Nepal Engineers' Association, Gandaki Province, Technical Journal

Hybrid Energy Storage with PV for Islanded DC Microgrid

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Received: January 20, 2023; Revised Day: April 25, 2023; Accepted: July 03, 2023

Abstract

Cogitating the present national as well as global context, renewable energy sources are becoming increasingly popular as a source of electricity in places, where connecting to the utility grid is either impossible or excessively costly. Several trends that have emerged as electrical distribution technology in the twenty-first century will change the requirements for energy transmission. Green power generating methods are receiving more attention due to the world's deteriorating environmental conditions, growing prices, the limited nature of fossil fuels, and rising energy demand. The increasing depletion of fossil fuels and the escalating need for energy has made renewable energy sources a global topic of discussion. The incredible advancement of renewable energy has allowed us to address environmental problems. However, the production from these sources could be more predictable which requires an appropriate energy storage system. The main aim of this research paper is to study the hybrid energy storage with solar photovoltaic for islanded DC microgrid. This research study simulates, analyzes, and presents an islanded mode DC microgrid with solar PV, battery, and supercapacitor through the use of MATLAB Simulink. The MPPT (Maximum Power Point Tracking) system uses a twin-stage DC converter. The regulated Battery Energy Storage System (BESS), coupled through a bidirectional converter, helps to maintain a steady dc bus voltage. The transient and steady-state characteristics of the storage systems are examined. This study demonstrates how quickly hybrid energy storage can adapt to sudden changes in the load.

Keywords: *Battery Energy Storage System (BESS), DC Microgrid, Hybrid Energy Storage System, Maximum Power Point Tracking (MPPT), State of Charge (SOC)*

1. Introduction

The demand for renewable energies has grown dramatically in recent years due to the dearth of fossil fuels and major environmental problems. As a result, in the current global setting, environmentally friendly Distributed Generation (DG) and associated technologies are increasingly being highlighted as a study field (J, J, & X, 2016) (J, F, & Z., 2015) (Yang, LI, He, & Zhang, 2019). The microgrid that is the focus of today's in-depth research results from the numerous dispersed generations forming in the fast-changing power system. The microgrids may run on ac or dc power (Kumar, Singh, & Srivastava, 2012). Microgrids come in two varieties: ac and dc. Since dc MGs are more sophisticated than ac MGs, they can more efficiently deliver electricity to users (TL, B, & J D M , 2012) (SK, MK, & A, 2016) (Mahmud, Roy, & Kumar, 2021). The dc microgrids sustain the distributed generation units' increasing capacity to build a perfect power grid by enabling DG's coordinated and interconnected integration into the electrical power grid (A F, R, & S, 2016). Additionally, DC microgrids are mostly applicable in industrial settings with DC loads. Examples of these settings include railway, telecommunication, irrigation, and aviation (Mahmud M. , Roy, Saha, Haque, & Pota, 2017). Additionally, microgrids significantly impact highlighting and focusing on dependable sources of supply and adaptable control options, even on the distribution side (Kumar & Tyagi, 2020) .

As a result of the depletion of fossil fuels and the need for clean, green energy for sustainable development, renewable energy sources are currently being used to their full potential. The transmission and distribution levels of this clean energy are combined. The primary sources are wind and solar photovoltaic electricity. Single-distributed generation is nearly impossible because of the unpredictable and sporadic nature of production, necessitating the utilization of the storage system (Lehman & Bass, 1996) (Tahim et al., 2015). A distributed generating and storage system gives users reliable, high-quality power. The microgrid is therefore created as a result. Power and energy flow management is accomplished via the storage system.

