AUTOMATIC POWER CONTROL AND MANAGEMENT BETWEEN STANDALONE DC MICROGRIDS USING FLC

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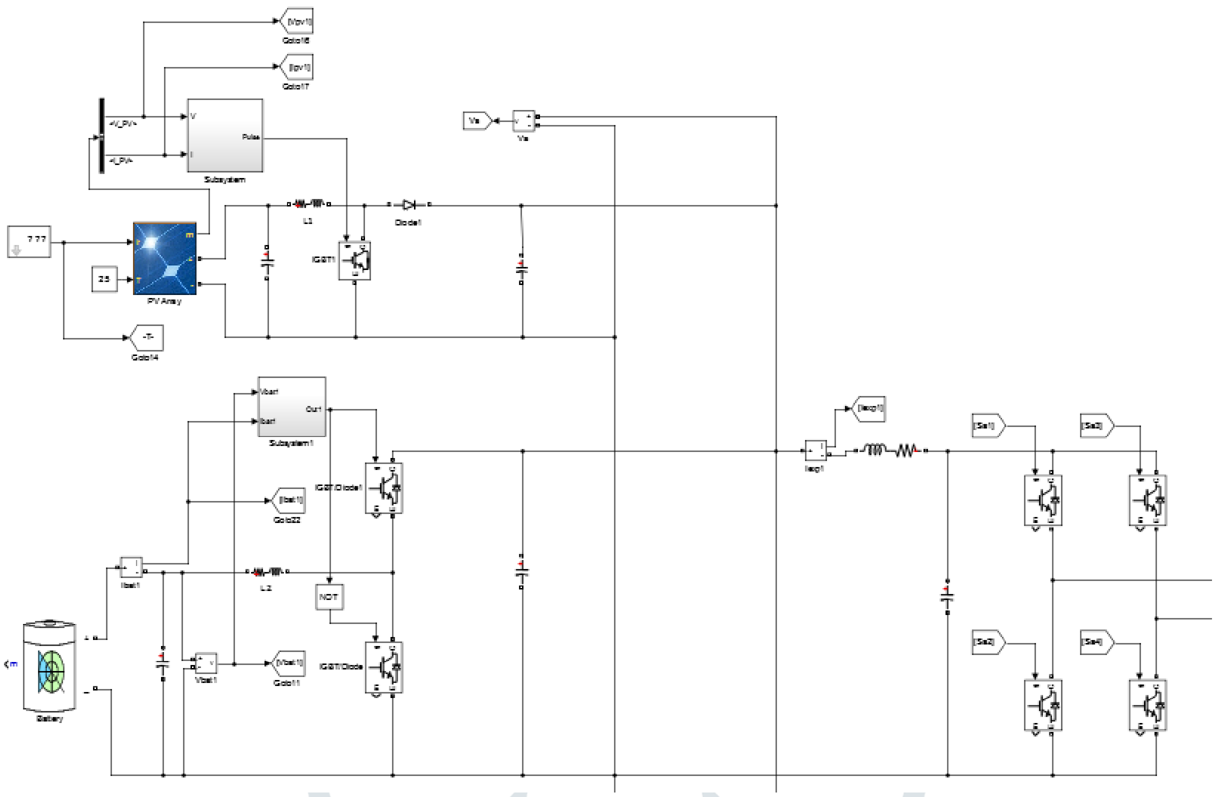
Abstract: A Microgrid is an integration of distributed energy sources, loads and energy storage systems. It gives opportunity to utilize renewable energy sources for green and clean environment. Energy storage systems are required in order to ensure reliability and power quality because of the intermittent nature of renewable energy sources and changes of load demand. Renewable Energy Sources (RES) are limited to their available power with intermittent nature. Battery-based energy storage sources have limitations in the charging and discharging capabilities to avoid depleting the battery and preserve the State of Charge (SOC) within its satisfactory limits. The battery balances the power difference between RES and loads. However, in severe cases where the SOC is very low, load shedding is crucial. In this paper, a Fuzzy Logic Controller (FLC) has been proposed to coordinate the power flow of PV unit and battery to satisfy the load by full use of the available PV power. It controls the PV's output power and keeps the SOC and charging / discharging power of the battery within their required margins regardless of the variations in load. Control strategy based on the fuzzy logic ensures balanced stored energy among distributed energy storage units, as well as low voltage deviation in a DC microgrid.

