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Analysis Of Hybrid Models: Comparative Analysis Of Different Battery Types And Solar Panels With Matlab Simulink

[1.] Nikhil Malik , [2.] Dr. Surender Singh (Guide) , [3.] Dr. Gurdiyal Singh (Co-guide)

ABSTRACT

Growing populations, more sophisticated technology, and stringent rules to reduce carbon dioxide emissions are the main forces propelling the need for renewable energy sources. Photovoltaics, concentrated solar power, and solar heating and cooling systems are just a few examples of the technologies developed to harness the Sun's heat, which has been around for a long time and is a sustainable energy option. However, as the percentage of photovoltaic (PV) systems in low voltage (LV) networks grows, power quality challenges emerge. Supercapacitors (SCs) are one potential option because, because of their higher power density, they can store more energy in less time than batteries. Hybrid energy storage systems (HESS) use supercapacitors to store peak power to prolong the life of batteries. For optimal performance, active HESS systems provide independent voltage regulation of the battery and supercapacitor. Battery management, which seeks to combine high efficiency with little stress, is crucial to the successful functioning of hybrid electric vehicles (HEVs). The rising popularity of plug-in electric automobiles is, however, impeded by the need for affordable, long-driving batteries. Because of its extended lifespan, quick charging capabilities, and high power, lithium-ion batteries have emerged as the best choice for hybrid and solar PV applications. Different kinds of solar panels and batteries were compared in terms of their availability, variety of technological representation, and usefulness in hybrid energy systems. The analysis was carried out using MATLAB Simulink. This study sheds information on the technical diversity of solar panel types and battery technologies, which is helpful for academics, lawmakers, and engineers developing and implementing hybrid energy systems.

Keywords: *Hybrid energy systems, Comparative analysis, Battery types, Solar panels, MATLAB Simulink.*

INTRODUCTION

Rising populations, more advanced technologies, and stricter regulations aimed at lowering carbon dioxide e[1]missions are driving up the need for renewable energy sources throughout the world. Although renewable energy resources are dispersed across the globe, many people still need help accessing power. Nearly one billion people do not have access to electricity, according to the International Renewable Energy Agency (IEA) (Aleem & Hussain, 2020). Solar power, an alternative renewable energy source, has long been available and regenerative. A small quantity of solar energy can be transferred to Earth every second, and it is both replenishable and endless (Hayat et al., 2019). The huge radial dispersion of the faraway Sun means that solar energy has little impact on Earth's surface, and it is pure and produces no carbon emissions. Photovoltaics, concentrated solar power,

[1]Research Scholar.
[2]Assistant Professor, Electrical Engineering, UIET, MDU, Rohtak.
[3]Assistant Professor, Electrical Engineering, UIET, MDU, Rohtak.

and solar heating and cooling systems are just a few of the technologies that have been created to capture the power of the Sun (Oyedepo et al., 2021). UtilizingUtilising the Sun's heat, these technologies provide hot water and air conditioning by converting photons into electrons, which in turn generate electricity.

Worldwide, there has been tremendous advancement in the installation of photovoltaic (PV) systems that link to the grid and systems that are incorporated into buildings. Concerns about power quality, which may arise from either excessive power output or uncontrolled energy demand, are technical concerns that arise when PV penetration increases in low voltage (LV) systems. One possible answer to these problems is the use of supercapacitors (SCs), which can store more energy in a shorter amount of time than batteries can because of their greater power density. Power smoothing applications also take advantage of SCs, which may meet suddenly spiked demand in a matter of seconds. Nevertheless, SCs are charged only when energy consumption is less than generation, and they are unable to provide very high power (Buller, 2005). Various battery-supercapacitor topologies may reduce the negative effects of charge/discharge stress on battery health. Immediate power supply with a high load current increases the battery's discharge rate and current, causing damage more quickly. Hybrid energy storage systems (HESS) use supercapacitors to store peak power, which extends the life of the batteries (Shrivastava, 2017). But a system that allows motor startup all day long without going over the low voltage limit requires more battery capacity, which means a bigger battery pack and more money spent on the system during its lifespan. To get the most out of each component and the energy stored in the supercapacitor, active HESS systems let you run the battery and the supercapacitor at separate voltages (Logerais, 2013).

Successful operation of hybrid electric vehicles (HEVs) relies on battery management, which aims to combine high efficiency with minimal stress. For efficient battery management, precise information on the battery's status and properties is crucial (Bohlen, 2013). Increasing sales of plug-in electric cars is hindered by the lack of inexpensive, long-driving batteries. When compared to conventional lead-acid batteries, the ones used in hybrids and fully electric cars are bulkier, heavier, and costlier. Canis (2013) notes that these batteries are bulkier, heavier, and cost more due to the need for electronically regulated cooling systems.

