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Design of Hybrid Energy Storage Systems in DC Microgrid Applications

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***Abstract*—Due to smooth integration with renewable power resources in addition to the proliferation of dc-well suited loads, dc microgrids are gaining recognition. Because of the excessive penetration of renewable strength sources in dc microgrids, those microgrids are relatively vulnerable to fluctuations in the electricity era. It is harmful, so extreme voltage balance is considered. To absorb these fluctuations within, a battery-primarily based electricity storage gadget and hybrid energy storage machine (HESS), including a battery and supercapacitor (SC), are proposed. The specific traits of the cell and supercapacitors cause them to a super aggregate for HESS applications. The HESS is interfaced with dc microgrid using a double-enter bidirectional converter. This bidirectional converter gives decoupled manipulate of battery and supercapacitor power. This thesis provides a converter modeling technique for the double-input bidirectional converter. A controller was designed based totally in this for voltage law utility for a dc microgrid. The operation of the converter made it feasible to use the equal controller for each HESS charging and discharging process, consequently making it a unified controller. The designed controller was also capable of reject disturbances from the source facet in addition to load facet even as keeping the voltage balance of the dc microgrid. Operation of the converters and overall performance of the designed controller in voltage stability was tested with simulation consequences for each battery by myself garage gadget and hybrid power storage systems.**

***Index Terms*—microgrid, battery, hybrid energy storage machine, controller.**

I. INTRODUCTION

As fossil fuels are diminishing; therefore, there is a demand for renewable energy sources has been increased in the power sector. Also, due to the usage of fossil fuels, there is a lot of impact on the environment. To avoid environmental pollution gradually, we are switching towards renewable energy sources, while solar energy has higher demand amongst other renewable energy sources. As there is a lot of research is going on, solar energy storage and DC-DC converters, the DC microgrid becoming popular nowadays. The room of solar energy became more comfortable and more efficient and reutilizing the storage energy by using a DC-DC converter, whenever their deficiency of power at the grid. Furthermore, the integration of the electrical storage system also improves the reliability of the power system.

A. DC-DC Converter Control Schemes

DC-DC converters are very widely used in many applications such as microgrid, smart grid, plug-in hybrid electric vehicles, etc. The boost converter is non-linear and has a non- minimum phase structure due to the presence of right half zero. Disturbances present in the source side or load side also affects the system. So, it is required to control the output voltage and reducing the steady-state error. Several linear and non-linear, analog and digital control techniques are already designed, each having its own set of advantages and disadvantages. The classical control technique uses the state-space averaging method and linearization of non-linear system equations around the equilibrium point.

Some general control methods are:

- Proportional integral derivative(linear PID) control
- The sliding mode control scheme
- Dynamic evolution
- Model prediction control (Non-linear control technique)
- Boundary
- The fuzzy logic control method
- Digital control techniques

Switching strategies are:

- PWM (Pulse width modulation) control
- SPS (Single phase shift) control technique
- PWM-SPS (Phase shift + PWM)

PID controller has low cost, reliable, and excellent dynamic performance, but their efficiency and robustness for disturbances is very less. Sliding mode control has a speedy and finite response, robust for both large and small disorders, but its complexity is because of the specific parameters and state information requirement. Dynamic evolution has appropriate overall performance traits and not like SMC; it does no longer require precise knowledge of version parameters; however, it's miles hard to implement it in analog circuit shape. Model predictive management has reference monitoring and easy implementation, but it is restrained to the use of a linear converter model. Fuzzy logic control applies to the non-linear system also, and it is fast and robust. Digital control has high EMI immunity, flexibility, easy use, and low switching losses. Boundary control has a first massive signal operation, fast dynamics, but its cost is more and is sensitive to parameter variations.

B. *Energy Storage systems*

Electrical strength can be saved in lots of particular bureaucracy along with electrochemical energy, kinetic strength, ability power, and many others. This stored energy is then converted back to electrical form, but while conversion, some losses may be present. Energy storage systems can be considered as their essence for providing continuous, reliable, and sustainable electricity.

Batteries

Batteries are the electrochemical energy storage systems in which a pair of oxidation and reduction reaction (or redox reaction) occurs in an electrolytic medium to store DC power through the flow of ions and electrons. A battery cell comprises an external circuit and an internal circuit. The internal circuitry includes the electrodes, electrochemically active substances, and an electrolyte closed in a container. Fig shows the working of battery and movement of ions and electrons in both internal and external circuits.

