Control Design of HESS (Hybridization Energy Storage System) Based on Fuzzy Logic Control

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Abstract. Renewable energy-based electricity generation may fluctuates frequently, resulting in unmet demand. Energy storage can be used to solve such problem though each kind of energy storage have their own weaknesses hence hybridization of more than one type energy storage system (ESS) was created. Hybridization of ESS require energy management strategy in order to function properly and effectively. In this work, a fuzzy logic energy management strategy is proposed to control the charging and discharging of a hybrid energy storage system consisting of battery and super capacitor that occur to accommodate varying power demand placed on ESS by the connected DC microgrid. This strategy works by factoring the power produced by photo voltaic, the state of charge of both battery and super capacitor. This strategy is tested by using simulation of MATLAB/SIMULINK and the results show that the strategy works as intended to.

Keywords: Energy management, HESS, fuzzy logic control

INTRODUCTION

The rising demand for electricity, combined with dwindling supplies of conventional resources, is driving an increase in the use of alternative renewable energy to generate electricity. Beside being abundantly available and free, renewable energy resources (RES) are also ecologically benign but the downside is that some type of RES are intermittent and not always available [2]. The intermittent nature of RES and other external factor will affect performance of electricity generation and would result fluctuations on the generated electricity. Energy storage system (ESS) can be used to solve this problem [3].

As one of most widely used energy storage, battery has many advantages but also has some weaknesses, one of which is owning a finite lifetime moreover charging and discharging cycle of high frequency would reduce its lifetime and its performance was affected by environment's temperatures. To address this problem, hybrid energy storage system (HESS), which was created by using more than one type of energy storage, can be used.

Battery has a low power density and the ability to store energy for a long duration, hence, to complement these characteristics, an ESS with a high power density, such as a flywheel or super capacitor, should be used to form HESS so that the HESS formed possessed high power density [4].

Super capacitor have a long life cycle and wider range of operating temperature as compared to battery [1]. The disadvantage of super capacitor is its low stored energy and short duration time. Considering both advantage and disadvantage of both ESS, the HESS formed by combining battery and super capacitor is a combination of fast response ESS and long term ESS. HESS that combine battery energy storage system (BESS) and super capacitor energy storage system (SCESS) has been proven to be able to prolong battery life and counter battery aging.

Fuzzy logic control (FLC) was utilized in [5] to control the energy management system for a photo voltaic system that included a battery and a super capacitor. This method allowed super capacitor to be used for little power demand thus helping maintain the state of charge (SOC) of both battery and super capacitor. [6] proposed FLC to regulate energy management system for electric vehicle with battery and super capacitor preventing battery being overloaded and making EV last longer than just using battery [8].

In this paper, HESS consisted of BESS and SCESS is used on DC microgrid that is connected to photo voltaic and load. In this paper we aim at developing a method that could achieve energy management of HESS using fuzzy as the control strategy to control charge and discharge to improve the steady state performance and dynamic response performance while lightening battery's workload. Modeling and implementation of control strategy as well as the resulting performance are obtained using MATLAB/SIMULINK.

I. H. Agustin (ed.), *Proceedings of the 2nd International Conference on Neural Networks and Machine Learning 2023 (ICNNML 2023)*, Advances in Intelligent Systems Research 183,
https://doi.org/10.2991/978-94-6463-445-7_2

THEORETICAL BASIS

Battery Energy Storage

Battery energy storage system (BESS) is one of the most commonly used ESS. BESS stored energy in the form of chemical energy and can be store for long duration [7]. According to [9, 11], despite its low response capability, BESS can ensure high energy supply reliability and achieve a high storage capacity with a fairly low cost of installation. Due to owning a low power density, battery is unable to produce a high output of power and instantly producing power close to the limit of battery will reduce its own health.

Super Capacitor

The capacitance of super capacitors is much larger than that of ordinary capacitors and is considered halfway between capacitors and rechargeable batteries. Super capacitors have a greater power density but have a lower energy density when compared to batteries. With their high power density, super capacitors are suitable for responding to high power demands but fast load fluctuations or transients [12].