***Index Terms* – Renewable energy, DC Microgrids, Fuzzy logic controller.**

. INTRODUCTION

Control schemes based on centralized controller provide the optimal operation among various units by acquiring the information from them and manage the data centrally. But system reliability is degraded due to high dependence on central controller and communication link. Droop control is a basic decentralized control method which works based on local information but lacks with optimum utilization of resources of microgrid. To overcome above drawbacks, a distributed control strategy based on DC bus signaling method (DCBSM) was introduced. But it fails to consider the overcharging and discharging of battery. In state of charge (SoC) of battery is included in primary level control based on DCBSM. Secondary level control is designed for adjusting bus voltage as per the reference voltage. As the battery alone regulates the bus voltage, reliability of system degrades. In decoupling the operating regions in primary level control is proposed using DC bus voltage levels. And, coordination among various storage devices is achieved in secondary level through communication. However, excess generation is inefficiently managed by using dump loads. Multilevel energy management strategy is proposed, where hybrid storage devices are utilized to suppress both low and high frequency components during power variations. During over charging or discharging conditions, the hybrid storage devices are poorly managed if the communication fails among control levels. The different control modes based on bus voltage deviation for regulating the DC microgrid under variable generation and storage. These papers utilize bus voltage for indicating status of DC microgrids. Both the papers consider the utility grid and assigns slack role to different sources (i.e. utility grid side converter or storage converter) in each mode based on conditions of DC microgrid and utility grid. Distinct control loops are employed under each mode for optimizing the system performance which requires frequent switching between control loops that causes switching transients and also increases burden on control processor. Besides this, excess power beyond the battery charging rate and grid side converter rating is not explored. Although it is considered, but the deviation of bus voltage is more than 10% of nominal value in islanded mode which affects the sensitive loads connected. Power line signaling method is proposed to overcome problem of limited number of operating modes based on fixed voltage deviation in DCBSM. It dispatches the status of batteries and other sources in terms of distinct frequency signals superimposed on bus voltage. Various sources can shift their operating modes by extracting the information from different frequency signals. However this method is not suitable for increased number of storage systems (SS) and distributed energy resources (DER) since available carrier signal frequencies are limited and also varies based on different converter parameters, which makes proposed scheme cumbersome to implement for more number of DERs and SSs. Besides, it consumes additional current from battery for dispatching the various signals.

II. PROPOSED STRUCTURE



Source and storage units of ADCMGs are operated based on bus voltage levels in the grid by making bus voltage as information carrier between the units for proper coordination and management. Loads are managed depending on the state of charge (SoC) of battery and power condition of ADCMG which is expressed in terms of bus voltage deviation. Instantaneous SoC can be estimated by using coulomb counting method: Where SoCi, SoC0, CN and ibat denotes instantaneous SoC, initial SoC, nominal capacity and input current of battery respectively. δ is loss coefficient which typically varies in the range of 0.98- 1 SoC of battery can be regulated by limiting the charging and discharging currents. Voltage levels envisioned throughout the analysis are in compliance. Operation of each ADCMG is bifurcated into five zones in which each zone will be active depending upon particular bus voltage threshold as Va and Vb are grid voltages of ADCMG1 and ADCMG2. In order to leverage maximum power from PV source, it is operated at maximum power point (MPP) using perturb & observe method in all zones excluding zone-5. PCMS is explained with respect to ADCMG1. Region1 and region2 indicates power flow directions from ADCMG1 to ADCMG2 and ADCMG2 to ADCMG1 respectively. Bisection line used to differentiate the regions of power transfer from one ADCMG to other ADCMG with distinct background colors. Total power generation and load in each ADCMG is indicated by pg and pL respectively.

1) Zone-1 (Balanced power mode): As power generated by PV source (PV1 p) is more or less equal to demand (L1 p) in the ADCMG1 which keeps battery in idle state. Small variations of load and source will not trigger the storage unit in this mode because predefined voltage limits are able to sustain these fluctuations. As there is no fixed source to regulate the bus voltage in this zone, which in turn allow its voltage to vary between the limits VaH1 and VaL1 that are treated as boundaries of this mode for ADCMG1. Similarly VbH1 and VbL1 are boundaries for ADCMG2. Neither of the ADCMGs share power to other ADCMG in this zone.

