Optimal Design Analysis of Multimodal Hybrid AC/DC Microgrids

Rohan Sharma
Research Scholar,
Amity School of Engineering & Technology,
Amity University Rajasthan, Jaipur

Dr. Pramod Kumar Bhatt
Associate Professor,
Amity School of Engineering & Technology,
Amity University Rajasthan, Jaipur

Article Info
Page Number: 138 – 150
Publication Issue:
Vol 71 No. 2 (2022)

Abstract
The objective of this study is to test the proposed Interconnected hybrid microgrid model with inclusion of Photovoltaic Sub-System (PVSS), Wind Energy Sub System (WESS), Battery Energy Storage Sub System (BESSS) in a DC / AC Connected model which will be playing an important role in analysis of transition from electric grids to Smart Grids Systems (SGS). In the proposed model, IEEE 14 busbar distribution systems is used as a test case for the interconnection of the various Sub-systems in AC/DC hybrid mode for justifying the benchmarks of the system. Furthermore, various individual Linear and Non-Linear connected loads are used for studying the further complexities in the real power system network. A complete proposed test model is simulated and analyzed using MATLAB – Simulink Platform. The suggested electrical system will be used to examine reactive power compensation, stable and inertia evaluation, reliability, demand response research, hierarchical control, fault - tolerance control, optimization, and power storage approaches. This benchmark study allows researchers to look into dynamic stability, evaluate control techniques and structures, model diesel generator dynamics, and adjust voltage profiles, among other things. Even if it depends to a considerable extent on the application and the integrated environment, the inquiry provides for further exploration of various topologies of interconnected AC/DC HMGs, as well as dynamic studies for various AC/DC Multimodal Hybrid Microgrid (MHM) configurations. Finally, this research lays the groundwork for future research into MGs, their possible applications, and ways to increase device reliability, efficiency, and cost.

Article History
***Article Received**: 28 December 2021*
***Revised**: 25 January 2022*
***Accepted**: 10 March 2022*
***Publication**: 25 March 2022*

1. **Introduction**:

Renewable energy sources (RES) present a greener technology capable of meeting the rising electrical consumption of interconnected and isolated areas. MGs have piqued the scientific community's interest in recent years, along with a possibility of alternate future conventional energy systems. MGs are being considered as a potential solution for integrating variable renewable systems into traditional grids.[1-2]
As a consequence of the introduction of new digitalization such as microprocessor systems and improvements in power electronics, several applications were used in SG, particularly in the creation of controllers and

electronic energy converters. On recent decades, researchers have made important contributions which have had a substantial impact in various sectors, with an emphasis on data collection, automation, and MG regulation. MGs not only connect distributed energy resources to the Main Grid in a reliable and clean manner, but they also provide high reliability in terms of its ability to execute in the face of natural events and active Distribution Grids, as well as reduced energy economic loss in transmission lines, as well as reduced building and investment time.

A MG is a low-voltage distributed energy network to which tiny modular generation systems, such as renewable energy, other distributed generators, and intermediate storage units, are attached and capable of meeting load demand. This power systems are considered as a controlled load or generator by the utility grid. Although MG configurations might be solely DC, AC, or a combination of the two technologies, certain studies are concentrating on AC MG [3]. This is owing to the fact that it may work in tandem with the Main Grid. It is well recognized that each has distinct benefits, making the HMG benchmark a pivotal point in our inquiry.

All MG technologies must contend with the distribution generators' (DG) dynamics and steady state characteristics, as well as the imbalance and non - linearity of loads and the correct dynamism of BESSS. MHMs must also deal with the possibility of an unintentional or pre-programmed disengagement from the Central Grid. As with any other Distribution Grid, a MHMs benchmark must be exposed to two common scenarios: minimum and maximum demand scenarios.[4] MHMs are responsible for overseeing the electrical infrastructure's abnormal operations. A well-known technique for controlling MG settings is to use a series of three-level control structures. Operational and experimental MGs have been documented throughout Europe, Africa, Asia, and America, according to specialized literature. In fact, there is a debate regarding whether or not it should be accepted. Depending on the nature of most renewable generation methods, power electronics are incorporated in MG configurations. Controlling the injected power given to the MG is essential. [5-6] Its power quality issues may be solved if proper closed-loop control mechanisms are used. The use of multilevel inverter can increase the performance of MG configurations and various technologies.

A thorough model of a MHM has been simulated in this work. The original IEEE-14 distribution-bus paradigm provides the foundation for this approach. For the functioning of regulated rectifiers or inverters as interfaces to renewable energy, there are a variety of control mechanisms. These rectifiers or inverters also employ pulse width modulation methods with various carrier frequencies.

On the MG, you may find examples of stable and unstable loads, nonlinear and linear coupled loads, energy storage devices, distribution transformers, and line impedances, all of which are accessible in various configurations. This document also includes a detailed explanation of the model, as well as all of the data needed to undertake the aforementioned research. [7-9] Both demand situations are examined, as well as a discussion of the issues that have arisen and their potential remedies. All power flow findings for all situations are included in this study. The results then highlight the potential conflicts that these factors may cause with bidirectional power flows and the introduction of mostly solar photovoltaic distributed energy. Finally, the current study serves as a springboard for further investigation into a variety of contemporary concerns that will be discussed in future research.

2. Microgrids:

MGs are one of the most intriguing alternatives for researchers, even on a smaller scale. Through the integration of DGs, renewable sources of energy, BESSS, and loads, MGs are able to enhance power flow in the Distribution Network while reducing power failures in the transmission system, according to the

International Energy Agency. Several studies in the literature point to various control tactics, including test beds, optimization approaches, and accessible software tools, among many others. MGs are examined on a tiny scale, but their modeling and simulation technical complexity is higher than a standard energy system. As a result, models that allow for dynamic analysis are critical to ensuring that future MGs operate in a stable manner.