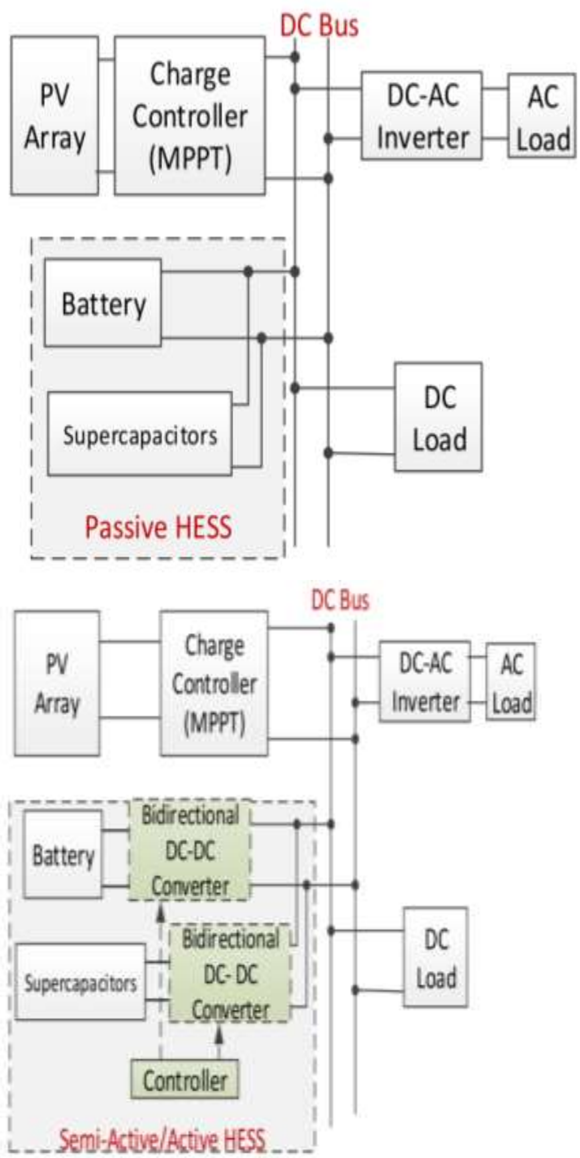
The acceleration and range of a vehicle are both impacted by the power density and energy density of the battery technology used. The low energy density of lead acid batteries makes them unsuitable for use in electric cars despite their long history as the industry standard. Electric and hybrid cars would be bulkier and heavier with lead-acid batteries installed (Canis, 2013). A variety of starting tasks and ignition is performed by lead-acid batteries, while electric motors are powered by NiMH batteries. Due to their high power, rapid charge capabilities, and long life, giving high energy and power densities, lithium-ion batteries have become the ideal option for hybrid and solar PV as they undergo constant development (Wencheng, 2010).

In the realm of sustainable technology and renewable energy systems, the paper "Analysis of Hybrid Models: Comparative Analysis of Different Battery Types and Solar Panels with MATLAB Simulink" has great promise. It improves system efficiency, guarantees robustness, and sheds light on the performance of various battery types and solar panels in hybrid energy systems. Policymakers, engineers, and academics may use the data to make better judgements about which battery technologies to use and how to integrate them into different applications, from homes to factories. In order to make choices that strike a balance between performance and cost-effectiveness, it is essential to compare the economics of different kinds of solar panels and batteries. Findings from the research may inform system designers as they work to achieve sustainability goals. Study results may be applied to real-world circumstances via realistic simulations done using MATLAB

Simulink. This enhances the study's usability in designing and implementing hybrid energy systems.

Hybrid Energy Storage Systems

Some research has suggested hybrid energy storage systems (HESS), such as fuel cells or PV-battery supercapacitors, as a possible option (Uzunoglu, 2006). Research on these hybrid systems is mostly limited to load management and demand sharing. Studies on active source management on the PV side of hybrid systems are uncommon. The way storage devices are connected to the DC bus determines whether a HESS is passive, active, or semi-active in topology. The DC bus is linked directly to the passive HESS, while a bidirectional DC-DC converter is used to connect the semi-active HESS to the DC bus. A controller or energy management system connects the two bidirectional DC-DC converters to the DC bus in an active HESS. As an example, Jing et al. (2014) suggest a system for active or semi-active hybrid energy storage that can stand alone.



(a) (b)

Figure 1: (a) A static energy storage system; (b) a dynamic energy storage system that uses supercapacitors. (Şahin and Blaabjerg, 2020)

Management System for Hybrid Energy Storage (HESS)

Utilities may better manage their power supply and demand with the use of energy storage, which encompasses a variety of technologies. Energy management, operational reserves, and frequency response and control are some of the applications for these technologies, which are classified according to capacity and discharge time. Frequently used for regulating and responding to frequency changes, high-power storage systems (SCs) swiftly store energy. Possible uses include transmission and distribution, preventing postponed system inertia, and ensuring power quality. A growing number of photovoltaic (PV) systems that are linked to the grid are adding renewable energy sources to the existing power grid mix. Yet, problems such as overloading during peak-power production times, voltage variations caused by solar energy's intermittency, and inadequate frequency control capabilities are potential issues with large-scale PV system installations (Roy, 2017).

PV System Model

Solar photovoltaic (PV) systems are the major energy source in the proposed model, which is based on Bellini's [24] model and takes into account irradiance, ambient temperature, and wind speed as input parameters and outputs PV current and voltage.

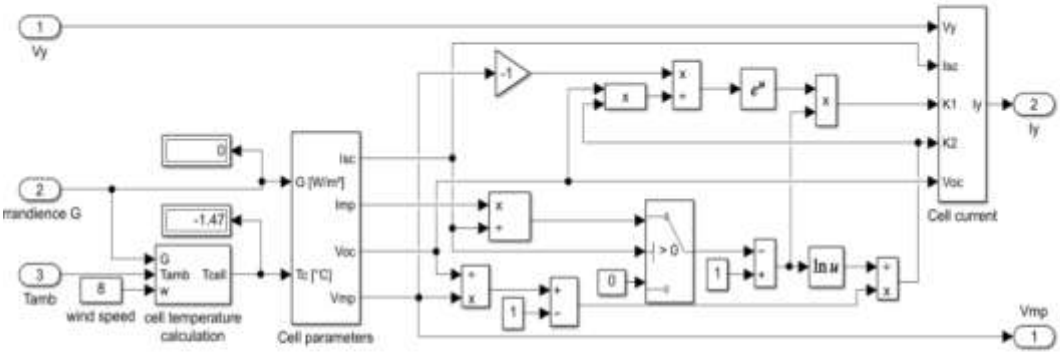


Figure 2: Simulink model of the PV system (Ayaz, 2014)

The PV output voltage and the two parameters $K1$ and $K2$ determine the PV cell current Iy. These mathematical formulas are used.

