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Optimal Coordination of Hybrid AC/DC Microgrids based on IEEE-12 Bus System: An Analytical Approach

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ABSTRACT- Recently, the microgrid's design and implementation techniques have placed a significant emphasis on alternating current (AC) systems. Due to their many benefits, DC microgrids are becoming more and more popular than AC microgrids. The benefits include the elimination of frequency modulation and the requirement for synchronization. DC microgrids are better suited for distributed energy resources (DERs) and DC loads. When it comes to hybrid microgrids, the options are practical and reasonably priced. Graphical depictions of the voltage profiles, wind generation, and total PV generation show how the system operates and performs. The removal of power converters between AC, DC systems is the cause of this. This article suggests an analytical approach for the best possible coordination between AC, DC microgrids using the IEEE 12 bus system.

Keywords: Optimal coordination, hybrid AC/DC microgrid, PV Generation, Wind Generation, Voltage profiles.

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1. INTRODUCTION

Now-a-days, Renewable energy sources are widely used in the distribution system at the moment. RES provide numerous advantages for the system, but they also have certain disadvantages, like the possibility of unintentional islanding, security risks, reverse power flow, etc. Unexpected issues or scheduled maintenance schedules may cause a distribution system to be divided into several islands if there are enough dispersed generation units available. Distribution systems should therefore be able to recognize islanding situations in order to guarantee a smooth transition to an islanded mode [2]. The diverse inclinations of microgrid (MG) users efficiently incite the requirements of MG concerning energy administration. To A new Demand Side Management (DSM) and Power Management Regulation Control (PMRC) approach taking into account varying preferences. In the microgrid, wind and photovoltaic systems are integrated with a hybrid Storage System that consists of batteries and a fuel cell/electric generator set as Renewable Energy Sources (RES). In order to achieve Net Zero Energy Supply, a microgrid of this kind is appropriate for remote, communities with AC-controlled essential loads [3]. offers a comprehensive control approach for distributed generation (DGs) based on inverters used in grid-connected microgrids (MGs). To adjust the o/p voltages of the distributed generators in the case of faults and balanced or unbalanced loading, the recommended control method adjusts the DGs' active and reactive power [4].

Microgrid (MG) technologies offer users attractive benefits including improved power quality and are made possible by integrating these distributed energy sources into the utility system. Even though ordinary MPPT controllers work well under uniform solar irradiation, they perform badly when PV modules are partially shaded. Furthermore, traditional droop-based primary controllers are considerably simpler and more effective in most situations [5]. The power o/p of the storage at every node is calculated using the DC power flow sensitivity for forward-back generation. When making judgements about charging and discharging, the energy storage system's state of charge (SOC), current voltage, and prior and subsequent charging and discharging scenarios are considered. The efficient operation of the bidirectional interlinking converter (BIC) control requires only two consensus indexes, one from each AC/DC sub-grid [6]. Moreover, an unrestricted power control methodology was proposed for the system [7]. The simulation experiment's conclusions show that the system operates normally during the first sample time and that the MPC algorithm divides up the energy storage devices' discharge into two different types in order to meet the net load requirement without using any external network power. An integrated energy system can be designed in a variety of ways [8]. Energy storage system that stores both electricity and heat, and a combined cooling, heating, and power system. An optimal two-tier scheduling model is then constructed for an integrated energy system with many energy storage types at its core. Through appropriate placement and sizing, battery energy

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storage systems (BESS) and renewable distribution generators (DG) are integrated in the distribution network (DN) to improve the bus voltage profile and decrease active power loss [9, 10]. This work computes the best placement for distributed generators (DGs) considering a loss sensitivity factor, power flow along the branches, and bus losses.

