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Performance Comparison of Proportional-Integral and Fuzzy-PI for a Droop Control of DC Microgrid

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***Abstract*—This work presents the droop control performance for sharing loads on the DC microgrid network. The traditional droop control consists of voltage control and current control where the PI controller is used as compensation for the error. The droop control performance can be seen from the fast response of the system when load power sharing between two DC generating sources is enabled. The Fuzzy-PI controller as an intelligent control functions to improve the performance of droop control on the DC microgrid. The Fuzzy PI controller suggested is built with the aid of a closed loop control based on the power of each unit DCG (DC Generator), and accurate power distribution has been realized proportionally to the power ratings of each DCG taking into account load changes. The use of Fuzzy-PI in droop control makes the dynamic reaction quicker (0.06 s rise time) and microgrid system stability better compared with PI controllers. The proposed control strategy is completely tested with a Mathlab/Simulink simulation.**

Keywords—droop control, power sharing, DC microgrid, fuzzy-pi, DC House

I. INTRODUCTION

DC Microgrid (DCMG) is an ideal option for integrating multiple DG (Distributed Generation) units such as wind power, PV, fuel cell and battery storage systems [1,2]. DCMG is flexible and is able to operate in either on-grid [3,4] or off-grid modes [5,6]. DCMG can reduce losses on energy transformation by minimizing DC-AC or AC-DC transformations compared to AC microgrid [7-9].

The difference in DC nanogrid (DCNG) and DCMG is explained in [10], which are both different in scale. DCNG is a single point distribution network, such as a DC house [11,12] or small building, while DCMG is a distribution network system that connects DCNG [13].

DCNG acts as a DC generation (DCG) when it has more electrical power; thus, it is able to inject power to the DCMG network. Otherwise, DCNG absorbs electrical power from DCMG when the electric power decreases [14].

Several studies have been developed related to energy management system (EMS) and control strategy of DCMG or DCNG. Centralized control is operated in a small scale DCMG network [15,16]. This control has a single controller that collects and processes all relevant data. It guarantees reliability and resiliency during various mode of operation. However, this control technique features a single point of failure and flexibility reduction [17].

Another control strategy is the decentralization method. This method uses a droop control that has been widely used for power sharing [18,19]. The droop control uses virtual resistance for current sharing, and does not need a communication link, making the distribution system cheap and simple. However, the conventional droop control has several disadvantages including the presence of voltage drop in DCMG and error current sharing [20]. Therefore, several studies have been established to improve the performance of the conventional droop control. In the traditional droop equation, the droop characteristics are shifted along the voltage axis by adding Δv, so the voltage drop can be minimized [21-22]. For each DCMG converter, the droop resistance is modified to reduce the current sharing error and the current sharing reference is determined on the basis of the ratio of its rating to the current load. [23-24].

However, previous research studies have not discussed the performance of voltage control (VC) and current control (CC) used in droop control. VC and CC use Proportional-Integrator (PI) controller as compensation error where its performance needs to be improved. In this study, we propose the Fuzzy-PI controller as an error compensation in the droop control. The Fuzzy-PI method has been found to accelerate a system to reach settling time and reduce overshoot [25-27]. Although the Fuzzy-PI has already proposed in many refferences, the utilization of Fuzzy-PI for voltage control on droop control has not yet been presented. The efficacy of the proposed fuzzy-PI is checked by comprehensive simulation in the Matlab/Simulink environment.

II. SYSTEM CONFIGURATION AND DROOP CONTROL FOR POWER SHARING IN DCMG

A. Configuration System

The system configuration follows a decentralized scheme consisting of 2 layers: 1) DCNG, which represents every single home, and 2) DCMG is an aggregation of many DCNGs into an external DC bus. [26]. Depending on the amount of power, aach DCNG may consume or transfer power to others [27]. DCNG which has excess power acts as DC generation, and DCNG which absorbs power acts as a DC load (DCL).

