International Journal of Engineering Innovation & Research
Volume 7, Issue 2, ISSN: 2277 – 5668

Control of Microgrid: Literature Review

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Date of publication (dd/mm/yyyy): 02/05/2018

***Abstract* – Microgrid (MG) is a one of the novel concept in power generation. The Microgrid concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides both power and heat to its local area. Not much is known about Microgrid behavior as a whole system. Some models exist which describe the components of a Microgrid. This paper aims to emphasis some research works in Microgrids. It is intended that the works appraised in this paper will supportive for further developments in microgrid. The long term objective is to provide a highly sophisticated works done on Microgrid, so as to allow fully understand how microgrids behave.**

***Keywords* – Microgrid (MG), Proportional-Integral (PI) controller, Fuzzy Logic Controller (FLC), Model Predictive Controller (MPC), Wind Turbine (WT), Inverter, PV array.**

I. INTRODUCTION

Microgrids are becoming feasible alternatives to centralized generation and bulk transmission of power by offering a localized power generation, regulation, and consumption. There are a various set of benefits stemmed from microgrids, including but not limited to, enriched reliability by enabling self-healing, enhanced resiliency by responding to extreme events and utility grid supply interruptions, increased efficiency by reducing losses, deferred transmission and distribution upgrades by providing a local supply of loads, and enhanced integration of approachable and adjustable loads. Enhancing a swift integration of renewable energy resources, however, cannot be considered as one of the benefits of microgrids.

Energy is the considered to be the pivotal input for development. At present owing to the depletion of available conventional resources and concern regarding environmental degradation, the renewable sources are being utilized to meet the ever increasing energy demand [1]. Due to a relatively low cost of electricity production [2] wind energy is considered to be one of the potential sources of clean energy for the future [3].

With this renewed interest in wind technology for stand-alone applications, a great deal of research is being carried out for choosing a suitable generator for stand-alone wind energy control system (WECS). A detailed comparison between asynchronous and synchronous generators for wind farm application is made in [4]. The major advantage of asynchronous machine is that the variable speed operation allows extracting maximum power from WECS and reducing the torque fluctuations [5]. Induction generator with a lower unit cost, inherent robustness, and operational simplicity is considered as the most viable option as wind turbine generator (WTG) for off grid applications [6]. However, the induction generator requires capacitor banks for excitation at isolated locations.

The excitation phenomenon of self-excited induction generator (SEIG) is explained in [7]–[9]. The power output of the SEIG depends on the wind flow which by nature is erratic. Both amplitude and frequency of the SEIG voltage vary with wind speed. Such arbitrarily varying voltage when interfaced directly with the load can give rise to flicker and instability at the load end. So, the WECS are integrated with the load by power electronic converters in order to ensure a regulated load voltage [10]. Again due to the intermittent characteristics of the wind power, a WECS needs to have energy storage system [11]. An analysis of the available storage technologies for wind power application is made in [12] and [13]. The advantage of battery energy storage for an isolated WECS is discussed in [14].

From a technical perspective, there are significant drawbacks in integration of renewable energy resources to the electric power system. Major sources of renewable energy, i.e., wind and solar, are significantly dependent on meteorological factors. These resources are highly unpredictable and cause considerable variability in power generation. Two major characteristics of renewable generation are intermittency (i.e., not always available—such as solar generation which is not available during nighttime), and volatility (i.e., constant fluctuations from seconds to minutes to hours—such as wind generation that depends on the speed and availability of wind, or solar generation which could radically change as the cloud cover changes). To enable an efficient integration of renewable energy resources, system planners have traditionally considered backup generation for smoothing out the generation variability. Backup generations typically offer a fast response to generation changes; common examples are fast-response gas units, hydro units, demand management, and energy storage systems. In these cases, there is a chance that the true value of the backup generation installation cannot be achieved, since the backup is typically used for the sole purpose of coordinating the renewable generation. Hence, its cost will be added to the already large capital cost of the renewable energy resource and further question the economic viability of the deployment. Another major issue that results from the generation variability of these resources is that the interruption in power supply from the utility grid cannot be fully compensated by these resources as the generation cannot be controlled. In other words, these resources, if deployed stand-alone, cannot ensure generation reliability. A viable alternative to backup generation, while at the same guaranteeing reliability, is to deploy microgrids. Combining these two issues, the following can be stated [14].