2. LITERATURE REVIEW

Numerous studies have been conducted to address the problems related to these systems, according to the literature review. The P&O MPPT algorithm controls the duty cycle of the PV and wind system, which connect to the DC bus. This is the Islanded DCMG that was covered by Kumar J.,[1] et al. An artificial gorilla troop optimizer was created by Murugan S [2] et al. to control energy consumption in DC–AC hybrid distribution networks using artificial neural networks. An IC and a hybrid energy storage system (HESS) was presented by Jithin S. [3] et al. to improve the HMG. The basic design and coordination control methodology of an AC–DC-Hybrid microgrid were built by Li Q. et al. [4]. Additionally, a better microgrid model is proposed. Based on power flow estimates, Mousa H.H.H.,[5] et al. proposed a compensation method employed in MV-level buses and LV-level load buses. To effectively depict load dynamics, W.V Jahnavi., et al. [6] used a composite load model (CLM) to study the signal stability of hybrid MGs. A unified small-signal dynamic model for microgrids was created by Wu X., et al. [7]. Lee S.-J. [8] et al. introduced the distributed multi-microgrid control technique. An approach to microgrid coordination control based on reconfigurable Petri-net technology was presented by W.V. Jahnavi [9]. et al. in order to improve the efficiency and security of power supply from renewable energy microgrids. Rasool A. et al. [10] introduced a novel control approach called bouncy control. This control uses a variable emergency gain to adjust the power contribution of each VSG during a disturbance. Jalali M., [11] et al. provided a distributed resilient operating technique for a distribution system with many microgrids. The PMRC that Younis R.A[12]., et al. described utilizing a Multi-Agent System suggests two levels of control. Babaiahgari B.,[13] et al. presented a ground-breaking solution here for optimally reconfiguring a DC microgrid system as operating conditions change. Voltage and current may be controlled simultaneously in real time with this technology. Pannala S. [14] et al. developed a revolutionary power management method (PMS) to ensure proper coordination. Voltage control and energy management strategies for active distribution systems were discussed by Dinakar Prasad Reddy., [15] et al. with reference to two types of dc microgrids: one connected to the grid and the other located on an island and using hybrid energy resources. Using real-time recorded solar and wind data with a 12-month loading period, used MATLAB to construct and simulate different source and load variation scenarios. Ui H. [16] et al. proposed a coordination control strategy to leverage flexibility from supply-side DGs as well as demand-side load resources. Salman M. [17] et al. proposed a coordination-based power management strategy based on a consensus algorithm. The keys to microgrid clusters, however they did not fully address the varied configurations and coordinated operation across several microgrids. A regulated AC/DC integration system combines the benefits of both AC and DC integration approaches. Baseer M.,[18] et al. introduced a novel HMG planning model in the context of microgrid markets with the aim of maximizing net social welfare (NSW). Ademulegun O.O.,[19] et al. developed a power electronic converter based on fuzzy-logic controller to handle power transmission and control in a grid-connected household solar (PV) system with battery storage. Feeder placement that maximizes efficiency, and the hybrid microgrid's cost-effective control methodologies are some of the major issues pertaining to hybrid microgrids that were covered by Azeem O. [20] et al. Rajkumar A.[21] et al. suggested an effective energy management scheme in the microgrid (MG) architecture to help lowering energy usage by taking into consideration the integration of renewable energy sources.

3. PROPOSED METHODOLOGY

3.1. Hybrid AC/DC Microgrid

The schematic layout of a hybrid AC/DC microgrid is presented in *figure 1*. Grid-tethered operation mode for the hybrid microgrid is dependent upon the utility grid. Operating in grid mode, the hybrid microgrid is continuously linked to the utility grid. To keep the energy balance on both girds is necessary. This will maintain a steady DC side terminal voltage [2], [3].

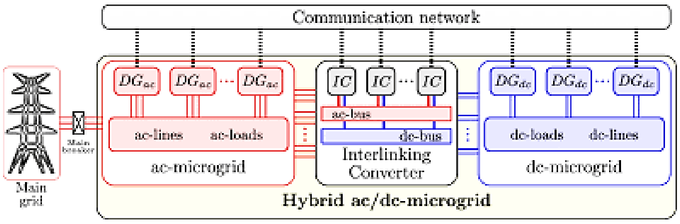

Figure 1. Hybrid AC/DC Microgrid

Hybrid microgrids are challenging to plan and maintain since they need synchronized operating and protection strategies in addition to managing power flow between the AC and DC subsystems. For hybrid AC/DC microgrids to function well and consistently, effective coordination techniques are essential. These tactics include, for instance, optimal power flow algorithms, enhanced control techniques, and energy management systems.

