the energy balance through demand response.

For easier management and operation, Microgrid Controls and other intelligent systems ensure grouping of these variable energy sources into smaller subsets, enabling islanded operation when there is a fault in the sub-transmission network. Effective controllers absorb the challenges during transients making a quick recovery from faults.

2. Overview of Basic Microgrid

Microgrid, according to (Hu, Zhang, Du, and Zhao, 2014) is divided into three kinds: utility microgrid, industrial or commercial microgrid and autonomous microgrid based on architectural functions, location, and type of distribution network, ownership, and purpose. Despite these variable factors, the system has same basic structure. Authors (Hu, et al., 2014) describe this structure (figure 1.) as a scalable, sustainable local power grid consisting of electrical and thermal loads that correspond to decentralized generation units with independent ability to operate overlaid grid.

For proper integration of micro sources to the grid, according to (Salam, Mohamed, and Hannan, 2008), the energy distribution network can increase reliability as a back-up or standby power to its consumers. A Micro-grid (µg) is a self-guided conceptual System, a part of the distribution network with a solution that utilizes the process of variable renewable energy (VRE) penetration to fulfil delivery of a reliable power for the future (Salam, et al., 2008; Škrlec, 2011; Shen, Jiang, Liu and Wang, 2016; Ravichandrudu, Manasa, Babu and Anjaneyulu, 2013; Lasseter, and Piagi, 2006). Cochran, Denholm, Speer, and Miller, (2016) and Shen, et al, (2016) agree that microgrid is a system based on the interactive and integrative network control capabilities that offer increasing penetration of distributed generators.

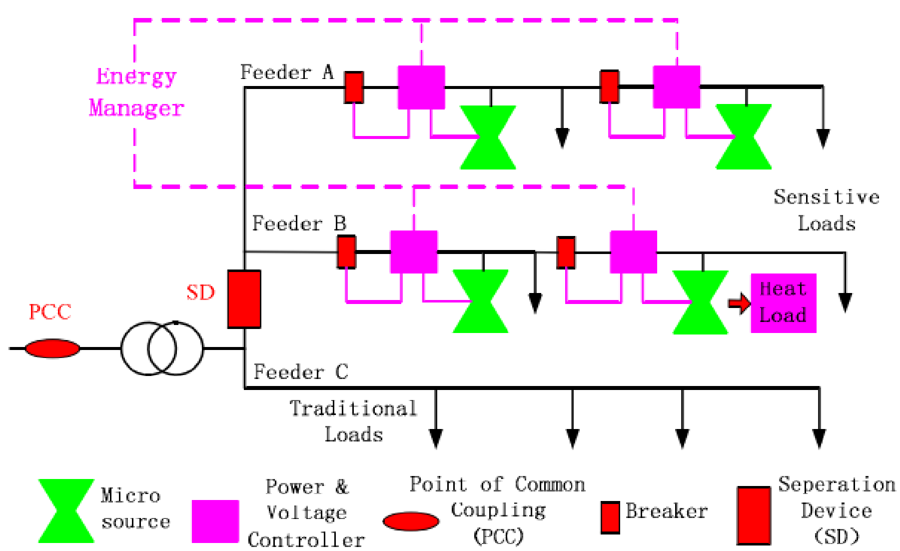

Figure 1. Basic Structure of Microgrids

However, Nonnenmacher, and Coimbra, (2016) and Cochran, et al, (2016) describe this system as a group interconnected loads and distributed energy resources of low voltage (LV) network which users and generators are in close proximity with its electrical boundaries clearly defined, acting as single controllable entity, at the point of common coupling (PCC) to either connect or disconnect from the distribution (<100KW) network (either in grid operation or islanded mode), serving tens to hundreds of electricity users. This European Union based research study highlights that systems can be operated either in a non-autonomous or autonomous way, emphasizing that careful control of the operation in the network can provide distinct benefits to the overall system performance, when managed and coordinated efficiently (Nonnenmacher, and Coimbra, 2016). In addition, US Energy Department in its definition In (Li, and Nejabatkhah, 2014) recognizes microgrid as a system acting as a single controllable entity with respect to the main grid which connection and disconnection from the grid enable it to operate in either mode. To this extent, Ravi, et al, (2014) agree with Li, and Nejabatkhah, (2014) that this concept is primarily driven by two basic fundamental principles of a *systems perspective* and *business case.*

According to Aminu and Solomon, (2016) the function of this technology is to generate and maintain quality, reliable and sustainable power to a local elastic and inelastic load which control and protection are challenged by occasional bidirectional power flow, stability issues, uncertainty and mechanical inertia making control and protection of this flow a prerogative. The control system maintenance, therefore, must guarantee robust and economical operation, a function embedded within most of its technical features of output control, energy balancing, modes transitions, distribution system management, demand response and energy management system (Aminu and Solomon, 2016).

