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Design of Luo Converter for Energy Harvesting and Adaptive Charging in EVs

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Abstract — *Idea presented here introduces an ingenious approach to Electric Vehicle (EV) charging, integrating regenerative braking technology with a Luo converter. The system harnesses kinetic energy generated during braking, converting it into electrical energy efficiently regulated by the Luo converter for charging the EV battery. This innovative integration results in enhanced EV efficiency and reduced energy consumption, contributing to environmental sustainability. The Luo converter ensures stable power output through advanced control mechanisms, optimizing the utilization of regenerated energy. The proposed system addresses the demand for sustainable transportation, exploring energy recovery in automotive applications. In conclusion, this regenerative braking-based EV charging system with the Luo converter presents a promising avenue for advancing green transportation technologies.*
Keywords— *Regenerative Braking, Luo Converter, Voltage Lift Technique (VLT), EV Battery, SoC – State of Charge, Duty Cycle, PI Controller.*

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I. INTRODUCTION

In the pursuit of sustainable transportation, electric vehicles (EVs) have become a focal point, promising a cleaner and greener future. However, the efficiency of EV charging systems is a continuous challenge, requiring innovative solutions to optimize energy utilization [1]. This paper delves into a new approach that addresses this challenge and also propels the evolution of EV technology by integrating regenerative braking with a Luo converter. With a variety of charging technologies attempting to increase EV efficiency, reduced charging times, and minimal environmental impact, the landscape of EV charging has witnessed significant advancements in recent years. Regenerative braking is one such technological advancement that involves harnessing kinetic energy produced during braking and converting the same into electrical energy. Regenerative braking has shown to be a viable way to improve electric vehicles' overall efficiency; however, integrating it with the current charging infrastructure has faced difficulties in achieving optimal energy recovery and regulation.

Conventional charging systems often encounter limitations in effectively harnessing and regulating the energy harvested through regenerative braking. In this context, the proposed idea - regenerative braking with a Luo converter introduces an ingenious solution to these challenges. There are many types of topologies used for having output gain such as buck-boost converters. Luo converters, a group of DC-DC converters that have been developed to efficiently transfer electrical energy between different voltage levels. The key characteristic of Luo converters is their ability to provide a continuous input-output energy transfer, making them suitable for applications requiring high efficiency and precise voltage regulation. Whereby the Luo converter serves as the backbone for achieving enhanced efficiency in the EV charging process.

Traditional charging systems, including fast charging and slow charging methods often face challenges in managing the variability of energy input, resulting in suboptimal charging rates and reduced overall efficiency. Furthermore, these systems may not fully exploit the potential of regenerative braking, leading to missed opportunities for energy recovery and reduced environmental benefits. The proposed idea of regenerative braking with the Luo converter offers an entirely new approach to EV charging systems to address above said issues. The proposed system aims to maximize energy recovery, reduce energy consumption, and provide an efficient charging method for EVs.

II. PROPOSED SYSTEM

In existing systems, regenerative braking is applied in the electric vehicle and kinetic energy been retrieved and converted as electrical energy. It is being used for the supplementary services in the same EV by employing conventional buck-boost chopper. The presented system flow is given in Fig 1. comprises of regenerative braking activation system, a rectifier module, a Luo converter and a battery charging system which comes with a PI controller. The idea applied is, the integration of Luo converter as it possesses enhanced output performances. The presented system steps are as follows:

A. Regenerative Braking Activation

When the vehicle decelerates or brakes, sensors detect this action and trigger the regenerative braking system. Kinetic energy from deceleration is converted to electrical energy by generator.

B. Energy Harvesting

The electrical energy generated from regenerative braking is collected. Since, the output from regenerative braking is a low ac voltage, it is converted to DC voltage to charge the EV Battery. For which a rectifier module is attached and the obtained dc input voltage is directed to the Luo converter for boosting operation.

C. Luo Converter Operation

Luo converter, a chopper which boosts up the given input voltage to a required level according to the designing of L & C values of the converter. Here, the Luo converter receives the harvested electrical energy. It regulates the voltage to ensure a stable and controlled output suitable for charging the EV battery.

D. Battery Charging

The regulated electrical output from the Luo boost converter is then supplied to the EV battery for charging. Charging parameters such as voltage and current are monitored and controlled to optimize the charging process and ensure battery health.

E. Monitoring and Control

Throughout the charging process, the system continuously monitors various parameters such as battery level, charging rate. Control algorithms adjust the converter's operation to maintain optimal charging conditions and prevent overcharging or undercharging of the battery.

