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HYBRID GRID ENERGY MANAGEMENT USING RENEWABLE ENERGY SOURCES: A STRATEGIC SOLUTION FOR POLLUTION-FREE POWER SYSTEMS

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ABSTRACT

The global demand for clean and reliable energy has accelerated the integration of renewable energy sources (RES) such as solar and wind into power grids. Hybrid AC/DC microgrids, leveraging distributed generation (DG) and energy storage systems (ESS), have emerged as a promising solution to mitigate power quality issues, reduce dependency on fossil fuels, and enhance operational flexibility. However, the unique characteristics of RES—such as intermittency and variability—pose significant challenges to energy management systems (EMS). This paper explores a multi-agent based hierarchical EMS framework to optimize power flow and ensure efficient integration of distributed energy resources. Simulation and case studies demonstrate the potential of hybrid microgrids to support a stable and resilient future energy infrastructure.

Keywords: Hybrid, Energy, Renewable Energy, Power

1. INTRODUCTION

Numerous power quality issues have been brought on by the rising use of switching-element-based nonlinear loads. With the advancement of power electronics technology, the harmonic emission is visibly rising. The introduction of harmonics into the power grid affects the consumers of these power networks in a number of ways. It interferes with the grid's connected devices' ability to operate normally. Harmonic voltages can be produced by harmonic currents, and their propagation can be hazardous for many electrical power users. The items most impacted by harmonic pollution are communication systems, protection circuits, control systems, and biomedical equipment. International electrical organizations like IEC and IEEE have adopted a number of rules and guidelines aimed at minimizing the harmonic emission of loads.

A micro grid is a grouping of modestly sized electrical sources that might be AC, DC, or hybrid and rely mostly on renewable energy for power. The utility grid enables the independent operation of micro grids. As the use of energy storage, DC integral loads, and renewable energy sources increased, so did the use of DC micro grids in the power sector. A DC micro grid reduces the amount of time needed for power conversion. Because it doesn't need frequency, phase, or reactive power regulation while operating, it has an advantage over AC micro grids. Energy storage devices can create income by being charged when local electricity prices are low and discharged when prices are higher, making them a practical solution to deal with renewable energy intermittency and increase the grid's utilization of renewable energy sources. The simulation and outcomes demonstrate the planned idea's electiveness. It is crucial in metropolitan areas without a utility grid to integrate DC micro grids because they provide steady electricity. A micro grid is made up of linked distributed energy resources that can continually meet a sizable portion of the energy requirements of internal loads. Problems of system voltage unbalance and sudden changes in the grid voltages are essential issues in electrical engineering.

Storage batteries, solar, wind, and other distributed renewable energy sources can all be seamlessly integrated into micro networks. The DC micro grids use a variety of controlling techniques to alleviate some issues. The boost converter in a micro grid can use it to support a wide range of input voltages and output voltages from diverse sources. PV array are connected to the main grid as a group in order to provide electricity to the users. Maximum power point tracking performances in the dc area and grid-connected DC PV systems. There are mainly three different types of micro grid being used in present scenario. It is described in below.

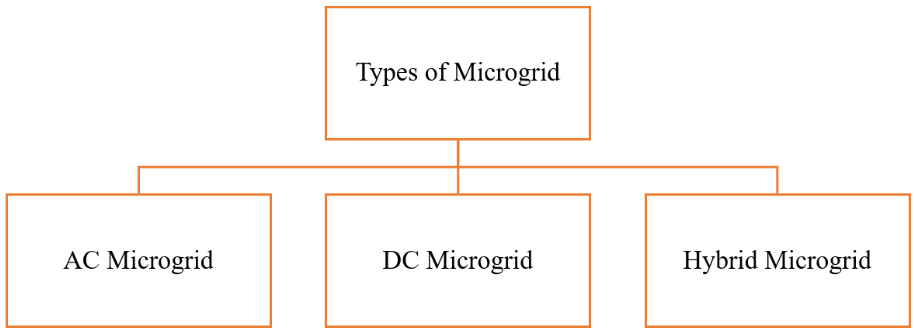

Figure 1 Types of Micro grid

AC Micro

Due to historical reasons, the bulk of current and loads are alternating current (AC), which a transformer can effectively step-up and step-down. The PCC connects the supply system, AC grid, and utility grid because it enables the transition between grid-connected and island modes. DC DERs, such as solar generators, require a DC-AC converter in order to connect to an AC bus. An inverter is connected to the AC system and a converter is needed to achieve power flow for charging or discharging. Since AC micro grid construction is more complicated than DC micro grid, more translating is needed.