For microgrid system to operate either mode, it utilizes the power electronics and energy storage technology as a composite subsystem of generators, storage, inverters, loads and monitoring devices. Critical loads only receive electricity from the grid-connected mode, enabling the loads to continuously operate even at the breakdown of the regular grid (Nonnemacher, and Coimbra, 2016). Control of bidirectional power flow is deemed as the core technology in the process of switching and penetration of micro-grids tied systems, (Hu, et al., 2014; Aminu and Solomon, 2016) conclude. The microgrid stops power supply to less critical loads by disabling their interfacing converters to supply power especially to highly critical loads when the system is in distress, forcing the supervisory controller to a switch in response between the modes, thereby prioritizing the loads to be powered in island mode, (Aminu and Solomon, 2016).

On the stochastic nature of micro-sources, Nonnenmacher, and Coimbra, (2016) agree with Aminu and Solomon, (2016) that VRE penetration presents various types of management, risk and operational challenges for a reliable operation. Shen, et al, (2016) contend that major technical issues and other associated risks dominate in power quality, protection, voltage stability, harmonics, control, reliability, mode of operation and topology. Requiring a more sophisticated, intelligent systems of advanced sensing, switching and control technologies demand an effective integration of automation technologies and distributed generation, (Ravichandrudu, et al, 2013). Sager, (2014) attest that responding to change in demand and supply, variable and uncertain load, power systems as elements of the degree of operational flexibility must be reached. This author further warns that increasing amount of individual distributed generators possess difficulties of control and manage. Three major power requirements of secure operation anchored in optimization, support, control integration, and communication of the network, (Ravichandrudu, et al., 2013) are used to address the dysfunctionality of variability and uncertainty of micro sources. According to Sampathet al, (2016), the combination of the functional requirements of the control system considering the intermittent factors of randomness, uncertainty, interoperability and other heterogeneous issues ensures flexibility.

3. System Common Components

Microgrid consists of heterogeneous types of energy components; Micro source generator, loads, energy storage, Controllers and the grid, (Lemmon, 2009; Geev, Siano, Piccolo, and Calderaro, 2012). The storage devices perform two major functions; balancing of power demand and providing smooth transient conditions between the modes, (Perera, Ciufo, and Perera, 2016; Martinot, 2016; Luu, 2014).

Primarily, this subsystem act as a voltage source when a sudden change occurs ensuring uninterrupted power supply (UPS); acts as a balance between the short-term power disturbances and energy demand with generation, (Luu, 2014). Such energy storage devices as supercapacitors, flywheels, and batteries, permit the daily demand curve minute–hour peaks to match the intermittent supply with demand, influenced by its size and the generated inertia (Ravichandrudu, et al, 2013; Sager, 2014; Luu, 2014). Energy storage overrides the need for peak generation and provides transmission congestion relief, (Lemmon, 2009).

Controllers of micro Source, load, distribution, and management system, has the basic functionality to manipulate the processes to follow the plan mapped out by the intelligent director, (Luu, 2014; Gil, and Lopes, 2006). This subsystem supports storage devices to maintain high energy demands during peak and off-peak hours and able to supply all loads when required, (Perera, Ciufo, and Perera, 2016; Škrlec, 2011; Sager, 2014; Gil, and Lopes, 2006). The coordinated (supervisory control) uses various methods such as linear programming, the Rule-based, dynamic programming and artificial intelligence for optimal allocation of power output among DER, and daily energy consumption of the utility grid. The local intelligent enhances the efficiency of systems operations by regulating the frequencies and voltages in different operational modes of a microgrid, using the conventional method of a single master, master/slave, and the droop controls, (Cochran, et al, 2016).

Critical and non-critical load components, according to Parhizi, Lotfi, Khodaei, and Bahramirad (2015), categorized either as static or electronic, plays a vital role in the system operation, and control. Critical (sensitive) loads such as hospitals, traffic lights, industrial sites, military base and institutions demand high-level reliability with a fast and accurate protection system, (Perera, et al, 2016; Škrlec, 201; Geev, et al, 2012; Parhizi, et al, 2015). For power quality improvement, priority is accorded to critical loads, which enhances pre-specified load categories. Parhizi, et al, (2015) indicates that the load is adjusted in the system design through the application of energy efficiency measures that include the demand response controls, equipment upgrades, and other system adjustments to reduce the overall generation needs.