2.1. Architecture of Microgrids

In addition to microgrids, energy storage, and varied load types, MGs are comprised of a variety of other systems and subsystems as well. They can operate in three different modes: paralleled with the Electric Grid, with no power balance; isolated mode, with a single power supply; and integrated mode, in which the Main Power system set points are assumed. [10-11]

The parallel configuration features an AC bus that connects the generation systems and loads directly. The DC equipment are connected to the AC bus by inverters or bidirectional VSC, or via a DC bus attached to the AC bus via an inverter. However, because to the benefits they provide, such as the absence of reactive power and harmonics, DC MGs have recently sparked a lot of attention.[11]

The idea of AC/DC HMGs is born from the mixture of both configurations, and it proposes a superior strategy that incorporates the primary advantages of both AC and DC MGs. Future trends indicate a larger need for and investment in research on qualities including scalability, identification and characterization, design, and controlling structures that enable HMG integration with the Main Grid. Some publications are primarily concerned with AC and DC MG architecture. HMGs might be an attractive option in which the benefits of both AC and DC configurations are combined. Interconnected (coupled) or solo AC MGs are both possible (decoupled).[12-13] In decoupled MGs, two approaches have been identified: fully isolated topology and partially isolated topology.

There are a number of aspects to consider while designing an AC/DC HMG, including reliability, controllability, observability, economics, and adaptability. The following design principles have been culled from the literature and are taken into account.

- The division principle and the hierarchy principle.
- Utilize all available resources to the fullest extent possible.
    - Getting the most out of resources.
    - Energy complements each other.

3. Proposed Model

The suggested three-phase paradigm is described in depth in this section. It was simulated in the MATLAB/Simulink R2021a environment with the associated Simscape module. The goal is to give a tool for scientists to better understand the dynamics of the MG and each one of its elements, and also their performance under various operating situations.