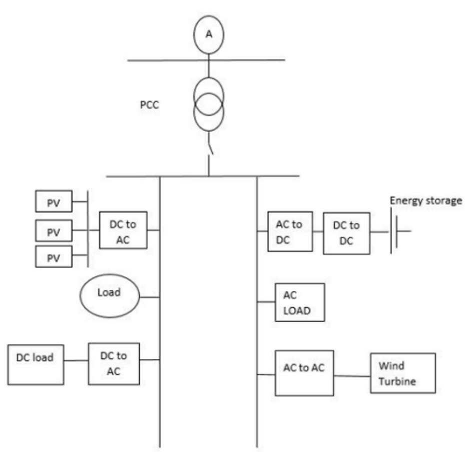

Figure 2 AC Microgrid Operational Structure

DC Micro grid:

It is a growing technology as a result of the increase in recent DC loads like electric vehicles, LED lights, and the fact that the majority of electronic devices are DC. In this regard, DC grid has shown the scope of its applicability. Like an AC microgrid, a DC micro grid connects to a multiple grid through the PCC, enabling smooth connections and detach transitions. DC micro sources like solar, batteries, and loads can be swiftly connected to a dc bus using a single step DC-DC converter. For AC loads like moving machinery, all that is required to communicate with the DC bus are rectifiers with controllers. AC generators, similar to windmills. The author found that DC micro grids are more effective in reducing power transfer losses when compared to AC micro grids in suburban structures. Additionally, when an ESS is utilized, the slight loss of DC micro grids may be considerably greater than that of their AC counterparts DC network, necessitating network redesign and requiring a sizeable expenditure.

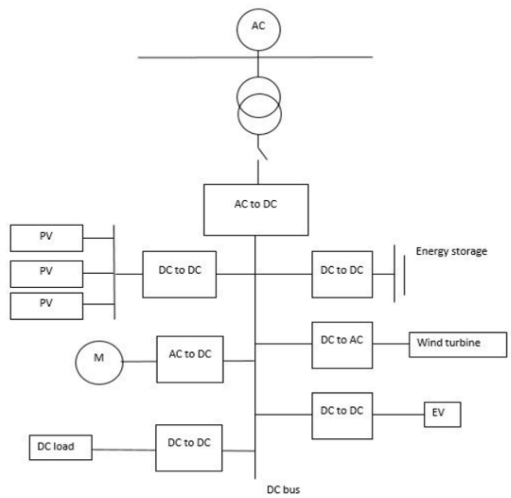

Figure 3 DC Microgrid Operational Structure

Hybrid Micro grid:

A hybrid microgrid is one that is connected to both an AC and a DC MG. A DC micro grid is generally connected to the AC bus using an AC/DC unidirectional converter, but in a hybrid, it is connected directly to the PCC. In essence, hybrid topology comprises both Micro and Nano topologies. An AC grid network that is connected to a sub-DC microgrid is referred to as a hybrid micro grid; this architecture is more effective than an AC MG. An AC-DC converter serves as the main converter connecting the AC micro grid and DC microgrid in a hybrid micro grid. The power flow of these two subsystems is controlled by this converter. Additionally, managing many converters in concert is essential for a hybrid microgrids stability and effectiveness.

