Optimal Control of BESS in Microgrid for Islanded Operation Using Fuzzy Logic

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Abstract—The microgrid operates in grid-connect mode, but, when a fault occurs in the upstream grid, it should disconnect and shift into islanded operation mode. In grid-connect mode, the controlling power at the PCC(Point of Common Coupling) is necessary management function rather than the frequency and voltage. However, the controlling the frequency and voltage is asked in islanded mode. To achieve these management goals appropriately, the coordinated control strategy between Diesel generator and BESS(Battery Energy Storage System) is needed. This paper presents PI Controller that is used as BESS charge and discharge process in Microgrid for islanded operation. Most PI Controllers have fixed PI gains, but real-time updated gains are applied to PI Controller using Fuzzy logic in this paper. The performance of suggested PI Controller was simulated by PSCAD/EMTDC. As a result, output characteristic of BESS applied real-time updated gains to PI Controller using Fuzzy logic is faster and more accurate than using fixed gains.

Keywords-Microgrid; Coordinated Control; BESS; Fuzzy Logic Controller; PI Controller.

I. INTRODUCTION

Microgrid is composed of DGs(Distributed generators), DS(Distributed Sources), renewable energy sources, Load. A microgrid can provide greater technical benefits and control flexibility to the utility grid. the Microgrid operates in grid-connect mode, but, when a fault occurs in the upstream grid, it should disconnect and shift into islanded operation mode. In grid-connect mode, the frequency of the microgrid is maintained within a tight range by the main grid. Therefore, the controlling power at the PCC is necessary management function rather than the frequency and voltage. In an islanded operation, however, which has relatively few microsources, the local frequency control of the microgrid is not straightforward. During a disturbance, the frequency of the microgrid may change rapidly due to the low inertia present in the microgrid. Therefore, local frequency control is one of the main issues in islanded operation. To achieve the management goals in two different operation modes, the cooperative control strategy is needed[1].

This paper presents coordinated control between Diesel generators and BESS using PI Controller. PI Controller is used at BESS charge and discharge process in microgrid for islanded operation. Most PI Controllers have fixed PI gains, but real-time updated gains are applied to PI controller using Fuzzy logic in this paper. The performance of suggested PI controller was simulated by PSCAD/EMTDC. As a result, output characteristic of BESS applied real-time updated gains to PI controller using Fuzzy logic is faster and more accurate than using fixed gains.

II. MICROGRID

A. Configuration of the Microgrid

Microgrid consists of low Voltage distribution system with DGs, renewable energy sources, ESS(Energy Storage System), load and etc.. Fig. 1 is typical configuration of microgrid.

![Figure 1. Typical configuration of Microgrid](image)

B. Hierarchy control of microgrid

Microgrid has a hierarchical control structure. It has two layer : MGCC(Microgrid Central Controller) and LC(Local Controller). The MGCC is a centralized controller that deal with management function and provides power output set point to LC. LC is transmission power output set point to microsources and BESS[1].
III. COORDINATED CONTROL FOR ISLANDED MICROGRID

The main concept for islanded operation involves the cooperative control of the ESS and other controllable microsources, as shown in Fig. 3. During islanding, the power balance between supply and demand does not match at the moment. As a result, the frequency and the voltage of the microgrid will fluctuate, and the system can experience a blackout unless there is an adequate power-balance matching process. The controller of inverter in the ESS responds in milliseconds. Otherwise, the diesel generator, gas engine, and fuel cell have a relatively slow response time. Obviously, the ESS should play an important role in maintaining the frequency and the voltage of the microgrid during islanded operation. In islanded operation, proper power-balancing action of the ESS, the frequency, and the voltage of the microgrid can be regulated at the normal values. Therefore, the power output of the ESS should be brought back to zero as soon as possible by the secondary control in MMS in order to secure the maximum spinning reserve.

The MMS receives the information about system state as an input, e.g. power outputs of the ESS and DGs, frequency and voltage, and the closed loop issues the power output set point for the dispatchable DGs. The LCs are responsible regulating the power output locally in each component. Fig. 4 shows the coordinated control strategy in this paper [1].

IV. CONTROL STRATEGY OF ACTIVE & REACTIVE POWER OF BESS

A. PI Controller in BESS

According to unit commitment, difference between injected to grid of active, reactive power reference value $P_{\text{ref}}$, $Q_{\text{ref}}$ and active power actual value $P_{\text{grid}}$, $Q_{\text{grid}}$ is input value of PI Controller. Outputs the $d$ and $q$-axis current commands, $I_{d_{\text{ref}}}$ and $I_{q_{\text{ref}}}$, these reference values are transformed into the a-, b-, c- reference values $I_a$, $I_b$, $I_c$. These values are operated input signal of PWM (Pulse Width Modulation) [1].

B. Fuzzy PI Controller

1) Fuzzy Logic Controller

A Fuzzy Logic Controller can be regarded as a nonlinear static function that maps controller inputs onto controller outputs. A Controller is used to control some system, or plant. The system has a desired response that must be maintained under whatever inputs are received. The
inputs to the system can, however, change the state of the system, which cause a change in response. The task of the controller in then to take corrective action by providing a set of inputs that ensures the desired response. As shown in Fig. 6, a fuzzy logic controller consists of four main components, which are integral to operation of the controller[3-4].

- Fuzzy rule base : The rule base, or knowledge base, contains the fuzzy rules that represent the knowledge and experience of a human expert of the system. These rules express a nonlinear control strategy for the system. While rules are usually obtained from human experts, and are static, strategies have been developed that adapt, or refine rules through learning using neural networks or evolutionary computing.