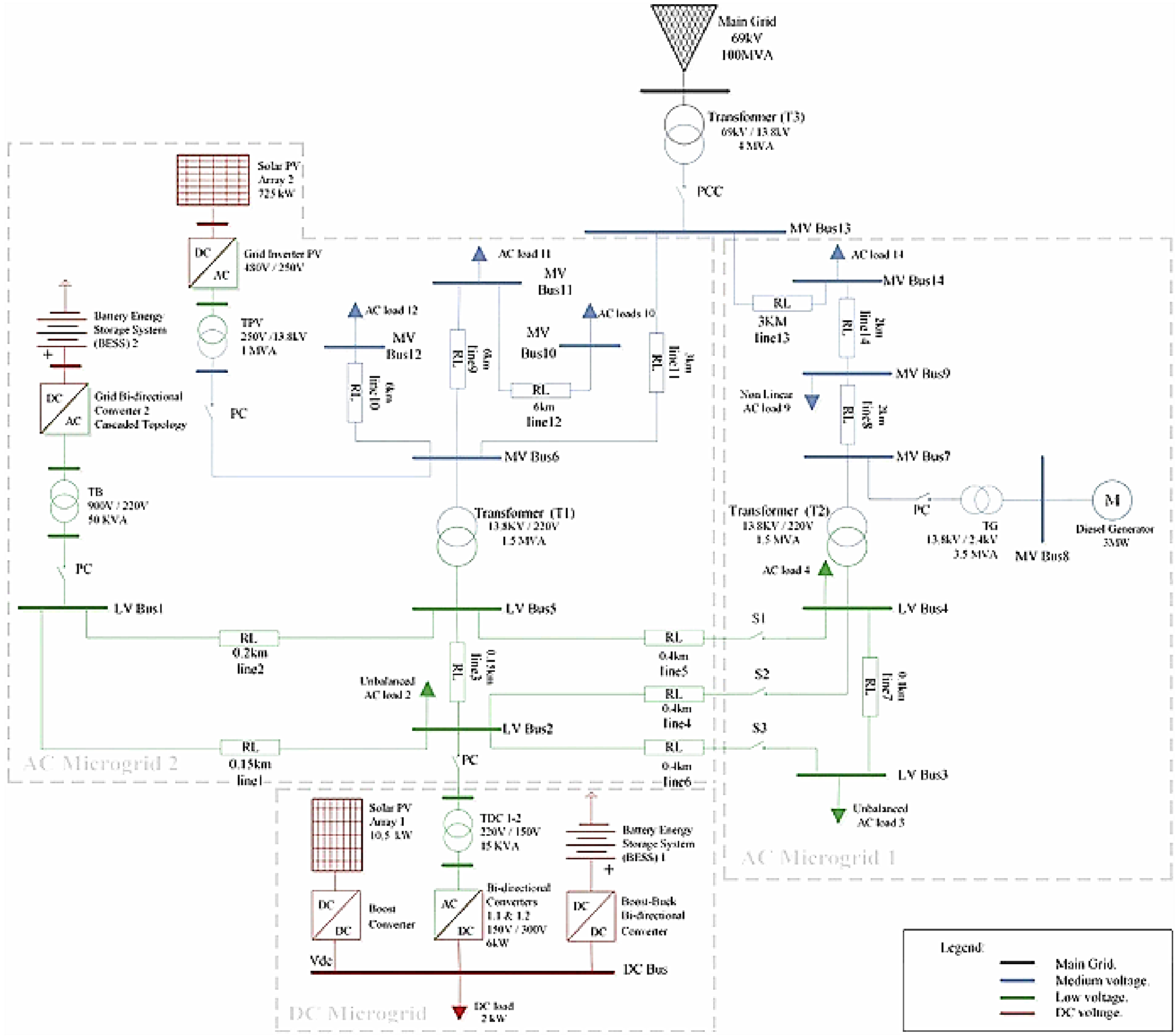

Figure 1: AC - DC Microgrid Architecture

The proposed MG is linked to the PCC point of a 69-kV electrical sub-transmission system, as shown in the diagram. With an X/R ratio of 10, this power system has a No load voltage of 100 MVA. A main 13.8-kV voltage level represented in blue and a secondary 0.22-kV voltage level depicted in green are the two voltage distribution levels. Three sub-MGs are displayed: AC MG 1 is a region connected to AC MG 2 at a voltage of 0.22 kV through lines 4, 5, and 6. In this study, the switches S1, S2, and S3 are considered linked. It runs on a diesel generator and supplies power to four loads. Another area that works with the PVSS 2 and the BESSS 2 is AC MG 2. The BESSS 1 and the PVSS Array 1 are connected by a DC busbar in the third region. [14-15]

Furthermore, the WECSS 1 is linked to Bus 14 for power distribution to the loads connected to load 14 and load 13. A boost-buck rectifier connects the BES system 1 to the DC connection, while a boost converter connects the PVSS 2 to DC link. The DC busbar is connected to the AC MG 2 by two parallel bidirectional converters, numbered 1.1 and 1.2, that can be used as rectifiers or inverters to interchange active and reactive power via two transformers, TDC-1 and TDC-2. Rather than the two original converters, a comparable bidirectional converter has been included in the one-line. As is the case with transformer TDC 1–2, which replaces both TDC-1 and TDC-2 transformers. These one-line diagram simplifications are produced for the sake of clarity. Finally, a diesel generator and a MHM system with linear and nonlinear loads are included in this AC/DC MHM.

3.1. Photo Voltaic Sub-Systems PVSS

One of the main renewable resources in the HMM is solar-photovoltaic technology. Both arrays run at a temperature of 27°C and a total irradiance of G 1250 W/m2 on the solar cells. For the DC Bus, array 1 has 40 modules with a power rating of 10.5 kW, whereas array 2 has 1550 modules with a power rating of 725 kW. Power converter interfaces are required for both DC and AC energy sources. Array 1 uses a voltage-controlled DC-DC boost converter. It features a 6000F link capacitor with a 300 VDC working voltage. A 5 kHz frequency is used in a PWM closed-loop control method. [16]

3.2. Wind Power Sub-Systems WPSS

Wind turbines generate electricity utilizing generator such as PMSG, SCIG, and DFIG [9]. Wind energy systems are more expensive to install, but they are less expensive to maintain than traditional fossil fuel-based power producing systems. PMSG and DFIG are used in wind energy conversion systems. Currently, most WECS use DFIG. PMSG has recently increased in popularity as a result of its benefits. PMSG is easier to manufacture and does not require the use of a gear system. The benefits of gearbox-free wind systems include enhanced overall performance, dependability, low weight, and low maintenance. [17] PMSG does not require external magnetization because permanent magnets are used. This functionality is especially important in isolated WECS in distant places where reaching the grid for delivering reactive power for induction generator magnetization is difficult. Due to the obvious low resistance, the losses are negligible. The ferrous losses are minimal due to the laminate stator and the lack of the armature response.

3.3. Battery Energy Storage Sub-System (BESSS)

The Fuel Cell (FC) generates DC power via chemical processes. Anode and cathode are the positively and negatively electrodes of FCs. The FC uses an electrolyte to move charged particles between electrodes. FCs are usually used in conjunction with catalysts to speed up chemical reactions. Hydrogen is the principal fuel for FCs. However, FCs require oxygen to function. After the process, the FCs combine hydrogen and oxygen to generate safe water. Water from fuel cells may be electrolyzed to make hydrogen. A single FC generates a little electricity. Stacks of FCs are common.

The DC bus is served by BESS #1. It comprises of a single lithium-ion battery unit with a maximum load of 800 mAh and a nominal voltage of 120 VDC (Ah). BESS #2 runs close to LV Bus 1. It comprises of three 650 VDC rated voltage Ni-MH, each with a rated capacity of 1.5 kWh (Ah). In a cascaded architecture, the parallel-connected cells are linked to an inter-faced inverter, which rises to the occasion from 650 Volts DC to 900 Volts AC. All of these battery kinds are accessible in the MATLAB Library as devices. The BESSS system is shown in the figure 2. The similar is connected at the section II of the network mentioned previously.

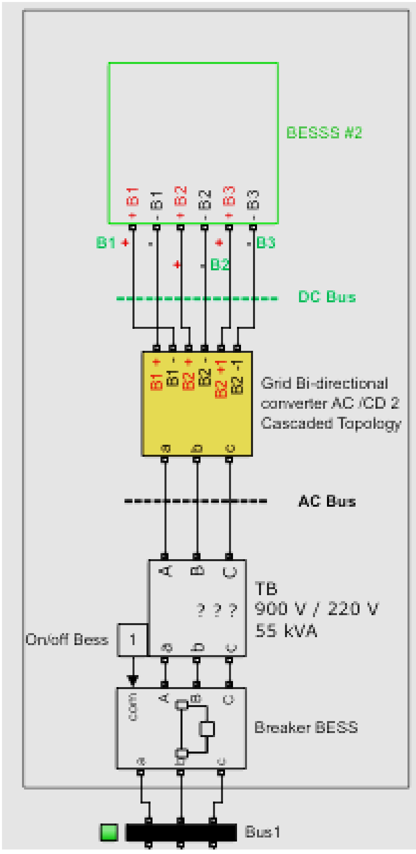

Figure 2: Battery Energy Storage Sub System Connected at Bus 1

3.4. DC-AC VSC Model

The second solar PV array connects to the AC 13.8 kV network linked using an inverter that converts 480 VDC to 250 VAC. AC inverter to MGM base distribution transformer TPV. An IGBT 3-level PWM bridge models the converter. In both cases, the PWM frequency of the carrier is 1980 Hz with closed-loop control. [18]

In addition, the BESSS #2 is connected to the 0.22 kV system via an inverter that converts 650 VDC to 900 VAC. A recent research compared five distinct approaches and picked the CMLI (Cascade H Bridge Multi Level Inverter).

