Microgrid Applications

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Microgrids need control and management at different levels to allow the inclusion of renewable energy sources. In this paper, a comprehensive literature review is presented to analyse the latest trends in research and development referring to the applications of predictive control in microgrids. As a result of this review, it was found that the application of predictive control techniques on microgrids is performed for the three control levels and with adaptations of the models in order to include uncertainties to improve their performance and dynamics response. In addition, to ensure system stability, but also, at higher control levels, coordinated operation among the microgrid's components and synchronised and optimised operation with utility grids and electric power markets. Predictive control appears as a very promising control scheme with several advantages for microgrid applications of different control levels.

Keywords: Microgrig ; Model Predictive Control ; Remewable Energy

1. Microgrids and Renewable Energy

Since the growth of the use of renewable energy resources and the installation of new renewable-based power plants is a global focus shift towards a sustainable society, with all the preplanned new installations, it is imperative to use renewable energy with the highest efficiency and reliability that technological advances can make possible [1].

With the introduction of distributed generation and microgrids, a revolution is occurring in the way power systems used to work, with not just power flowing from a generator to the final consumer, but in both directions, with electricity consumers also becoming energy active producers, known as prosumers in an energy market context [2][3][4].

Prosumers can reduce their energy costs by generating power when the marginal generation cost is lower than the price of electricity from the utility. They can sell the energy back to the grid, supplementing the grid power supply using clean renewable energy when there is abundant energy generation from these renewable sources and low-cost generators [5]. Microgrids, when they are connected to the utility grid through a PCC, may operate as a prosumer that has several distributed generators (DG) and controllable loads [2]. In this case, the tertiary level control operates to manage the power delivery from and to the microgrid and to optimise the economic dispatch from the DGs [6].

The developed predictive control schemes from [7] applied to the interfacing power converters in the hybrid microgrid allowed coordinated operation among the energy storage system and the AC subgrid through the AC/DC interlinking converter. To control the DC and AC buses voltages, the fluctuating renewable energy outputs are smoothed using the energy storage system controlled by the bidirectional DC-DC converter. It seems that controlling the energy storage systems, its SOC, and working operation modes helped to deal with fluctuating power from solar PV and wind energy generation system.

In order to use these distributed resources on small electrical grids, microgrids, power electronic conversion systems have led to a better and smoother coupling between these new distributed sources and loads, as well as the rest of the electrical grid [8]. Nevertheless, this ever-increasing penetration of power electronics in modern power systems is making them more complicated, where stability challenges, e.g., low inertia, multiple time scales, and the dynamics when power converters are connected to weak grids, appear as very important in terms of the control of the whole system [9].

It is clear that predictive control techniques applied to microgrids, at different hierarchical control levels, can play a very important role in dealing with the challenges of these more complex power systems and with the variable nature of renewable energy sources. One interesting aspect of the papers surveyed and focused on in model predictive control is the inclusion of uncertainties in the models for predicting, in this case power supply and power demand on a microgrid. These uncertainties are introduced in the MPC, making them stochastic based, mostly. These modifications to the control schemes are possible because predictive control offers flexibility and versatility in contrast with the classic control schemes, which are more rigid [10][11][12].

2. Primary Level Control

MPC presents several variations in order to improve its performance over microgrids systems. In [13], finite control set MPC was established as a very reasonable primary control option to improve the performance of power converter-based AC microgrids. Additional terms were added to the cost function, taking advantage of the flexibility that MPC has as a control scheme. On the other side, the same occurred with the added terms to the MPC's cost function to improve DC link voltage stability in DC microgrids in the work developed by [14].

Additionally, MPC is used for controlling the operation of a DFIG of a wind turbine embedded in a DC microgrid with a simple, but effective approach that improves the steady-state performance with proper robustness [15]. The use of DFIG wind energy conversion systems has been very successful in the industry and academia [16][17][18], with several digital control techniques. DFIG can be controlled by field-oriented control (FOC), direct torque control (DTC), or direct power control with the reference frame fixed to a stator flux or voltage [19]. Then, MPC can be used instead of classical control schemes to improve control performance [11][20].