2) Zone-2 (Battery discharging mode): As the PV power is not sufficient in fulfilling the demand that yields to continuous deviation in bus voltage (Va). Once Va fall below threshold value (VaL1) then storage steps into discharging mode from idle state in order to cover the gap between supply and demand. Battery clamps the bus voltage at same threshold (VaL1) by keeping it in bus regulating mode. ADCMG1 is ready to absorb the excess power from ADCMG2 if available (i.e. operating point h but reverse power transfer is not possible. Extreme conditions of battery are taken care in control loop.

3) Zone-3 (Battery charging mode): If the PV source is producing excess power than required, then this mode comes into picture where voltage Va rises continuously due to surplus power and halts at threshold limit (VaH1) by shifting the battery into charging mode. Battery is allowed to charge until its cutoff limit is met. ADCMG1 cannot feed the power to ADCMG2, but absorb the power from it when Vb is at VbH2 and battery1 in ADCMG1 is not fully charged or maximum charging rate is not met (shown as operating point i

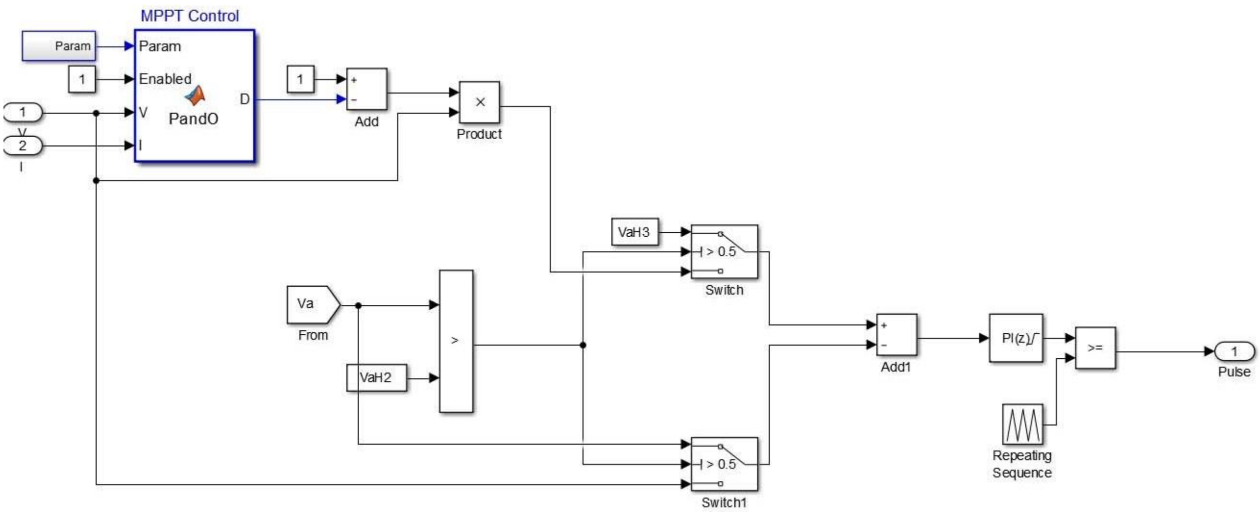
4) Zone-4 (Power deficit mode): It is an extension of zone-2 and comes into active state when load rises beyond discharging rate of battery. In this mode, battery runs at maximum discharging current limit. There are two sub cases exist in this zone, in which first case deals with power import from ADCMG2 whereas in the second case, there is no power import from ADCMG2.

5) Zone-5 (Excess power mode): This zone is further split into two sub cases, where one case deals with exporting surplus power from ADCMG1 and another case is without exporting power.