4. Results and Discussion

The reported findings are examined and power quality and efficiency indicators are established. The routine curve of the proposed MHM is the total of the hourly needs of each load, with commercial and industrial loads dominating. Because the loads were simulated with constant impedance, a little difference between nominal and real power consumption was found. This is related to system voltage dips.

4.1. Voltage profile analysis

The ADVS of the system has been calculated as by the given equation,

$$V_{avg\ deviation} = \frac{\sum_{j=1}^{i} |V_{dj} - V_j|}{i}$$

Furthermore, the maximum system voltage deviation can be prescribed by the given equation,

$$V_{dm} = max\ (|V_{dj} - V_j|)$$

Where, i is the MG's bus count, V_{dj} is the intended voltages at j^{th} bus in p.u. (1 p.u.), furthermore It is needed that $V_{avg\ deviation}$ be minimised in a prospective optimization challenge for improving voltage profiles.

In the peak power analysis, the average variance of the power system cannot exceeds 0.039 per unit (Figure 3). That said, the system's maximum voltage deviation (MVD) is 0.0691 (phase a 0.0879; phase b 0.50; phase c 0.0462), this result highlights the necessity for further research aimed at improving the voltage profile in this system.

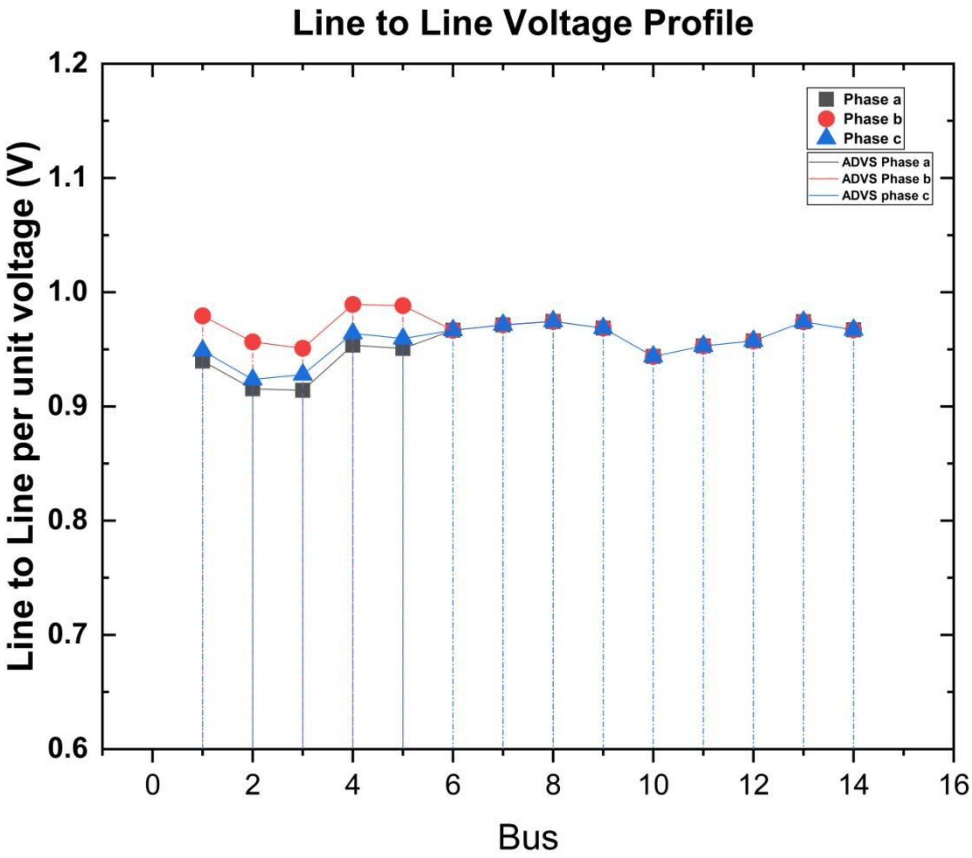

Figure 3: Line to line per unit voltage profile of each bus

4.2. $P_{active}Balancing$

Figure 4 show the kVA produced and consumed by each of the system's buses, including the DC bus's kW power. Except for bus 14, where a -ve power is given, which is transported from buses 9 to bus 14 as a power distribution contribution from the Diesel generator and the other of connected to the negative syndicate production in the bus to which it relates.