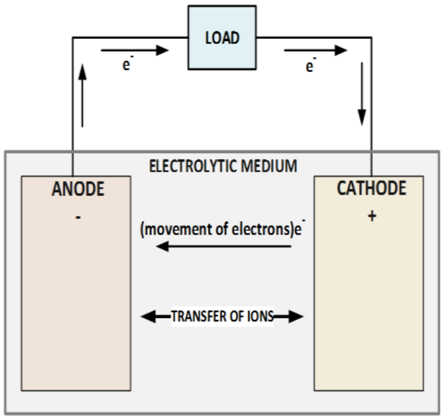


Figure **Error! No text of specified style in document.** Battery working model

Hybrid Energy Storage Systems (HESS)

Many energy storage are presently used, but no device can provide rapid response for a long time-span. Two essential terms are useful, especially while designing hybrid energy storage systems, namely Energy Density and Power density. The difference between these two is that a high energy density device can store the energy for a longer duration of time while power density describes the dynamics of the invention to deliver energy, i.e., its response. Energy density is defined in Watt-hrs/kg, whereas power density is defined in watts/kg.

II. PROPOSED CONFIGURATION

A. *Proposed Topology*

Figure 2 shows the schematic of the proposed topology. The given topology consists of a boost converter, a Bi-Directional DC-DC converter connected through inductors. The given topology has a boost converter with V_{DC} as input voltage, L as source inductance, a diode D, filter capacitance C_f, switch S, and a load resistance R_L. A bi-Directional buck-boost converter is chosen using a configuration similar to inverter two-leg configuration. Where the switches S1, S2 are connected in the first leg and switches S3, S4 are connected in the second leg. D1, D2, D3, D4 are the antiparallel diodes of switches S1, S2, S3, S4, respectively. To understand the working of the proposed topology, the modes of operation are explained in step by step manner as follows. First, the procedure is demonstrated using a single-leg structure, and then the control strategy for the two-leg system are explained.

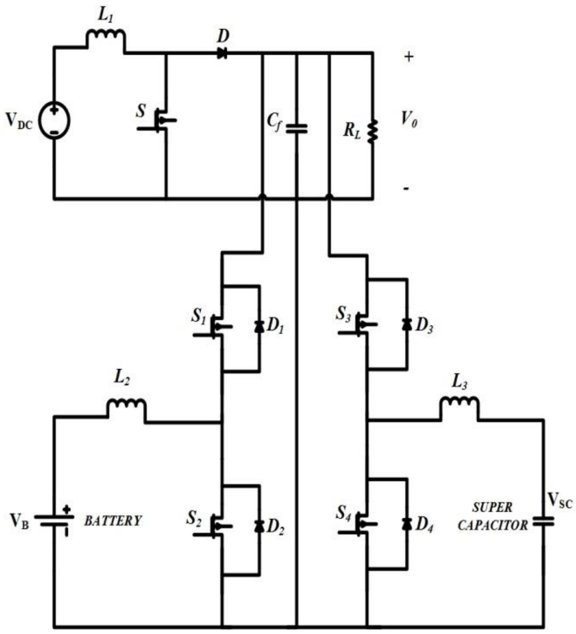


Figure **Error! No text of specified style in document.** Architecture of the microgrid system with battery and supercapacitor HESS.

B. DC Microgridconfiguration using the battery alone

A supply Bi-Directional DC-DC converter is used to modify the DC microgrid with the battery is attached proven in Fig.3 The Photovoltaic panel is designed for MPP voltage of 12V is emulated by way of using a regulated power supply of 0-24V/zero-3A and is hooked up the input to the raise converter.