$$I_y = I_{SC}\left[1 - K_1\left(e^{(V_y/(K_2 \cdot V_{OC}))} - 1\right)\right]$$

$$K_1 = \left(1 - \frac{I_{MP}}{I_{SC}}\right)e^{\left(-\frac{V_{MP}}{(K_2 \cdot V_{OC})}\right)}$$

$$K_2 = \frac{((V_{MP}/V_{OC}) - 1)}{ln(1 - (I_{MP}/I_{SC}))}$$

Both the irradiance and the temperature influence the changes in the parameters $K1$ and $K2$. The temperature dependence formulae are provided by

$$I_{SC}(G,T_c) = I_{SCS}\cdot\frac{G}{G_s}\cdot[1+\alpha(T_c-T_s)]\ V_{OC}(T_c) = V_{OCS}[1+\beta(T_c-T_s)]$$

$$I_{MP}(G,T_c) = I_{MPS}\cdot\frac{G}{G_s}\cdot[1+\alpha(T_c-T_s)]V_{MP}(T_c) = V_{MPS}[1+\beta(T_c-T_s)]$$

A comprehensive account of the test parameters (Gs = 1000 W m2, Ts = 298.15 K) for a cell is given in the text, which includes the real irradiance and temperature of the cell, as well as the particular temperature coefficients for current and voltage, and the actual temperature of the cell Tc (K). The ambient temperature, irradiance, wind speed, and coefficient are used to compute the wind speed, whereas the values for temperature and irradiance are derived from the normal test circumstances.

$$T_c = 0.93\cdot T_a + 0.031\frac{\mathrm{m^2K}}{\mathrm{W}}\cdot G - k_r\cdot\omega + 3.6\ \mathrm{K}$$

The parameters for a full PV system are calculated using the Maximum Power Point (MPP) current and voltage in this research, with the cell parameters block adjusted. The number of parallel strings determines the current, whereas the temperature-dependent voltage is multiplied by the number of modules in series inside a single string.

An east-west split PV system was made possible by integrating two PV systems into the energy system, each of which takes use of a unique irradiation profile depending on its direction. The voltage from the PV system is converted to the nominal voltage of the electrolyser electrolyser using a DC/DC converter. By taking things like module contamination and conduction losses into account, efficiency parameters lower power and current.

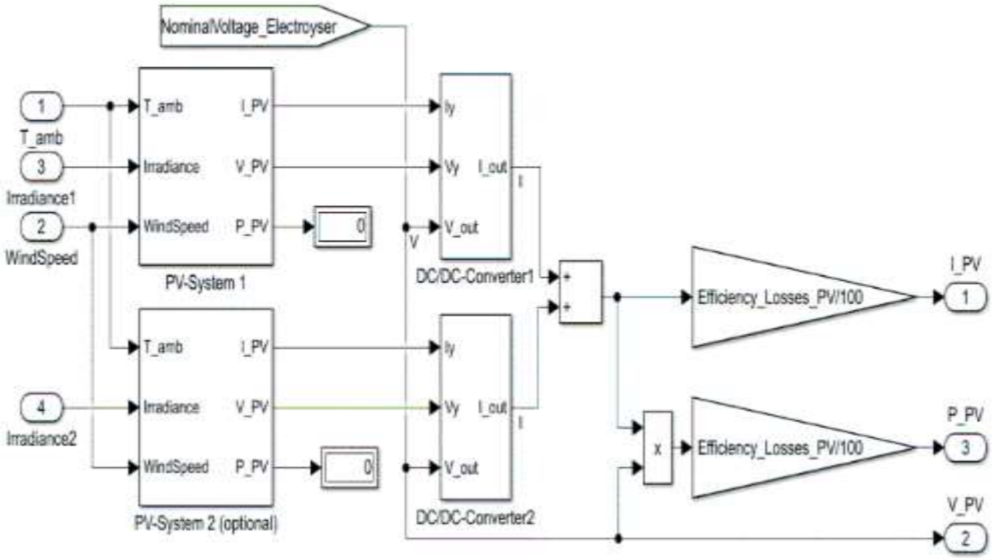


Figure 3: Layout of PV system in Simulink.(Möller and Krauter, 2022)

Lithium-Ion Battery Model

The lithium-ion battery stores excess energy from the photovoltaic (PV) system until the top charge limit is reached; it is mostly used for short-term electrical power requirements. When the maximum charge is attained, any excess energy is put to use by producing hydrogen. Assuming we don't hit the predetermined SoC, we may additionally store any excess energy generated by the fuel cell in the battery. In the event that the PV supply is inadequate or if there are sudden fluctuations in the load, this stored energy is used to meet the energy requirement.

Depending on the electrical loads and energy consumption preferences of the home, the maximum energy given throughout the examined time period is the crucial criterion for energy-autonomous operation. Electric energy storage systems are often utilised as a backup to fuel cells when electrical loads need to be supplied (Motapon, 2014). This is because electric storage has a quicker ramp time.

A model of a lithium-ion battery was adjusted to suit the sort of home system in this investigation. A maximum limit of 80% and a lower limit of 20% have been specified for the lithium-ion battery system on a chip. A straightforward control algorithm determines the quantity of energy flowing into and out of the storage, allowing for the delivery and transfer of the rated power. The rated power limits the amount of leftover energy that may be sent to the battery from a PV system if its output exceeds the load requirement.