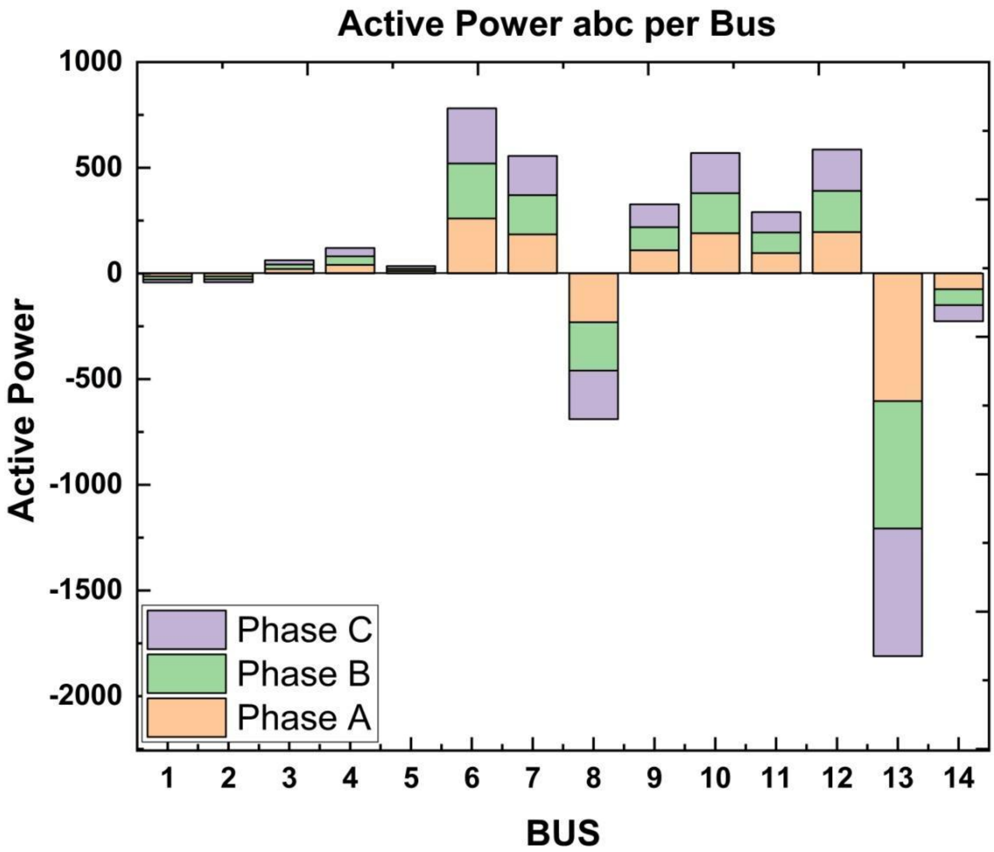

Figure 4: Active power of phases

4.3. Angular and Reactive power balance per bus analysis

In maximum and lowest demand, Figure 5 illustrates the reactive balance of power per bus, overall voltage profile per bus, and the phase difference in the voltages angle at the system bus. As observed in both figures, the reactive injection increases the voltage profile at the bus in which the reactive power is balanced by the system's existing generation. Bus 8 contributes reactive power from the diesel generator, whereas Bus 13 contributes reactive power from the external grid. Buses 9 and 14 appear to inject reactive electricity at peak demand. Transfer buses have negative powers owing to the power flow direction. These scenarios help analyze reactive power compensation to enhance voltage profiles.

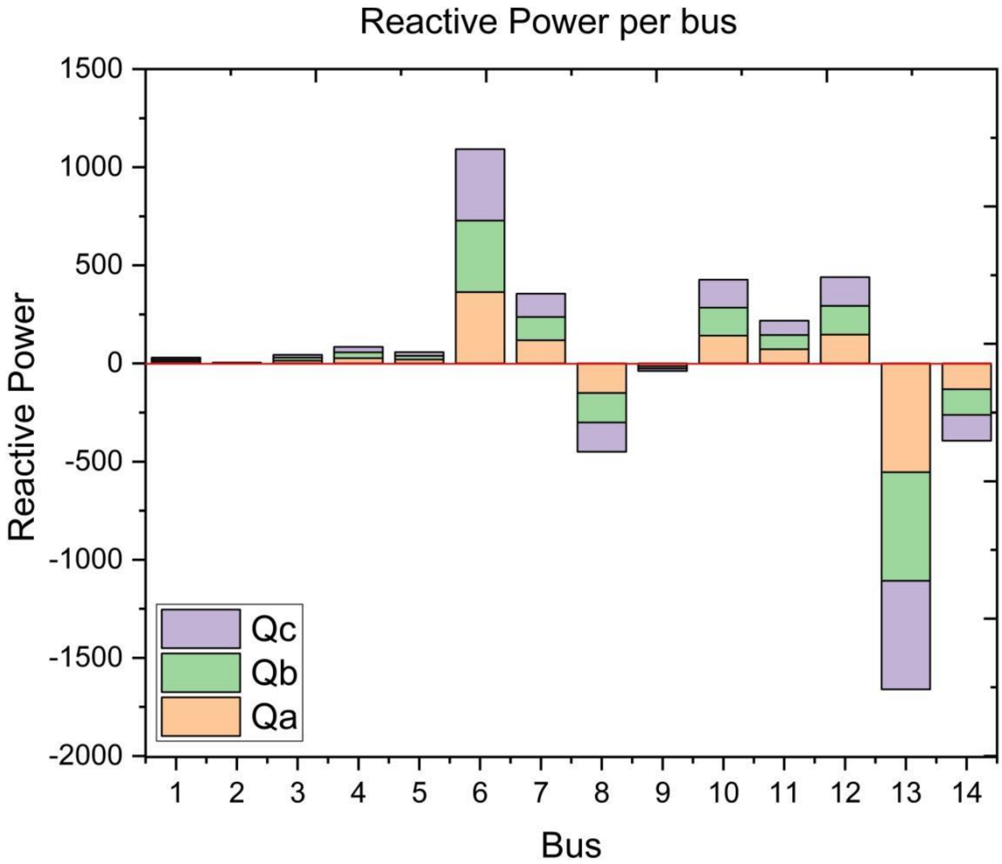

Figure 5: Reactive power at each bus

4.4. Transmission Losses Calculations

P_{active} losses were computed for both balanced and unbalanced currents, which were then compared. The Power losses are calculated as

$$\Delta P_l = R_l \times \sum_{j=1}^{i} |I_j|^2 + R_n \times \sum_{j=i}^{i} |I_j|^2$$

Where, Ij depicts the circulating current in the phase during charge state of phase a, R_n&R_l Phase and Neutral Resistors, i is the phase no's.