Power electronic interface modules are designed to include conversion of power, conditioning of power, output interface and filters protection, Distributed Energy Resources (DER) and load control, monitoring, control and ancillary services, (Parhizi, et al, 2015). These components change the voltage and current characteristics to suit any particular application, (Gaur and Singh, 2016; Parhizi, et al, 2015). Converters are deployed to facilitate frequency and voltage regulation of the grid, harmonics control (IEEE-519-1992), and unbalance voltage compensation, (Li, and Nejabatkhah, 2014), and ensures voltage and frequency stability, converting the energy sources output to the grid ready voltages; enhancing flexibility for the distributed generation operation and energy management, (Gaur and Singh, 2016).

Connecting the Microgrids to the main power grid is done through an intelligent coupling switch called PCC. This switch, according to several authors disconnects from the grid when the power quality is no longer acceptable resulting to the islanding of the microgrid, (Hernandez, Canesin, Zamora, and Srivastava, 2014; Lemmon, 2009; Luu, 2014; Gaur and Singh, 2016; Lasseter, and Piagi, 2006). Martinot, (2016) warns that the major challenge involves assuring the microgrids transient stability in the presence of such disconnect events.

The PCC and other "intelligent" agents (power, price, and loads), according to (Lemmon, 2009) monitor the global operation of the grid and use that information to adaptively reconfigure both generation assets and load connectivity. It determines conditional safety for loads to connect to the microgrid, coordinate their requests in order to minimize the overall cost of operating the generators, (Lemmon, 2009). This author claims that these reactive, proactive, and social abilities solve economic dispatch problem in a distributed manner.

Describing the functions of the agents, (Lemmon, 2009) states that the agents determine what real power levels to be requested from the generator. The price agent coordinates the selection of their individual power requests whilst the load agent monitors the quality of the power at the load and broadcasts forecasted load power levels to the price agent. Power quality agents keep track of the "quality" of the power being delivered by the generator. The load agent is attached to each load and enables the reconnection of the particular load to the grid" (Martinot, 2016; Rivera, et al, 2013).

The agents negotiate and cooperate in a decision with artificial intelligence interactively through wireless communication protocol; peer-to-peer communication mode, (Rivera, et al, 2013). Using gateways to buy and sell power interfaced (IEC/ISO 14045/18012) with the agent hardware that ensures connectivity between the device and the cloud, the emergency demand response (EDR) offers an incentive to the customers who instantly reduce the load (Rivera, et al, 2013), as controlled by the MicroGrid Central Coordinator (MGCC). Such sensors, actuators, as MGCC, mine relevant data for microgrid operation, manage and monitor multiple agents' status. When a special control request such as emergency demand responses arrives from the main grid, it dispatches the control command to the agents after receiving respective agent's individual proposal, (Rivera, et al, 2013) concludes.

4. Control System Functional Requirements of Future Microgrid

Based on IEEE P2030.7 (Standard for the Specification of Microgrid Controllers), transforming the stakeholder(s) requirements driven view into a technical view of the control system forms the basis for the architectural design and integration. Future microgrids using Master Software Controller standards, programmability, interoperability, fog computing, software components/subsystems attempt to resolve security, resilience, stability, safety, variability, optimization problems and dynamic load fluctuations ties the systems together (Integration).

4.1 Energy Management and Control Systems (EMS)

Essentially EMS is the information and communication system based on prediction and experience, managing off-peak periods to feed the peak periods energy demand, (Ganesan, Padmanaban, Varadarajan, Subramaniam and Mihet-Popa, 2017). The structure of EMS that includes (Figure 2.) Load scheduling, Generation forecast, Renewables Generation and economic dispatching, are used in the analysis, operation, and management of power generation, distribution and consumption (Ganesan et al, 2017). To reduce the cost of operation, minimize energy, maximize profit, environmental CO_2 reduction and enhance power quality, energy management system (EMS) performs real-time energy forecasting, energy storage, and loads control. Pedrasa and Spooner, (2006) enlisted four functionalities of this system which interoperability depends on energy service interfaces (ESIs), flexible and extensible. It further supports a resource-oriented architecture adopting plug-and-play of DER devices, loads, and other functionalities, (Rivera, et al, 2013) abstracting energy components as its resources (Pedrasa, and Spooner, 2006).