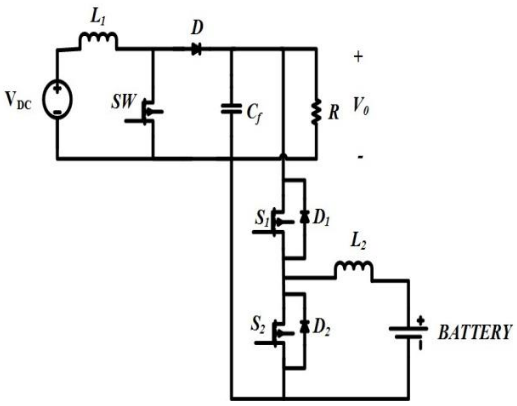


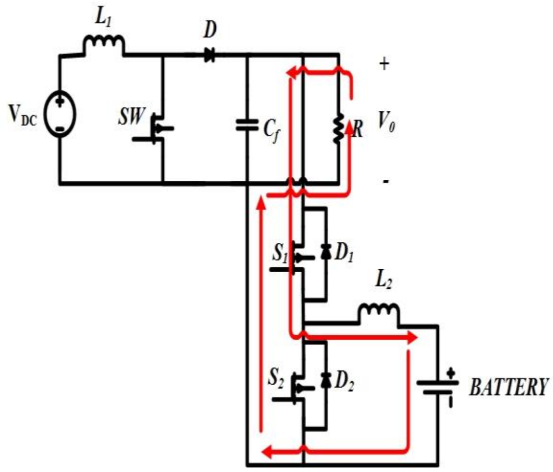
Figure 3. Architecture of the DC microgrid system with battery.

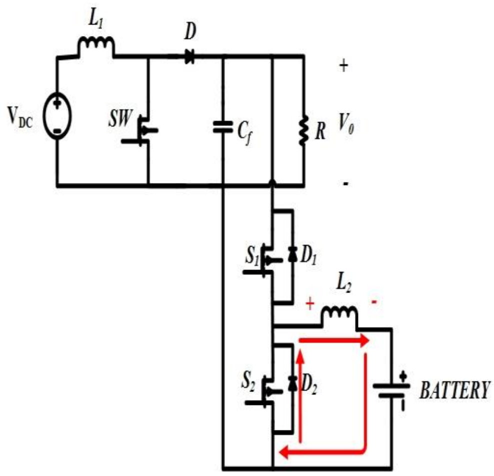
The output side of the boost converter, a battery, is connected using complementary switching devices.

In Fig 3 switches S1 and S2 are complimentary. Diodes D1 and D2 are the feedback diodes to switches S1 and S2, respectively. The high-frequency inductors L1 and L2 are connected to the boost converter and battery side. The high-frequency inductors are sufficiently high to make continuous conduction mode. (CCM) and to maintain constant DC. $C_f$is filter capacitance. It keeps output voltage ripple under control, and R is the load resistance.

C. Mode-I: Power flow from DC grid to the battery(charging mode)

The battery charging operation is explained in Fig.4. The battery charging is possible only when increasing PV generation or reducing the load demand. If PV generation increases load demand is constant, the excess power existing at the load side. According to the switching logic, excess energy charges the battery to maintain the grid voltage constant. In Fig 4(a) switches S1 turn ON and S2 turn OFF current flow from DC microgrid to the battery (charging operation of cell).





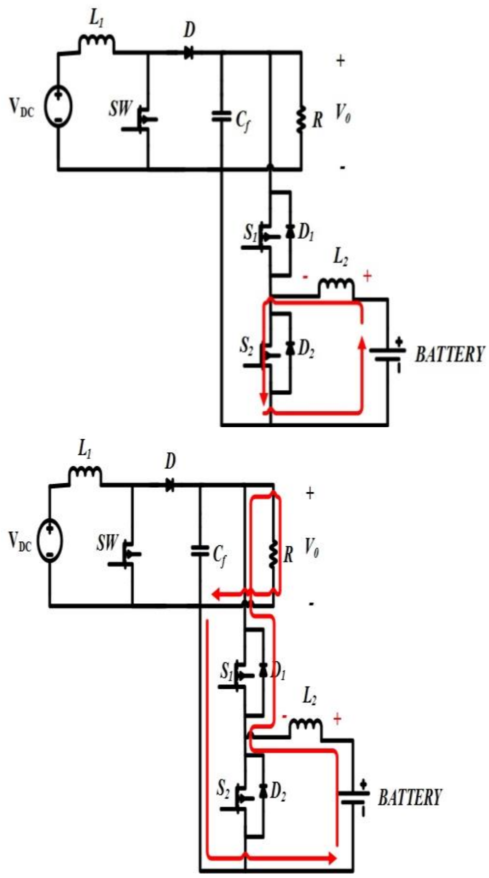
a) S1 ON, D2 OFF, S2 OFF, D1 OFF(b) S1 OFF, D2 ON, S2 OFF, D1 OFF

Figure 4 (a), (b)ESS charging operation (Buck Operation).