Regarding the application of the generalised form of the predictive control for microgrids, this kind of strategy results in a useful tool for establishing a proper multi-objective predictive control of a relatively new topology for a low power inverter (SPQZSI) and, thus, reduce harmonics and other power quality problems in microgrids, as was shown in [21]. As the usefulness of the SPQZSI is to improve the power quality, avoiding the low-frequency power ripple with small capacitance, conventional control lacks flexibility to include several control objectives. MPC in its generalised form plays an important role, allowing the fulfilment of the necessary control objectives of these sorts of power converters in microgrid systems.

In the paper [22], deadbeat predictive torque control was used for controlling a PMSG through a thyristor bridge where the dynamic performance of the predictive model could be improved compared to classical DTC, and a superior performance could be obtained. The main tasks of the deadbeat predictive control method are to track the maximum power point of the wind turbine generator instantaneously, to track the electromagnetic torque reference, and to maintain the direct stator current component close to zero. Nevertheless, the main objective of the work developed by the authors was the design and implementation of an online-trained artificial neural network-based control system for a hybrid microgrid. On the other side, deadbeat predictive control was used with large sampling times to generate the reference currents that enter the FCS-MPC, which finally controlled the CSC of an onboard aircraft DC microgrid [23]. Thus, the resulting hybrid predictive control scheme operated the CSC. This control scheme allowed eliminating the weighting factor, necessary to combine control objectives among the input and output circuits of the DC microgrid. The authors successfully proposed a control scheme with very low control complexity, which created the capability to operate with a high sampling frequency (up to 150 kHz).

At the primary level of control, the main control objectives of predictive control strategies refer to the stability of the system control, for realising voltage control, current control, power-sharing, and local protection in the microgrids [6].

3. Secondary Level Control

A high-level centralised technique for controlling the required DC voltages on a DC microgrid is used for improving the power quality by reducing the power loss in the distribution lines [24], applied to the secondary level of a microgrid. The centralised model predictive control is proposed with both non-adaptive weighting factors and adaptive weighting factors to further mitigate the power loss in the DC microgrid, with adaptive weighting factors being the best energy saver control strategy.

The control of power converters for dealing with wind variability as disturbances to the DC microgrid is aimed to control the stability in the whole system, a paramount aspect to be controlled in microgrid systems. As microgrids have a small inertial reserve if compared with utility grids, the role that the VSCs may play in the system stability is essential. To improve the inertial response, each converter of the microgrid is controlled using MPC. This control strategy was applied for cooperating to have a rapid inertia adjustment strategy to avoid control hysteresis and adjustment error, and not having control delay that classical control strategies may present [25].

The application of MPC as a secondary level controller of the AC microgrid under study in [26] was developed as a stochastic MPC, including inherent uncertainties to the intermittent nature of renewable energy sources and their dependence on the weather conditions. It is, indeed, for the secondary level of control that stochastic MPC is used more [8], for the necessity of having a stable and reliable source of electric energy, as the highest priority. The stochastic MPC algorithm developed in [26] allowed for the minimisation of the discrepancies with the optimal plan in the presence of stochastic disturbances that may appear in the photovoltaic power produced and in the load consumption versus the forecast values for those two variables in the microgrid. This technique allows the update of the high-level plan to redefine the nominal profiles according to the temporarily optimal solution. This enhances the performance of the microgrid system and contributes to compensating for any forecast error.

The use of tube scaling MPC of a microgrid includes stochastic variables to consider the nature of energy consumption and renewable energy-based DGs' availability. With the inclusion of additional optimisation variables like scaling factors, the established algorithm permits an optimal balancing among disturbance compensation by the microgrid's subsystems (DGs, prosumers, energy storage systems). The latter allows a robust optimal MPC-based control of the microgrid operation for voltage regulation in the microgrid system [27].

In the hybrid AC/DC microgrid developed in [7], an EMS was developed to ensure stable operation under different operation modes. Its effectiveness was validated based on a PV-wind-battery system with real-world solar and wind profiles, showing better control capability and improved voltage quality. Nevertheless, to establish the EMS, communication facilities are needed, and at level of the power converters, additional measurements need to be considered if compared with traditional cascade PID controllers.

At the secondary level of control, the main control objectives refer to the power quality control, with the development of mathematical models to predict and optimise the actuation for frequency regulation, voltage regulation, and synchronisation with the main grid [6].