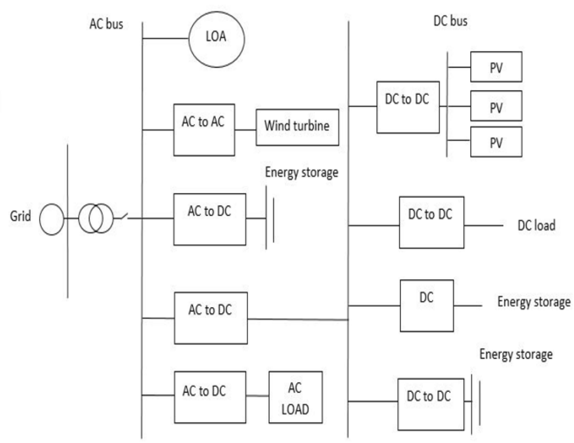

Figure 4 Hybrid Microgrid Operational Structure

Many appliances have voltage and frequency operating ranges that are restricted. The devices' functionality may be impacted by rapid voltage changes or even permanently stopped. Use of various voltage regulators and protective devices is therefore an essential precaution. By maintaining the load side of the grid at a constant voltage level, these regulators can shield the linked devices from voltage fluctuations. The frequent starting and stopping of electrical motors is the main reason for voltage changes in power systems. For several seconds, during the initial stages of operation, these motors absorb significant currents. The voltage of the grid might vary significantly when numerous motors are started concurrently. Addressing the harmonic problems, different solutions have been proposed. These solutions differ from applying modifications on the grid or the load, so it emits fewer harmonics to connecting specially designed devices to suppress the harmonics and filter them. [1, 2]

1.2. RESEARCH AREA OF POWER QUALITY

Using RLC elements in the form of filter banks that were set to provide a short circuit or low impedance for the frequencies of harmonics to be canceled was the simplest way of harmonic filtering. These filters, which are referred to as passive filters, will exhibit high impedance for the core frequency. Because of their simplicity and simplicity in installation, passive filters were the first suggested alternatives. In the case of stable static systems, where many fluctuations are not anticipated, they can be seen as a promising method. Because of their static behavior and inability to respond to changes in the load, passive filters may be less suitable in the event of dynamic, unpredictable systems. Additionally, they may generate resonance at certain frequencies, which may result in stability. The 1980s saw the introduction of active filters into electrical power grids. They are dynamic systems that were meticulously created to dynamically correct for harmonic currents and voltages. They can respond without delay to changes in the load and the system. Since the day they were first presented, active filters have drawn increasing amounts of attention from researchers. The adaptability of the active filters for the system parameters is their key benefit. Based on the conditions of the system, they can efficiently alter their behavior. [1.1]

Different sorts of active power filters are utilized for different voltage regulation and voltage harmonics abatement purposes. The currents can be filtered, and their harmonics can be removed, using further active filters. The third form enables simultaneous harmonic current cancellation and voltage adjustment. For voltage regulation, series active power filters are employed. To compensate for current harmonics and reactive power, shunt APF was devised. The Unified Power Quality Filter or Conditioner, which is responsible for the simultaneous payment of voltage, current harmonics, and reactive power, combines the two types of Shunt and Series APF in one device. The term "Hybrid APFs" (HAPFs) refers to a variety of APF and passive filter combinations that have been utilized and proposed in the literature. The goal of combining the simple and the modern in one HAPF is to improve the performance of various forms of APF compensation while minimizing the expense and complexity of compensation systems. It is thought to combine the benefits of the previous passive filter. [1, 2]

FACTS (Flexible Ac Transmission Systems) Power Electronics have not lived up to expectations as the solution to all transmission system issues. Power electronics, however, are still in use today in practical applications to fix issues with distribution systems. In power distribution, power electronics can take on three different roles: one that introduces useful commercial and household equipment, another that causes issues, and a third that aids in resolving those issues. On the one hand, power electronics and microelectronics have developed into two technologies that have significantly raised the standard of living in the modern world by enabling the introduction of high-tech, programmable energy-efficient machinery. On the other hand, those same delicate technologies are in conflict with one another and making it harder to maintain the quality of service in the delivery of electric energy, which is also expensive in terms of lost consumer productivity and costs billions of dollars. Distribution networks increasingly use modern semiconductor switching devices in a variety of applications, particularly for residential and commercial loads.

The focus of this project work is mostly on micro grid-related power quality issues and control strategies. The main area of study in both academia and industry is the grid interaction of renewable energy systems with improved performance criteria. Concerns with power quality including voltage oscillation and current harmonics when it is incorporated with an AC microgrid. To lower the harmonics and enhance power quality, numerous active filters and an inverter were used instead of a big rated active filter.

- Some control strategies, management considerations, or system requirements must be made for the protection of power quality.

- The current MG system conversions to extra strong, exclusive, smart, and active power delivery to network but research provided the facility of continuous, steady, and safe power & also needs a useful outcome.
- Harmonics must be reduced since they are caused by non-linear loads from the use of power electronic devices and various motors. Therefore, more study is needed to reduce the quantity of harmonics for the Micro grid system to perform better.

