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Stability Assessment of Power Supply Systems Employing Supercapacitors

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Abstract: -

With the increasing popularity of electric vehicles, there is an urgent need for a reliable and stable power supply for charging batteries. Charging multiple electric vehicles simultaneously often leads to a noticeable reduction in voltage levels and current supply. To address this challenge, the integration of supercapacitors is proposed. Supercapacitors, renowned for their high-power density and swift charge-discharge capabilities, offer a potential solution. This study aims to compare power supply systems, examining their stability in delivering consistent power with and without the integration of supercapacitors. The research endeavors to contribute to the development of stable and reliable power supplies, specifically designed for charging multiple vehicles simultaneously.

Keywords— **Electric Vehicle, Stability, Supercapacitor, Power Density,**

1. Introduction:

Electric vehicles are gaining popularity, driven by escalating oil prices and environmental concerns linked to pollution and global warming. Despite their advantages, electric vehicles face several challenges, including limited range, high initial costs, a restricted model variety, charging infrastructure issues, supply chain challenges, weather effects, service support concerns, technological advancements, prolonged charging times, and battery degradation.

Beyond these challenges lies an additional issue, not directly tied to electric vehicles but rather to the power supply used for charging. Traditional power supplies, when employed to charge multiple electric vehicles simultaneously, experience a decline in voltage levels and current supply values. This decline in voltage and current has a dual impact: it hampers the proper charging of electric vehicles and poses the risk of overloading the power supply, potentially causing undesired transients in voltage and current levels. This sudden surge may result in damage to the power supply system.

2. Literature Survey:

Supercapacitors, batteries, capacitors, and fuel cells possess unique characteristics concerning their energy storage and delivery capabilities. Supercapacitors, alternatively known as ultracapacitors or electro-chemical capacitors, feature an expansive electrode surface area and thin dielectric electrolytes, resulting in a capacitance several orders of magnitude higher than that of conventional capacitors [1]. Despite offering higher power density, supercapacitors exhibit lower energy density when compared to batteries. The charging and discharging processes in supercapacitors involve the rapid adsorption of ions on the electrode materials, demonstrating swift reversibility. In contrast, batteries store energy through chemical reactions, boasting higher energy density but lower power density than supercapacitors. Notably, batteries come with extended charging times and lower cycle lives. Capacitors, or conventional capacitors, utilize a dielectric material to separate double conducting electrodes, storing energy by separating charges. Capacitors demonstrate lower energy and power density compared to both supercapacitors and batteries. Fuel cells, in contrast, distinguish themselves by generating electricity through a continuous electrochemical reaction between hydrogen and oxygen, eliminating the concept of energy storage observed in supercapacitors, batteries, and capacitors [1]. Super capacitors add on the benefit of long life as supercapacitors can be charged and discharged almost million times compared to batteries which have limited charging and discharging capacity. This helps in increasing lifetime of power supply systems and capacitors take off most of the load for charging and discharging. Also, the rate of charging and discharging is high as compared to batteries as it works on the concept of electrostatic charging and discharging as opposed to chemical reactions. This helps in making durable, long life and maintenance free circuits [2] Comparison of super capacitors and conventional batteries was performed using experimental data, mathematical models and manufacturer data. And it was found that supercapacitors offer various advantages over regular Li-Ion batteries such as high energy density and reliability. Furthermore, Super capacitors can be used to make DC-DC converters for maintaining constant voltage [3].

A thorough analysis was performed to find out the reliability aspect of supercapacitors in context of their use in energy storage applications. Further existing lifeline-based models for analysis are compared with mission profile-based approaches. Additionally, it also states that lifetime of SCs depends on environment conditions and mission based profile. Misson based profile gives better idea about super capacitors as in this approach a mission is set for SCs and then its performance is evaluated based on how it reacts to[4].

Supercapacitors offer a high energy density and power density, making them suitable for smoothing strong and short-time power solicitations in distribution networks. Additionally, they allow for flexible and fast power control and optimized energy management, making them well-suited for transportation networks with varying voltage conditions. Furthermore, the use of supercapacitors as energy storage devices enables the system to provide constant power injections, ensuring a stable voltage level in the presence of strong perturbations [5]

Main parameters which affect the operation of capacitors in electric circuits are capacitance, self-resistance and self-discharge. capacitance should be as high as possible, Self resistance should be as low as possible ideally zero and Self Discharge should be zero ideally. Super capacitors have high capacitance, low internal resistance and small leakage current. High capacitance and low resistance make it an ideal choice for power application [6-7]. Battery life is dependent on various factors and one of the main factors is surge current. Surge current plays a significant role in deciding battery life. [8]. To strengthen the lifetime of batteries it is necessary to have a hybrid power supply system which uses Super capacitors. Hybrid Power systems can be implemented using battery and supercapacitors which comes with various benefits like longer battery life, Gain and in overall power efficiency. This kind of power supply can be employed for current UPS which helps in implementing a flexible power supply [9] Super capacitor are now mainly used in the application to support batteries to maintain electrical parameters to a certain level. There are various types of power supplies designed and developed like SCALDO, SCASA, SCATMA, SCASCA for efficient power supply. All these systems depend on the output side of the circuit after power station. [10] In this work we are trying to develop a system which will depend on the transmission line for all the surge value.