2. Literature Review

Due to the depletion of fossil fuels and the idea of clean, green energy for sustainable development, renewable energy sources are now being utilized. This renewable energy is mixed at the levels of transmission and distribution. Electricity from wind and solar photovoltaic sources is the main source. Due to the unpredictable and sporadic nature of production, single-distributed generation is practically impossible, necessitating the use of the storage system. The customers of a dispersed producing and storing system receive dependable, superior power. As a consequence, the microgrid is produced. Utilizing the storage system, it is possible to manage the power and energy flow (Carrizosa et al., 2015; Guerrero et al., 2013). (Institute of Electrical and Electronics Engineers et al., n.d.) proposed a model of dc microgrid that comprises of solar photovoltaic array, battery, SC, and a three-step variable dc load. (Tan et al., n.d.) proposed a novice method of power flow control for a hybrid AC-DC microgrid with solar photovoltaic energy. Energy storage was also proposed for integrating pulse load. (Wu et al., n.d.) proposed hybrid microgrid system for Tagajo campus of Tohoku Gakuin University, Japan and illustrated that the microgrid and its control system were operated more efficiently. (Das et al., 2020) performed islanding at MVAC grid where issues of synchronization during re-closure didn't arise for all DG converters.

3. Methodology

2.1 DC Microgrid Model

Figure 1 depicts the suggested model for a dc microgrid. It comprises solar photovoltaic panels, energy storage batteries, and a supercapacitor linked to a DC grid and a load. The MPPT approach is used to track the highest amount of power coming from renewable sources. A power electronics interface known as a bidirectional converter is used to transmit power back and forth between a storage system and a DC grid. The voltage level for the solar photovoltaic is increased using a two-stage converter. Batteries and supercapacitors are utilized for energy storage. The battery manages the energy flow, and the supercapacitor manages the power flow. Over extended periods, batteries have a high energy density and is used to stabilize the energy flow as needed by the power sources, networks, or loads. Batteries, however, are unable to adapt to sudden changes in load. Due to its high-power density and quick discharge rate, the supercapacitor is used in this circumstance as it can respond quickly to large power demands (Chen et al., 2014; Choi et al., 2014; Shen & Khaligh, 2015).

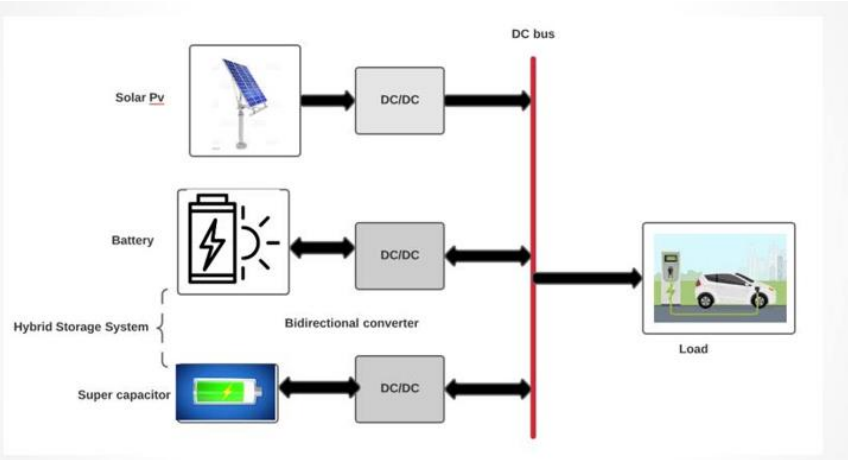


Figure 1: DC Microgrid Model

2.2 Solar PV Modeling

Figure 2 depicts the suggested model for a dc microgrid. For the real solar cell, the cell can be numerically modelled through the use of the following characteristics equation.

