Advancements in Microgrids with Model Predictive Control

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Contributor: Karan Singh Joshal, Neeraj Gupta

Microgrids face significant challenges due to the unpredictability of distributed generation (DG) technologies and fluctuating load demands. These challenges result in complex power management systems characterised by voltage/frequency variations and intricate interactions with the utility grid. Model predictive control (MPC) has emerged as a powerful technique to effectively address these challenges. By applying a receding horizon control strategy, MPC offers promising solutions for optimising constraints and enhancing microgrid operations.

Keywords: microgrid ; model predictive control

1. Introduction

Model predictive control MPC-based microgrid control techniques have limitations in dealing with grid effects, including diverse topologies, high PV penetration, and switching techniques. Intelligent approaches are needed for addressing these challenges at both basic and higher power flow regulation levels. DC microgrids face network delays in sensor, controller, and actuator communication, hindering MPC-based control [1]. Introducing compensatory schemes such as network delay compensators can enhance controller robustness. Moreover, complications arise from nonlinearities, model uncertainties, and divergence between the converter controller and plant in microgrid operations. Soft computing methods such as fuzzy logic, genetic algorithms, and neural networks are employed to enhance MPC-based microgrid control [2][3]. While these methods can enhance control effectiveness, they may introduce complexities and increased computational requirements. Automatic selection of weighing parameters for cost functions in MPC control of power converters is another challenge. AI techniques, such as combining artificial neural networks with particle swarm optimisation, have been proposed for optimising control objectives [3]. However, determining the optimal weighing parameters remains challenging.

Overcoming these limitations is vital for ensuring robust and effective microgrid operation. Ongoing research focuses on developing intelligent approaches, exploring economic analysis, and resolving associated challenges in MPC-based microgrid control. By leveraging soft computing methods, advancing communication technologies, and refining control strategies, researchers aim to mitigate these challenges and enhance overall performance.

2. Intelligent MPC Approaches

Microgrid operations are based on the application of power electronics and a power system. The MPC-based microgrid control technique still comprises some gaps related to the grid effects on the regulation of converters, its topologies with high PV penetration, and switching techniques. Therefore, it requires an intelligent approach for better operation to deal with such problems on basic levels of converter control and higher levels of power flow. Soft computing methods are incorporated with MPC-based microgrid control to add more smoothness and intelligence to microgrid operations with MPC. In [2], a fuzzy adaptive MPC approach was used to control the load frequency in a grid-forming microgrid. The cost function with its tuning parameters was fuzzified based on the proposed fuzzy MPC approach with a controller based on the fuzzy rule, showing faster and adaptable responses under different conditions. Implementing the Takagi–Sugeno (TS) fuzzy-model-based MPC can deal with the delays due to networked communication between sensors, controllers, and actuators in DC microgrids [1]. In [1], the paper implemented two network delay compensators to make the controller more robust with minimal computational weights. The delays in networked systems with nonlinearities can also be dealt with by implementing the proposed scheme presented in [1]. Other soft computing technologies, such as genetic algorithms and neural networks, are used with MPC to improve its control goals. A temperature-regulating system based on the implementation of MPC and genetic algorithms was developed for residential structures in [4]. According to the simulation results in [4], residents will have higher comfort at a lower cost and with reduced energy consumption. Dealing with the uncertainties of models and divergence between the converter controller and plant leads to complications in microgrid operations. In [5], an outlier–robust extreme learning machine (OR-ELM) algorithm was combined with DMPC to provide a framework that comprises a robust data-predictive control strategy for lowering operating costs and dealing with the volatility of the electricity retail pricing market. A model-free MPC scheme for a three-phase converter based on the recurrent neural network method (state-space neural network) was proposed in [6] to mitigate these consequences. Compared to conventional MPC, the proposed neural-network-based model-free predictive-control method shows more robustness under different scenarios. The control of power converters with finite-set MPC deals with the challenges of the automatic selection of the cost function's weighing parameters. In [3], an artificial neural network (ANN)-based approach along with particle swarm optimisation (PSO) technique was proposed for powerful and fast optimisation of the control objectives in MPC. Soft computing methods such as fuzzy logic and ANN are being used with MPC control to provide more flexibility and intelligence for MPC approaches with microgrid applications.

3. Microgrid Economic Analysis with MPC

Microgrid design requires DG installations, leading to the high capital cost of energy produced by it. Due to the changing nature of equipment cost and the continual development in renewable energy technologies, it also shows variations in per kW installed for renewable DG installation. Compared to central generation systems, the high capital cost of installed power is a critical disadvantage of DG technologies (in microgrid systems). The economic operation of DG units in microgrid applications has been dealt with by including compensation mechanisms with policies and regulation systems [7][8]. The new research studies on MPC-based microgrid control minimise the acquired system operational costs and make the most out of economic profitability. Many research studies show that the predictive model-based approaches in microgrid operations lead to cost minimisation with a lower running cost of operations and optimal economic schedule [9][10][11]. In [12], the MPC-MILP control scheme was tested on an experimental microgrid (located in Athens, Greece), and the outcomes of the experiment with the MPC-MILP control scheme were more cost-effective (compared to the original practice of the experimental microgrid) for microgrid operations. The intermittent nature of non-dispatchable renewable energy resources has difficulty achieving a committed generation schedule, leading to economic penalty charges imposed by the electricity markets. MPC with an objective function, including energy prices, plant state, weather forecast, and penalty cost estimation, is beneficial for obtain profit from microgrid operations [13]. The photovoltaic-based combined heat and power (CHP) home microgrid with an electrical and thermal energy storage (TES) system has problems related to the uncertainties of CHP systems and the uncontrolled charging of the TES system. In such cases, MPC methods are beneficial for optimum usage of storage systems, which leads to smaller storage systems with lower investment costs of both the storage system based on TES and batteries [14]. The MPC method proves to be a highly effective instrument in achieving optimal EMS in microgrid operations. By employing the MPC approach, numerous advantages can be harnessed, such as advanced forecasting techniques, effective constraint management, multivariable control capabilities, and the ability to address uncertainties [15]. These factors collectively contribute to the development of a highly efficient EMS, resulting in more cost-effective and economically viable microgrid operations.

4. Challenges with MPC-Based Microgrids

After being implemented in process industries, the MPC has proven immensely beneficial in power electronics and power systems in microgrid control operation. Certain aspects require improvements in dealing with the restrictions and challenges for optimal performance in microgrid control operations. These challenges mainly include more accurate predictive model design, MPC-based microgrid operation stability analysis, and cost functions considering various parameters. One of the critical issues with MPC-based microgrid operations is the exchange between processing time, performance level, and financial costs. It is challenging to maintain the performance of system operations while minimising the costs and calculation time. In MPC, developing an accurate predictive plant model of high quality is essential and challenging to achieve. The complex calculation for designing an accurate predictive model can be complicated and remains a significant challenge [16][17][18] that requires a fast and powerful processor. The stability analysis of a microgrid operation with MPC-based converter control is still in its initial phase compared to droop control with conventional closed-loop PI controllers. Hence, a comprehensive stability study for MPC-based microgrids still requires a large number of authentications [18][19]. To deal with all the aspects of control targets in MPC-based microgrid control, the design of the cost function is a significant limitation. It becomes problematic to achieve stability with large numbers of variables associated with the cost function. These variables begin with power quality and control issues and progress to include economic management challenges of microgrid operations. Implementing such a large number of control parameters is incredibly challenging, and certain operations are still hypothetical. Given the challenges of adopting MPC in microgrid control operations, it has become an exceptionally motivating and appealing research topic.

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