3. Methodology:

Our work is organized into two distinct phases. Phase 1 covers experimental setups to check behavior of circuits with and without capacitors. In Phase 2 we propose a solution to overcome variations

Phase 1

Case 1

In the initial phase we have 3 different cases where we have explored the behavior of voltage and current when an electric motor is connected to a power source without utilizing a super capacitor. The setup involves a 12V DC power supply connected to a load (Electric Motor), as depicted in the image below. Electric motors typically draw a significant current during regular operation, and the startup phase often induces sudden transient currents. This abrupt surge in current results in a reduction in the voltage value. The circuit illustration shows an Andy mark 2.0, 12V DC motor connected to a live 9.5 V DC power supply without any capacitor. As evident in the setup, there is a noticeable approx. 7 V drop in voltage when the motor is initiated, representing nearly 50% of the maximum value. Such transient occurrences can have detrimental effects on the power supply, potentially leading to permanent damage. Beyond the impact on the power supply, these transients may also introduce irregularities in the operation. This highlights the importance of implementing a system capable of regulating voltage to the desired level while accommodating current surges and withstanding transients.

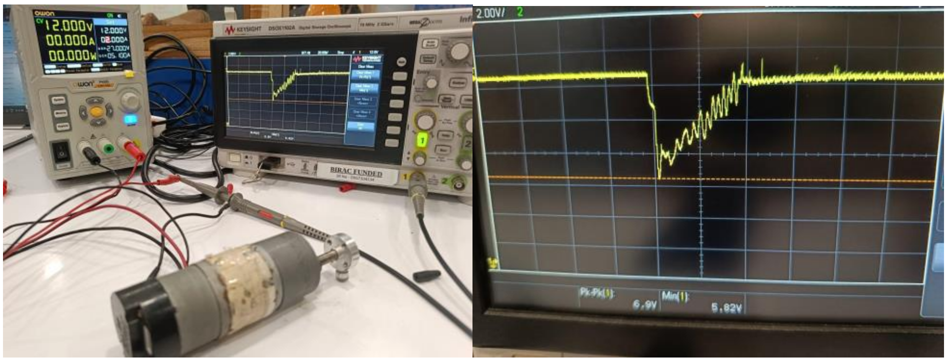

Figure 1. Experimental setup to test drop in the value without capacitor in the circuit

We have plotted values of voltage variations with respect to time and it can be seen that there is sharp reduction in voltage level when we connect s load. Drop in voltage is almost 7.5 V. it is approximately about 80% of actual value. This high range of variations can prove fatal for circuit operation. To prevent possible damage we need to take care with an additional component like super capacitor.

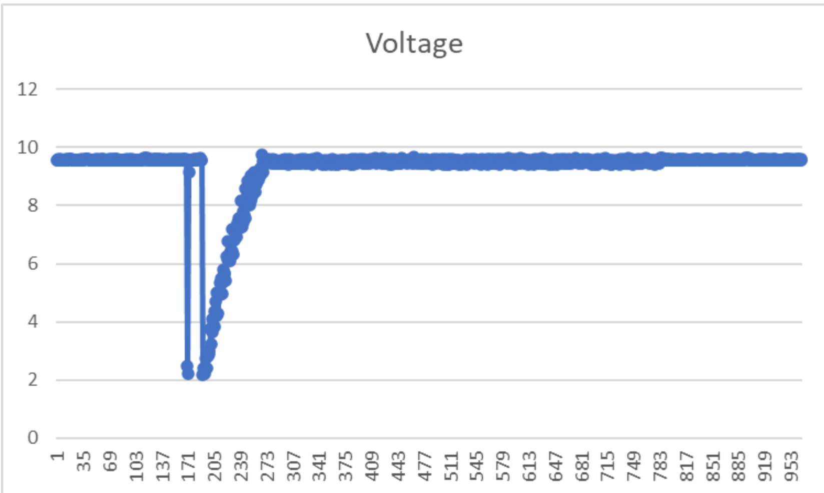

Figure 2. Linear plot with voltage on Y-axis vs Time on X-axis

Case 2

In the second case we do analysis of circuits implemented with normal capacitors and the voltage and current variations are compared. For this phase we use 4 capacitors of 500uF capacitance. Then we connected a motor to the 9V power supply as shown in figure 2. Compared to case 1 it can be seen that the percentage voltage drop is lesser as compared to the scenario where we did not use a capacitor. As shown in the figure there is drop of approximately 4V. Apart from this it can also be seen that variations are less fluctuating than the one for circuits without capacitors. So this means inclusion of capacitors leads to improvement in stability. So even though there is a reduction in the transient value still it is not nearing 0. These variations are still large enough to affect the operation of the power supply. So, we go for the third case which is implementation of power systems with super capacitors.