4. Tertiary Level Control

MPC is applied on a distributed model for optimising the function of the different distributed generators in several microgrids to work coordinated and together, allowing the independent system operator to manage the different microgrids as multi-microgrids and as virtual power plants. According to the authors, the energy management system was based on a distributed algorithm, which considered time-sharing price among the microgrids that composed the multi-microgrid and the distributed network of the main grid. For autonomous functioning of the multi-microgrid, a multi-objective function based on source-load prediction and using receding optimisation to solve it for each microgrid central controller permitted the optimal operation in the multi-microgrid without purchasing electric power from the main grid and fulfilling the constraints related to power availability coming from photovoltaic and energy storage systems [28].

The development of distributed predictive controllers allows coordinating inside a microgrid the energy dispatch optimisation, the load shedding, and the use of the electric vehicles when charging as storage systems [3][29][30][31].

MPC is applied to an energy management system for a microgrid in order to control the state of charges of battery energy storage [32] and to another one that works in isolated mode to control the power output of a wind turbine by active stall (change of the blade pitch angle of the wind turbine) and the functioning of plug-in hybrid vehicles as energy storage systems [33].

At this tertiary level of control, the main control objectives refer to the power flow control, with the development of mathematical models to predict and optimise the microgrid operation when it is in grid-connected mode, establishing, thus, power management and economic dispatch strategies [6].

5. Predictive Control Trends

Among the control techniques of power converters and electrical drives, MPC is one method that is gaining great popularity [1]. Consequently, it has agglutinated the most significant amount of research and publications related to its application on microgrids, with some variations of the original predictive control.

In general, MPC is applied to local control and protection, the control of the microgrid, and for the upstream network interface [8], thus encompassing the three hierarchical control levels of a microgrid [10].

Additionally, predictive control is comprised of several methods that are used in power electronics, with MPC being very promising and having significant potential and versatility for controlling microgrids in their three control levels, when necessary.

The investigation of microgrids has increased in the last few years, as well as the research on their control. Furthermore, microgrid control is comprised of the technical feasibility functioning of each distributed generator, energy storage unit, and the loads of the microgrid (primary control), the feasibility of running the whole system from a power quality point of view (secondary microgrid control), as well as the technical and economical feasibility of the microgrid in an electrical market context (tertiary control).

It is at each of the control levels where power converters and electrical drives play an important role. These devices have to fulfil a determined objective of control since the strategies applied for controlling them are paramount when establishing and operating a microgrid.

In this way, predictive control schemes have several applications to microgrids, with advantages compared with other control strategies: intuitive and easy to understand; flexible to apply to different power converter topologies and situations, allowing the inclusion of constraints and nonlinearities; control of several variables at the same time; and for considering uncertainties when renewable energy sources are embedded into microgrids.

MPC strategies may present, in some cases, a lack of robustness in front of unavoidable modelling uncertainties and external disturbances that affect the controlled systems. Regarding this, all the surveyed works included some new techniques to overcome this disadvantage. These techniques considered the following: the inclusion of new terms in the cost function; the addition of a modulation stage for inner control; its combination with advanced novel control techniques as fuzzy-logic control and artificial neural network control; the combination of different MPC-based schemes for a system with multi-variable control objectives, to avoid heuristic selection of weighting factors.

The aforementioned aspects prove the versatility and flexibility of the MPC-based family of controllers when applied to power converters, drives, and to power-electronics-controlled microgrids with a high inclusion of renewable energy-based DGs. These predictive control methods permit proper operation of microgrids under different modes and under external disturbances. Furthermore, at the tertiary level, MPC permits efficient power management and an economic dispatch under electricity market conditions.

In this work, MPC presented the most significant amount of research associated with microgrid application, as it considered several variations and improvements to the basic model, for instance stochastic-based MPC, represented as a different control, but with the same bases, highlighting the importance of this technique.

Regarding AC, DC, and hybrid microgrid topologies and the application of predictive control, it was found that AC microgrids have had larger development, especially in the secondary control level. Furthermore, for DC microgrids, although there was less development, primary and secondary control had several applications that used predictive control schemes. Hybrid microgrids presented fewer applications of predictive control schemes, and the application found was aimed at carrying out a primary control.

In a world that requires cleaner and more reliable electric power grids, variable renewable sources are more and more integrated as embedded generation with the necessity of overcoming their variability for accurate and robust predictions for proper control. It clearly appears that the inclusion of uncertainties introduced by renewable source-based distributed generators is essential and a trend in the research for developing proper control of microgrids using predictions of power supply and demand in advance.

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