1) Microgrids could play a viable role in ensuring a rapid and widespread integration of renewable energy resources in distribution networks by providing a flexible backup generation and addressing the prevailing technical constraints.
2) Microgrid developers are not in favor of renewable en-

-ergy resources since these resources are associated with higher capital costs and also cannot be used for islanding purposes to reliably supply critical loads when the supply of power from the utility grid is interrupted.

This paper is organized as follows. In section II literature review of microgrid is briefly discussed. Section III deals some studies with controllers in microgrid. In section IV conclusions based on the scope for works in microgrid are marked.

II. MICROGRID

Microgrid technology has provided a new technical approach for the large-scale integration of renewable energy and distributed generation [15], [16]. As a key building block of smart grid, microgrid has the potential to improve the utilization efficiency of energy cascade and improve power-supply reliability and power quality (PQ).

Microgrid consists of the ingredients shown in Fig. 1 (a) and Fig. 1 (b). It includes generally Wind turbine (WT), Permanent magnet synchronous generator (PMSG), Converter (DC-DC) and Inverter (DC-AC). In some studies solar cell (PV array) is also used. Some of the components of microgrid also comprises micro-turbine, diesel generator etc.

The basic idea behind the microgrid is to provide the ease of power availability to the local area as per the power demand.

Fig. 1. (a) Microgrid Tree

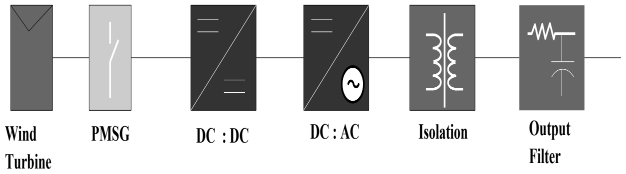

Fig. 1. (b) Basic components of sample Microgrid

Peer-to-peer control is one of the hotspots of microgrid research. The primary objective of the peer-to-peer control of the microgrid is to assign power and distribute load among distributed generators without communication, for reducing the cost of microgrid, and enhancing the reliability and flexibility. In addition, a game-theoretic approach is presented to the control decision process of individual sources and loads in small-scale and dc power systems, and this game-theoretic methodology enhances the reliability and robustness of the microgrid by avoiding the need for central or supervisory control [17].

In recent years, the research attention on dc grids has been resurging due to technological advancements in power electronics and energy storage devices, and increase in the variety of dc loads and the penetration of dc distributed energy resources (DERs) such as solar photovoltaics and fuel cells. Many research works on dc microgrids have been conducted to facilitate the integration of various DERs and energy storage systems. In [18], [19], a dc microgrid based wind farm architecture in which each wind energy conversion unit consisting of a matrix converter, a high frequency transformer and a single-phase ac/dc converter is proposed. However, the proposed architecture increases the system complexity as three stages of conversion are required. In [20], a dc microgrid based wind farm architecture in which the WTs are clustered into groups of four with each group connected to a converter is proposed. However, with the proposed architecture, the failure of one converter will result in all four WTs of the same group to be out of service. The research works conducted in [21] – [24] are focused on the development of different distributed control strategies to coordinate the operation of various DERs and energy storage systems in dc microgrids. These research works aim to overcome the challenge of achieving a decentralized control operation using only local variables. However, the DERs in dc microgrids are strongly coupled to each other and there must be a minimum level of coordination between the DERs and the controllers. In [25], [26], a hybrid ac/dc grid architecture that consists of both ac and dc networks connected together by a bidirectional converter is proposed. Hierarchical control algorithms are incorporated to ensure smooth power transfer between the ac microgrid and the dc microgrid under various operating conditions. However, failure of the bidirectional converter will result in the isolation of the dc microgrid from the ac microgrid.

III. CONTROLLERS IN MICROGRID

Many research works on designing the controllers for the control of inverters in a microgrid during grid-connected and islanded operations is conducted by researchers. A commonly adopted control scheme which is detailed in [27] contains an inner voltage and current loop and an external power loop to regulate the output voltage and the power flow of the inverters. In [28], a control scheme which uses separate controllers for the inverters during grid-connected and islanded operations is proposed.

Design technique for a class of gain-scheduling adaptive controllers for variable-speed constant-frequency (VSCF) wind generator systems using induction generators with an AC/DC/AC rotor link is presented by Ghandakly and Sbeiti [29].

Ciobotaru *et al.* discussed the issue of control strategies for single-stage photovoltaic (PV) inverter is addressed. Two different current controllers have been implemented and an experimental comparison between them has been made. A complete control structure for the single-phase PV system is also presented [30].