The proposed topology can be shown in Fig. 1 DCNG is linked through a bidirectional converter to the external DC bus. The interconnection is intended to make the system reliable, expandable, and power sharing. This topolgy also

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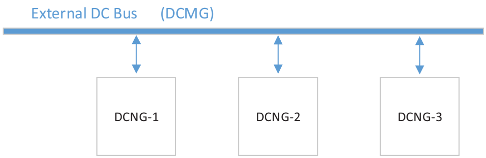

Fig. 1. A DCMG composed of connected DCNGs

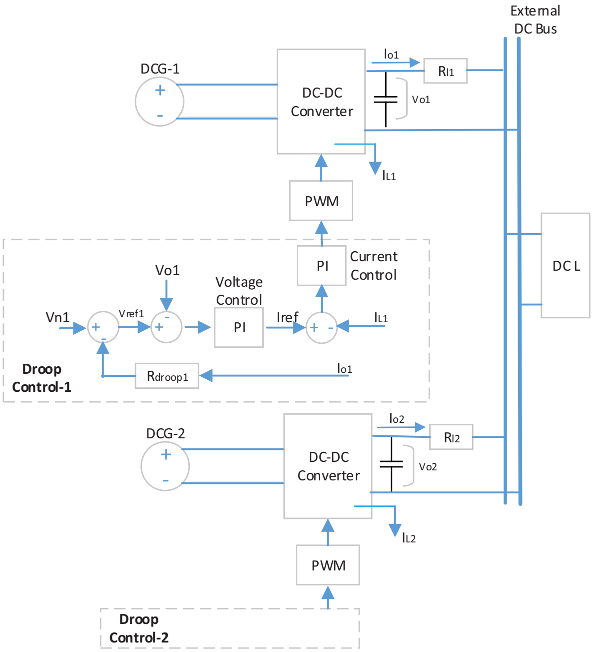

Fig. 2. Droop Control Architecture for DCMG

make system expandable, since DCNG will freely connect or disconnect based on the specifications of the consumer. Furthermore, since there is no data transmission connection in the proposed topology, each DCNG can operate independently and rely on local measurements and controllers to improve system reliability.

B. *Droop Control*

Fig. 2 illustrates droop control architecture in DCMG, where just two DCGs and one DCL are considered to simplify the analysis. The purpose of the drooping control loop is to ensure that each DCG delivers power according to its power capacity. The real voltage of each converter V_{oi} is compared to the reference voltage V_{refi} obtained from the discrepancy between the nominal voltage V_{ni} (at no load) and the voltage drop.

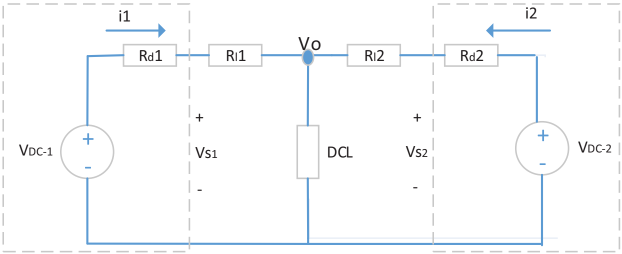

Fig. 3. Circuit model of two DCG units paralleling connected

The droop control loops consist of an voltage control loop and current control loop. The function of the voltage control is to set the reference current. While current control loop functions to regulate the output current (I_{oi}) to find the reference value. I_{Li} is the inductor current in the DC-DC Converter circuit. Both control loops use conventional PI to compensate for errors. The values of Kp and Ki can be tuned using the Ziegler Nichols method. However, the load conditions greatly affect the performance of the system. When the load curent fluctuates, the system performance changes. Therefore, the PI gains ought to be tuned based on the load condition such as the maximum load. This problem can be solved by a fuzzy PI and so the system performance could also be better than PI control.

From Fig. 2, the equivalent circuit may be simplified to the equivalent circuit shown in Fig. 3 R_{d1} and R_{d2} are droop gain or virtual resistances, where each resistance value can be easily adjusted. R_{l1} dan R_{l2} are line resistances of DCG1 and DCG2, respectively.

Using the voltage kirchoff law the following equation is obtained

$$V_{DCj} = V_{sj} + i_j . R_{dj} \text{ , where j = 1,2} \quad (1)$$

where V_{DCj}, V_{Sj}, i_j, and R_{dj} are reference voltage at no load, output voltage, output current of source converter, and droop resistance. The output voltage of source converter can be deduced from (2).

$$V_{s\,j} = V_O + i_j . R_{lj} \quad (2)$$

From (1) and (2), the output current is given as:

$$i_j = \frac{V_{DCj}-V_O}{(R_{dj}+R_{lj})} \quad (3)$$

The error of current sharing by two DCG is specified as:

$$\Delta i_{1,2} = \frac{(R_{d2}+R_{l2})\,(V_{DC1}-V_O)-\,(R_{d1}+R_{l1})\,(V_{DC2}-V_O)}{(R_{d1}+R_{l1})\,(R_{d2}+R_{l2})} \quad (4)$$