- Fuzzifier : The fuzzifier receives the actual outputs of the system, and transforms these non-fuzzy values into membership degrees to the corresponding fuzzy sets. In addition to the system outputs, the fuzzification of input values to the system also occurs via the fuzzifier.

- Defuzzifier : The action interface defuzzifies the outcome of the inference engine to produce a non-fuzzy value to represent the actual control function to be applied to the system.

- Inference engine : The inference engine performs inferencing upon fuzzified inputs to produce a fuzzy output.

While rules are usually obtained from human experts, and are static, strategies have been developed that adapt, or refine rules through learning using neural networks or evolutionary computing. In addition to the system outputs, the fuzzification of input values to the system also occurs via the fuzzifier.

V. SIMULATION

Fig. 8 shows the configuration of the microgrid test model. The Microgrid system consists of Diesel generators, BESS, STS, Load and Wind generators. The details of test system are given in Table 1.

![Figure 8. Microgrid test model](image)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Description and Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test System Configuration</td>
<td>Diesel generators, Wind generator, BESS, Load</td>
</tr>
<tr>
<td>Generation Capacity</td>
<td>Diesel generator : 50kW, 40kW, Wind generator : 20kW, BESS : 20kW</td>
</tr>
<tr>
<td>Load</td>
<td>90kW+j25kVar</td>
</tr>
</tbody>
</table>

A. Simulation result

A simulation platform under the PSCAD/EMTDC environment was developed to evaluate the dynamic behavior of the microgrid. The initial value of Microgrid Load is 60kW+j25kVar, Diesel 1 is 30kW+j8kVar, Diesel 2 is 20kW+j4kVar and BESS is 0kW because microgrid is grid-connected mode. The two consecutive events were applied. A disconnect from the utility grid occurred at t=5s and the active load increased from 60kW to 90kW at t=15s.

In this paper, compare PI Controller and Fuzzy PI Controller at BESS. Fig. 9,10 is graph of BESS active, reactive power output. Compared applied PI Controller and Fuzzy PI Controller. Fig. 11 is graph of Microgrid Voltage and Frequency. Compared applied PI Controller and Fuzzy PI Controller.

![Figure 7. Configuration of Fuzzy PI Controller of the BESS](image)

Value of compensation of BESS is $P_{\text{com}}$ and differential of $P_{\text{com}}$ is $dP_{\text{com}}$ is input value of the Fuzzy Logic Controller. Using Fuzzy Logic Controller, find the PI Controller’s gain $K_p$, $K_i$. $K_p$, $K_i$ is real-time update to PI Controller. In other words, PI Controller’s gains are variable not fixed. So, more and faster response and control than fixed PI gains[2].
In fig. 12, After islanding, the power output of BESS changes from zero to certain value to control the frequency and the voltage in microgrid and settled down to zero. At the time, Diesel generators power output also changes for meeting power supply and demand in microgrid. In the event of a active load increased from 60kW to 90kW at t=15s. The power output of BESS changes immediately. In succession the power output of BESS changes to zero for preparing to inject or absorb power in microgrid. In Fig. 9, 10 are compared graph applied PI Controller and Fuzzy PI Controller. Fig. 9, 10 are active, reactive power graph of BESS in same scenario. $P_{\text{BESS}_{FZ}}$ is active power output applied to Fuzzy PI Controller at BESS and $P_{\text{BESS}_{PI}}$ is active power output applied to PI Controller at BESS and $Q_{\text{BESS}_{FZ}}$ is reactive power output applied to Fuzzy PI Controller at BESS and $Q_{\text{BESS}_{PI}}$ is reactive power output applied to PI Controller at BESS. As shown in Fig. 9 $P_{\text{BESS}_{FZ}}$ is faster and more accurate than $P_{\text{BESS}_{PI}}$. For these reasons, Using Fuzzy PI controller is rapidly recovery microgrid voltage and frequency than PI Controller in Fig. 11.
B. Verify the robustness of the Fuzzy PI Controller

In this chapter, verifying the robustness of the presented Fuzzy PI Controller. To verify the robustness, simulation was performed by using two scenarios with PI Controller and Fuzzy PI Controller.

1) Load change

The active load changed from 60kW to 40kW at t=15s, 40kW to 90kW at t=20s, 90kW to 50kW at t=25s and 50kW to 30kW at t=30s. Results of simulation are as below graph.

In this case, according to the load changing output power of BESS are properly controlled both Fuzzy PI Controller and PI Controller in Fig. 14. As a result microgrid voltage and frequency are properly controlled.

2) Load change and Diesel generator fault

Load change is same Fig. 13 and Diesel generator2 is fault at t=25s in Fig. 16

In this case, according to the load changing output power of BESS are properly controlled both Fuzzy PI Controller and PI Controller in Fig. 14. As a result microgrid voltage and frequency are properly controlled.
In this case, applied PI Controller at BESS isn’t controlled at t=25s but, applied Fuzzy PI Controller at BESS is properly controlled at t=25s to 40s. So, Fuzzy PI Controller is more robust than PI Controller.

VI. CONCLUSION

In this paper, proposed a Fuzzy PI Controller for active, reactive power control at BESS in islanded microgrid operation. Microgrid is non-linear system and difficult for mathematical modeling. So, PI Controller that using fuzzy logic is easier than general PI Controller to model analysis. Because fuzzy logic has strength to non-linear model analysis and need not mathematical modeling and robustness. As a result, applied Fuzzy PI Controller at BESS is more accurate and faster than PI Controller at BESS. In addition to robustness is more outstand than PI Controller.

The coordinated control between BESS and Diesel generators, during islanding, results that the BESS can handle the frequency and the voltage. But, BESS have a capacity for energy storage. Therefore, power output of ESS should be brought back to zero as soon as possible. At the time output of diesel generators are increased to meet power demand and supply.

REFERENCES