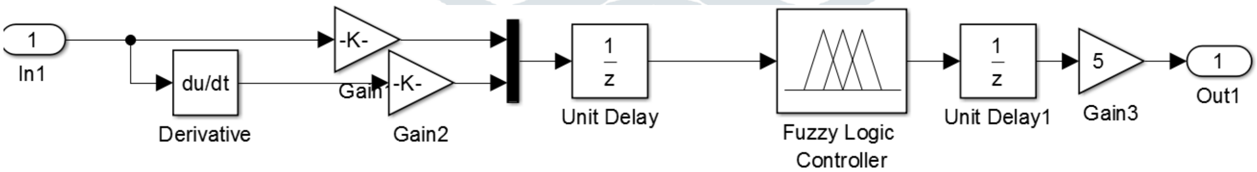
III. PROPOSED POWER CONTROLLER

PV CONTROLLER

PV source always remain at MPP except in zone5 irrespective of change in load and power import/export so that maximum renewable power is extracted and utilized efficiently. PV control loop of ADCMG1 and the same is followed for PV source in ADCMG2. PV source can be operated in two modes, one as MPP mode and other as bus voltage regulation mode. First one consist of two loops in which outer loop is mainly for tracking MPP voltage (V) through perturb and observe (P&O) method and provides voltage MPP reference as input to inner loop. Inner loop works at faster speed for tracking the given reference through PI controller and produce the duty cycle ($\delta pv1$) as its output. Second mode encloses only one loop and comes into picture when case2 of zone-5 occurs. Bus voltage is regulated at its reference ($VaH3$) through PI controller by adjusting duty cycle. Both the modes use the PWM comparator to generate the required pulses for switches inside the converter by feeding duty cycle to it. Switching between two modes is done selectively by observing the bus voltage. If the Va increase above the upper threshold VaH2, then PV enter into the bus regulation mode, otherwise PV keeps running in MPP mode. Though battery1 is fully charged, but PV is not pushed into regulation mode since excess power transfer may takes place from ADCMG1 to ADCMG2 for the effective utilization of renewable energy which increases reliability of system.



FUZZY LOGIC CONTROLLER



A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively ...A Fuzzifier which transforms the measured or the input variables in numerical forms into linguistic variables. A Controller which performs the fuzzy logic operation of assigning the outputs based on the linguistic information. The controller consists of the knowledge base and the inference engine.

Followings are the major components of the FLC as shown in the above figure −

- Fuzzifier − The role of fuzzifier is to convert the crisp input values into fuzzy values.
- Fuzzy Knowledge Base − It stores the knowledge about all the input-output fuzzy relationships. It also has the membership function which defines the input variables to the fuzzy rule base and the output variables to the plant under control.

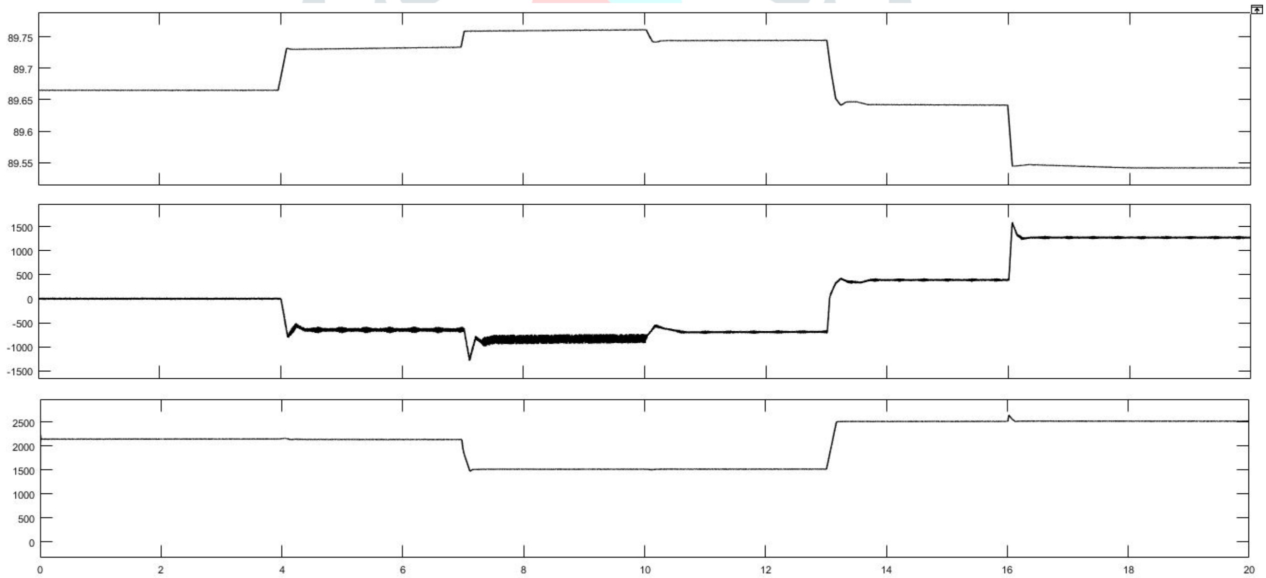
- Fuzzy Rule Base − It stores the knowledge about the operation of the process of domain.
- Inference Engine − It acts as a kernel of any FLC. Basically it simulates human decisions by performing approximate reasoning.
- Defuzzifier − The role of defuzzifier is to convert the fuzzy values into crisp values getting from fuzzy inference engine.