$$I = I_{ph} - I_d - I_{sh} \quad \text{Equation 1}$$

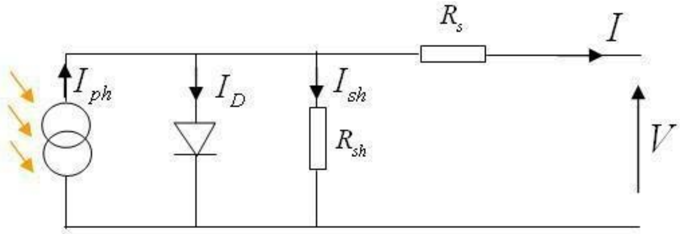


Figure 2: Modeling of Solar Cell

2.3 Maximum Power Point Tracking

The maximum power point (MPP), the ideal operating point of each photovoltaic cell, changes with cell temperature and irradiance intensity. For PV modules to supply the most easily accessible electricity, this optimization algorithm frequently alters the modules' electrical operating point. One of the simplest and most often used methods is the perturb and observe approach, which works by perturbing current as well as terminal voltage of the array, analyzing and comparing output power of the solar photovoltaic through the aid of preceding perturbation cycle. By adjusting the duty cycle in this case, the MPPT tracks the boost converter (Adhikari & Li, 2014; Zoka et al., 2004). Figure *3* elucidates the flowchart for Maximum Power Point Tracking.

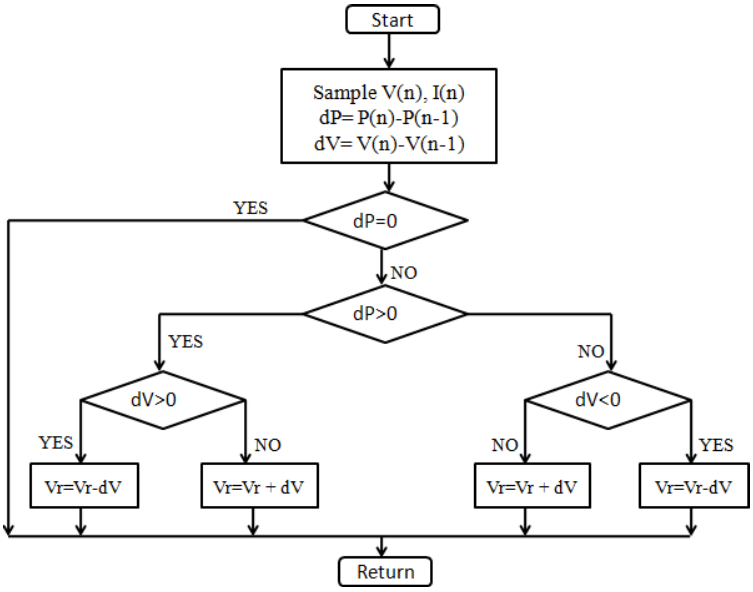


Figure 3: Flowchart for MPPT

2.4 Boost Converter

This step-up converter works on the fundamental two-state ON/OFF concept to increase the input DC voltage to the output. Figure 4 and Figure 5 shows the functional circuit and state condition of DC-DC boost converter respectively.

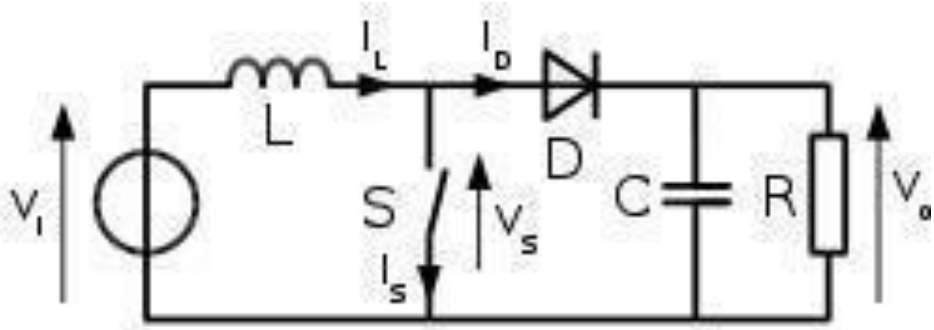


Figure 4: Functional circuit of boost converter

The output voltage of boost converter is given by:

$$V_0 = \frac{1}{1-\alpha} \times V_1 \quad \text{Equation 2}$$

, where α is the duty cycle. As the cycle increases from 0 to 1, it is clearly seen from the above expression that output voltage always exceeds the input voltage. It also increases with α, theoretically, reaching infinity as α approaches 1. Consequently, this converter is also known as a step-up converter.