Hybrid Energy Storage

The frequency of charging and discharging has a large effect on battery life. Too high a frequency can reduce its service life. This hybrid energy storage system is one of the solutions. Hybrid energy storage system is an energy storage system that stores energy using more than one type of media. In this study, the energy storage media used are batteries and super capacitors to cover each other's weaknesses [10].

Batteries can store energy for a long time and have a low self-discharge rate while super capacitors have a high self-discharge rate so they will experience energy loss in the short term but have a fast response time and high power density. So that batteries are more suitable for long-term energy storage, while super capacitors are more suitable for short-term energy storage to respond to high power demands, transients and fast load fluctuations.

There are several HESS topologies of battery and super capacitor such as passive topology, semi active topology and active topology. In this study, active topology is used in order to be able to completely regulate power distribution of HESS. Fig. 1 shows active HESS topology where each ESS is connected to a converter so that each ESS can be actively controlled.

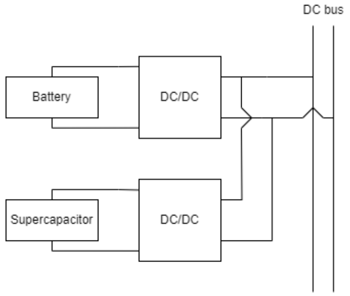

FIGURE 1. Topology of active-type HESS

Bi-Directional Converter

Being directly connected to both DC bus and ESS, bi-directional converter (BDC) can be used to control the action of charging and discharging of both ESS, which is why the topology is referred to as active-type. BDC is composed of two switch, inductor and capacitor.

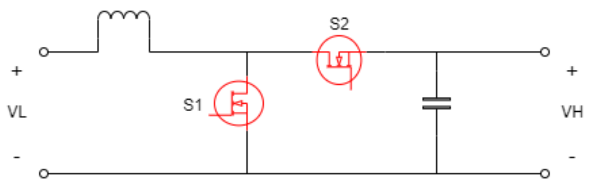

FIGURE 2. Buck-boost bi-directional converter topology

Fig. 2 shows topology of bi-directional buck-boost converter in which VL represented the side that had lower voltage and VH represented higher voltage side. BDC had two modes of operation namely buck mode and boost mode. In buck mode, power flows from VH to VL and the opposite happens in boost mode. Whether in buck mode or boost mode, either one of S1 and S2 will be switched on and the other will be switched off hence S1 and S2 will not be switched on together.

PROPOSED METHOD

DC microgrid used in this research composed of PV as main power source, battery and super capacitor as ESS that can store energy and function as power source as well and load.

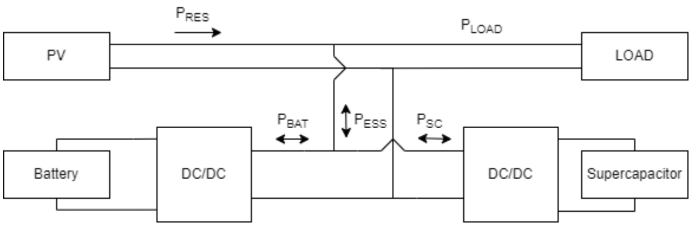

FIGURE 3. Power flow on DC microgrid

Fig. 3 shows that there are several kind power flow namely PRES which represent power power produced by PV; PLOAD which represent power consumed by load; PESS which represent total power input or output of HESS; PBat and PSC representing power input or output of battery and super capacitor respectively. The value of each variables can be determine using (1), (2) and (3).

$$P_{DEM} = \mathrm{P}_{\mathrm{RES}} - P_{LOAD} \quad (1)$$

$$P_{DEM} = P_{ESS} \quad (2)$$

$$P_{ESS} = P_{BAT} + P_{SC} \quad (3)$$

P_{ESS} solve the difference of power between P_{RES} and P_{LOAD}. P_{ESS} is the total of P_{BAT} and P_{SC}. The measurement of P_{BAT} and P_{SC} is decided by fuzzy logic control on energy management system (EMS).

Fuzzy on BDC

FLC that control BDC and decide the duty cycle used on BDC. This FLC has two input, namely Error and D_Error, and one output which is DutyCycle. The Error input is the difference between voltage of DC microgrid and calculated reference voltage, meanwhile D_Error input is Error input of previous moment. DutyCycle output is directly used as duty cycle by PWM generator.