The growing significance of DC micro grid and its applications is the primary driving force behind this dissertation. Give a plan for building a PV system that is connected to the grid.

DC micro grids have a number of benefits, including:

- This is mostly caused by the lack of warning tools.
- Small PV DC micro grid is more economically sensible.
- Trustworthiness is more.
- Improved transmission effectiveness.
- More affordable converter circuits that can result in further cost savings on top of the savings from using renewable energy sources.
- A DC micro grid may easily integrate with renewable energy sources, resulting in fewer power converter steps.

2. LITERATURE REVIEW

Numerous studies have explored:

- Integration and optimization of solar and wind in microgrid configurations.
- Control and mitigation of harmonics introduced by inverters.
- Hybrid microgrid structures and operation protocols.
- Deployment of intelligent EMS using multi-agent systems, AI, and IoT.

Yet, the scalability, cost-effectiveness, and real-time adaptability of hybrid systems require further investigation, particularly in developing economies.

3. PROBLEM STATEMENT

As more distributed generations (DGs) using RES connect to the grid, they bring technical challenges:

- Harmonic distortions from power electronic converters.
- Voltage and frequency instability.
- Reduced system inertia.
- Bi-directional and reverse power flows.

A hybrid AC/DC microgrid offers a potential solution but requires a sophisticated EMS for stability, efficiency, and resilience.

4. SYSTEM ARCHITECTURE OF HYBRID AC/DC MICROGRID

4.1. COMPONENTS

- Renewable Energy Sources (RES): Solar PV, wind turbines.
- Energy Storage System (ESS): Batteries for load shifting and voltage support.
- Power Converters: Interface DERs with grid, convert AC-DC and vice versa.
- Loads: Critical and non-critical residential, commercial, and industrial.

4.2. CONFIGURATION

- DC Bus: Connects PV, ESS, and DC loads.
- AC Bus: Connects conventional grid and AC loads.
- Interlinking Converters: Control power flow between AC and DC sections.

5. HIERARCHICAL ENERGY MANAGEMENT SYSTEM (EMS)

To manage the grid efficiently, a three-tier hierarchical EMS is proposed:

5.1. PRIMARY CONTROL

- Local voltage/frequency control.
- Immediate response to local changes.

5.2. SECONDARY CONTROL

- Grid synchronization.
- SOC balancing and reactive power control.

5.3. TERTIARY CONTROL

- Multi-agent optimization algorithms.
- Load forecasting and economic dispatch.
- Integration with utility grid and pricing mechanisms.

6. INTEGRATION OF PV AND BATTERY SYSTEMS

PV System Characteristics: PV output fluctuates with irradiance and temperature, making it unstable. A typical PV system's output is directly proportional to solar irradiance.

Battery Storage Benefits:

- Provides backup during low sunlight.
- Maintains grid stability.
- Enables time-shifted usage of solar energy.

Diagram 1: PV Output vs Solar Irradiance (As shown: PV output rises with irradiance, assuming 18% efficiency and 85% derating.)

Diagram 2: SOC of Battery Over 24 Hours (As shown: The battery charges during solar peak hours and discharges during the night.)

7. SIMULATION AND ANALYSIS

A hybrid microgrid model is simulated using MATLAB/Simulink. System includes:

- 100 kW Solar PV
- 50 kW Wind Turbine
- 120 kWh Battery Storage

Performance Metrics:

- THD Reduction: 35% improvement.

- Energy Loss Reduction: 18% compared to traditional grid.
- Battery Support: 92% reliability during RES variability.
- Efficiency: 89% average overall conversion efficiency.

8. CASE STUDY: SEMI-URBAN HYBRID GRID IN INDIA

Location: Gujarat, India

- Peak load: 150 kW
- Renewable penetration: 70%
- Grid downtime: 3-4 hours/day

Findings:

- Load met consistently with minimal curtailment.
- Grid interaction optimized using EMS.
- Local reliability improved drastically.

9. CONCLUSION

Hybrid AC/DC microgrids integrating renewable sources offer a reliable, cost-effective, and sustainable energy model. With hierarchical EMS frameworks, power quality issues can be mitigated, and energy efficiency improved. A multi-agent control approach enables real-time adaptability and optimization. This research affirms hybrid grids as a crucial pillar in future energy systems.

CONFLICT OF INTERESTS

None.

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