IV. SIMULATION RESULTS

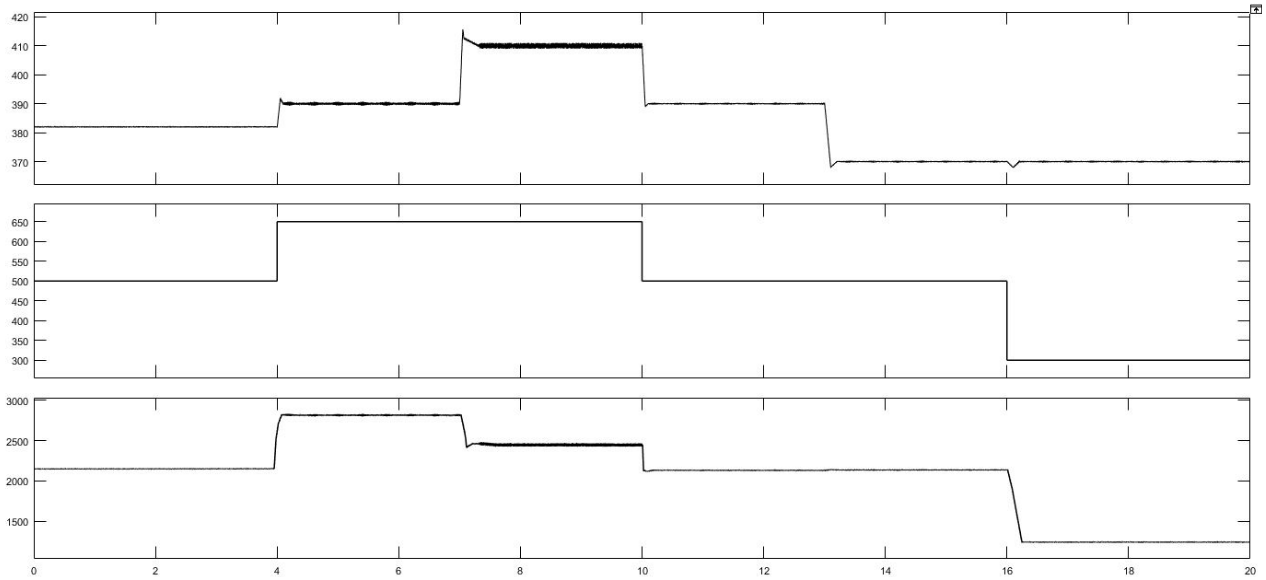
TABLE I
SIMULATION PARAMETERS

Components	Parameters	ADCMG1	ADCMG2
PV Capacity	Maximum power @1000W/m^2	4.5 kW	750 W
Battery	Capacity	200 AH	100 AH
	Nominal voltage	96 V	24 V
Nominal grid voltage	Rated voltage	380 V	48 V
Voltage Thresholds	V_{xH3}	410	54 V
	V_{xH2}	400	52 V
	V_{xH1}	390	50 V
	V_{xL1}	370	46 V
	V_{xL2}	360	44 V
DC load	Fixed Load	1 kW	200 W
	Variable Load	2 kW	300 W
Line parameters	Resistance(R)	0.15 Ω	
	Inductance (L)	0.24mH	