3.2. IEEE 12 Bus System

A common test system for power system analysis and research is the IEEE 12 bus system. With its twelve buses (nodes) and several interconnecting transmission lines, transformers, and generators, it is a simplified depiction of a tiny power grid.

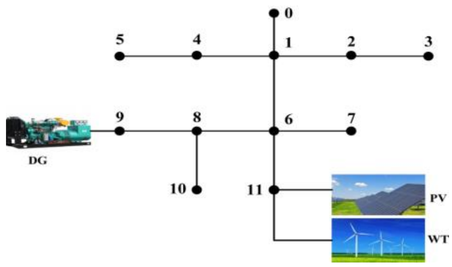

Figure 2. Single line diagram of IEEE12 Bus System

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Many power system analysis methods, including power flow studies, contingency analysis, optimal power flow computations, and other power system simulations, are tested and evaluated on the IEEE 12 bus system. It gives scientists and engineers a standard by which to measure and verify their techniques and algorithms against a recognized and commonly used test case.

3.3. Load Flow Technique

A high R/X ratio characterizes distribution networks as radial. The load flow problem has gotten worse as a result. Numerous strategies have been developed and tested, from conic programming formulation to sweep methods. Load flow technique related on the Newton methodology was proposed by Esposito and Ramos. A bus incidence matrix has been used to establish the relationship b/w complex branch and bus powers [5, 6]. This load flow approach has the advantages of not requiring a beginning value and having all equations expressed in matrix form. Distribution networks with voltage-controlled buses may employ this technique [1].

The following actions are taken to ensure that the hybrid AC/DC microgrid is coordinated as well it may be.

Step 1: First, the microgrids' line and bus data are initialized.
Step 2: The entire real and reactive loss are computed using LF
Step 3: Initially, the DC microgrid's 13th bus is linked to the AC microgrid's second bus.
Step 4: At this connection, the power losses are calculated.
Step 5: The 3rd bus is linked to the DC side 13th bus.
Step 6: Carry out *Step 4* again.
Step 7: Switch the 13th DC microgrid's connection from the third bus to the fourth bus of the AC microgrid, until we get to the AC microgrid's twelfth bus.
Step 8: Calculate each connection's losses.

$$P_{jk} = G_{jk}(|V_j^2| - |V_j||V_k|\cos(\phi_{12})) - B_{jk}|V_j||V_k|\sin(\phi_{12})$$

To determine each PV bus j's phase angle, trigonometric equations must be solved, and the reactive power needs to be revised as

$$Q_{jk} = B_{jk}(|V_j|^2 - |V_j||V_k|\cos(\phi_{12})) - G_{jk}|V_j||V_k|\sin(\phi_{12})$$

Symbols:
V_j –node j bus current
V_k - node k's bus vol
P_{kj}-Real power received from *j* at node-k
S_{jk}–Reactive power from node-j to node-k

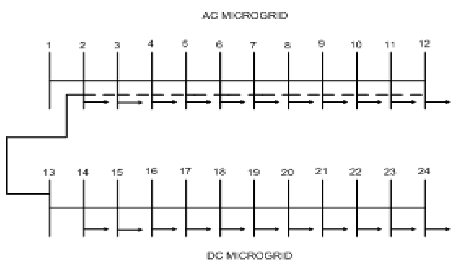

Figure 3. IEEE12 Bus System

The link at which we have the fewest losses is the best one for synchronizing AC and DC microgrids. *Figure 3* depicts the hybrid AC/DC microgrid Line representation with 24 buses.

4. DISCUSSION

Here, two IEEE 12 bus systems combine to form the hybrid microgrid. In total, there are 24 buses in the hybrid system. Among 24 buses, 12 have been designated as an AC microgrid, meaning they are from bus 1 to bus 12, while the remaining 12 are designated as a DC microgrid, meaning they are from bus 13 to bus 24. The sole difference between the data for AC, DC microgrids is that the reactive power, line reactance for the DC microgrid is treated as zero.