Later switch S_1 is turned OFF, and D_2 gets forward biased to store energy into the battery from the inductor, which is given in figure 4 (b). A solid line indicates the flow of current within the circuit.

d. Mode-II: ESS Discharging

The discharging operation of the battery is possible only when decreasing PV generation and increasing load demand. In this case, a deficit power exists at DC microgrid, immediately battery discharge to supply deficit amount of energy to maintain the grid voltage constant.



(a) S1 OFF, D2 OFF, S2 ON, D1 OFF (b) S1 ON, D2 OFF, S2 OFF, D1 OFF

Figure 5 (a), (b) ESS discharging operation (Boost Operation).

When DC grid voltage less than the PV generation, than immediately battery discharge and supply power to the DC grid to maintain the grid voltage constant. Switch S2 is turn ON and stores energy in an inductor by using a battery. Inductor stores energy as shown in with current directions, as shown in Fig 5(a). After the next switching state sum of battery voltage and inductor voltage is higher than DC grid voltage, than turn OFF the switch S2 and diode D1 turn ON, so power frow from the battery to DC grid to maintain the grid voltage constant. Bi-Directional power flow between source and load, as shown in Fig.6.

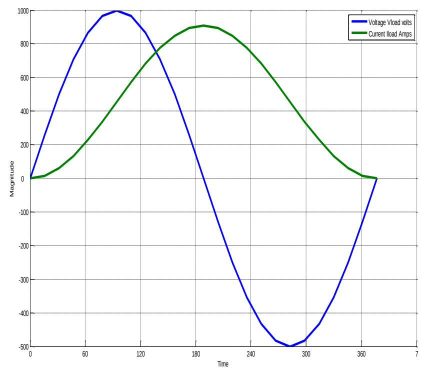


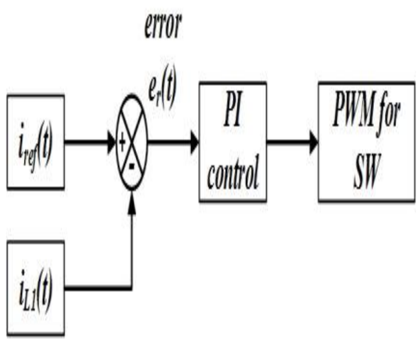
Figure 6 Graphical representation of bidirectional power flow.

III. CONTROL STRATEGY

A. Control Strategy for Battery Energy Storage System

A control scheme is implemented for stabilizing the DC grid voltage for source and load disturbance conditions. Switches are controlled according to the switching logic for charging/discharging operation of battery to maintain the DC grid voltage constant. Proportional integral controls scheme is used for controlling the switches in battery energy storage systems. For calculation of control gains, used single input single output (SISO) toolbox in MATLAB. For complete control, the tuning controller gains selected as 60 phase margin (PM).

Fig 7 represents the control scheme for battery alone DC microgridsystem. The total reference current, which is the input current of the boost converter, is compared with inductor current and error is applied to the PI controller. PI controller generated control signal depending upon error input. The pulse generator generates control pulses according tothe control signal. Under source and load power variations, DC grid may cause imbalance. To maintain the DC grid voltage constant charge/discharge battery to maintain the DC grid voltage constant.



(a)

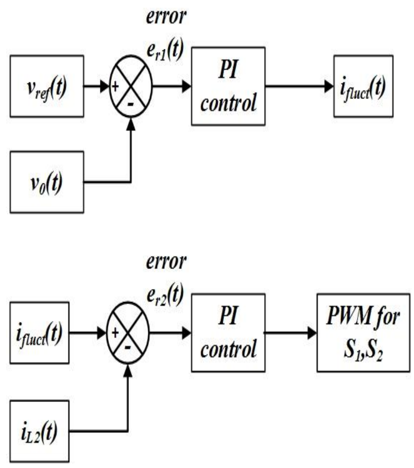


Figure 7 (a) Control logic of boost converter in BESS (b) Control logic of Bi-directional buck-boost converter for the battery.

A control scheme of the bidirectional converter is shown in Fig 7 (b). The reference voltage is compared with the actual DC grid voltage error is generated. The error is applied to the PI controller, and the controller generates a control signal. The pulse generator generates pulses according to the control signal. The controlled pulses are applied to the switches S1 and S2, which are complementary to each other.