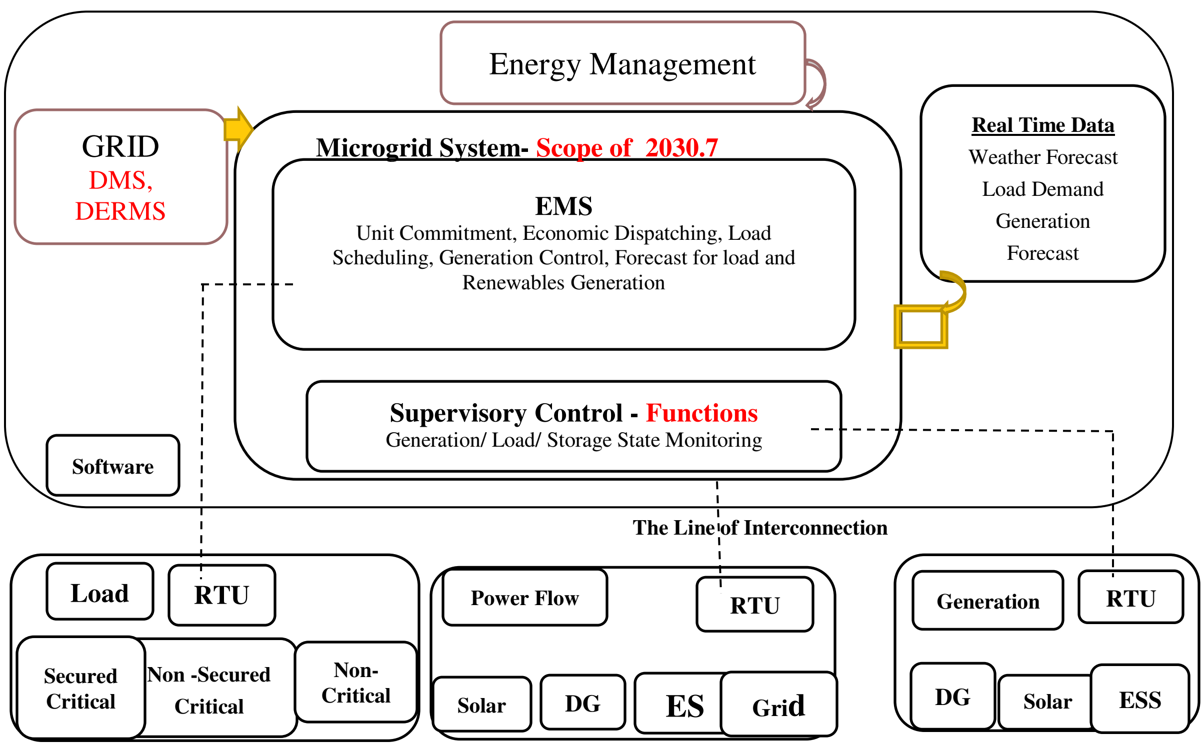

Figure 2. EMS Control Framework

The following therefore constitutes the functional requirements based on deterministic generation, stochastic generation, deterministic load, stochastic load and energy storage systems, (Whaite, Grainger, and Kwasinski, 2015):

- Data forecast, analysis, and transmission could describe the quantity and type of fuel available at specific locations and time to power energy systems.
- The data analysis provides insights into DERs characteristics, market optimizations, the loads, and utilized to adjust the short-term forecast, event detection, local demand response and the optimization models for better performances, (Parhizi, et al., 2015; Rivera, et al., 2013; Shi, Lee, Yao, Huang, Chu, and Gadh, 2014)
- Transmission data provides data visualization, archiving, rated line capacities, impedance, and line ratings.

These functionalities are performed through the Hardware vendor and network protocols. This protocol further assesses the energy demand (load profile) of the area, and how quickly energy demand changes; determines the size, location, and timing of electricity demand and the demographics of economic activities and population, (Parhizi, et al, 2015).

4.2 Control System Standards

This provides the foundation for the allocation of functions and sub-functions to hardware/software data of the intelligent inverters and interfacing converters, (Cochran, et al, 2016; Degner et al., 2004). According to Cochran, et al, (2016), various types of loads can be fed from the main employing different converters mostly the tightly regulated, closed-loop converters that generate the suitable type of electric power for each type of load. The stability of the microgrid depends on the ability of this converter to stabilize the dc bus voltage effectively, (Degner et al., 2004). The dynamic characteristics of the distributor generators directly or indirectly connected through the interface inverters determine the dynamic behaviors of Microgrids.

These microgrid controllers based on IEEE 2030.7/8 standards for Specification and testing respectively, are stipulated in IEEE 1547 requirements. To minimize interference between electrical equipment IEEE 519-1992 describes the interface between sources and loads at the PCC stage (or Active Distribution Network, ADN) with a strict recognition of the design goals. Other Internet of Things (I_oT) protocols includes IEEE 802.11 (Wi-Fi), 1901(broadband power line com), 802.15.4, and other networks (802.3 for GPRS). IEEE 1888x and IEC 61850, IEC 61850-90-15 and IEC 61968/61970 Common Information Module (CIM) power utility automation standards depict IoT global standard of managing renewable energy that ensures energy efficiency using communication protocols and information technologies common syntax and semantics.

