STABILITY IMPROVEMENT OF A MICRO GRID SYSTEM USING DIFFERENT OPTIMUM CONTROL TECHNIQUES- A REVIEW

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Abstract

Micro grids have gained significant attention in recent years due to their potential to enhance the stability and reliability of power distribution systems. The integration of renewable energy sources, such as solar and wind, into micro grids poses challenges related to their intermittent nature and fluctuating power output. To address these challenges, various optimum control techniques have been proposed to improve the stability and performance of micro grid systems. This paper presents a comprehensive review of different optimum control techniques employed to enhance the stability of micro grid systems. The discussed techniques include model predictive control (MPC), droop control, fuzzy logic control (FLC), and artificial intelligence (AI)-based control algorithms. The review highlights the advantages, limitations, and applications of each technique and provides insights into their effectiveness in stabilizing micro grid systems.

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1. Introduction

The increasing penetration of renewable energy sources and the growing demand for reliable power supply have motivated the development of micro grid systems. Micro grids are small-scale power distribution networks that can operate independently or interconnected with the main grid [1]. They consist of distributed energy resources (DERs) such as solar photovoltaic (PV) arrays, wind turbines, energy storage systems, and conventional generators. However, the integration of intermittent renewable energy sources introduces challenges related to the stability and control of micro grids. Micro grid stability is crucial to ensure the reliable operation of the system. The inherent characteristics of renewable energy sources, such as variability and unpredictability, pose challenges to maintaining stable voltage and frequency in micro grid systems. These challenges can lead to power quality issues, voltage deviations, and frequency fluctuations, which may adversely affect the performance and reliability of the micro grid [2]. Micro grid stability faces several challenges due to the integration of renewable energy sources and the complex nature of the system. Some of the key challenges include:

- **Intermittent Generation:** Renewable energy sources such as solar and wind power exhibit intermittent generation patterns. The output power of these sources fluctuates based on weather conditions, time of day, and other factors. The unpredictable nature of these sources poses challenges in maintaining a stable power supply within the micro grid [3].
- **Voltage and Frequency Control:** Micro grids need to maintain stable voltage and frequency levels to ensure reliable operation of connected loads. Fluctuations in voltage and frequency can lead to equipment damage, inefficient power delivery, and disruptions to critical processes. Integrating renewable energy sources requires effective control mechanisms to regulate voltage and frequency deviations [4].
- **Power Balance and Control:** The balance between generation and load demand is crucial for micro grid stability. With varying power outputs from renewable sources, maintaining a balance becomes more challenging. Proper control strategies are necessary to manage power flow, optimize energy dispatch, and prevent overloading or underutilization of resources [5].
- **Islanding and Grid Connection Transitions:** Micro grids should be able to seamlessly transition between islanded (operating in isolation) and grid-connected modes. The transition process can introduce voltage and frequency transients, which can affect stability. Efficient control techniques are required to ensure smooth transitions and stable operation during both modes [6].
- **Communication and Coordination:** Micro grid stability relies on effective communication and coordination among distributed energy resources, energy storage systems, and control devices. Timely exchange of information, accurate measurements, and coordinated control actions are essential for maintaining stability. However, communication delays, data inaccuracies, and coordination challenges can impact stability and control performance [7].
- **System Parameter Uncertainties:** Micro grids consist of various components with uncertain parameters, such as renewable energy sources, storage systems, and loads. Uncertainties in these parameters can lead to stability issues, as control algorithms may not accurately account for the system's dynamic behavior. Robust control strategies are needed to handle parameter uncertainties and ensure stable micro grid operation [8].

Addressing these stability challenges requires the development and implementation of advanced control techniques that can effectively manage power fluctuations, regulate voltage and frequency, balance generation and load, facilitate seamless transitions, and account for system uncertainties. Optimum control techniques, as mentioned in the introduction, offer promising solutions to enhance micro grid stability and improve the overall performance of these systems.