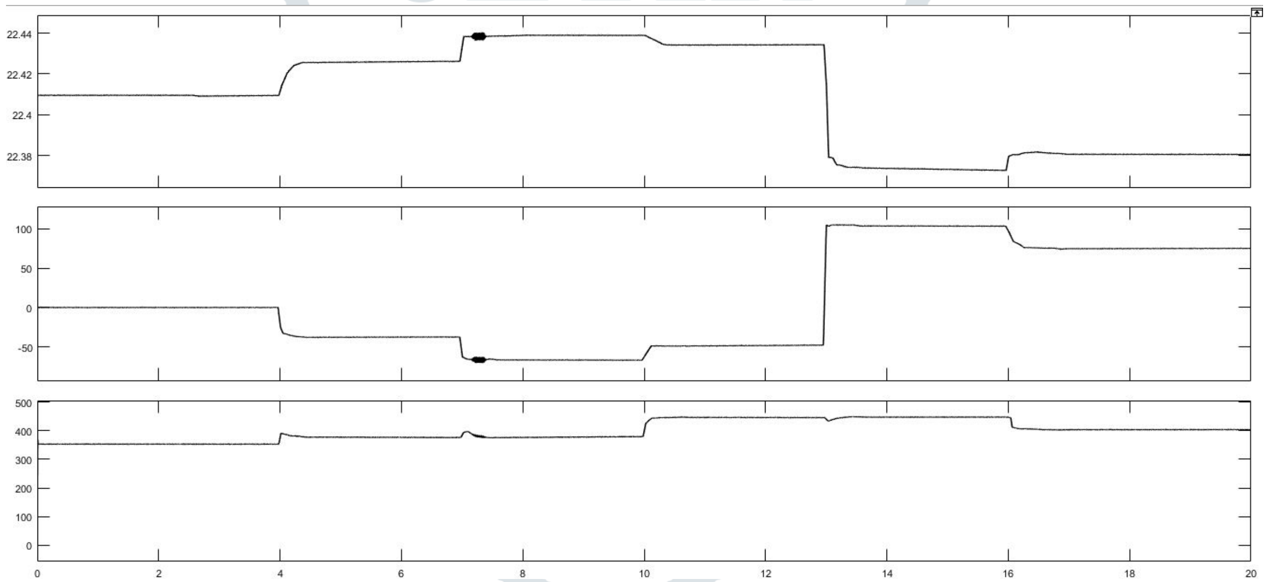
* x=a for ADCMG1and x=b for ADCMG2



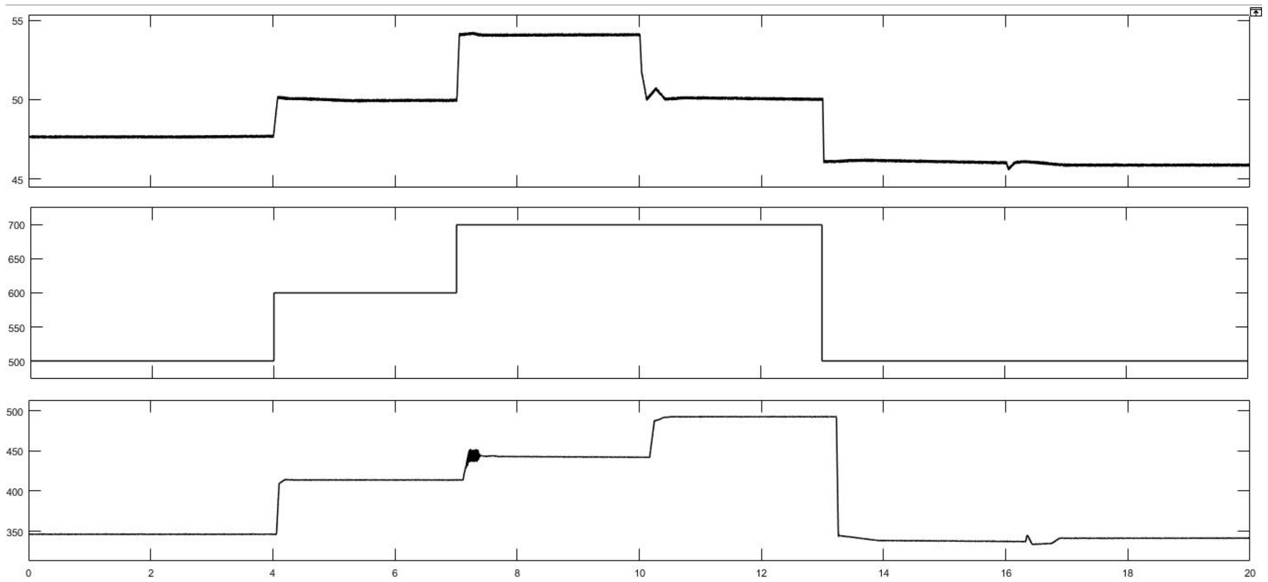
Operating zones of ADCMG1 a) Battery terminal voltage b) Battery output power c) Load power