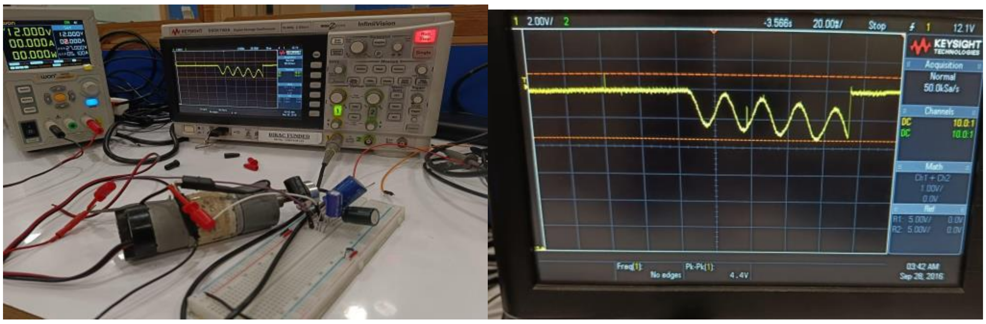

Figure 3. Experimental setup for voltage variation observation with normal capacitors

As shown in figure 6, charge in voltage with respect to capacitors is almost nearing to zero. This will allow us to design a power supply system with stable voltage and current when we connect load to it.

In this experiment we have connected only one load. When we connect multiple loads this effect will become even more significant and there is a high possibility of damaging itself.

Case 3

As discussed in the third case we do analysis of circuits implemented with super capacitors and the voltage and current variations are compared. For this phase we use 4 capacitors of 2.7F capacitance. Then we connected a motor to the 12 V power supply as shown in figure 3. It can be seen that the percentage voltage drop is lesser as compared to the first two phases. The percentage change nears value zero. This shows that the employment of super capacitors for stabilizing voltage is efficient and can help in regulating voltage and current levels for high loads as well.

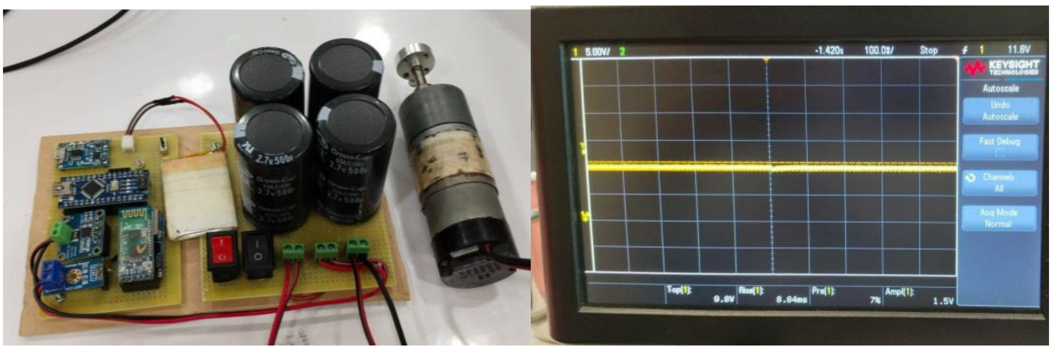

Figure 4 Experimental setup for voltage variation observation with super capacitor

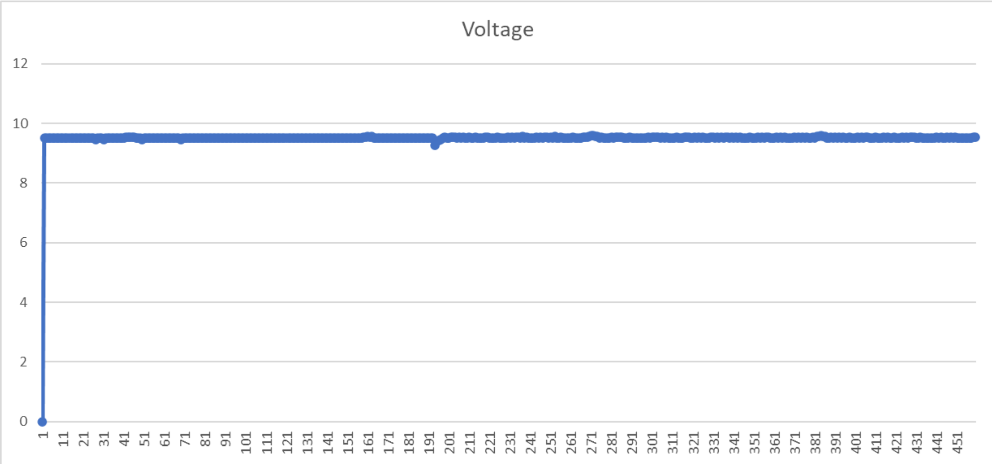

Figure 5 Linear plot with voltage on Y-axis vs Time on X-axis for circuit with super capacitor