4.3 Integration Requirement, Issues, and Control Measures

Due to RES correlation between the climate, weather and other environmental factors, securing proper system operation are therefore necessary. Effective integration and control measures assist a microgrid to maintain a long-term island operation, meeting the demand flexibility and execute the following capabilities; Grid Connected Capabilities, Islanding Capabilities; Generation; Secure Operations. Optimization for Economic Operation, (United States Department of Energy, 2014). United States Department of Energy, (2014) further details these capabilities into the following functionalities: Support Integration of Renewables, Support for DER Market Participation, Emergency Islanding Support, Managing Critical/Non-Critical Loads to Available, Island Operations with High Penetrations of Renewables, Optimized Island Operation for Longevity (Fuel, Maximizing REs) Cyber Secure Communications Network.

The issues of power quality, communication, demand, and supply balance must be considered prior to the utilization of microgrid. Other issues in consideration include technical and non-technical: operational management, stability and protection, Lack of technical skill Labour force, Less availability of transmission lines, Grid congestions, Cost reliability, and integration issues (Hernandez, et al, 2014; United States Department of Energy, 2014). A major technical issue lies in control of the micro source generation, a failure of one may affect the whole complex system, (Lasseter, and Piagi, 2006). On stability, (Hernandez, et al, 2014; Gil, and Lopes, 2006) emphasize that issues are common in microgrids than main grid as the power and energy ratings are much lower. In contrast, there are no reactive power interactions in DC microgrid systems, hence no stability issues, (Perera, et al, 2016).

Other challenging issues of integration as listed in Hernandez, et al, (2014) are: the interconnection of the DER units increases the complexity of the automatic or smart control functions of the Smart Distribution Management System (SDMS) as SDN requires periodic and fast estimations of network security, as well as collecting a variety of real-time information from the network components, (Chukka, Pinninti, and Venkatesh, 2014; Gil, and Lopes, 2006).

The automation power Systems protocol called Supervisory Control and Data Acquisition (SCADA) could aid to resolve the network anomaly. SCADA system is only used when the automated processes are geographically or spatially located sites, VPP in multiple sites is a good example. Contrarily, the Distributed Control System (DCS) which automate the flow of data with all components at one platform and at one geographic location (Mostafa, Hooshmand, and Gholipour, 2016).

4.4 Hierarchical Control Scheme and Intelligent Director

Hierarchical controllers and intelligent agents according to IEC/ISO 62264 standard as explained in, (Perera, et al, 2016) are Multi-Agent System (MAS) called autonomous computational entities challenging to define analytically, but which make decisions based on goals within an environment. Hernandez, et al, (2014) states that the functions of the multi-agent system are to communicate and provides both intelligence to improve an algorithm, data transfer, power quality, load sharing, and execution capability Each simple problem is solved by an agent, functionally assigned, which duty cannot affect the entire system.

The control scheme normally has 3 levels namely Grid level: Distribution Network Operator and Market Operator that ensures reliable operation; Management level ensures synchronization of the main grid and the microgrid: power quality optimization (minimize the average of all voltage and frequency deviations); whilst the fields scheme balances generation and load consumption, (Hossain, et al, 2014; Gil, and Lopes, 2006; Muni-Fed – Antea Group Energy, 2016). Muni-Fed – Antea Group Energy, (2016) in figure 3 shows the conceptual hierarchical control system which complexity increases from local to the tertiary and the real-time increases from milliseconds to hours in responses.