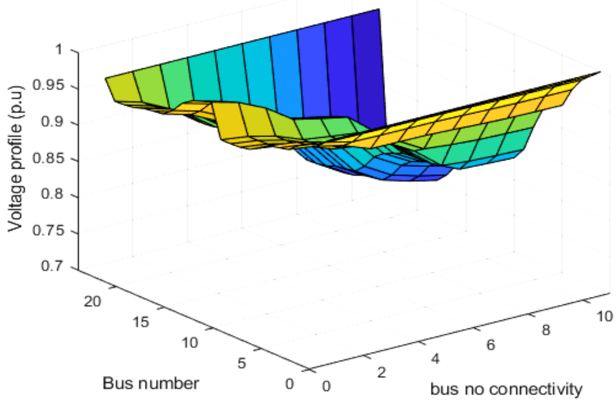

Figure 4. Voltage Profile

Figures 4 and *figure 5* represent the corresponding voltage profiles, The analysis of voltage profiles in both the AC and DC subsystems guarantees that the voltage levels stay within reasonable bounds. Voltage profiles at various buses or nodes can be graphically represented to demonstrate the influence of integrating renewable energy sources and the efficacy of voltage management techniques. Talks can center on the voltage variations seen, the efficiency of the voltage control techniques used, and the hybrid microgrid system's overall voltage stability.

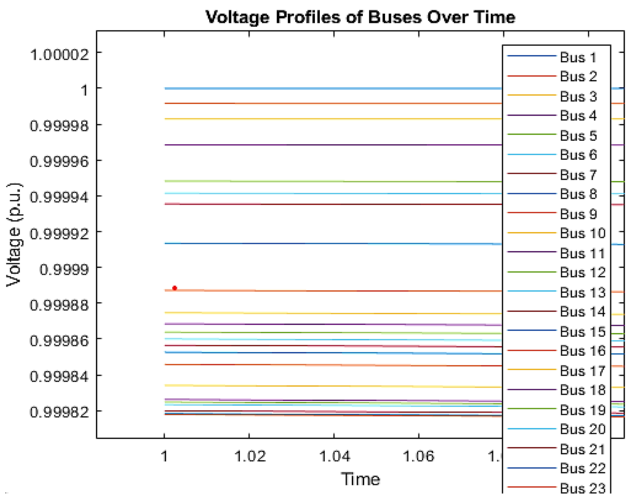

Figure 5. Voltage Profile of the microgrid in 2D (Zoomed Plot)

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Figure 6 depicts the power losses respectively. The optimization procedure seeks to reduce the system's overall power losses, both reactive and actual. The total real and reactive power losses under various scenarios or optimization techniques might be represented graphically or numerically in the results. In comparison to conventional or non-optimized scenarios, discussions can emphasize the decrease in power losses in Table-I attained by efficient coordination, integration of renewable energy, and utilization of energy storage. The outcome demonstrates that the second bus is the best position for coordinating DC and AC microgrids.

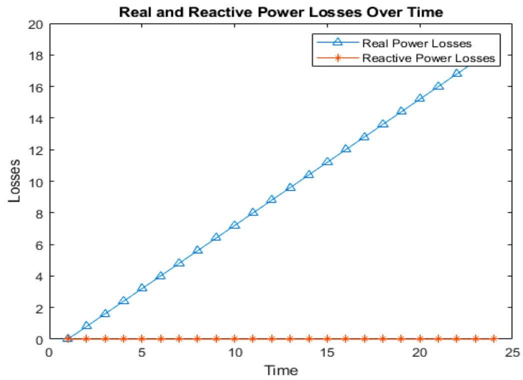

Figure 6. Real and Reactive power Losses over time

Table 2. Total losses in KWh

Power Losses	BUS NO CONECTIVITY										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
TPLOSS	0.4660	0.05310	0.0643	0.08110	0.869	0.09210	0.1137	0.1420	0.1613	0.1733	0.1810
TQLOSS	0.82000	0.8226	0.8276	0.83590	0.83900	0.84180	0.84860	0.85950	0.86880	0.87280	0.8768