Smooth mode transfers and accurate current sharing are performed in a multi-inverter-based microgrid system by the designed system level controls with control area network communication proposed by Chen and Wang. Controllers of individual inverters within the microgrid in both grid-tie and islanding modes are also designed to ensure high-quality output waveforms [31].

Wang and Liuping presented Model Predictive Control (MPC) has a long history in the field of control engineering. It is one of the few areas that have received on-going interest from researchers in both the industrial and academic communities. Three major aspects of model predictive control make the design methodology attractive to both engineers and academics. The first aspect is the design formulation, which uses a completely multivariable system framework where the performance parameters of the multivariable control system are related to the engineering aspects of the system; hence, they can be understood and 'tuned' by engineers. The second aspect is the ability of method to handle both 'soft' constraints and hard constraints in a multivariable control framework. This is particularly attractive to industry where tight profit margins and limits on the process operation are inevitably present. The third aspect is the ability to perform process on-line optimization [32].

Chen and Gui proposed a new method for optimal sizing of an energy storage system (ESS) in a microgrid (MG) for storing electrical/renewable energy at the time of surplus and for re-dispatching [33].

Chung and Liu implemented controller design and optimization methods to stably coordinate multiple inverter-interfaced DGs and to robustly control individual interface inverters against voltage and frequency disturbances. Droop-control concepts are used as system-level multiple DG coordination controllers, and control theory is applied to device-level inverter controllers. Optimal control parameters are obtained by particle-swarm-optimization algorithms, and the control performance is verified via simulation studies [34].

Control strategy for a single-phase series-connected inverter with the microgrid is proposed by Dasgupta and Sahuto interface ac loads not only to regulate the load voltage under voltage disturbances, but also to control the load power drawn from the microgrid [35].

Ebad and Song presented an improved current control technique for a three-phase grid-connected DC/AC inverter using proportional resonant (PR) control. The proposed PR current control strategy is designed with tracking the reference current produced by an instantaneous power-based current reference generation method. In the controller the instantaneous power-based current reference generation method eliminates the delay in average power-based current reference generation methods, so a fast controller is required to maximize power delivery [36].

Eren *et al.* introduces a fast and optimized control scheme for grid-connected voltage source inverters (VSI) used in renewable energy applications. To deliver power from a renewable energy source to the utility grid, a fast controller is required to maximize power delivery. Many grid-side control methods have been proposed in the literature, which present different approaches to this problem. The proposed method provides solutions for the drawbacks associated with conventional PI-controller-based grid-side controllers [37].

Power electronics converters play an important role in realization and performance improvement of electrical power system. With the demand for new power resource and better power supply quality, more and more distributed energy resources (DERs) come into practice. A model predictive controller is designed to decrease common mode voltages and errors between the capacitor voltages and their reference values. Finally, simulation diagram, parameters and results using software PLECS are provided to demonstrate the merits of multilevel inverters and the validity of proposed control method by Bo and Yang [38].

Singaravelan and Kowsalya presented fuzzy controller for voltage-frequency control scheme for microgrid in islanding operation. The proposed scheme of fuzzy based voltage-power/frequency-active power (VP/FQ) sets the real power output to regulate the microgrid voltage and the reactive power output to regulate the frequency. This supervisory control scheme allows the voltage source converter (VSC) with standard inductor interface and dq-frame current control in islanding mode in the instantaneous synchronization operation. The results demonstrate that the proposed approach perfume well and has a significance for the control of inverters in microgrid [39].

Conventional proportional-resonant controller is widely accepted and adopted in micro-grid applications. Some trade-off strategies proposed in previous works are usually favored. Cai*et al.* proposes a novel fuzzy proportional-resonant control strategy for a three-phase inverter, which can obtain better outcomes of three contradictory performance characteristics simultaneously. The detailed mathematical models and design procedure of the controller for the studied inverter are presented [40].

Mahmud et al. presented a robust nonlinear distributed controller design for islanded operation of microgrids in order to maintain active and reactive power balance. In this paper, microgrids are considered as inverter-dominated networks integrated with renewable energy sources (RESs) and battery energy storage systems (BESSs), where solar photovoltaic generators act as RESs and plug-in hybrid electric vehicles as BESSs to supply power into the grid [41].

Gonzalez *et al.* presented the design and implementation of a resonant controller into a PI-P control configuration (PI-P+ Resonant controller). The design of this controller is conducted for inverter operation in island mode within the context of microgrids the main PI-P control is avoid that large control signal causing the saturation phenomena in the systems. [42].