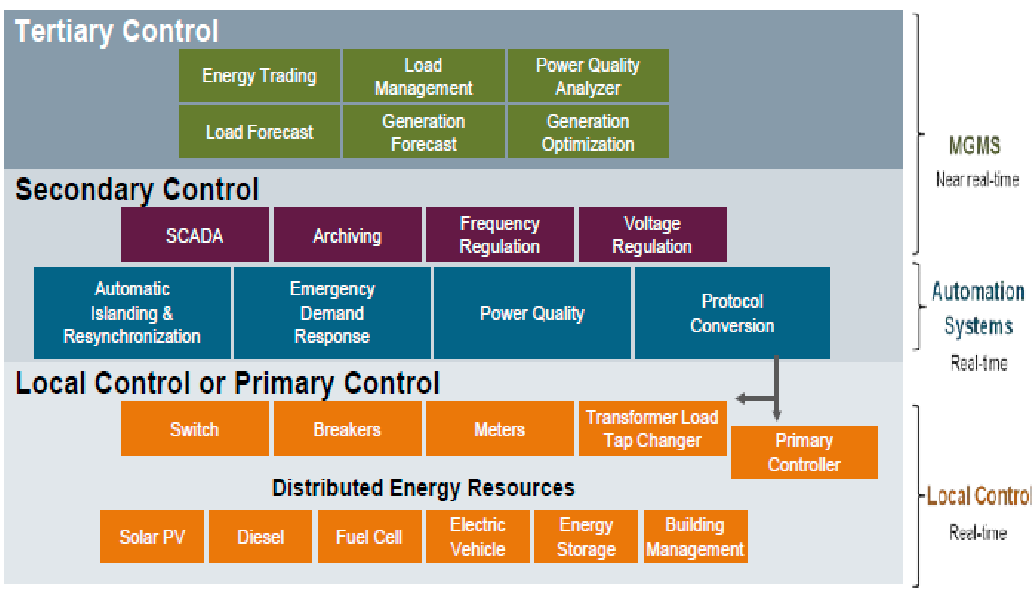

Figure 3. Hierarchical Controls Levels

The communication methods either centralized or decentralized based wireless communication networks (fiber-optics, infrared, power line carrier (PLC), and/or wireless radio networks multiple-port power converters) are used to connect various power sources to the grid and load, (Hossain, 2014; Gil, and Lopes, 2006; Parhizi, et al, 2015). System information is used in the microgrid to determine operation point of each Distributed Generation (DG) (Parhizi, et al, 2015) using communication intelligence.

4.5 Control Techniques and Strategy

The primary role of the Control techniques is ensuring that no modification of existing tool exist even when new micro sources are added. Based on standard and requirements, control can be centralized or decentralized. Each micro source controller using a feedback control mechanism must autonomously respond effectively to system changes without requiring data from the loads. In power quality, the voltage signal on a power system is not independent of the current signals, (Hossain, et al. 2014; Whaite, et al, 2015; United States Department of Energy, 2014). However, according to (Hernandez, et al, 2014), the overall control of microgrid operation and management is performed by the central controller which usually has two main functional modules, (Hernandez, et al, 2014; Whaite, Grainger, and Kwasinski, 2015). To minimize power loss, and cost, profit maximization, and environmental emission reduction various optimization techniques ranging from analytical, numerical and heuristic could be adopted.

The Solution to issues and effective management of the microgrid in small or large scale is dependent on the development and use of cost-effective and grid-friendly converters by introducing real-time computer controllers that implement advanced and complex control algorithms. Again, the use fast semiconductor switches capable of switching quickly in milliseconds and handling high powers is suggested to maintain reliability and flexibility in DER energy consumptions through microgrid.

However, due to the stochastic and des-patchable nature of RES and DG, a faster and effective heuristic control method called Action Dependent Heuristic Dynamic Programming (ADHDP) and/or another multi-objective programming method could be used in evaluating the DG impacts in system reliability, losses and voltage profile.

5. Recommendations for Future Work

Due to many unknowns faced in the design of Microgrid and its operating system, great challenges arise in its integration process especially in the use and operation of control interfaces. In order to achieve an optimized integration of Microgrid system, the extra study should be engaged especially in Stabilization and flow optimization of renewable energy integration. Apart from ensuring grid stability, studies on upgrading an existing fuel-generation based microgrid with micro sources generation may assist in determining ways to maximized fuel savings and increase the security of supply. Ways to maximized utilization and Return on Investments of renewable energy plant should also not be overlooked.

6. Conclusion

This paper presented the basic component requirements, Energy Management system, the hierarchical control levels, Standards and regulatory policies, the challenges and issues, and the basic control techniques that facilitate the understanding and design of the microgrid structure that ensure energy production, distribution, optimization, and consumption. For a better integration of micro-sources, and its intelligence generation to distribution, new software technologies, sensors, actuators and other wireless communication networks, EMS techniques must be employed in ensuring power reliability, quality, and stability which must be void of losses and harsh environments. Essentially, the control process is a derivative of energy demand, time functions, and critical load.

References

Aminu M. A., and Solomon, K., A Review of Control Strategies for Microgrids, *Advances in Research, DOI:* 10.9734/AIR/2016/25722, vol. 7, vo.3, pp. 1-9, July 2016.

Basu, M., and Conlon, M.F., Design, and Simulation Study of a Microgrid System, *Energy Lab. Dublin*, pp.1-26, 2014.

Chukka, G., Pinninti, S., and Venkatesh, P. S., Modeling and Simulation of Microgrid Connected Renewable Energy Resources with MPPT Controller and by Using SVPWM Technique, *International Journal of Engineering Research & Technology (IJERT)*, ISSN: 2278-0181, vol. 3 Issue 1, pp.445-462, Jan. 2014.