2. Control in Micro Grids

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There are two main energy source types in micro grids. One of them is a DC source comprising fuel cells, solar panels and batteries, whereas the other source is AC, comprising micro turbines and wind turbines in which output voltage is rectified. Both source types are generally DC sources created by use of an inverter [9].
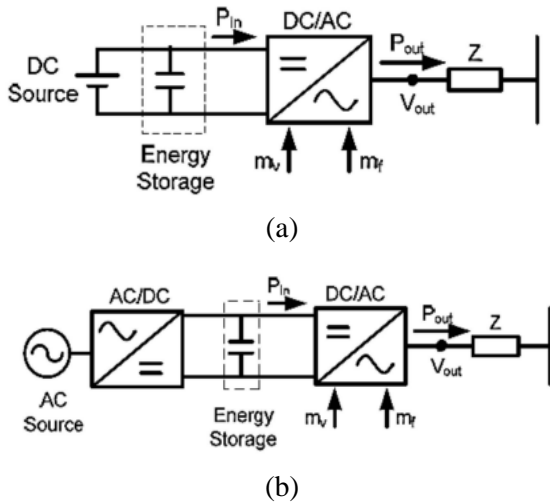

(a)

(b)

Figure 1: (a) Inverter for DC Source, (b) Inverter for AC Source

The inverter structure for a DC source is shown in Figure 1(a), and the inverter structure for an AC source is shown in Figure 1(b). Figure 1. (a) Inverter for DC source. (b) Inverter for AC source. Current, voltage and frequency parameters in the output of the inverter are determined by the control method of the inverter. The output voltage is directly related to the intensity of the capacitor voltage on the side of DC. Storage quantity in the capacitors is less than the storage quantity in the rotating field and, therefore, control methods are of great significance. Different application strategies are used to manage the power flow control by depending on source number. It requires an energy management system to activate and deactivate of the sources. Moreover, power flow in the grid connected mode is provided by using sliding mode control (SMC), model predictive control (MPC), power-reactive (PQ) control and droop control a robust, fuzzy logic control. A transient in an electrical system is defined by a sudden change in circuit conditions, such as when a system is switched on and off, or a fault occurs. These faults are small signal faults, unbalanced voltage or steady state faults. Firstly, small signal faults cause droop gains and load fluctuations to influence the voltage stability of a grid or micro grid. The small signal faults of grids are analyzed using a linearized model of the network, distributed generations (DGs), control units of DG, and loads. Secondly, voltage and frequency amplitude generated from energy sources cause unbalanced voltage and frequency. As such, voltage and frequency stability should be provided in power systems. Thirdly, steady state fault causes to the tracking error on control operations [10]. Dynamic and transient analyses are important concepts in power systems. The infrastructure of the main electric grid evolves with the integration of hybrid energy systems that form renewable energy systems. The hybrid micro grid is a grid structure comprising both grid and renewable energy sources, or renewable energy sources only [11]. As shown in Figure 2, hybrid micro grids can comprise more than one energy source in the same distribution grid. In renewable energy sources or hybrid energy systems, this situation can be prevented using control algorithms that run independently of system parameters, such as the sliding mode control method, whereas unknown system parameters or changes in system control algorithm parameters that depend on model parameters, such as the model predictive control method, adversely affect control efficiency [12].
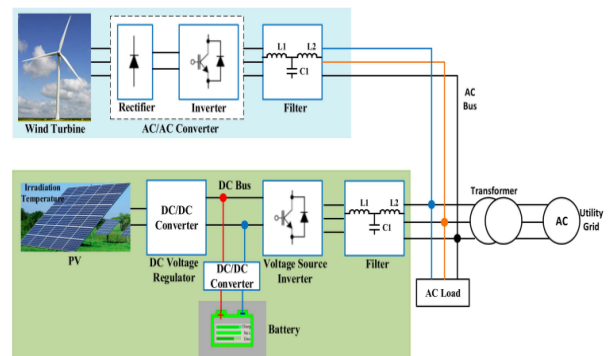

Figure 2: Structure of Hybrid Micro Grid

The stability conditions in micro grids used in the literature are presented in Figure 3. Stability methods have been applied in both grid-connected mode and islanded mode. These methods are used to provide small signal, voltage and frequency stability. The stability is implemented in the short term, ultra-short term and long term.
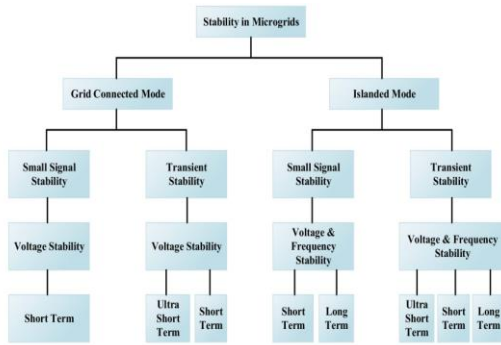
Figure 3: Methods for Stability in Micro Grids

3. Optimum Control Techniques

To address the stability challenges in micro grids, various optimum control techniques have been proposed and implemented. This review focuses on the following control techniques:

Model Predictive Control (MPC)