A new control method to regulate various parameters such as voltage, current and power of the inverter interfaced with Distributed Generation (DG) in a microgrid is given by John *et al.* in which Model Predictive Control (MPC) is used to control the inverter of the DG using a state-space model of the inverter based microgrid [43].

A universal controller for three-phase inverters (called UC3) is proposed to operate converters of a microgrid (MG) in grid connected (GC) and islanded modes and ensure seamless transition between these modes without reconfiguration of the control structure. [44].

Inverter-based distributed generation (DG) system is becoming an attractive solution for high penetration of renewable energy sources to the main grid. DG system should be able to supply power to the local loads whenever necessary even in case of utility power outage. Li and Zhang presented a new control strategy with seamless transfer characteristics for a grid-connected voltage-source inverter using model predictive control (MPC) framework [45].

Issa *et al.* presented a microgrid control strategy to unify the control topology for energy storage systems (ESS) and renewable energy sources (RES) inverters in an AC microgrid and to protect the microgrid reliability from unintentional islanding instability using control loops which use the DC link voltage as a feedback [46].

Tellez *et al.* described an optimal and robust nonlinear control scheme to achieve trajectory tracking for disturbed nonlinear systems, which is applied for the control of power converters in DC microgrids [47].

From above works it is clear that three types of the controller are mostly focused while microgrid system is considered which are discussed in upcoming paragraphs. In process control applications, more than 95% controllers namely PI, PD and/or PID are in use. Their easily comprehensible principles and relatively simple implementations have been the main reason for their wide use in process industry. But in conventional control, linear approximation of the plant parameters has some disadvantages such as the linear approximation becomes computationally impractical if the plant is complex and highly dynamic. Also there are difficulties in adapting itself to changing plant parameters. Thus conventional controllers have drawbacks of approximating the properties of the system and are very sensitive to variations in the process parameters [48].

A. PI Controller

If the closed-loop system exhibits a sustained error in steady state, integral action is necessary. The integral action will increase (decrease) the control signal if there is a positive (negative) error, even for small magnitudes of the error. Thus, a controller with integral action will always return to the reference in steady state.
The PI controller is represented by,

$$U_{PI}(k)=K_P\left(e(k)+\frac{1}{T_I}\Delta e(k)\right) \tag{1}$$

where T_I is the integral time, $\Delta e(k)$ is incremental error and U_{PI} is output of PI controller.
Eq. (1) may be written as

$$U_{PI}(k)=\left(K_P e(k)+K_I\,\Delta e(k)\right) \tag{2}$$

Where, K_I represents the integral gain [48].

B. Fuzzy Logic Controller

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human’s heuristic knowledge about how to control a system. Basically, the fuzzy controller can be viewed as an artificial decision maker that operates in a closed-loop system in real time. Based upon process output and reference input it generates control signal to achieve the desired performance objectives [49].

If the closed-loop system exhibits a sustained error in steady state, integral action is necessary. The integral action will increase (decrease) the control signal if there is a positive (negative) error, even for small magnitudes of the error. Thus, a controller with integral action will always return to the reference in steady state.

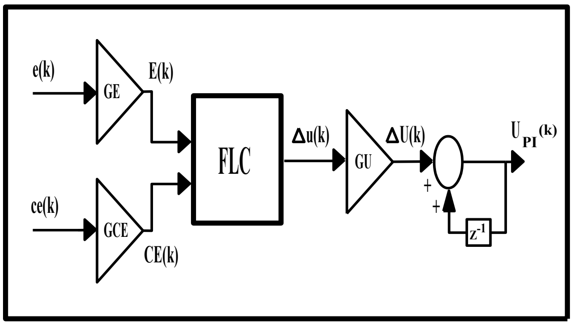

Fig. 2. PI like Fuzzy logic controller

The PI like fuzzy controller is depicted in Fig. 2. The gain on the output is, accordingly, G_U. The control signal $U_{PI}(k)$ at time instant k is the sum of all previous increments.
Output of fuzzy PI controller is given by

$$U_{FPI}(k)=\left(\Delta U(k)+U(k-1)\right) \tag{3}$$

Where $U\,(k\text{-}1)$ is delayed output.
while

$$\Delta U(k)=GU\cdot\Delta u(k) \tag{4}$$

$$\Delta u(k)=f\left(GE\cdot e(k),GCE\cdot ce(k)\right) \tag{5}$$

Where, GU is the scaling factor related to integral output of fuzzy controller.