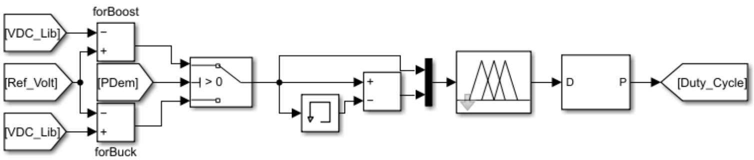

FIGURE 4. Diagram of FLC on BDC

Fig. 4 shows topology of FLC on BDC where duty cycle of BDC is decided. Duty cycle for boost mode and buck mode have a difference in the way they are calculated but have the same steps of deciding duty cycle, that is calculating the difference between referred voltage with the voltage on DC microgrid then compare the calculation result with the result of previous moment and then being inputted to FLC.

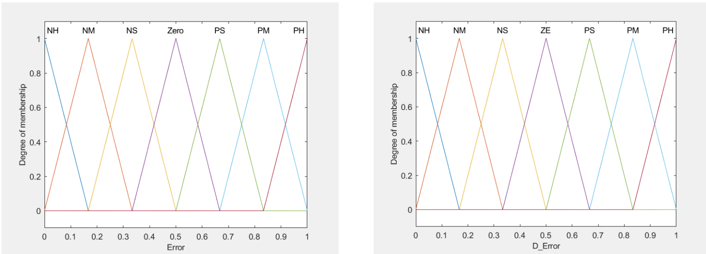

FIGURE 5. Membership function of error and *D* error

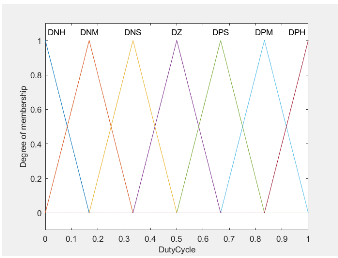

FIGURE 6. Membership Function of DutyCycle

Fig. 5 show input membership functions and Fig. 6 shows output membership function. Fig. 7 shows 3D surface plot of Error and D_Error to DutyCycle.

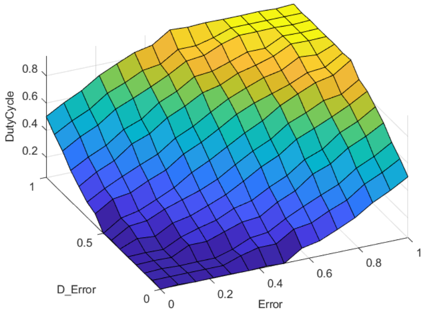

FIGURE 7. Surface plot of error and D_Error to DutyCycle

3D surface plot of Error and D_Error to DutyCycle show resulting value of duty cycle based on determined rules in fuzzy inference. It can be seen that the lesser D_Error is, the closer DutyCycle is to the value of 0 and the greater D_Error is, the closer DutyCycle is to the value of 1.

Fuzzy on EMS

FLC on energy management system has three input of Dem which represent calculated power difference between PRES and PLOAD; SOC_BAT and SOC_SC representing State of Charge of battery and super capacitor respectively.

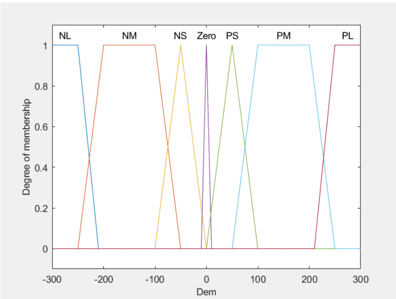

FIGURE 8. Membership function of dem

Fig. 8 show membership function of Dem which is one of inputs for fuzzy on EMS. This membership function can categorized the input into seven categories. Aside from “Zero” category where demand of power is met, the other category can be divided into two sides of N and P where N side represent demand of power is less than power generated and P side side represent otherwise. Both P side and N side were divided into S, M and L which represent small, medium and large respectively.