MPC is a control strategy that utilizes mathematical models to predict the future behavior of the micro grid system. By optimizing control actions over a finite time horizon, MPC can effectively regulate the power flow, voltage, and frequency in micro grids. Adaptability and Flexibility: MPC can adapt to changing operating conditions and system disturbances. It continuously updates the system model based on real-time measurements and adjusts the control actions accordingly. This adaptability allows MPC to handle uncertainties, such as variations in renewable energy generation, load fluctuations, and disturbances, effectively improving the stability of the micro grid [13].
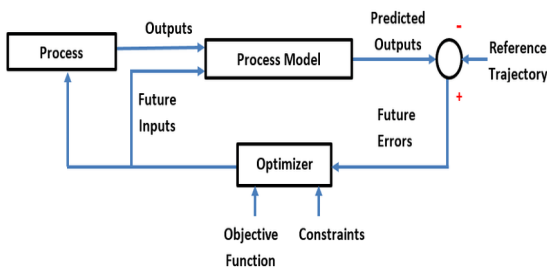

Figure 4: Block Diagram of Model Predictive Control (MPC)

One of the primary objectives of MPC in micro grids is to maintain stable voltage and frequency levels. By optimizing control actions, such as power dispatch and energy storage management, MPC can regulate voltage and frequency deviations within acceptable limits. This capability ensures reliable

power supply to connected loads and minimizes power quality issues. MPC facilitates the efficient integration of renewable energy sources into micro grids [14]. It optimizes the utilization of these sources based on their varying power outputs, taking into account the system's power demand and operational constraints. MPC helps maximize the renewable energy penetration while maintaining stability and minimizing reliance on conventional generators. The implementation of MPC in micro grids has shown promising results in improving stability, enhancing power quality, optimizing energy utilization, and facilitating the integration of renewable energy sources. However, the complexity of system modeling, computational requirements, and the need for accurate measurement data pose challenges to its practical implementation. Nonetheless, ongoing research and advancements in MPC algorithms continue to enhance its effectiveness in stabilizing micro grid systems.

Droop Control

Droop control is a decentralized control technique widely used in micro grid systems. It employs local voltage and frequency measurements to adjust the power output of DERs. The droop control technique provides load sharing among the DERs and helps maintain system stability.

Droop control is an essential mechanism used in micro grids to regulate the power output of distributed energy resources (DERs) such as generators, solar panels, and energy storage systems. It is designed to maintain stability and balance power generation and consumption within the micro grid. In a micro grid, multiple DERs operate in parallel to meet the overall power demand. Each DER is equipped with a droop control mechanism that adjusts its power output based on the frequency or voltage level in the system. The droop control ensures that the load is shared proportionally among the DERs and helps maintain grid stability. The basic principle of droop control is to mimic the behavior of synchronous generators in large power systems. In a conventional power system, generators are synchronized and share the load by responding to changes in the grid frequency. As the load increases, the frequency tends to decrease, signaling the generators to increase their power output. Similarly, in a microgrid with droop control, each

DER adjusts its power output in response to changes in the system frequency or voltage. The control mechanism is typically implemented by modifying the voltage or current reference of the DERs based on their droop characteristic. The droop characteristic determines how the power output changes with respect to the frequency or voltage deviation from the nominal value. It is usually defined as a slope or a droop coefficient. A steeper slope means a more significant change in power output for a given frequency or voltage deviation, resulting in tighter load sharing among the DERs. When the system frequency or voltage deviates from the nominal value, the DERs respond by adjusting their power output according to their droop characteristic. If the frequency or voltage decreases, the DERs increase their power output, and vice versa. This self-regulating behavior helps maintain the balance between power generation and consumption in the micro grid. Droop control is particularly useful in micro grids because it allows for decentralized control and reduces the need for complex centralized control systems. It also enables the integration of renewable energy sources by dynamically adjusting their power output based on the overall system conditions [15].
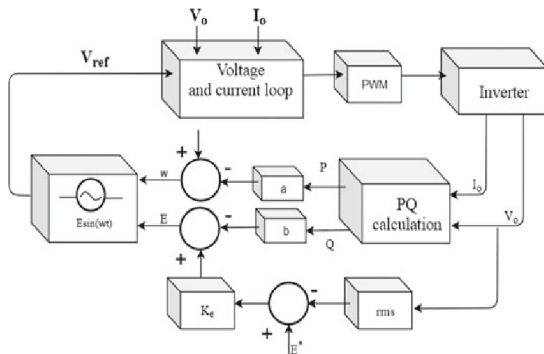

Figure 5: Block Diagram of Droop Control

Fuzzy Logic Control (FLC)