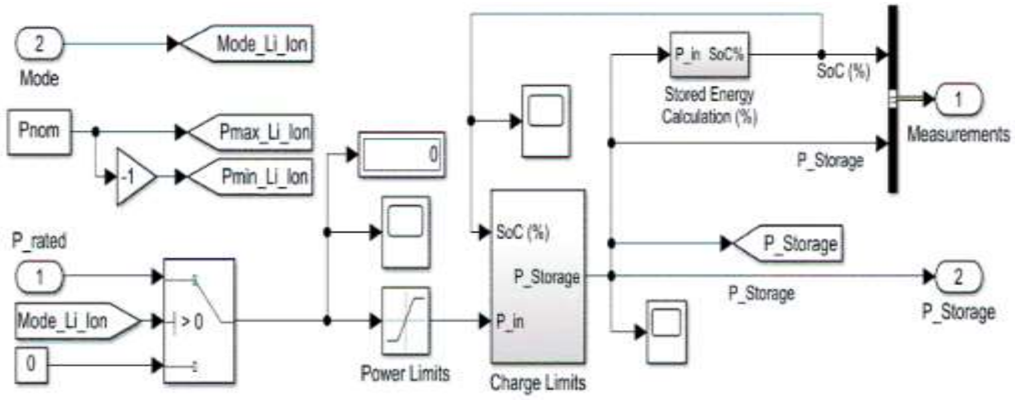


Figure 4: Simulink model of the lithium-ion battery (LeSage, 2021)

System Description

Figure (3.1) shows the block diagram of the system that was taken into account in this research. It includes a photovoltaic array, a boost converter with maximum power point tracking and voltage management, and two bidirectional, non-inverting buck-boost DC-DC converters.

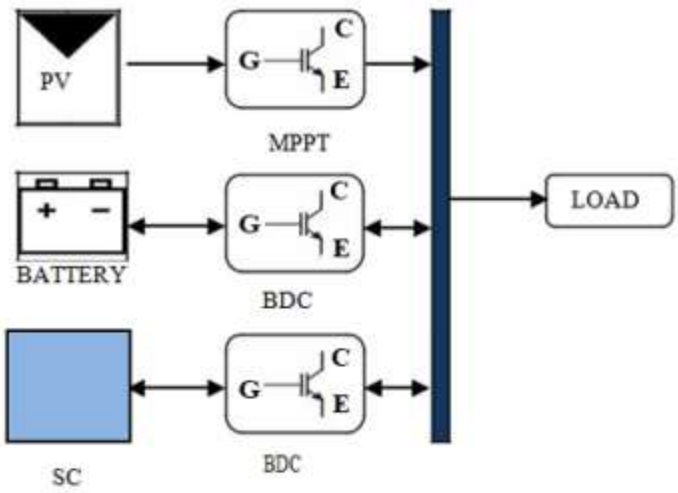


Figure 4: Block diagram of Hybrid Power System

Reliable power for DC loads and longer battery life when charging and discharging are the goals of the suggested PV system. In the event of a power mismatch, the SC converter controls the DC link voltage to match peak demand, and the BMS decides the battery's operating mode and current reference.

METHODOLOGY

The comparative study involved finding different kinds of solar panels and batteries and comparing their availability, diversity of technology representation, and usefulness in hybrid energy systems. MATLAB Simulink was used to model these systems, generating interactive models that mimicked the interplay of various solar panel and battery varieties. Various operational variables, including solar irradiance, temperature, and load profiles, were simulated via the development of many scenarios. For every possible outcome, simulations were run to catch fleeting behaviours and performance variances. To measure the effectiveness of the hybrid models, a number of performance indicators were established, such as total system efficiency, efficiency of energy storage and retrieval, reaction time to changes in load, and the effect of various battery types on system stability. In order to make meaningful comparisons, precise data gathering was guaranteed. Their strengths and flaws were brought to light via a thorough comparative study that compared and contrasted their performance under different scenarios.

Battery Life Improvement

When planning a PV system's battery bank, it's essential to consider the depth of discharge as well as the battery capacity. Although shallow-cycle batteries are more capacious, deep-cycle batteries may be discharged to depths higher than 50%. Both operational temperature and discharge rate impact the immediate or usable capacity of the battery. While it's true that battery capacity drops by about 1% for every degree below 20°C, extreme heat is bad since it speeds up ageing, self-discharge, and electrolyte use. An interplay between the charging/discharging regime, the DOD of the battery during its lifespan, exposure to lengthy low-discharge periods, and the average temperature of the battery over its lifetime determines the rate of capacity deterioration. Also, electrolyte consumption, self-discharge, and ageing are all hastened by high temperatures.