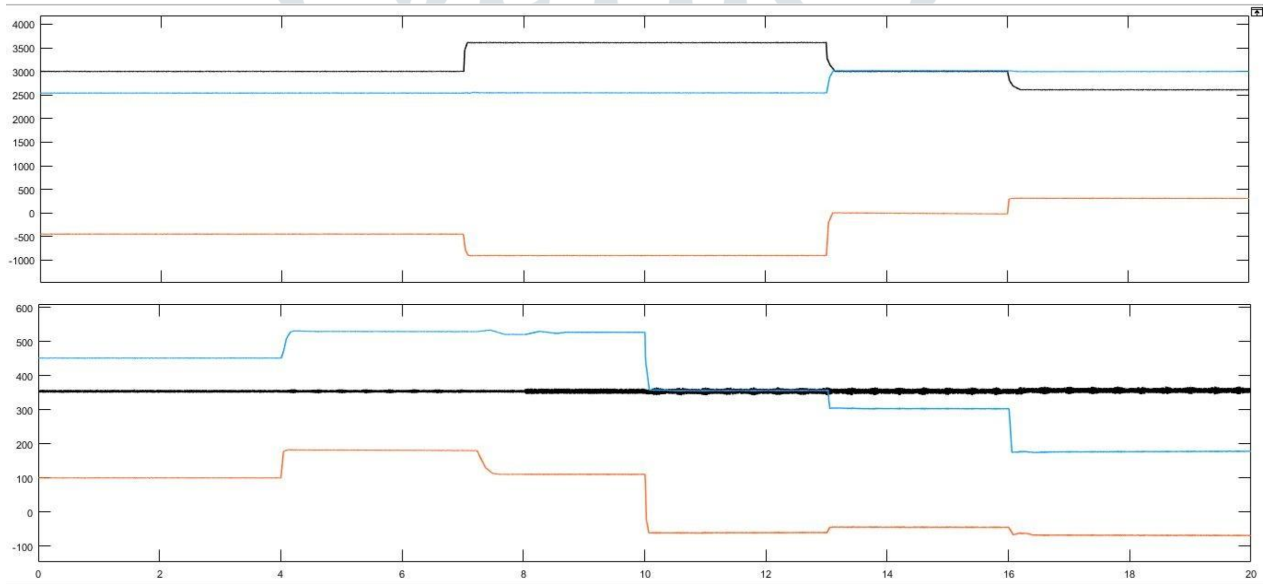
Operating zones of ADCMG1 a) Bus voltage b) Irradiation value c) PV output power



Operating zones of ADCMG2 a) Battery terminal voltage b) Battery output power c) Load power



Operating zones of ADCMG2 a) Bus voltage b) Irradiation value c) PV output power



Operating Zones of ADCMG1 and ADCMG2 power

V. CONCLUSION

A fuzzy logic controller has been proposed for DC microgrid to manage the power flow. The proposed controller provides an efficient use of the power of the battery within their required margins regardless of variations in load and intermittent power of renewable energy sources. If necessary, loads' shedding is done whenever required to prevent SOC from exceeding the lower limit and PV curtailment is carried out to realize over charging protection. Matlab/Simulink results validated the performance of the proposed FLC. Developing a FLC is comparatively cheaper then developing model based or other controller in terms of performance. FLC's are more robust than PID controllers because of their capability to cover a huge range of operating conditions. FLC's are customizable. FLC is designed to emulate human deductive thinking, the process people used to infer conclusion from what they know. FLC is more reliable than conventional control system. Fuzzy logic provides more efficiency when applied in control system.

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