FLC is a control technique that utilizes linguistic variables and fuzzy rules to model and control complex systems. Fuzzy logic controllers have been employed in micro grid systems to enhance stability by adjusting the power dispatch and control actions based on system conditions. Fuzzy Logic Control (FLC) is a control strategy commonly used in micro grids to optimize the operation of distributed energy resources (DERs) and enhance the overall system performance. FLC is a rule-based control method that uses linguistic variables and fuzzy logic to make

decisions and adjust control actions [16]. In a micro grid, FLC can be employed to manage various aspects such as power flow control, voltage regulation, frequency control, and economic dispatch. Here's a general overview of how FLC works in a micro grid context:

- **Fuzzy Rule Base:** The FLC system starts with a predefined rule base that consists of a set of linguistic rules. These rules define the relationship between the input variables (e.g., power generation, load demand, voltage, frequency) and the output control actions (e.g., adjusting power output of DERs, changing set points).

- **Fuzzification:** The input variables are fuzzified, which means they are transformed into fuzzy sets that represent different linguistic terms. For example, the power generation input variable can be divided into fuzzy sets such as "low," "medium," and "high" to capture different power generation levels.

- **Inference Engine:** The inference engine evaluates the fuzzy rules based on the fuzzified input variables. It uses the fuzzy logic operators (e.g., AND, OR) to combine the fuzzy sets and determine the degree of membership to each rule.

- **Rule Evaluation:** Each rule in the rule base is evaluated, considering the degree of membership obtained from the inference engine. This evaluation determines the contribution of each rule to the final control action.

- **Defuzzification:** The output of the FLC system is obtained through defuzzification, which converts the fuzzy control actions into crisp values. Various defuzzification methods can be used, such as centroid, weighted average, or maximum membership.

- **Control Action:** The crisp control outputs obtained from defuzzification are used to adjust the control parameters of the DERs or micro grid components. For example, the FLC system can modify the power output of generators or adjust the reference values for voltage or frequency regulation.

The strength of FLC lies in its ability to handle imprecise or uncertain information. Fuzzy logic allows for flexible and intuitive control decisions based on linguistic rules and human expertise. It can effectively handle nonlinearities and system uncertainties often encountered in micro grid operation. FLC in micro grids offers several advantages, including improved system stability, enhanced power quality, optimal power sharing, and efficient utilization of DERs. It enables adaptive and decentralized control, which is particularly valuable in complex and dynamic micro grid environments. Hence, Fuzzy Logic Control is a versatile and effective control strategy for micro grids, providing intelligent decision-making capabilities and enabling efficient and reliable operation of the system [17].
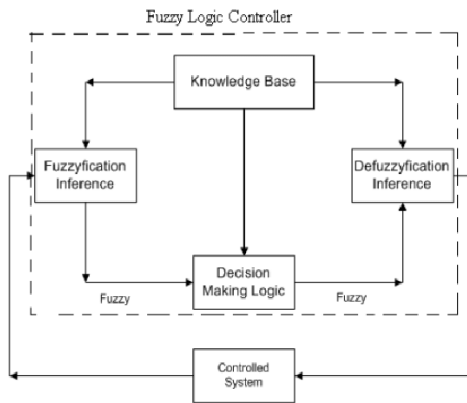

Figure 6: Block Diagram of Fuzzy Logic Controller

Artificial Intelligence (AI)-based Control Algorithms

AI-based control algorithms, such as neural networks, genetic algorithms, and reinforcement learning, have shown promise in improving micro grid stability. These algorithms leverage the computational power of AI to optimize control actions and adapt to dynamic system conditions. Artificial Intelligence (AI) has gained significant attention in the field of micro grid control due to its ability to handle complex and dynamic systems. Several AI-based control algorithms have been developed and applied in micro grids to optimize performance, enhance energy management, and improve system stability [18]. Here is some prominent AI-based control algorithms used in micro grids:

- **Reinforcement Learning (RL):** RL algorithms enable an agent to learn optimal control policies through interactions with the environment. In micro grids, RL can be used to determine optimal dispatch strategies for DERs, such as generators and energy storage systems. RL agents learn to make decisions based on reward signals, aiming to maximize system performance over time [19].

- **Neural Networks (NN):** Neural networks are widely used in micro grid control for various purposes. They can be employed to predict load demand, renewable energy generation, or market prices. By leveraging historical data, NNs can provide accurate forecasts, enabling proactive decision-making and optimized control strategies.