Chung, I., Yoo, C., and Oh. S., Distributed Intelligent Microgrid Control Using Multi-Agent Systems, School of Electrical Engineering, Kookmin University, Seoul, Korea, *Scientific Research,* vol.5. pp.1-6, January 2013.

Cochran., Denholm, P., Speer, B., and Miller, M., Grid Integration and the Carrying Capacity of the US Grid to Incorporate Variable Renewable Energy, *National Renewable Energy Laboratory*, Technical Report NREL/TP-6A20- 62607, Springfield, 2016.

Degner, T., *et al*., *Microgrid Architectures and Control*, Hatziargyriou, N., (ed.), National Technical University of Athens. IEEE Press, John Wiley and Sons Ltd, United Kingdom, pp.1-30, 2014.

Federau, E., Blasius, E., Janiki, P., Classification of control features related to microgrid operation standardization, doi:10.15199/48.2016.10.57, Brandenburg University of Technology Cottbus-Senftenberg, pp254-257, 2016.

Ganesan, S., Padmanaban, S., Varadarajan, R., Subramaniam, U., and Mihet-Popa, L., Study and Analysis of an Intelligent Microgrid Energy Management Solution with Distributed Energy Sources, *Energies*, vol. 10, doi:10.3390/en10091419, Vol. 10, pp.1-21, 2017.

Gaur, P., and Singh, S., Investigations on Issues in Microgrids, *Journal of Clean Energy Technologies*, India, vol.5, no.1., pp.47-51, 2017, [Online] http://dx.doi.org/10.18178/jocet.2017.5.1.342, Accessed November 26, 2016.

Geev, M., Siano, P. Piccolo, A., and Calderaro, V., A Fuzzy Logic Controller to Increase Fault Ride-Through Capability of Variable Speed Wind Turbines, *Hindawi Publishing Corporation Applied Computational Intelligence and Soft Computing,* doi:10.1155/2012/405314, Vol. 2012, pp.1-10, 2012.

Gil, N.J. and Lopes, J. A. P., Hierarchical Frequency Control Scheme for Islanded Multi-Microgrids Operation, *IEEE*, pp.1-6, 2006.

Hernandez, F. I., Canesin, C. A., Zamora, R., and Srivastava, A. K., Active Power Management in Multiple Microgrids Using a Multi-Agent System with JADE," *Smart Grid Demonstration and Research Investigation Lab*., pp1- 8, 2014.

Hossain, E., Kabalci, E., Bayindir, R., Perez, R., A Comprehensive Study on Microgrid Technology" International *Journal of Renewable Energy Research*, vol. 4, no. 4, pp.1096-1106, 2014.

Hu, J., Zhang, T., Du S., and Zhao, Y., An Overview of Analysis and Control of Micro-Grid System, *International Journal of Control and Automation,* vol. 8, no. 6, pp.65-76, 2015.

Hudsona, R., and Heilschera, G., PV Grid Integration – System Management Issues and Utility Concerns, PV Asia Pacific Conference 201, *Energy Procedia,* no. 25, pp. 82 – 92, 2012.

Katariya1, C. S. and Shriwastava, R. G., Power Quality Improvement Using D-STATCOM in Distribution System at Various Faults, *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, Vol. 2, Issue 6, pp1621-1627, June 2014.

Kaur, A, Nonnemacher, L and Coimbra, C., Net Load Forecasting for High Renewable Energy Penetration Grids, Centre for Energy Research, Jacobs School of Engineering, University of California. *Science Direct*, San Diego, vol.114, no.2016, pp1073-1084, 2016.

Lasseter, R.H., and Piagi, P., Control and Design of Microgrid Components" *Power Systems Engineering Research Center: A National Science Foundation Industry,* University Cooperative Research Center, University of Wisconsin, Madison, pp.1-244, 2006.

Lemmon, M.D., Advanced Distribution and Control for Hybrid Intelligent Power Systems, Final Project Report, University of Notre Dame, pp.1-23, 2009.

Li, Y., and Nejabatkhah, F., Overview of control, integration and energy management of microgrids, Electrical Research Institute, *J. Mod. Power Syst. Clean Energy,* DOI 10.1007/s40565-014-0063-1, vol. 2, no.3, pp.212–222, 2014.

Lopes, J. A. P., Moreira, C. L., and Madureira, A. G., Defining Control Strategies for Micro-Grids Islanded Operation, *IEEE Transactions on Power Systems*, vol. 21, no.2, pp. 916-924, May 2006.

Luu, N.A., Control and Management Strategies for a microgrid, *Unpublished PhD Thesis,* Université de Grenoble, pp.1-196, Dec 2014.