The loss per phases in each of the system's lines are depicted in Figure 6, which depict the losses in the situations of peak load and minimal demand, respectively. Both figures demonstrate that the lines that supply buses in the reduced voltage grid have the largest amounts of loss, which is consistent with previous findings. It can be noted that the line 7 phase a has the losses among the per phase are considerable, a number that correlates to the transportation of high imbalanced powers over a short distance, despite the fact that the line is relatively short.

Figure 6 depicts the imbalance of real power loss per phase that resides in the buses with loads in unbalanced scene as depicted in the previous paragraph. This imbalance is caused by a component of only one loads that are linked to the reduced voltage grid of the system under consideration.

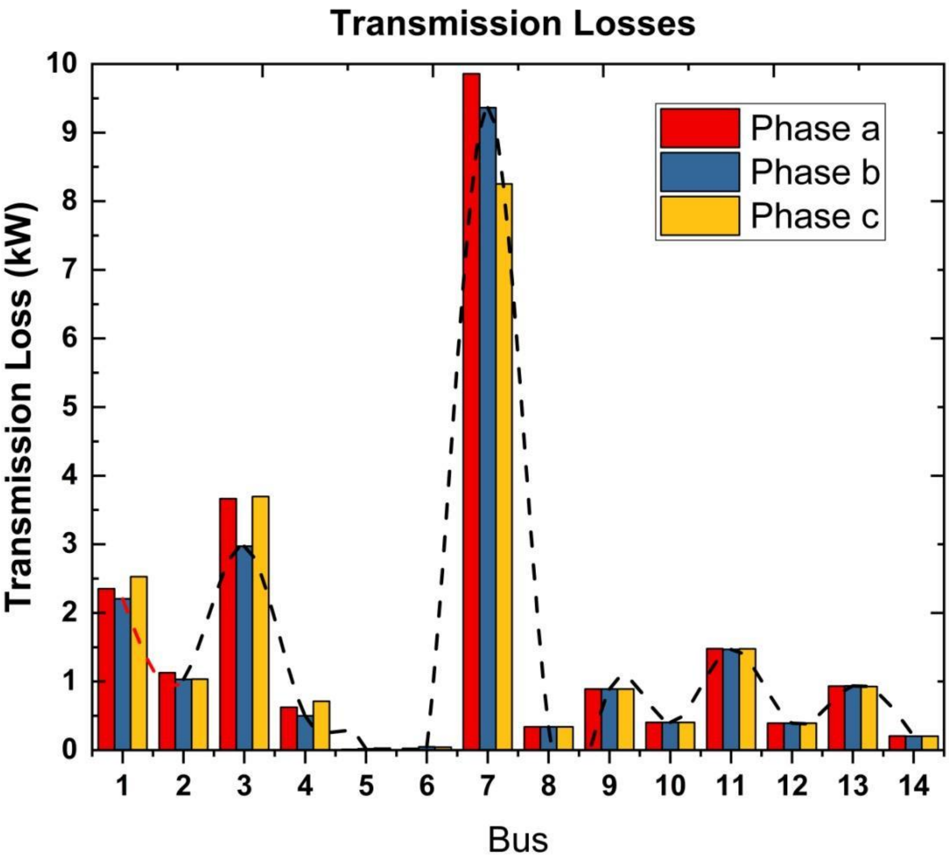

Figure 6: Per Phase Transmission Line Losses for maximum Demand

4.5. Power factor for 14 individual buses

Among the most significant factors to consider when calculating power flows in systems that need to be balanced is the maximum power per bus. Figure 7 depict the output power for each bus in the system under max demand situations. In the case of peak load (Figure 7), the active power in buses 2 and 9 is nearly equal to one. This is because, at maximum demand, Bus 2 only receives active power to the DC MG, but Bus 9 has a nearly unitary power factor given the fact that the measure was taken straight in the non-linear demand.

Because bus 14 is a transfer bus, there is a significant decrease of the active power in both case. Bus 5 is in a similar scenario because it solely serves as a transfer bus between lines 2, 3, and 5. In addition, this bus is conveying a reactive power that is more than the power output. BESSS #2 by itself is 0.8 seconds behind schedule. This striking disparity in power factors can also be seen in buses 5 and 6, which is related to the lack of active power contribution in solar photovoltaic generation, which does not occur in the situation of minimal demand. This research demonstrates the potential for conflict in the different PF when only active power is used to compensate a power electrical system. It can be observed that power factor in the network diminishes when just active power is injected, necessitating a need to adjust a systems with more criteria, including simultaneous active and reactive compensation.