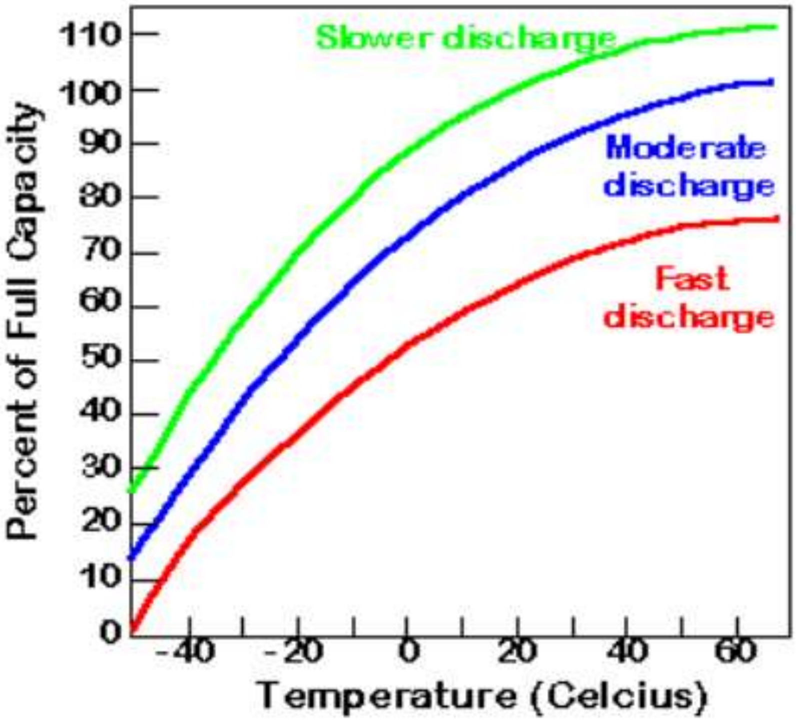


Figure 5: Relation between battery capacity, temperature and discharge rate

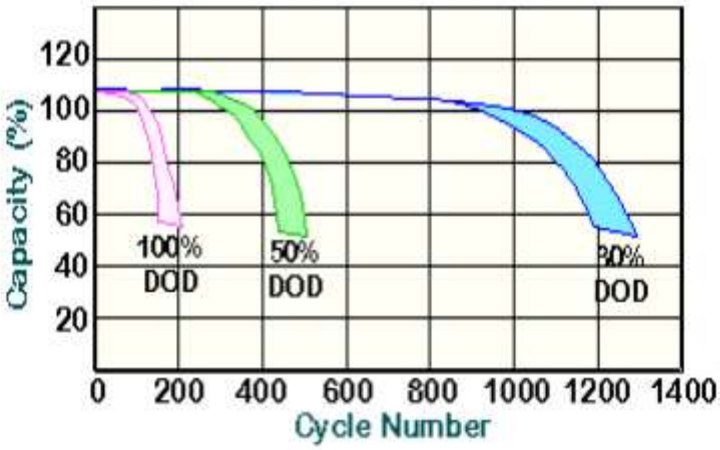


Figure 6: Relation between battery capacity, depth of discharge and life cycle for a lead acid battery

Although deep-cycle batteries may keep going even when the depth of discharge drops below 50%, the graph shows how the function of shallow-cycle lead acid batteries has changed over time. To improve the battery life cycle, the suggested study employs a supercapacitor to control the discharge depth.

Assessing a Battery Controller Based on PID and FPID

The construction of a battery controller using integer-order and fractional-order PID controllers is covered in this section. The controller's output is the current flowing through the inductor, and the control variable is the duty ratio.

Table 1: Time domain and frequency domain specifications of battery controller

Parameter	**Integer order PID controller**	**Fractional order PID controller**
Rise Time	0.50 ms	0.30 ms
Settling time	0.35s	0.25 s
Overshoot	0 %	0 %
Steady State error	0	0
Gain Margin	Infinite	Infinite
Phase Margin	91.5° dB	91° dB
Closed loop stability	Stable	Stable

In this research, we look into unity feedback systems and see how PID and FPID controllers fare. Table 1 shows that FPID controllers have shorter rising and settling periods. Figure 7 displays the bode diagram for both kinds. Also, Table 1 displays stability indicators such as phase margin and gain margin, which show that FPID-based controllers are more stable than PID-based controllers.

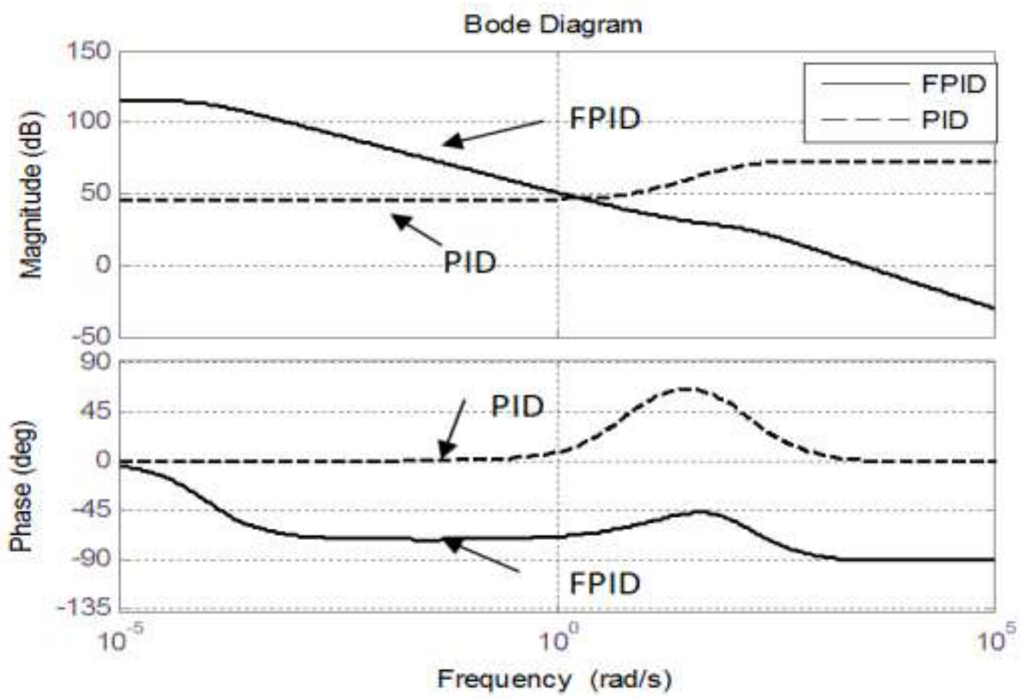
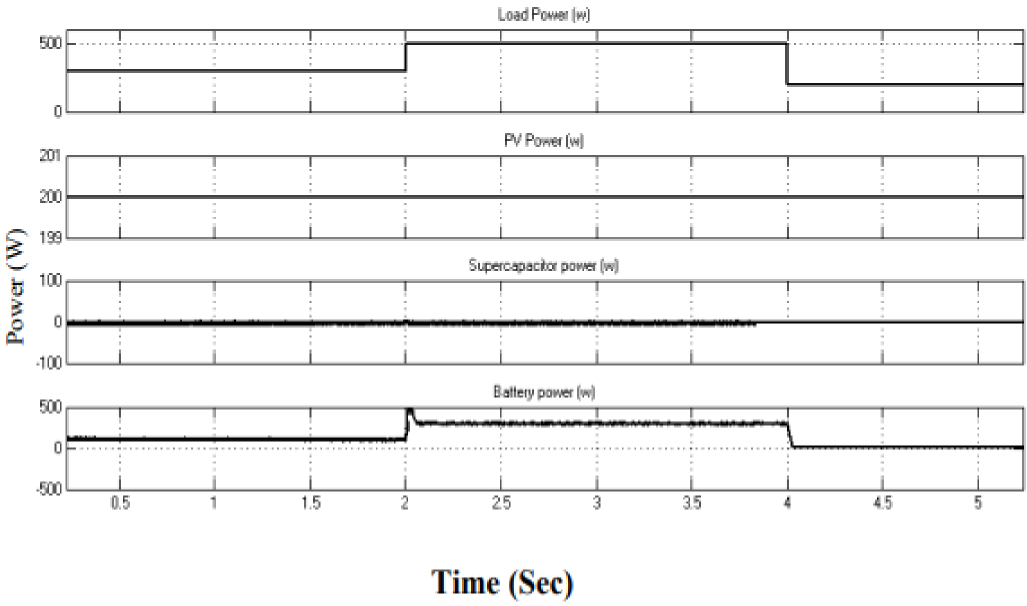