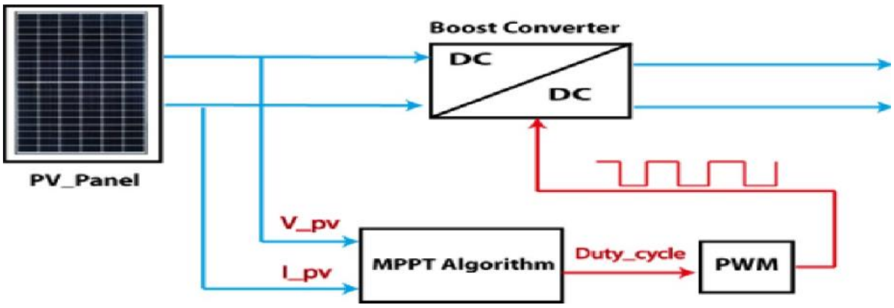


Figure 5: State condition of DC-DC Boost converter

Table 1: Comparison of characteristics of batteries and supercapacitor

Technology	Lead Acid Batteries	NaS Batteries	Supercapacitor
Charge Time Scale	1-5 h, 5-20 h	30 s to 7 h	0.3 to 30 s
Life Cycle	500 – 1000 times	+45000 times	1 million times
Operating Temperature	-20°C to +65°C	+300° C	-40° C to +75° C
Cell Operating Voltage	1.25 V to 3.6 V	2 V	2.5 V
Capacitance	N/A	N/A	0.1 – 1000F, 350 – 2700 F
Power Density	0.005 to 0.4 kW/kg	0.01 kW/kg	0.01 – 10.3 kW/kg
Energy Density	8 to 600 Wh/kg	170 to 400 Wh/kg	0.05 – 10 Wh/kg
Round Trip Efficiency	63% – 80%	89 – 95%	85 – 98%
Pulse Load	0.5 to 50 A	20 to 80 A	0.1 to 100 A

2.5 Super Capacitor Model

The electrical behaviour of an electrostatic capacitor in terms of capacitance and charging current is given by:

$$C = \frac{Q}{V} = \frac{\epsilon S}{d} \qquad \text{Equation 3}$$

$$i_c = C\frac{dV}{dt} \qquad \text{Equation 4}$$

where, C, Q, ϵ, V and i_c are capacitance of the component in Farads, charge in Coulombs, dielectric constant of the dielectric, electric potential in Volts and current through the capacitor respectively.

2.6 Battery Model

Figure 6 represents the flowchart for modelling of the battery.

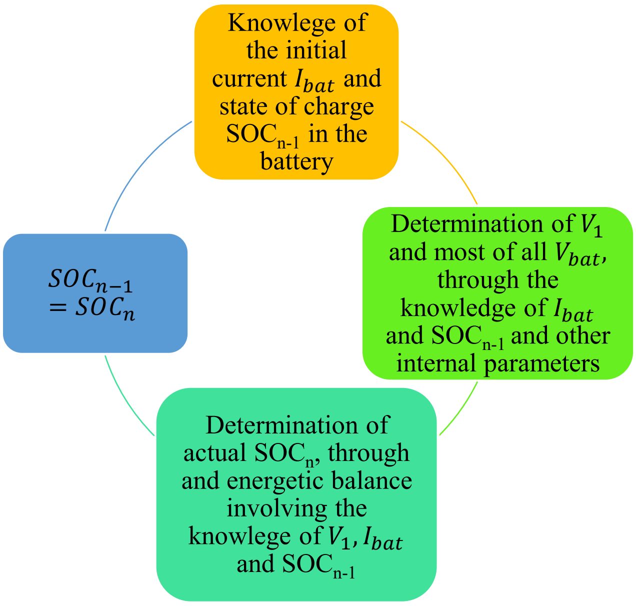


Figure 6: Modeling of battery

2.7 Microgrid Control

The DC grid controller's primary goal is maintaining the DC microgrid's voltage while ensuring a balanced power flow between the various energy sources and loads. The "think globally, act locally" concept or philosophy underpins this control system, which is realized using a system of systems methodology (*2008 IEEE International Symposium on Industrial Electronics.*, 2008; National Institute of Technology (Meghalaya et al., n.d.).