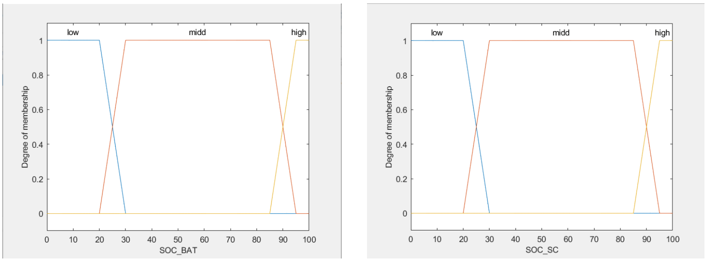

FIGURE 9. Membership Function of SOC_BAT and SOC_SC

Fig. 9 show membership function of two inputs for FLC on EMS which represent State of Charge (SOC) of both battery and super capacitor. Both membership functions can categorize the input into three categories of "low", "midd" and "high". Whereas it is recommended to avoid discharging when the input is in "low", it is also recommended to avoid charging when the input is in "high".

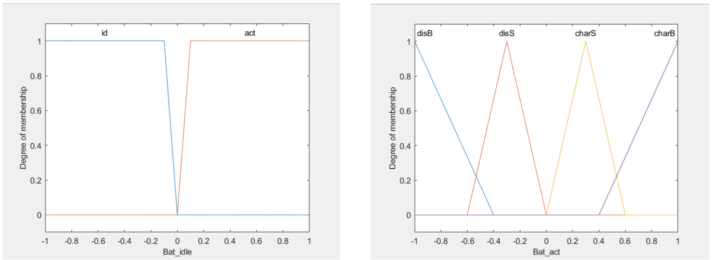

FIGURE 10. Membership function of Bat_idle and Bat_act

Fig. 10 and 11 show membership functions of four outputs to determine the action of both battery and super capacitor, whether it is "idle", "charging" or "discharging". Membership functions with the name that end with "idle" will determine whether the energy storage being active or being idle, while membership functions with the name that end with "act" will determined how the energy storage act (charging or discharging) and how much it will be. The first word of the name of membership functions will determine which energy storage it is intended to work for.

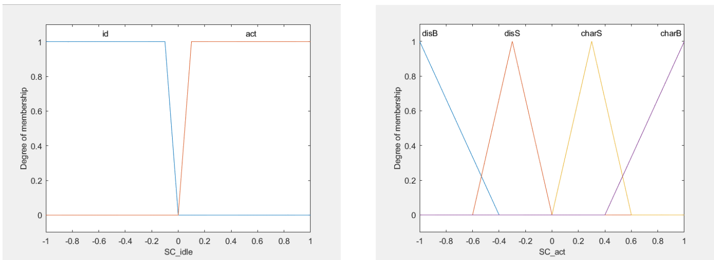

FIGURE 11. Membership function of SC_idle and SC_act

SIMULATION AND RESULT

The modeling and simulation of proposed strategy is carried out by using MATLAB/SIMULINK. The following figures are 3D surface plots of the proposed strategy.

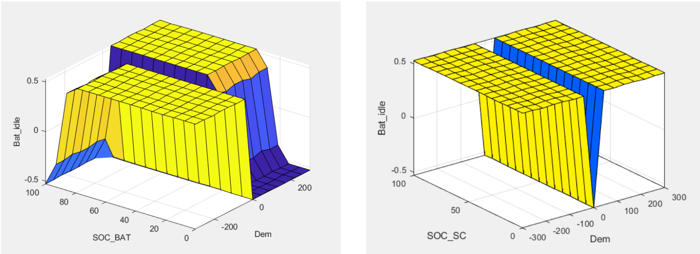

FIGURE 12. Surface plot of DEM and SOC_Bat to Bat_idle and surface plot of DEM and SOC_SC to Bat_idle

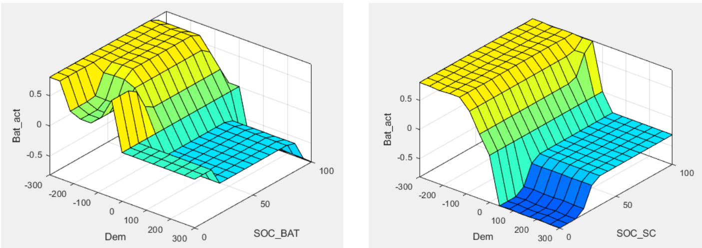

FIGURE 13. Surface plot of DEM and SOC_BAT to Bat_act and surface plot of DEM and SOC_SC to Bat_act

Fig. 12 show 3D surface plot of DEM and both SOC of battery and super capacitor to Bat_idle, while Fig. 13 show 3D surface plot of DEM and both SOC of battery and super capacitor to Bat_act. From Fig. 12, it can be seen that SOC_SC won't affect whether battery is idle or not and battery won't act if DEM is zero or if DEM is in negative while SOC_BAT is high or if DEM is in positive while SOC_BAT is low.