4. Comparative analysis and proposed solution:

Analysis:

Table 1 shows comparative analysis of voltage drop for different cases

	Without Capacitor	With Normal Capacitor	With Super Capacitor
Drop in Voltage	6V	4V	0.1V
Transient duration	~40ms	~100ms	~0

Experimental setup shows that in the case where a super capacitor is connected a very little variation is observed and hence this leads to a conclusion that supercapacitors help in line regulation. In the next section a unique solution is proposed to avoid line variations

Proposed Solution

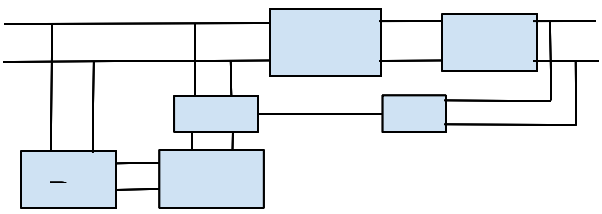

Figure 6. Block diagram of the proposed system

Local substation:

The purpose of a local substation is to convert high voltage, usually between 11 and 33 kV, to 415 or 230 volts. These substations are typically found close to homes or other communal areas. These substations are outfitted with transformers, circuit breakers, switch gears, capacitor banks, and other electrical components for the safe and effective distribution of energy.

Rectifier and filters:

Rectifiers and filters are necessary to convert AC signal into DC signal since the batteries run on DC current. Transformers, diodes, capacitors, and inductors make up this component.

Inverter:

Inverters are the circuits which convert DC quantities into AC quantities. Since AC quantities cannot be stored there is a need for conversion from AC to DC and DC to AC.

Digital Control Circuit:

These digital circuits will assist in sensing the current level and will activate the PLL block once the current surpasses a predetermined threshold. Digital integrated circuits (ICs) such as IC7408, IC7402, IC555, Op-Amp, and others can be used to create digital circuits.

Supercapacitor:

Super capacitors are passive components with high capacitance, High Energy Density, Faster charging and discharging capacity. These properties help in improving the battery life and effectiveness of operation

Working:

A| system is proposed in which a super capacitor is connected along with a rectifier and inverter circuit in the feedback loop. In normal situations or when a lesser number of loads are connected there won't be too much load on the transmission line and the substation will provide sufficient current. In the second scenario when we connect multiple vehicles together there will be a surge in current demand, especially when we connect multiple vehicles there will be sudden rise in the current requirement. This surge in current will put load on the transmission line causing a drop in voltage level if the circuit doesn't have a supercapacitor. But since we have a super capacitor with an inverter in the loop it will supply current while this transient and this will prevent a drop in voltage.

5. Result and Discussion:

Table 1 presents a comparative analysis of three distinct scenarios, elaborated as follows:

1.) In the initial case, a 12V-rated motor load is connected to a DC power supply without any capacitor in the circuit. This configuration exhibits a significant voltage drop of up to 50% of the power supply rating when the load is connected, alongside a transient period of 40ms.
2.) In the second scenario, the addition of a standard capacitor to the same setup reduces the voltage drop to 33%. However, this improvement comes at the cost of an increased transient response time, which rises by a factor of 2.5.
3.) In the third scenario, the utilization of a super capacitor results in nearly negligible variations in voltage and transient response, both approaching zero.

This indicates that while a standard capacitor can mitigate voltage drops during transients, a super capacitor is more effective in reducing these values to nearly zero. Hence, incorporating super capacitors in circuits enhances stability during transients, a crucial consideration in circuit design and implementation to prevent potential permanent failures.

6. Conclusion:

Electric Vehicles are becoming extremely popular nowadays and hence a lot of researchers are working on various issues related to Electric vehicles. One of the main issues is charging and discharging its battery. So as shown in the analysis it can be seen that when implementing a power supply, it is evident that with no capacitor it gives high variations compared to when we connect normal capacitors. These variations become nearly zero when we employ a supercapacitor for stabilizing voltage.

Additionally super capacitors along with rectifiers and inverter to cope up with the case of multiple loads/vehicles charging at same time and drawing larger value of current. This arrangement will make sure that surge in the current does not affect the operation of the circuit

Further to this we can also implement a circuit in future to stabilize the voltage level by taking series input from the rectifier-supercapacitor-inventor arrangement.

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