The power flow management for Islanded mode DC microgrid is given by:

$$P_{st} + P_{PV} = P_L \quad \text{Equation 5}$$

, where $P_{st} = P_{batt} + P_{sc}$, P_{st} is storage system power, P_{PV} is solar photovoltaic power and P_L is the load power. P_{batt} and P_{sc} are the battery power and supercapacitor power respectively.

4. Results and Discussions

For this research, hybrid model of energy storage system (battery and supercapacitor) are connected with solar photovoltaic system. The system is modelled through the use of

MATLAB Simulink environment. The simulation time is set for 2 sec, the corresponding results are shown herewith.

a. Solar PV

The irradiance set for this model is 980 W/m^2 for one second and 480 W/m^2 is set for the remaining simulation time, which is clearly shown in Figure 7. The temperature set for this model is 25° C.

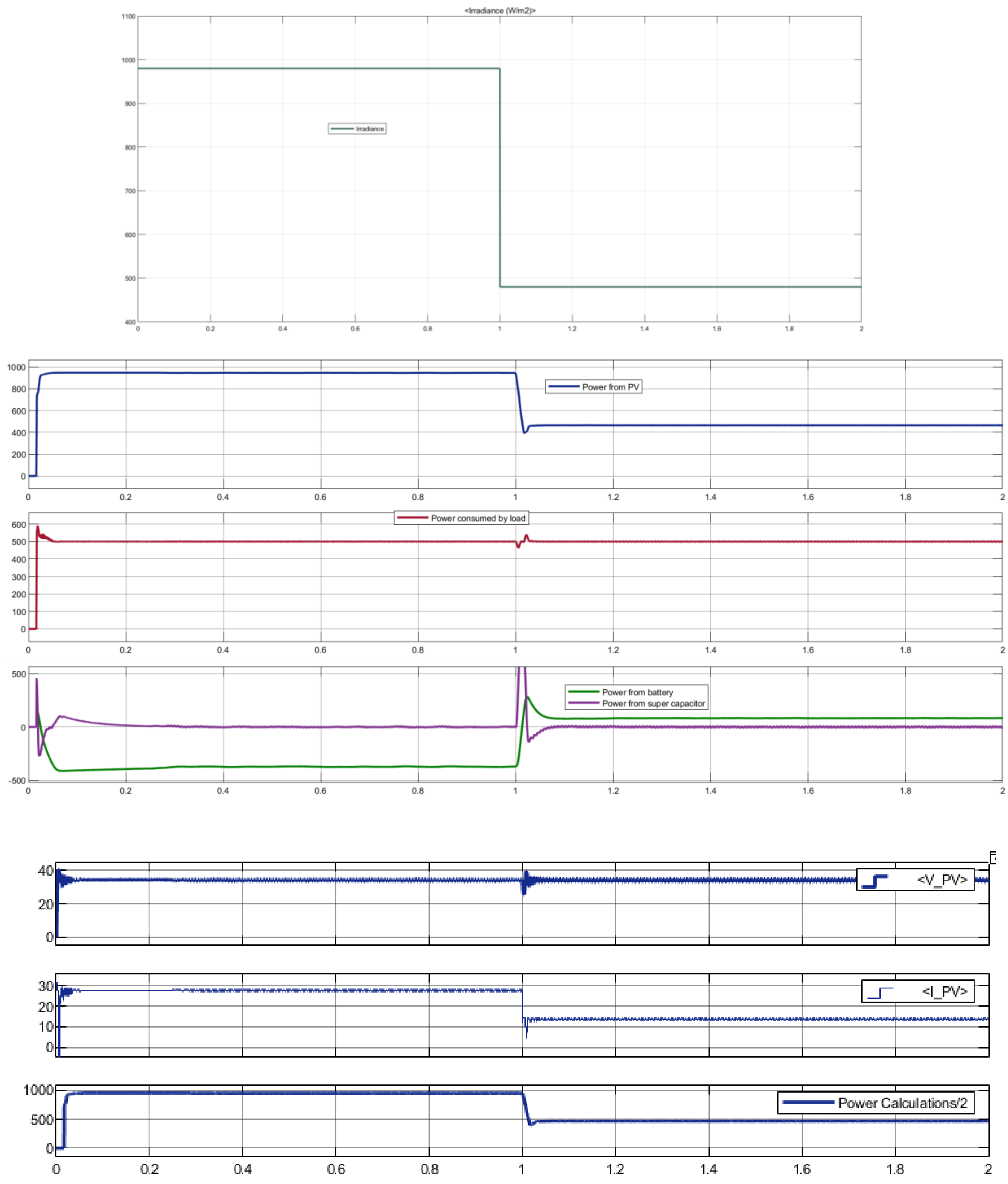


Figure 7: PV Output

P&O MPPT techniques is used for maximum power point tracking from the solar photovoltaic. The voltage obtained is 35 V and after one second, it is seen to be decreased. The current decreases from 28 A to 15 A after one second. The total power generated from solar photovoltaic is 960 Watts which falls to 450 Watts after one second.

Battery

The battery voltage decreases to 26 V from 26.5 V after one second. When power is surplus in a system, battery is charged. The negative power indicates the battery charging condition. Albeit, when the generated power is deficit, battery supplies power to the load and it is in discharging condition. In this case, in the first one second, battery is charging and in the remaining one second, the battery is discharging.