Martinot, E., Grid Integration of Renewable Energy: Flexibility, Innovation, Experience, Annual Review of Environment and Resources 2016, *Centre for Environmental and Energy Policy Research,* China, 2016.

Muni-Fed – Antea Group Energy Partners, Microgrid Technology White Paper, Port of Long Beach, Contract HD-8381, Job Task 150, *Muni-Fed Energy*, pp.1-51, August 2016.

Mostafa, S., Hooshmand, R and Gholipour, E. Stochastic profit-based Scheduling of industrial Virtual Power plant using the best demand response strategy. *Applied Energy*, University of Ishfahan, Iran, 2016.

Parhizi, S., Lotfi, H., Khodaei, A, and Bahramirad S., State of the Art in Research on Microgrids: A Review" *IEEE Access*, USA DOI:10.1109/ACCESS, 2015, 2443119, vol. 3, P.890-925, 2015.

Pedrasa, M.A., and Spooner, T., A Survey of Techniques Used to Control Microgrid Generation and Storage during Island Operation, *Australian Universities Power Engineering Conf,* pp.76-80, 2006.

Perera, Ciufo, P., and Perera, S., Advanced point of common coupling voltage controllers for grid-connected solar photovoltaic (PV) systems, *Renewable Energy*, vol. 86, pp. 1037-1044, 2016.

Ravi, N., Sumanth, Y., and Kumar, N., Impact of Renewable Energy Sources Penetration in a Microgrid, *International Journal of Engineering Research and Applications,* ISSN: 2248-9622, Open Access, vol.4, no.5, pp.45- 52, 2014.

Ravichandrudu, K.., Manasa, M., Babu Y., and Anjaneyulu, G., Design of Micro-Grid System Based on Renewable Power Generation Units, *International Journal of Scientific and Research Publications,* ISSN 2250-3153. India, Vol. 3, No.8, pp.1-5, 2013.

Rivera, S., Farid, A., and Youcef-Toumi, K., Coordination, and Control of Multiple Microgrids Using Multi-Agent Systems, *Energy Path*, pp.1-5, 2013.

Rodrigues, E.M.G., Godinaa, R., Santosa, S.F., Bizuayehua, A.W., Contreras, J., Catalãoa J.P.S., Energy storage systems supporting increased penetration of renewables in islanded systems, University of Lisbon, Portugal, pp.1-40, 2013.

Sager, M., Renewable Energy Vision 2030 - South Africa, Climate Change, and Energy, *World Wide Fund for Nature,* 2014.

Salam, A.A., Mohamed, A and Hannan, M.A., Technical Challenges on Microgrids, *Journal of Engineering and Applied Sciences*, Asian Research Publishing Network. ISSN 1819-6608, Malaysia, vol. 3, no.6, pp.64-69, 2008.

Sampath, M., Ramaswamy, M., Subramaniam, K., Smart Supervisory Control for Optimized Power Management System of hybrid Micro-Grid, *International Journal of Applied Engineering Research*, ISSN 0973-4562, vol. 11, no. 6, pp. 3980-3986, 2016.

Shen, J., Jiang, C., Liu Y., and Wang, X., A Micro-Grid Energy Management System and Risk Management under an Electricity Market Environment” *IEEE Access,* doi.org/10.1109/ACCESS.2016.2555926*,* vol. 4. pp.2349-2356, 2016.

Shi, W., Lee, E., Yao, D., Huang, R., Chu, C., and Gadh, R., Evaluating Microgrid Management and Control with an Implementable Energy Management System, *IEEE Smart Grid Comm.,* Venice, Italy, pp.3-6, Nov. 2014.

Škrlec, D., Control and optimization of micro-grids with electric and heat energy resources, Faculty of Electrical Engineering and Computing, University of Zagreb, Hungary, pp. 1-5, 2011.

United States Department of Energy, Smart Grid System Report, *Report Presented to Congress,* Washington, DC, 2014.

United States Department of Energy, Smart Grid System Report. Report Presented to Congress. Washington, DC, 2014.

Whaite, S., Grainger, B., and Kwasinski, A., Power Quality in DC Power Distribution Systems and Microgrids, *Energies,* doi:10.3390/en8054378, vol.8, pp.4378-4399, 2015.

Biographies

Nwauka Oliver Graduated with a B. Eng. Degree (Hons) from University of Nigeria. He Received the Faculty of Engineering Akinkunle Foundation Prize as the Overall Best Graduating Student in Academic Records, 1992. He also holds Master’s degree in Engineering Management from University of Pretoria (2013). Currently, he is a Doctoral Student at Postgraduate School of Engineering Management, University of Johannesburg, with Special interest on Energy, Industry 4.0, Assets and Operations Management.