- **Genetic Algorithms (GA):** GA is an evolutionary optimization technique that mimics the process of natural selection to find optimal solutions. In micro grids, GA can be used to optimize dispatch schedules, resource allocation, or parameter tuning. By iterating through generations and applying selection, crossover, and mutation operations, GA algorithms search for the fittest solutions in a large solution space.

- **Particle Swarm Optimization (PSO):** PSO is a population-based optimization algorithm inspired by the social behavior of bird flocking or fish schooling. It iteratively improves solutions by simulating the movement and cooperation of particles in a multidimensional search space. PSO algorithms have been applied to optimize micro grid operation and control, considering objectives such as cost minimization, emission reduction, or voltage stability [20].

- **Support Vector Machines (SVM):** SVM is a machine learning algorithm used for classification and regression tasks. In micro grids, SVM can be employed for fault detection, diagnosis, and protection. By training on labeled data, SVM models can accurately classify system conditions and

trigger appropriate control actions in response to abnormal events.

- **Deep Learning (DL):** Deep learning techniques, such as deep neural networks and convolution neural networks, have been utilized in micro grid control for various applications. DL algorithms can process large amounts of data and extract meaningful features, enabling tasks like anomaly detection, predictive maintenance, or real-time control decision-making [21].

These AI-based control algorithms offer advantages such as adaptability, learning capability, and the ability to handle complex and uncertain micro grid dynamics [22]. By leveraging AI techniques, micro grids can achieve optimized operation, increased efficiency, and improved system reliability in the presence of renewable energy sources, varying loads, and changing grid conditions.
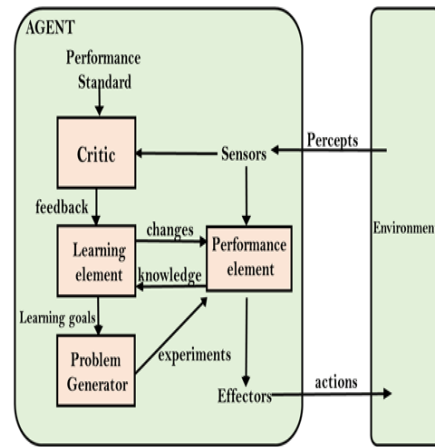

Figure 7: Block Diagram of AI Based Controller

4. Comparison of Optimal Control Techniques for Micro Grid

This review discusses the advantages and limitations of each control technique and provides insights into their suitability for different micro grid application. While comparing optimal control techniques for micro grids, several factors need to be considered, including system complexity, computational requirements, robustness, and real-time implementation feasibility. Here are four commonly used optimal control techniques for micro grids:

Table 1: Comparison of Optimal Control Techniques for Micro Grid

S.No.	Optimal Technique	Features
1	Model Predictive Control (MPC)	To predict future system behavior and optimize control actions accordingly
		Handle constraints on variables such as power generation, storage, and load demand.
		MPC is suitable for systems with moderate complexity but may have high computational requirements, limiting its real-time implementation.
2	Genetic Algorithms (GA)	GA is an optimization technique inspired by natural evolution and genetic selection processes
		It searches for the optimal control solution by iteratively evolving a population of control strategies. GA can handle complex systems with non-linear dynamics and multiple objectives.
		GA may require a large number of iterations to converge, leading to higher computational time.
3	Fuzzy Logic Control (FLC)	FLC uses linguistic rules and fuzzy sets to determine control actions based on system states and inputs.
		It is suitable for systems with uncertain or imprecise information. FLC can provide robust control performance and is relatively computationally efficient.
		Designing and tuning the fuzzy rule base can be challenging, and FLC may not capture complex system dynamics accurately
4	AI Based Control (AI)	AI-based micro grid control brings intelligence, adaptability, and optimization to the management of micro grid systems. It enables efficient utilization of resources, enhances stability, and facilitates the integration of renewable energy sources, ultimately contributing to a more sustainable and resilient energy infrastructure

5. Conclusion

The stability improvement of micro grid systems is a crucial aspect of their successful operation. This

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review provides a comprehensive overview of different optimum control techniques used to enhance micro grid stability, including MPC, droop control, FLC, and AI-based control algorithms. Overall it has been observed that, the choice of optimal control technique for a micro grid depends on the specific requirements and characteristics of the system. MPC is suitable for moderately complex systems with accurate models but may have higher computational requirements. GA can handle complex systems but may have longer computation times. FLC is robust and suitable for systems with uncertainty, but accuracy may be limited. LQR is computationally efficient but may not capture highly nonlinear dynamics. Each technique has its strengths and limitations, and a careful evaluation is necessary for selecting the most appropriate technique for a given micro grid application.

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