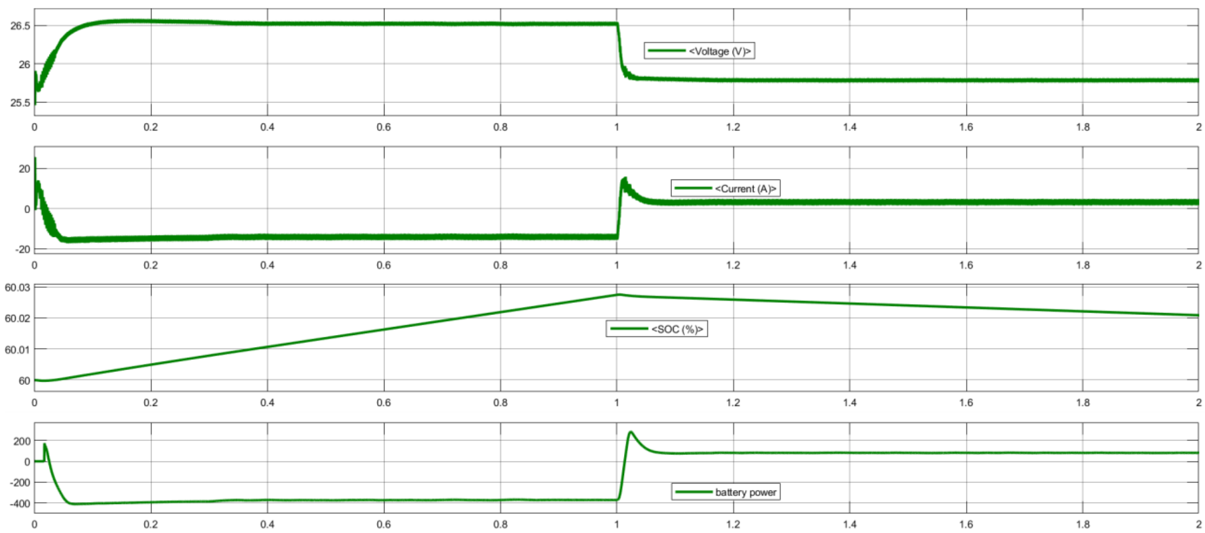


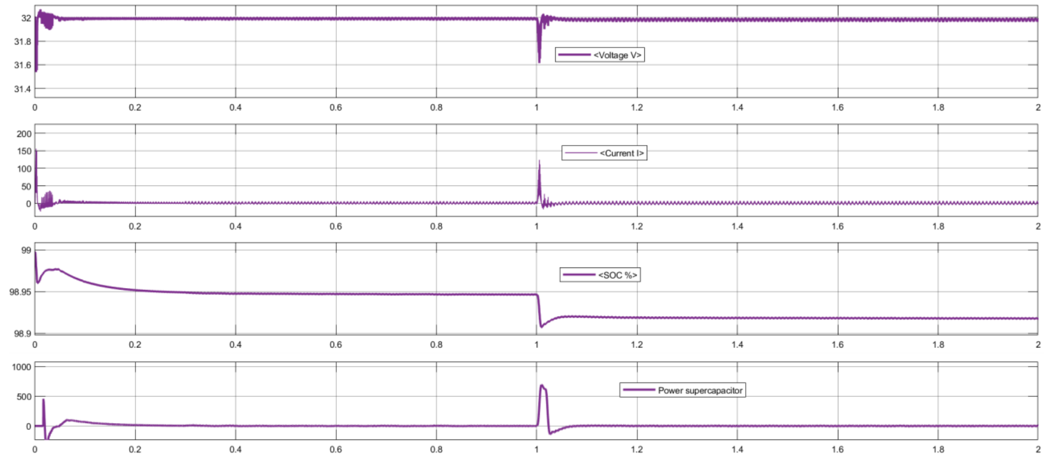
Figure 8: Battery Output

Capacitor

The voltage diminishes from 32 V to 31.6 V after a second for transient condition and finally settles down again to 32 V. The SOC of the capacitor falls down from 98.99% - 98.92%. It supplies the power for a small time. Figure 9 shows the high-power density of the capacitor and it responds in a short time. It clearly depicts that the battery has higher energy density and supercapacitor has the higher power density and is able to respond quickly.

DC Bus Voltage

DC bus voltage is maintained at 50 V. When the power and the load fluctuate, its voltage is affected and this is maintained by the storage system. Figure *10* presents the dc bus voltage.