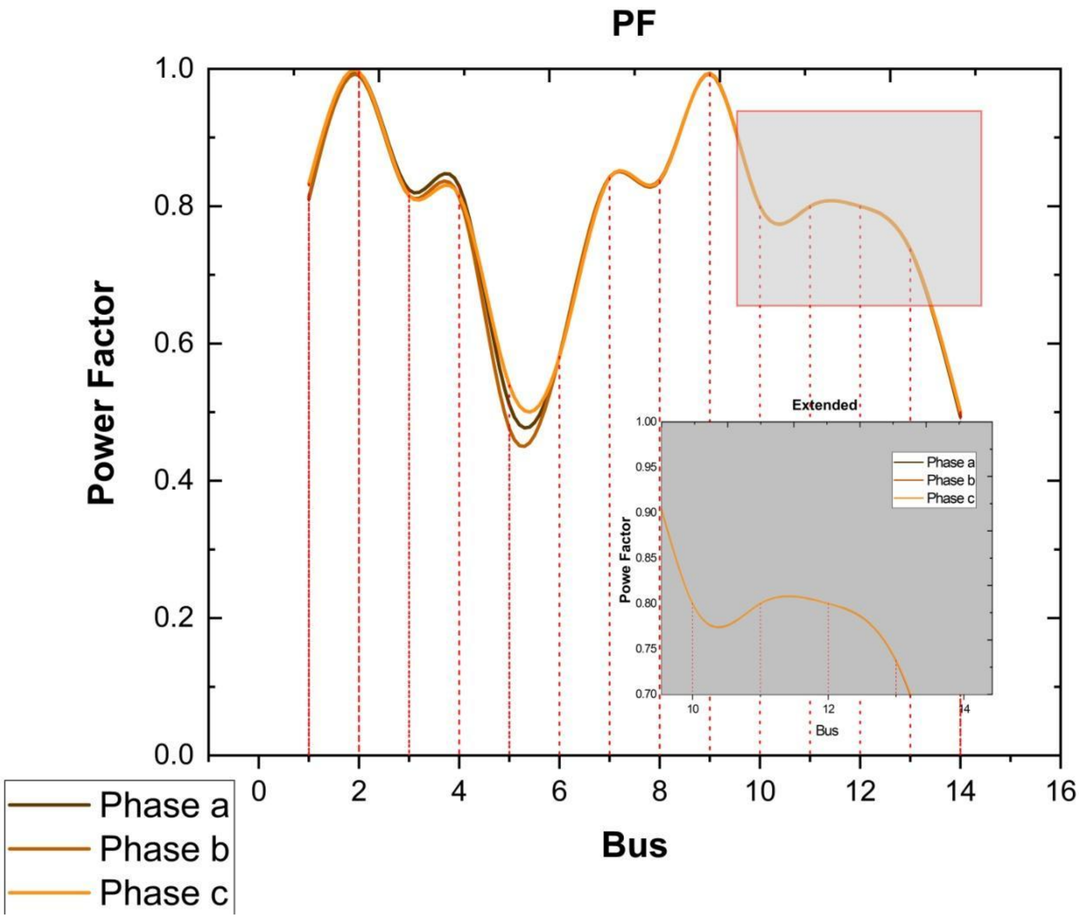

Figure 7: Power Factor

5. Future Research Areas

Fault modeling may be used in the future to not only better understand the many failure mechanisms (their causes and consequences), but also to research the best approaches for prompt detection, diagnosis, and localization. Furthermore, the MHM configuration will be analyzed based on the cost and optimization of the complete isolated and interconnected renewable and battery energy management system. The optimization and cost can be performed on the Homer resulting better and accurate results providing both economical and efficient system to implement.

6. Conclusion

In the work we have incorporated an AC/DC MHM using the standard test bed of IEEE 14. Both of wind energy, photovoltaic energy was chosen as a renewable energy source. There is a one-line schematic and critical info for the 13,8 kV primary and 0,22 kV secondary systems. The study considers two scenarios: minimal and maximum power needs. Each scenario's findings are disclosed. Every bus has a measuring module. Calculation of THDV and THDI for current and voltage, as well as transmission lines losses and power factor. A thorough grasp of the difficulty of each of the factors involved in the study of efficiency and quality of electricity has been achieved by analyzing the findings of the two situations predicted by this suggested model. Concerns about power factor have been raised owing to increasing adoption of photovoltaic solar and wind power output, which can reduce the power factor experienced by commercial companies that supply electric service connected to the grid.

In the future, MHMs may assist reduce fossil fuel usage and boost grid efficiency by integrating DG units into the Smart Grid. However, the following elements continue to pose problems: the great number and diversity of micro resources employed, electronic device power conditioning and other circuits/devices, parametric uncertainties, models, and high failure rates. The work allows the researchers to investigate transient stability, testing control techniques and hierarchical control structure, exploring isolated scenarios and simulating diesel generator dynamics. Even though it depends to a considerable extent on the application and the integrated environment, the inquiry provides for further exploration of the scenarios and topologies of the linked AC/DC HMGs, as well as dynamic studies for various AC/DC HMG configurations. In addition to improving device reliability, efficiency, and affordability, this study lays the groundwork for future research on MGs.

References

[1] Cai, Wei, Xing Li, Akbar Maleki, Fathollah Pourfayaz, Marc A. Rosen, Mohammad Alhuyi Nazari, and Dieu Tien Bui. "Optimal Sizing and Location Based on Economic Parameters for an Off-Grid Application of a Hybrid System with Photovoltaic, Battery and Diesel Technology." *Energy* 201 (June 2020). https://doi.org/10.1016/J.ENERGY.2020.117480.

[2] Chen, Yu Kai, Yung Chun Wu, Chau Chung Song, and Yu Syun Chen. "Design and Implementation of Energy Management System with Fuzzy Control for DC Microgrid Systems." *IEEE Transactions on Power Electronics* 28, no. 4 (April 2013): 1563–70. https://doi.org/10.1109/TPEL.2012.2210446.