For equal current sharing, $\Delta i_{1,2}$ can be reduced by adjusting the droop resistance. The voltage deviation can be written as:

$$\Delta V_j = V_{DCj} - V_{sj} = i_j . R_{dj} \quad (5)$$

To limit deviation in output voltage to acceptable levels, the droop resistance R_{dj} should be limitted as

$$R_{dj} \le \frac{\Delta V_{max}}{i_{flj}} \quad (6)$$

where i_{flj} is full load current of source DCG.

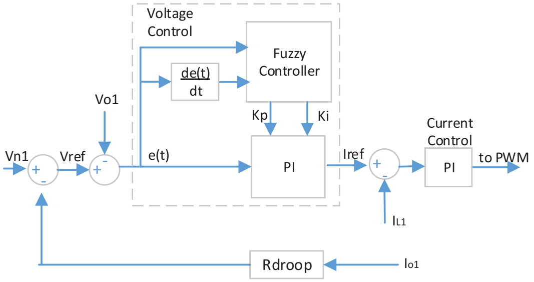

Fig. 4. The proposed control block diagram of droop control

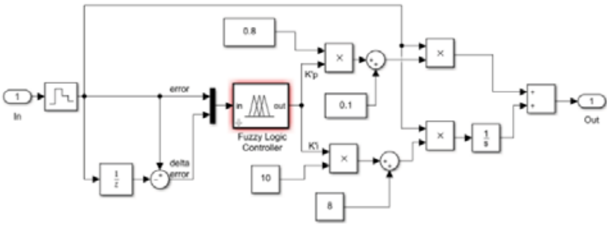

Fig. 5. Simulink block Fuzzy-PI

III. PROPOSED CONTROL STRATEGY

The main purpose of using Fuzzy-PI in droop control is to accelerate the response time of droop control and reduce overshoot. The proposed droop control design is shown in Fig. 4 Fuzzy-PI is applied to the voltage control. The tuning of PI gain is based on the knowledge base and the fuzzy inference.

Fuzzy controller has two inputs: the error value e(t) and the derived change in error value de(t), and the K_p and K_i parameters are two outputs of the fuzzy system. Range of parameter variables K_p, K_i of PI control is $[K_{p\,min}, K_{p\,max}]$, $[K_{i\,min}, K_{i\,max}]$. Initial simulations are performed to determine the value of each variable so that it gets the best PI controller parameter. The range of values obtained is $K_p \in [0.1,0.9]$ and $K_i \in [8,18]$. Determination of the PI control parameters follow Equations 7 and 8.

$$K'_p = \frac{K_p - K_{p\,min}}{K_{p\,max} - K_{p\,min}} = \frac{K_p - 0.1}{0.9 - 0.1} \qquad (7)$$

$$K'_i = \frac{K_i - K_{i\,min}}{K_{i\,max} - K_{i\,min}} = \frac{K_i - 8}{18 - 8} \qquad (8)$$

The resulting parameter value is $K_p = 0.8.K'_p + 0.1$ and $K_i = 10K'_i + 8$. Fig. 5 shows the adaptation of PI control using Fuzzy via Simulink.

The input membership function in the proposed design has 5 values of fuzzy linguistic variables, as shown in Figs. 6 and 7. Linguistic variables for the output are labelled as PB: positive big, PS: positive small, Z: Zero, NS: negative small, and NB: negative big.