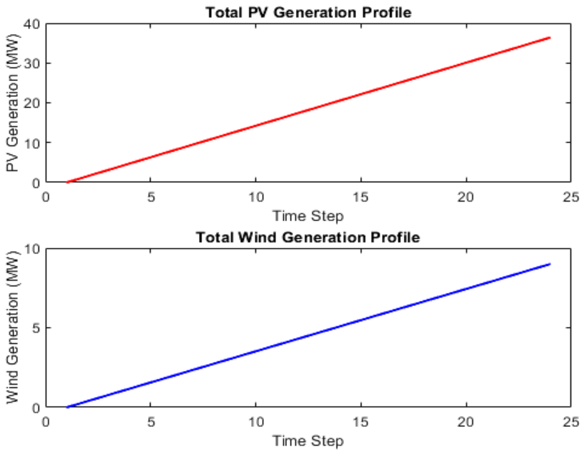

Figure 7. Total PV Generation and Wind Generation of the microgrid in KWh

Graphical representations of depicts the the hybrid microgrid system's total PV generation, such as line plots or bar charts, can be used to illustrate the contribution of solar energy over various time periods or situations. The influence of PV generation on the total energy mix, the efficacy of PV integration techniques, and the function of energy storage in reducing the erratic nature of solar energy can all be topics of discussion. Like PV generation, total wind generation can be visually displayed to show how wind energy contributes to the hybrid microgrid system. It may include the unpredictability of wind energy production in *table 2*, the difficulties in integrating wind energy, and the significance of precise wind forecasting and energy storage for efficient use.

Table 2. TOTAL PV Generation and Wind Generation in KWh

STEP SIZE	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total PV Generation	0.0	0.0	0.0	0.1	0.3	0.6	1.0	1.5	2.0	2.5	3.0
Total Wind Generation	0.0	0.01	0.03	0.03	0.07	0.09	1.0	1.3	1.5	1.7	2.1

Through comparison with baseline or non-optimized examples, the results can show the overall levels of penetration and utilization of renewable energy achieved through the optimal coordination technique. To demonstrate the possible cost savings or financial advantages of the suggested strategy, discussions can contrast the operating expenses with and without the inclusion of renewable energy.

5. CONCLUSIONS

This paper suggested an analytical method for the optimal coordination of microgrids with the addition of renewable energy sources, using the IEEE 12 bus system as a test example. The suggested methodology sought to optimize the utilization of sustainable energy resources, such as wind and solar photovoltaic (PV), while upholding the hybrid microgrid system's dependability and effectiveness. The outcomes showed how well the suggested methodology worked to provide the greatest possible coordination between the DC and AC subsystems. Voltage control techniques were used to keep the voltage profiles across the system within allowed bounds. Reductions in both reactive and real power losses increased the overall efficiency of the system. The hybrid microgrid system's successful integration of renewable energy sources was demonstrated by the graphical representations of total wind and photovoltaic generation. By using energy storage devices, the suggested strategy successfully took advantage of the complementing qualities of wind and solar energy to reduce the issues associated with intermittency. All things considered, the suggested technique for the best possible coordination of AC and DC microgrids with the incorporation of renewable energy shown its potential to improve the sustainability, dependability, and financial sustainability of hybrid microgrid systems. The study's conclusions support further initiatives to integrate distributed energy resources and move towards a more robust and sustainable energy environment.

Prospective study avenues may involve delving into sophisticated optimization methodologies, examining the effects of nascent technologies (such as vehicle-to-grid integration and hydrogen-based energy storage), and formulating all-encompassing control and safeguarding tactics for microgrid hybridization. It is also necessary to address practical implementation issues including stakeholder participation, legal frameworks, and infrastructure design to promote the widespread adoption of well-coordinated hybrid microgrids that integrate renewable energy.

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