[3] Dursun, Bahtiyar. "Determination of the Optimum Hybrid Renewable Power Generating Systems for Kavakli Campus of Kirklareli University, Turkey." *Renewable and Sustainable Energy Reviews* 16, no. 8 (October 2012): 6183–90. https://doi.org/10.1016/J.RSER.2012.07.017.

[4] El-Sattar, Hoda Abd, Hamdy M. Sultan, Salah Kamel, Tahir Khurshaid, and Claudia Rahmann. "Optimal Design of Stand-Alone Hybrid PV/Wind/Biomass/Battery Energy Storage System in Abu-Monqar, Egypt." *Journal of Energy Storage* 44 (December 2021): 103336. https://doi.org/10.1016/J.EST.2021.103336.

[5] Gupta, Ankit, Pawan Kumar, Rupendra Kumar Pachauri, and Yogesh K. Chauhan. "Performance Analysis of Neural Network and Fuzzy Logic Based MPPT Techniques for Solar PV Systems," October 2015, 1–6. https://doi.org/10.1109/POWERI.2014.7117722.

[6] Ishaque, Kashif, and Zainal Salam. "A Review of Maximum Power Point Tracking Techniques of PV System for Uniform Insolation and Partial Shading Condition." *Renew Sust Energ Rev* 19 (2013): 475–88. https://doi.org/10.1016/j.rser.2012.11.032.

[7] Kaabeche, A., M. Belhamel, and R. Ibtiouen. "Sizing Optimization of Grid-Independent Hybrid Photovoltaic/Wind Power Generation System." *Energy* 36, no. 2 (2011): 1214–22. https://doi.org/10.1016/J.ENERGY.2010.11.024.

[8] Li, Rong, Su Guo, Yong Yang, and Deyou Liu. "Optimal Sizing of Wind/ Concentrated Solar Plant/ Electric Heater Hybrid Renewable Energy System Based on Two-Stage Stochastic Programming." *Energy* 209 (October 2020). https://doi.org/10.1016/J.ENERGY.2020.118472.

[9] Maleki, Akbar. "Design and Optimization of Autonomous Solar-Wind-Reverse Osmosis Desalination Systems Coupling Battery and Hydrogen Energy Storage by an Improved Bee Algorithm." *Desalination* 435 (June 2018): 221–34. https://doi.org/10.1016/J.DESAL.2017.05.034.

[10] Akbar Maleki. "Modeling and Optimum Design of an Off-Grid PV/WT/FC/Diesel Hybrid System Considering Different Fuel Prices." *International Journal of Low-Carbon Technologies* 13, no. 2 (June 2018): 140–47. https://doi.org/10.1093/IJLCT/CTY006.

[11] Rai, Amit, Ashish Shrivastava, K. C. Jana, and Jayalakshmi N.S. "Techno-Economic-Environmental and Sociological Study of a Microgrid for the Electrification of Difficult Un-Electrified Isolated Villages." *Sustainable Energy, Grids and Networks* 28 (December 2021): 100548. https://doi.org/10.1016/J.SEGAN.2021.100548.

[12] Ramasamy, Krishnakumar, and Coimbatore Subramanian Ravichandran. "Optimal Design of Renewable Sources of PV/Wind/FC Generation for Power System Reliability and Cost Using MA-RBFNN Approach." *International Journal of Energy Research* 45, no. 7 (June 2021): 10946–62. https://doi.org/10.1002/ER.6578.

[13] Rezk, Hegazy, Mohammad Ali Abdelkareem, and Chaouki Ghenai. "Performance Evaluation and Optimal Design of Stand-Alone Solar PV-Battery System for Irrigation in Isolated Regions: A Case Study in Al Minya (Egypt)." *Sustainable Energy Technologies and Assessments* 36 (December 2019). https://doi.org/10.1016/j.seta.2019.100556.

[14] Salman, Salman, Xin Ai, and Zhouyang Wu. "Design of a P-&-O Algorithm Based MPPT Charge Controller for a Stand-Alone 200W PV System." *Protection and Control of Modern Power Systems* 3, no. 1 (December 2018): 1–8. https://doi.org/10.1186/S41601-018-0099-8/FIGURES/10.

[15] Sivakumar, P., Abdullah Abdul Kader, Yogeshraj Kaliavaradhan, and M. Arutchelvi. "Analysis and Enhancement of PV Efficiency with Incremental Conductance MPPT Technique under Non-Linear Loading Conditions." *Renew Energy* 81 (September 2015): 543–50. https://doi.org/10.1016/j.renene.2015.03.062.

[16] Zhang, Ge, Yong Shi, Akbar Maleki, and Marc A. Rosen. "Optimal Location and Size of a Grid-Independent Solar/Hydrogen System for Rural Areas Using an Efficient Heuristic Approach." *Renewable Energy* 156 (August 2020): 1203–14. https://doi.org/10.1016/J.RENENE.2020.04.010.

[17] Zhang, Weiping, Akbar Maleki, Ali Komeili Birjandi, Mohammad Alhuyi Nazari, and Omid Mohammadi. "Discrete Optimization Algorithm for Optimal Design of a Solar/Wind/Battery Hybrid Energy Conversion Scheme." *International Journal of Low-Carbon Technologies* 16, no. 2 (May 2021): 326–40. https://doi.org/10.1093/IJLCT/CTAA067.

[18] Zhou, Zhe, Pei Liu, Zheng Li, and Weidou Ni. "An Engineering Approach to the Optimal Design of Distributed Energy Systems in China." *Applied Thermal Engineering* 53, no. 2 (May 2013): 387–96. https://doi.org/10.1016/J.APPLTHERMALENG.2012.01.067.