Figure 7: Schematic of a PID-based and an FPID-based battery controller

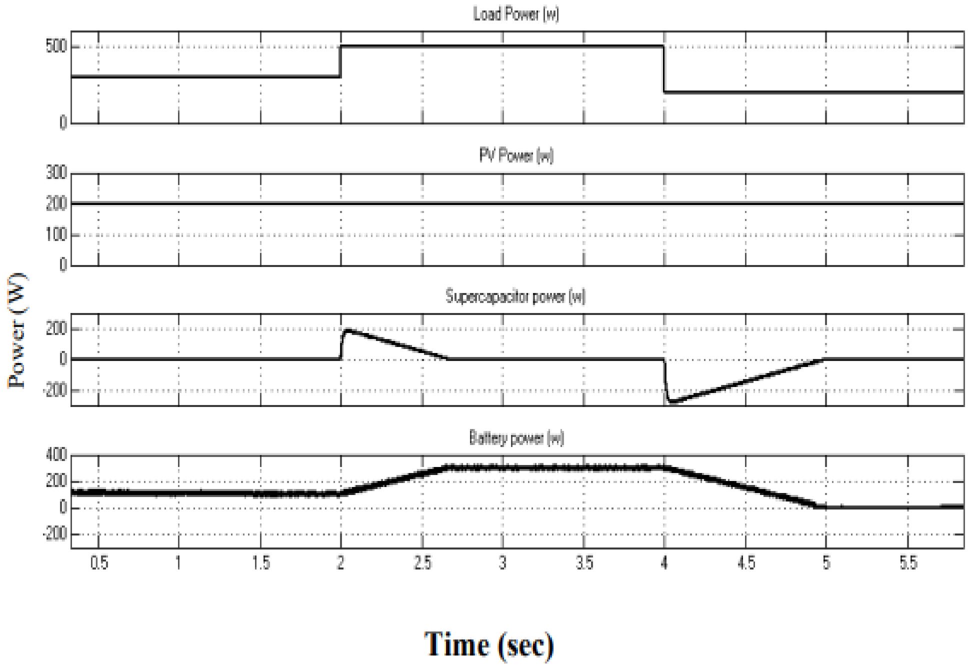
Results And Discussions

Several controllers are used to test the proposed system under different load circumstances. We ran the simulation in Simulink/MATLAB and looked at the results. Variations in load, whether step or ramp, impact system performance by changing variables such as DC link, battery voltages, and currents. A 200 W PV power output, steady temperature, and irradiation are some of the assumptions established throughout the simulation. Based on the availability of charge, the system meets the increased demand from the SC and battery as the load grows. **Table 2:** Specification of SC and Battery

Super Capacitor		Battery Bank	
Module Capacitance	166F	Each Battery Voltage	12V
Each Cell Voltage	2.67V	Each Battery Capacity	50Ah
Wh of each Cell	1.5Wh	Number of Batteries	2



(a)