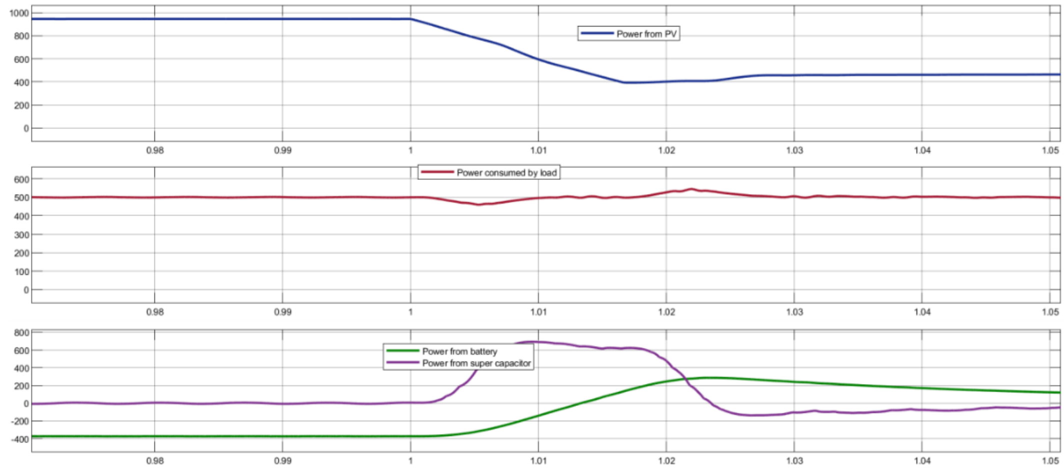


Figure 9: Capacitor Output

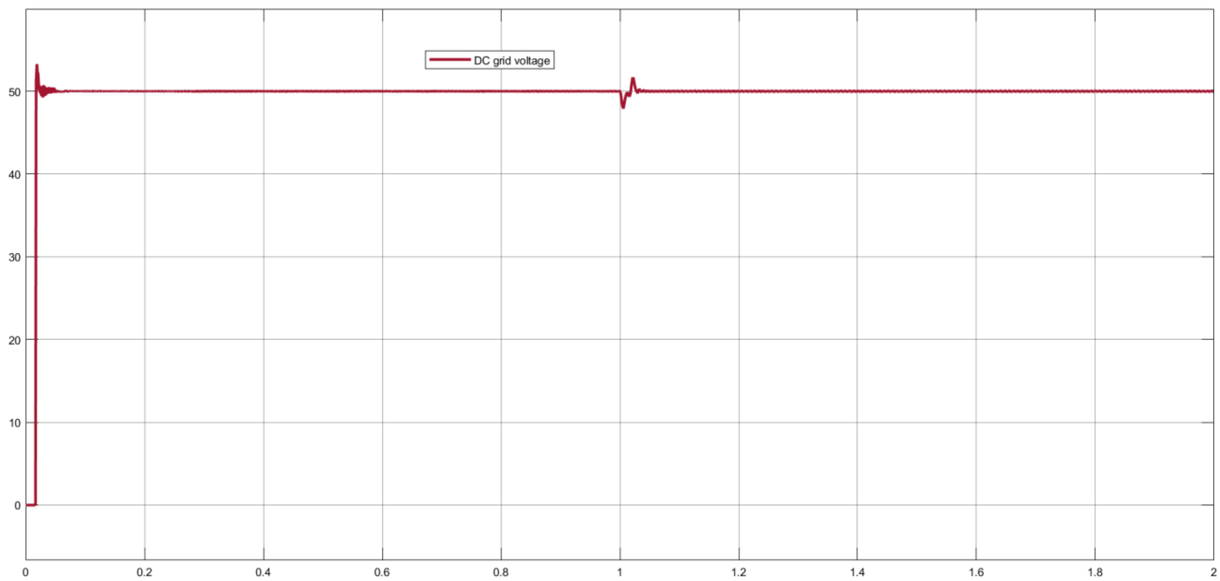


Figure 10: DC Bus Voltage

5. Conclusion and Recommendations

From the results obtained, it is seen that the major challenge is to build flexible network integration solutions based on the "Plug and Play" philosophy. Integrating decentralized energy generation, particularly sources like solar photovoltaic technologies, is crucial yet difficult and complex issue in the near future. An effective strategy to add this power to the main grid and provide ancillary services like voltage, frequency, and inertia support might be to use microgrids with storage devices.

The integration of intermittent renewable energy sources and their sustainability depend on the storage usage suggested in this paper. The proposed DC Microgrid offers a hybrid storage system that can function on two different time scales. The physical properties of storage components are employed to balance power generation and load demand when power, energy production, and consumption change. From this study, its is seen that control algorithms can keep DC microgrids stable in the face of sizable and rapid changes in production and demand. The control algorithms are developed that guarantee the stability of dc microgrids even in the face of extreme production and demand fluctuations. The suggested algorithms are found to be simpler and easier to adjust than the current linear control techniques. The suggested approaches can formally guarantee voltage stability and accurately provide a load under reasonable assumptions. Based on the power flow, a hierarchical control strategy employing local converter controllers such as DC-DC converters, an implicit control of main, and secondary is proposed as a remedy.

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