IV. SIMULATION RESULTS

A. Simulation results for the proposed Scheme

Simulation results are developed using MATLABsoftware 2016 version. 12V, 7Ah Lead-acid battery used for this simulation. Switching frequency selected for this operation is 10 kHz. The input to the boost converter is taken as 10V with the help of DC Source. High-frequency inductor are designed for boost converter under ripple content. MOSFET switches are used for the simulation study of boost and bidirectional DC-DC converter.

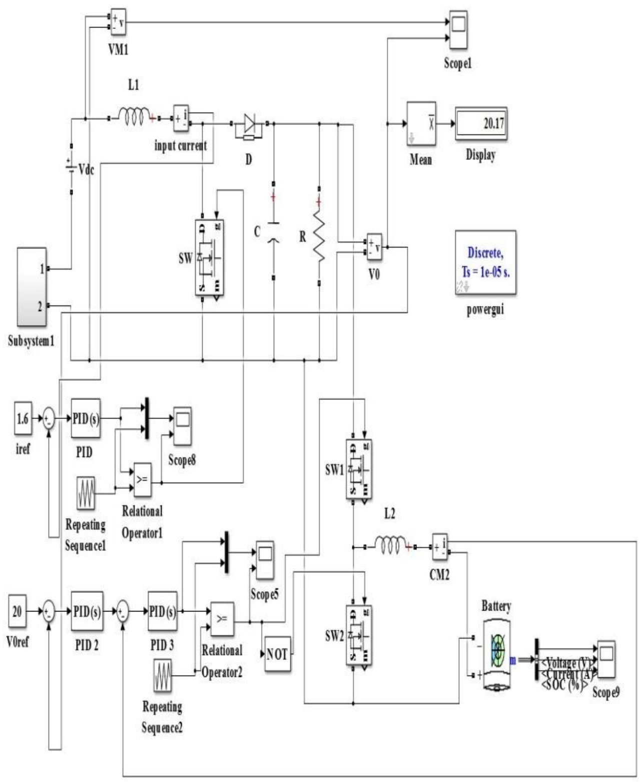


Figure 8 Simulation model for the battery alone system.

The simulation model for voltage regulation of DC microgridusing battery-based Bi-Directional DC-DC converter is illustrated in Fig.8

B. Simulation Results

In this segment, the results of the proposed technique are displayed, and two test cases are considered. The proposed Scheme has been made using dSPACE DS 1104 controller board. The control procedure is made using Simulink blocks in MATLAB. With the ultimate objective to exhibit the ampleness of the proposed procedure, it is differentiated and the traditional strategy. The model of lead-acid of 12V, 7Ah is utilized as a battery. Switching frequency is utilized for circuit operation is 10 kHz. With the assistance of a DC source, the PV output module is picked as 10V. In light of ripple content, the filter capacitance and inductor are intended for the boost converter. For boost and bi-directional DC-DC converters, MOSFET switches are chosen. The software utilized and the hardware prototype created to execute the proposed Scheme likewise clarified in this segment. Experimental results are contrasted to simulation results. The proposed approach simulation results for two test cases are examined beneath.

Case.1: Battery Alone System

In this case, the single battery system is studied. The simulation diagram of voltage regulation of DC Microgridusing battery-based bi-directional DC-DC converter is depicted in Fig 8.

Step Increase in Source Voltage

Fig 9 (a) demonstrates the source voltage with disturbances over the period frame. Here, the source voltage is all of a sudden expanded at the time instant of t=1.5 sec which is kept up at 12V up to t=2 sec. At the point when there is no battery storage, and bi-directional converter, the output voltage of the boost converter is likewise expanded to a value of 24V amid this disturbance period. At the point when a bi-directional converter is associated with battery and grid, the grid voltage is recovered back to 20V utilizing the proposed control strategy

Step Decrease in Source Voltage

Fig 9 (b) demonstrates the source voltage with ESS over some time. The source voltage is all of a sudden diminished at the instant of time at t =0.5sec which is kept up at 8V up to t =1sec. At the point when there is no battery storage and bi-directional converter, then the boost converter output voltage is likewise diminished to a value of 16V amid this disturbance period. At the point when a bi-directional converter is associated with battery and the grid, the grid voltage is recovered back to 20V utilizing the proposed control strategy.