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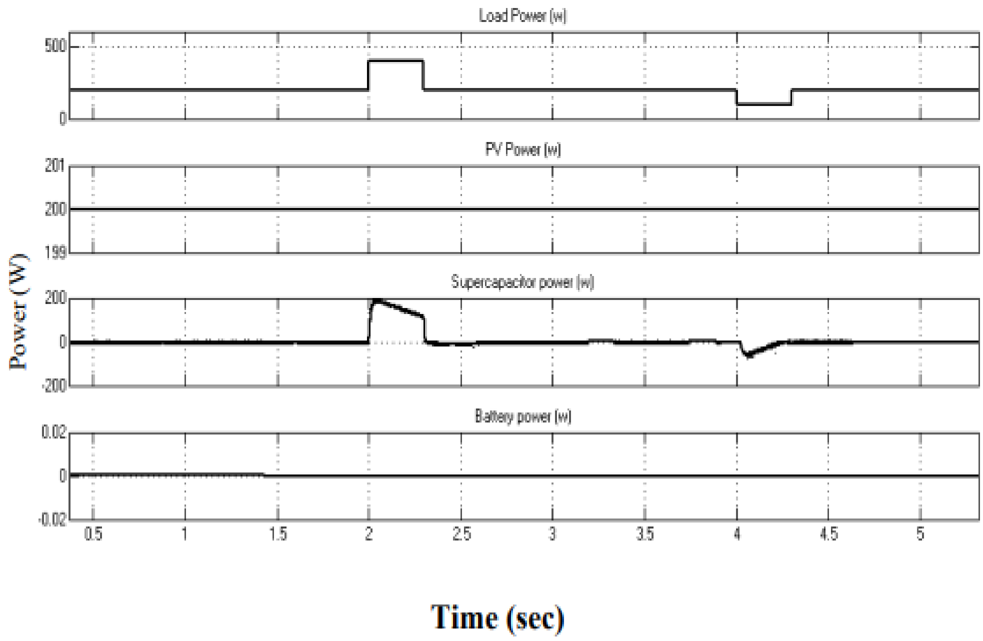
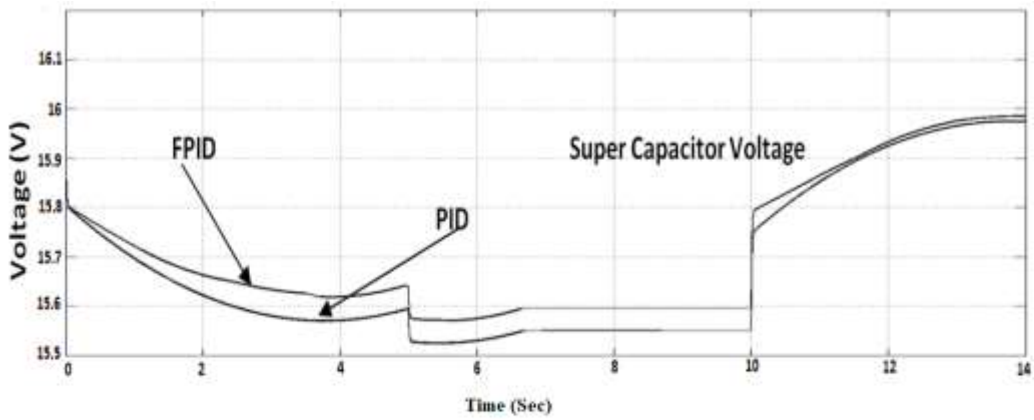


(c)

Figure 8: DC Grid Power Management (a) Power Balance with Full Battery and System Charging Capacity (b) Maintaining a 100% voltage in the SC and a 20% state of charge in the battery (c) Maintaining a steady power supply with a battery charged to 100% and a secondary capacitor voltage of 20%.

CASE 1:



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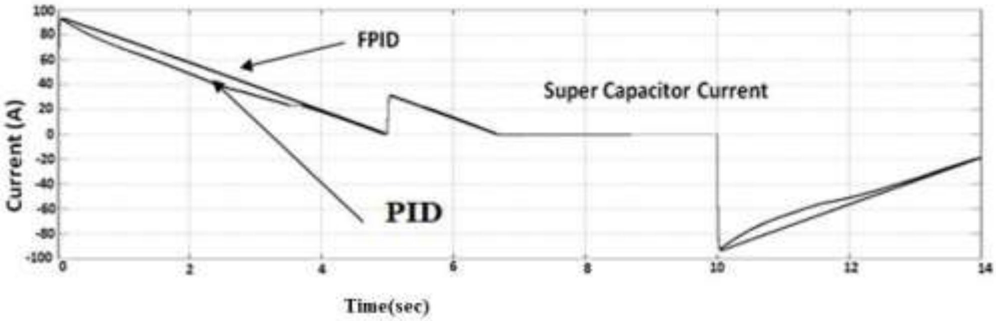
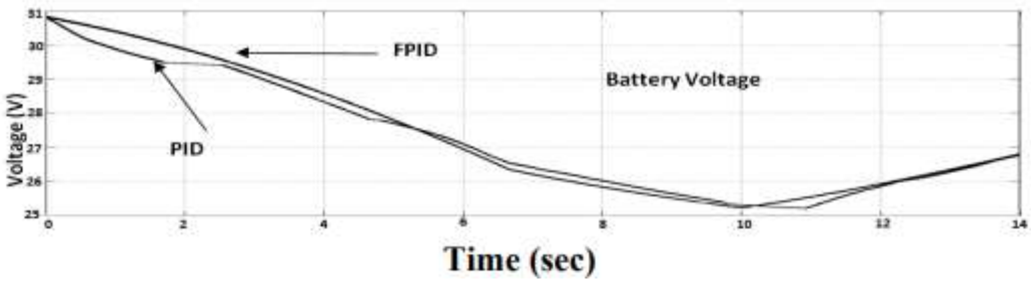


(b)

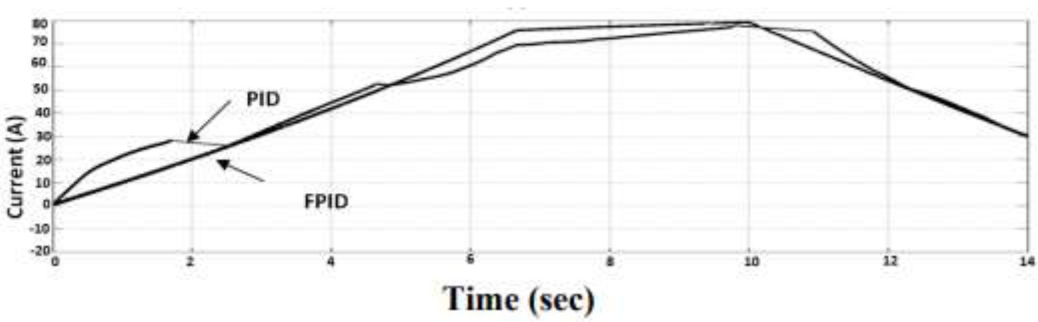
Figure 9: Performance comparison of (a) SC voltage and (b) SC Current

When the battery is not in use, the voltage across the capacitors ranges from 15 to 24 volts. In Figure 8(a), we can see how the DC grid handles power management when the demand is dynamically changing. In order to decrease the battery's depth of drain, the load is dynamically increased from 300W to 500W at t=2 seconds, with the initial supply coming from the SC. The load is reduced to 200W at t=4 seconds, creating an excess of power that may be used to charge the SC.