From mapping of PI and PI like fuzzy controllers relationship between conventional PI and fuzzy PI controller given as

$$K_P=GCE\cdot GU \tag{6}$$

$$K_I=GE\cdot GU \tag{7}$$

C. Model Predictive Controller

Model predictive control offers several important advantages such as the process model captures the dynamic and static interactions between input, output, and disturbance variables, constraints on inputs and outputs are considered in a systematic manner, the control calculations can be coordinated with the calculation of optimum set points, and accurate model predictions can provide early warnings of potential problems [50].

A block diagram of a model predictive control system is shown in Fig. 3. A process model is used to predict the current values of the output variables. The residuals, the differences between the actual and predicted outputs, serve as the feedback signal to a Prediction block. The set points for the control calculations, also called targets, are calculated from an economic optimization based on a steady-state model of the process, traditionally, a linear model. The MPC calculations are based on current measurements and predictions of the future values of the outputs. The objective of the MPC control calculations is to determine a sequence of control moves (that is, manipulated input changes) so that the predicted response moves to the set point in an optimal manner.

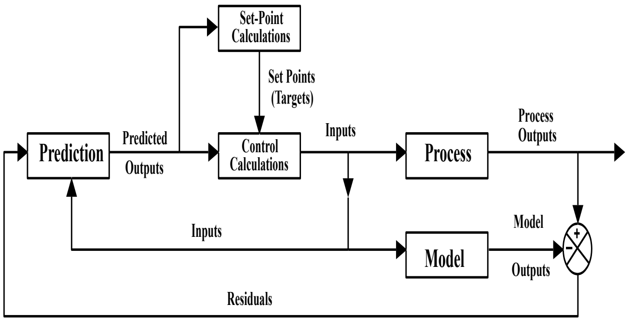

Fig. 3. Block diagram for model predictive control

The actual output y, predicted output $\hat{y}$ and manipulated input u are shown in Fig. 4. At the current sampling instant, denoted by k, the MPC strategy calculates a set of M values of the input $\{u(k+i-1)\}$, $i = 1, 2, . . , M$. The set consists of the current input $u(k)$ and M - 1 future inputs. The input is held constant after the M control moves. The inputs are calculated, so that a set of P predicted outputs, $\hat{y}(k+i)$, $i = 1, 2, . . . , P$ reaches the set point in an optimal manner. The number of predictions P is referred to as the prediction horizon while the number of control moves M is called the control horizon.

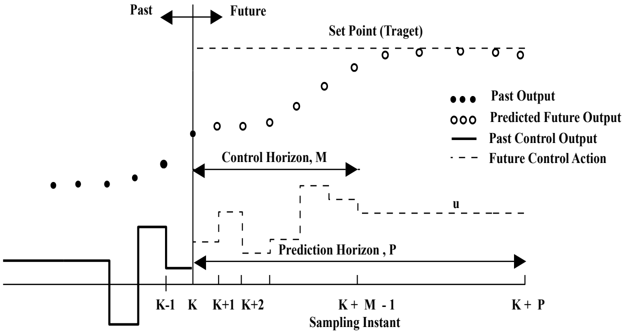

Fig. 4. Basic concept for model predictive control

Model predictive control is based on predictions of future outputs over a prediction horizon, P. In MPC k denotes the current sampling instant and $\hat{y}(k+j)$ denotes the prediction of $y(k+j)$ that is made at time k. MPC algorithm is represented in generalized form by

$$\hat{y}(k+j) = \sum_{i=1}^{j} S_i \Delta u(k+j-i) + \sum_{i=j+1}^{N-1} S_i \Delta u(k+j-i) + S_N u(k+j-N) \quad (8)$$

Where, S_i are the model parameters. First term on the right-hand side of Eq. 8 represents j-step-ahead prediction while, the second and third terms represent the predicted response when there are no current or future control actions.

IV. CONCLUSIONS

The microgrid works in recent years was discussed and structures, elements and controllers are elaborated in subsequent sections. This paper shows the significance of various components, controllers which are considered and need to be concentrated during next generation of intelligent and sustainable integrated power grids.

Microgrids are the alternatives and solutions to resolve the power supply problem by considering them as low to medium level power generation systems.

Microgrids, with a primary application of improving reliability for local customers and managing the ever increasing penetration needs that for proper execution and performance focus has to be made on design of the controllers for elements of the microgrid.

Thus, the advanced controller based microgrid can be considered as a viable concept to complement current research and development efforts on microgrids and further help advance microgrids to more practical energy systems

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