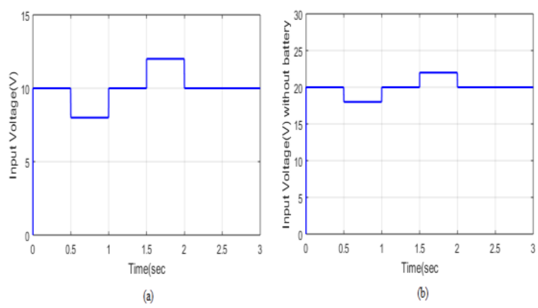


Figure 9 (a) Source Voltage With Disturbances (b) Load Voltage Without ESS

C. Performance Analysis of Battery Alone System

Fig 10. (a) demonstrates the graph of battery voltage versus time. It indicates battery performance amid step disturbance in the input voltage of the source converter. As it is observed from Fig 10 (a) the voltage in the battery is diminished to the operation of discharge from 0.5sec to 1sec amid step decrease in source voltage. Fig 10 (b) demonstrates the plot of battery current versus time. In input voltage of step decrease, current in the battery is controlled to supply the deficit voltage at the grid. Fig 4.4 (c) demonstrates the state of charge of a battery in (%). It is seen from the fig 10 (c) amid the duration of step decrease in source voltage, the battery current is expanded, and it keeps up a similar incentive till the disturbance is evacuated and SOC % of the battery diminishes. For step increase in input voltage, battery current is controlled to supply surplus voltage at the grid. For this, the battery voltage is expanded at t=1.5sec representing to the charging operation from 1.5sec to 2sec amid step increase in source voltage. It is seen from the fig 10 (c) battery current is diminished and keeps up the same value till disturbance is evacuated and SOC (%) of battery increments.

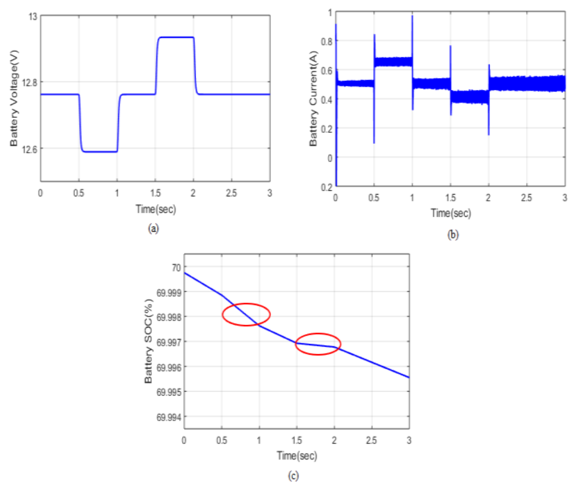


Figure 10 (a) Voltage (b) Current (c) SOC % of Battery

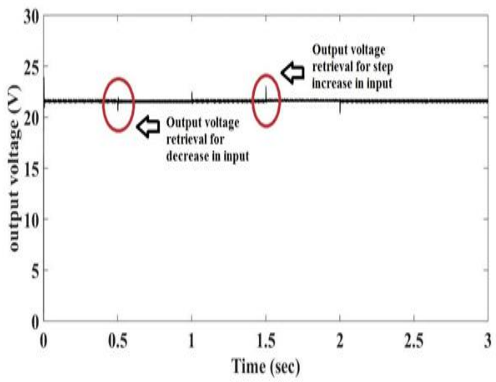


Figure 11 Output Voltage with Battery Energy Storage

The output voltage with BES demonstrates Fig 11. It outlines the recovery of output voltage while expanding or diminishing in the input voltage. As seen in Fig 11, amid the step decrease in source voltage, the output voltage is recovered at the time instant of t=0.5sec. After that the time instant of 1.5 sec, the output voltage is recovered amid the step increase in the source voltage.

V. CONCLUSION

A Bi-Directional converter is designed with a controller for the battery storage device. The performance of the ESS is analyzed for the supply version case. The controller ought to effectively stabilize DC microgrid against supply voltage variation. Charging and discharging waveforms of the battery are determined at some point in the supply voltage variant. The battery and superb capacitor blended energy garage is supplied. The electricity stability operation imposes extreme pressure on the battery if battery on my own is used as a strength garage medium. This is mainly because of the low strength density of battery. Thus, high strength density fantastic capacitor is mixed with excessive power density battery the usage of suitable manipulate approach to percentage the imbalance energy that exists between the supply and load of the microgrid.

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