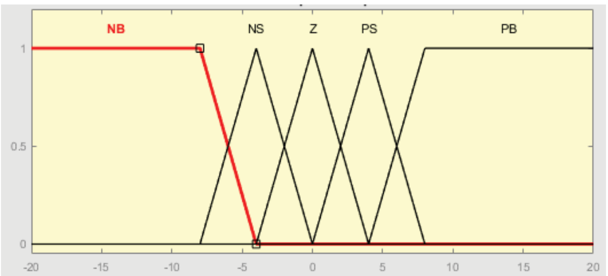

Fig. 6. Membership function of error

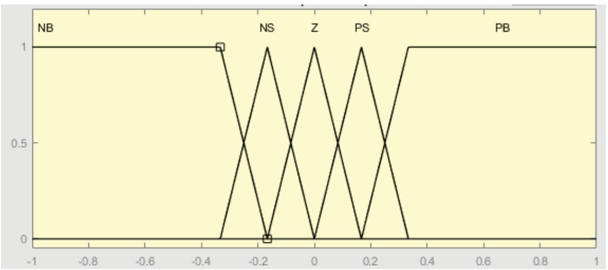

Fig. 7. Membership function of delta error

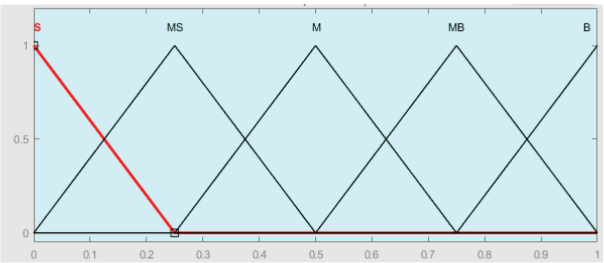

Fig. 8. Membership function of K_p and K_i

TABLE I. FUZZY RULES

e/de	NB	NS	ZE	PS	PB
NB	S	S	MS	MS	M
NS	S	MS	MS	M	MB
Z	MS	MS	M	MB	MB
PS	MS	M	MB	MB	B
PB	M	MB	MB	B	B

Membership of the fuzzy output function for K_p dan K_i is shown in Fig. 8. The linguistic variables used are B: big, MB: medium big, M: medium, MS: medium small, and S: small.

The fuzzy system with 5 linguistic variables is used in this study, and there are 25 fuzzy rules as shown in Table I.

IV. RESULTS AND DISCUSSIONS

The performance of the proposed DC microgrid control solution is evaluated by computer simulation using Matlab/Simulink. Each DCG has a boost converter with the parameters specified as: V_{in} = 48V; V_{nom} = 100V. Various simulation parameters are indicated in Table II.

TABLE II. SIMULATED PARAMETERS CASE STUDY

Description of parameter	Symbol	Value
Reference voltage for DC bus	Vref	100V
Droop resistance for conv1 and conv2	R_D	0.2 Ω,0.1 Ω
Switching frequency of each conv	F	10kHz
Inductance of each conv	L	3mH
Conductance of each conv	C	100µF
Line resistance for DCG1	R_{L1}	0.1 Ω
Line resistance for DCG2	R_{L2}	0.2 Ω

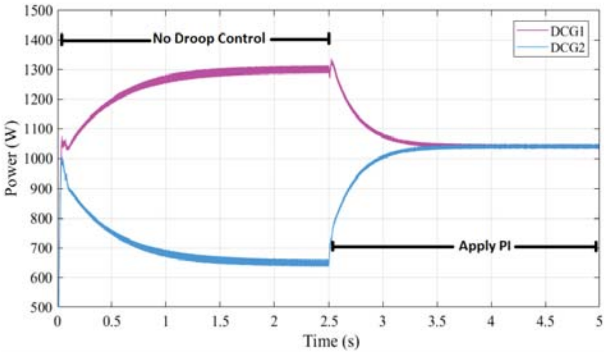

Fig. 9. Dynamic response of system with PI

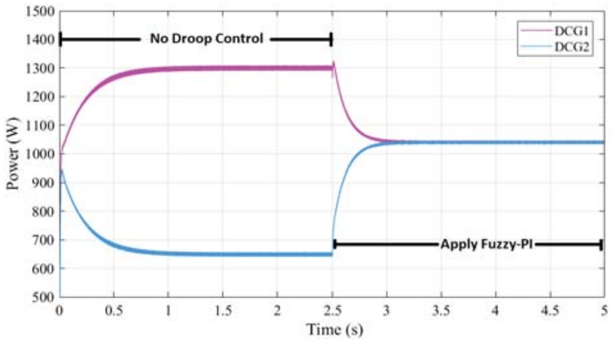

Fig. 10. Dynamic response of system with Fuzzy-PI

A. *Performance of Droop Control with Load Sharing*

Figs. 9 and 10 shows the system's dynamic performance in standard PI and Fuzzy-PI controller. From 0 to 2.5s, droop control is disable, each DCG has a different power due to the varying resistance of the line. The droop control is enabled at 2.5s. The Fuzzy-PI performs better with quicker response and shorter settling time compared to the conventional PI controller.