The developed control strategy were tested using MATLAB/SIMULINK under multiple conditions with varying value for SOC of both battery and super capacitor but the same irradiation condition, which is rising and setting value of irradiation value on first half of simulated time and zero value of irradiation on second half of simulation time. Fig. 14 and 15 show simulated results of SOC of battery and super capacitor respectively on case 1 with a condition of the beginning SOC of battery is at 29% and SOC of super capacitor is at 36.4%.

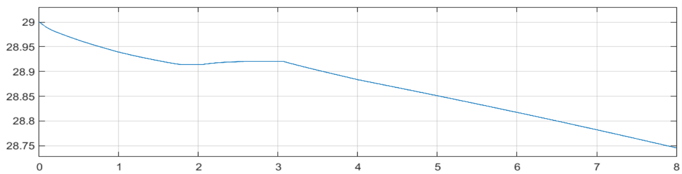

FIGURE 14. SOC of battery in case 1

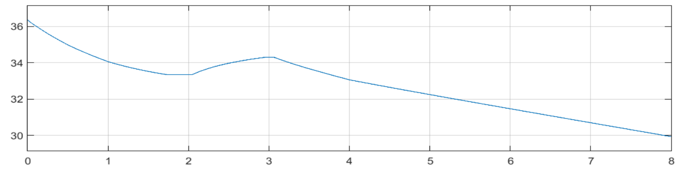

FIGURE 15. SOC of super capacitor in case 1

Fig. 16 and 17 show simulated results of SOC of battery and super capacitor respectively on case 2 with a condition of the beginning SOC of battery is at 97% and SOC of super capacitor is at 32.6%.

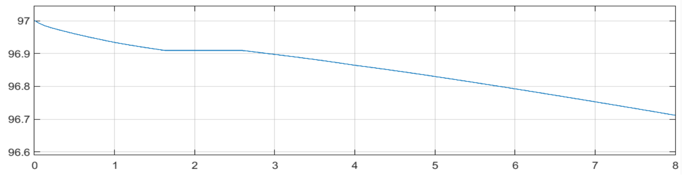

FIGURE 16. SOC of battery in case 2

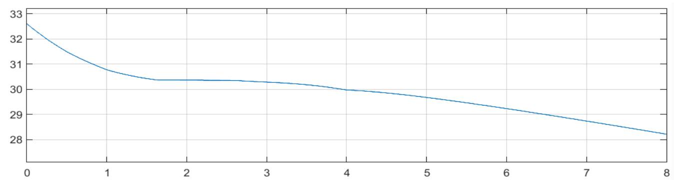

FIGURE 17. SOC of super capacitor in case 2

TABLE 1. Comparison of battery's SOC in case 1 and 2

Time	Case 1	Case 2	Explanation
0	29	97	Start of simulation irradiation on PV is near zero
1	28,93	96,93	Irradiation is starting to rise
2	28,91	96,9	Irradiation is almost reaching its peak
3	28,92	96.89	Irradiation has past its peak and starting to decline In case 2, battery won't charge
4	28,88	96,86	Irradiation has decline to its lowest because sun has set
5-10	28,93	96,943	SOC for both case continued to decline because of their continuous use

CONCLUSION

Considering energy storage is necessary for renewable energy power plant, the increasing utilization of renewable energy sources is driving an increase on the needs of energy storage. In this paper, a hybridization of battery and super capacitor as energy storage coordinated by a fuzzy logic control system was presented. The proposed fuzzy logic is designed to manage power distribution between grid and energy storage consisted of battery and super capacitor. The simulation result show that the proposed method can distribute power between battery and super capacitor.

Acknowledgment

The authors would like to offer thanks to friends and colleagues that help us motivated to finish this paper.

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