Upon startup, the system will function as if the SC and battery are both fully charged. At first, the SC powers the load before progressively shifting it to the battery. The power waveforms for the load, PV, battery, and SC are shown in Figure 8 (a).



(a)



(b)

Figure 10: Comparison of performance (a) battery voltage and (b) battery current.

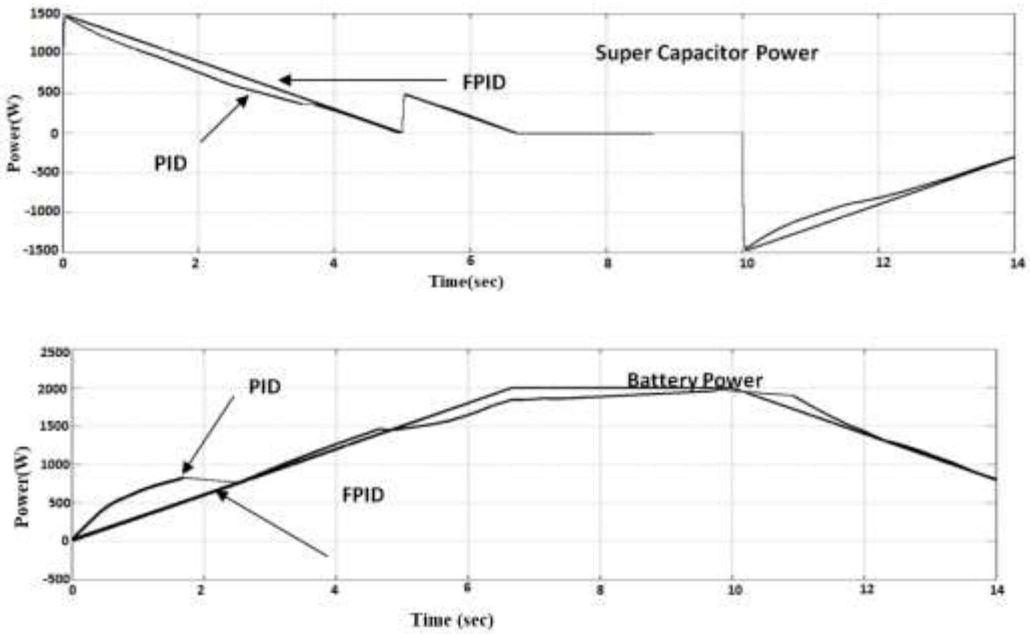


Figure 11: Comparison of (a) power from SC and (b) power from batteries

CASE 2:

In the second scenario, the battery is in standby mode, and the SC voltage is below 16 V. At the period t=2 seconds, the input PV power is 200 W, and the output power is raised from 300 W to 500 W. In this scenario, the load may be powered by the battery's current state of charge, but the 16V capacitor voltage is insufficient.

In the second scenario, the state of charge (SOC) of the battery is sufficient to generate electricity, and the voltage across the SC is lower than its lower limit. In order to charge the SC over 15V and meet the power demands of the load, it is necessary to drain the battery. The power waveforms for the load, PV, battery, and SC are shown in Figure 8(b).

CASE 3:

While the battery is in standby mode, the voltage across the capacitors in Case 3 is more than 24V. By increasing the output power from 300W to 500W, the input PV power is raised from 200W. The power needed to charge the batteries and run the load is supplied by the fully charged SC. Two separate controllers are used in the simulation experiments to ensure the system is functional. With a time constant of 5 seconds, the load power (PL) goes up to 2000W, and with a time constant of 100 seconds, it drops down to 1000W. Figures 9–11 depict the system's operation under these circumstances. A fractional PID controller, as opposed to an integer PID controller, is used to confirm the DC grid's behaviour and dynamic performance. When compared to integer PID controllers, fractional-order PID controllers provide superior transient and steady-state performance. No matter how little or large the change in load is, the system reacts smoothly.

To prevent the depth of discharge, the SC takes over the whole 1500W load power at t=0. The power is efficiently transmitted from the SC to the battery in only 5 seconds, extending the life of the battery. After 10 seconds, 1000W of load is disconnected from the DC grid, and the surplus power powers the SC in Figure 10. The battery and SC work together to prolong the battery life cycle by preventing deep charging and draining. Comparing the fractional-order PID controller to the integral PID controller, the former has a superior transient response. A battery-supercapacitor hybrid system may increase SOC while decreasing storage size and battery stress. The capacity of lead-acid batteries to charge may be enhanced by more than 25% in bright sunshine and by 10% in overcast conditions with the help of supercapacitors (Jing, 2016).

CONCLUSION

This article details an examination of a novel architecture for active power regulation in MATLAB/Simulink and a hybrid PV battery/supercapacitor system. To show that control strategies work, we run simulations in MATLAB/Simulink. Based on the study's findings, certain battery and solar panel combinations provide the most stable and efficient systems. Additionally, the research emphasises how operational factors greatly impact the effectiveness of hybrid models. Quantitative performance measures provide a foundation for system design decisions and include overall system efficiency, energy storage and retrieval efficiency, and response time to changes in load. The research adds to our awareness of available alternatives by highlighting the technical variety of battery technology and solar panel kinds. Engineers, legislators, and academics working on hybrid energy system designs and implementations may use the results in the real world. New problems with hybrid energy systems are always popping up. Thus, it's important that researchers look at these possibilities in the future. Our knowledge of hybrid energy systems was enhanced by the comparison, which laid the groundwork for well-informed decisions in the search for efficient and environmentally friendly energy sources.

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