B. *Performance of Droop Control with Load Changes*

In this case, we consider the changes in load from R = 6Ω to 5Ω at 0.5s, and then to 5.5Ω at 1s. Figs. 11 and 12 show the output power from the two DCG at different loading conditions. The Fuzzy-PI controller has faster response and smaller overshoot than the traditional controller PI. It can therefore be inferred that the proposed Fuzzy PI has the dynamic output better against the traditional PI controller. Results in Figs. 11 and 12 are justified in detail by data in Table III.

TABLE III. PERFORMANCE COMPARASION OF DROOP CONTROL

Parameter	Fuzzy-PI	PI
Rise time (s)	0.012	0.077
Settling time (s)	0.0620	0.1875
Overshoot (%)	0.617	0.926

Another effect of using the fuzzy-pid controller on the droop control is shown in Fig. 13. When the load changes, Fuzzy-pi has a faster voltage response compared to the PI controller. That occurs since the original Kp and Ki values were modified by the fuzzy logic controller so that the parameter suitable for PI were obtained. Results in Fig. 13 has been justified by Table IV.

TABLE IV. VOLTAGE PERFORMANCE COMPARISON OF DROOP CONTROL

Parameter	Fuzzy-PI	PI
Rise time (s)	0.0156	0.0686
Settling time (s)	0.0520	0.1970
Overshoot (%)	0.418	0.667

V. CONCLUSION

The droop control based Fuzzy-PI controller has been successfully analyzed and simulated. The validity of the proposed Fuzzy PI in droop control is verified through Matlab & Simulink simulation. The results show that the stability of the whole system can be assured. It further demonstrates that load changes in the DC MG can be regulated more adaptively. Overall, the proposed Fuzzy PID controller 's nonlinear properties with variable control gains is able to improve control performance compared to those observed from the traditional PI.

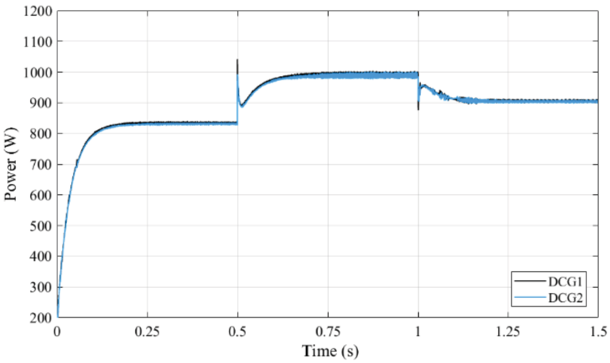

Fig. 11. Output power of the DCG with PI

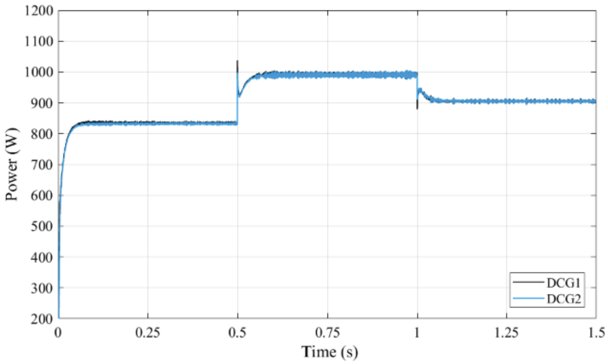

Fig. 12. Output power of the DCG with Fuzzy-PI

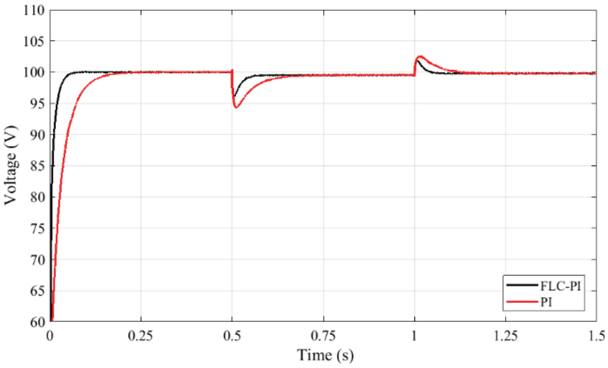

Fig. 13. Voltage comparison of droop control under load change

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