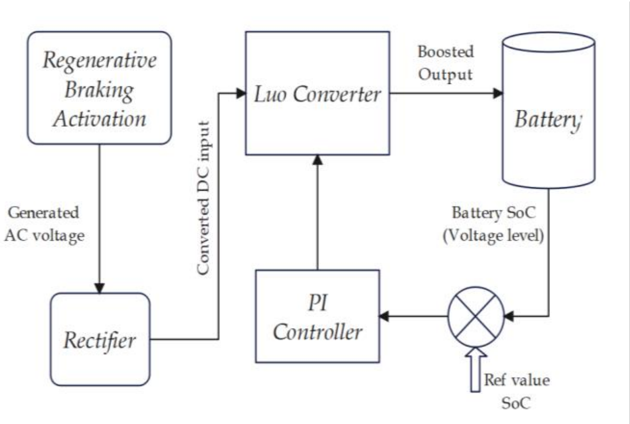

Fig 1. Block diagram of proposed system

III. LUO CONVERTER

A. Design of Converter

Here, the Luo Converter is designed to give a boosted output of 24V for charging the EV battery from the input voltage harvested through regenerative braking activation. The input voltage retrieved by the regenerative braking will vary between 10V to 13V according to the torque of the motor of EV. The circuit is attached in Fig 2. Also, the detailed design procedure of the converter can be found the reference papers [2-3]. In this application, the positive output luo converter type of converter is selected after considering variable factors such as compactness, number of switching devices, voltage gain and less complex than other Bridgeless (BL) topologies [4]. Voltage lift technique (VLT) is applied in this converter with the pair of diodes arrangement in the circuit diagram.

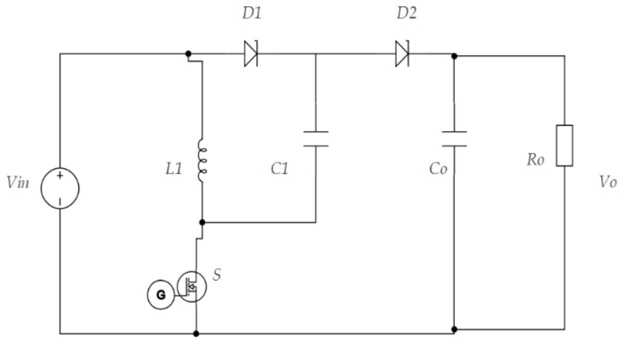

Fig 2. Luo Converter

B. Operation Modes

As mentioned earlier, the Luo converter is designed here to give a boosted output voltage of 24V. For which, the converter operation can be explained in detail with following modes of operation. Here, the switching device (S_1) used is MOSFET, and the switching frequency is defined.

i. Mode I

In Mode I, when switch S is ON, the inductor L_1 is energized with the voltage input given which is V_{in}. The inductor current i_L passes through inductor L_1 and switch S which is shown in Fig 3(a). At this period, diode D_2 is blocked. Hence, $i_{D2} = 0$. The output voltage is taken across R load and can be denoted as V_o. And the output current expressed in the equation (1),

$$i_o = V_o / R \tag{1}$$

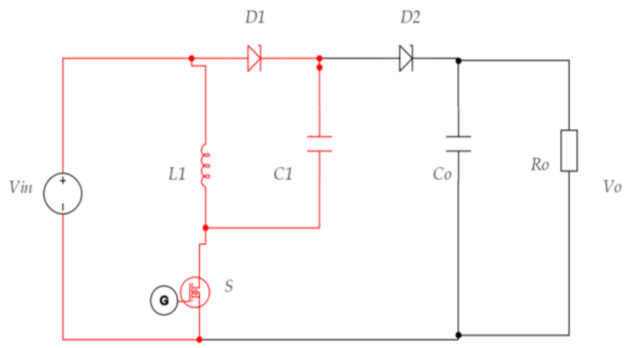

Fig 3(a). when Switch S is ON

ii. Mode II

In Mode II, when switch S is OFF, inductor L_1 become deenergized. The inductor current i_L will flow through C_1, D_2 and the output terminals as in equation (2). It is shown in Fig 3(b). Thereby, the input voltage is boosted with the capacitor arrangements.

$$i_{L1} = i_{D2} = i_O \qquad (2)$$

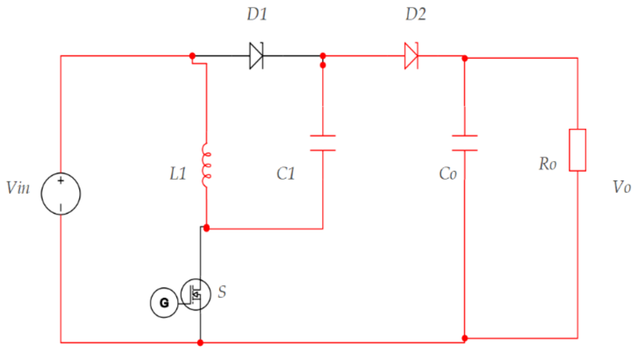

Fig 3(b). when Switch S is OFF

Voltage gain(M) of presented Luo Converter is obtained from above mode of operations and also considering the discontinuous current mode of operation which is expressed in equation (3),

$$M = \frac{Vo}{Vin} = \frac{1}{\lambda}\frac{2-k}{1-k} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, λ is VLC coefficient and *k* is the duty cycle.

IV. BATTERY CHARGING

The Boosted output voltage from the Luo converter is 24V which is then fed to the EV Battery for charging application. To ensure the better charging experience, a PI controller is employed here to provide an adaptive charging system for the electric vehicle. In this adaptive charging approach, the SoC i.e., the voltage level of the battery is measured and compared with the reference value set in PI controller. According to feedback signal received from battery, the PI controller generates duty cycle to operate the switch S. The PI values are fine-tuned by using the system identification toolbox in MATLAB.

V. SIMULATED RESULTS

The simulation of presented Luo converter integration with regenerative braking for EV charging application has been done in MATLAB-Simulink. These results express the performance of the proposed system under various situations.

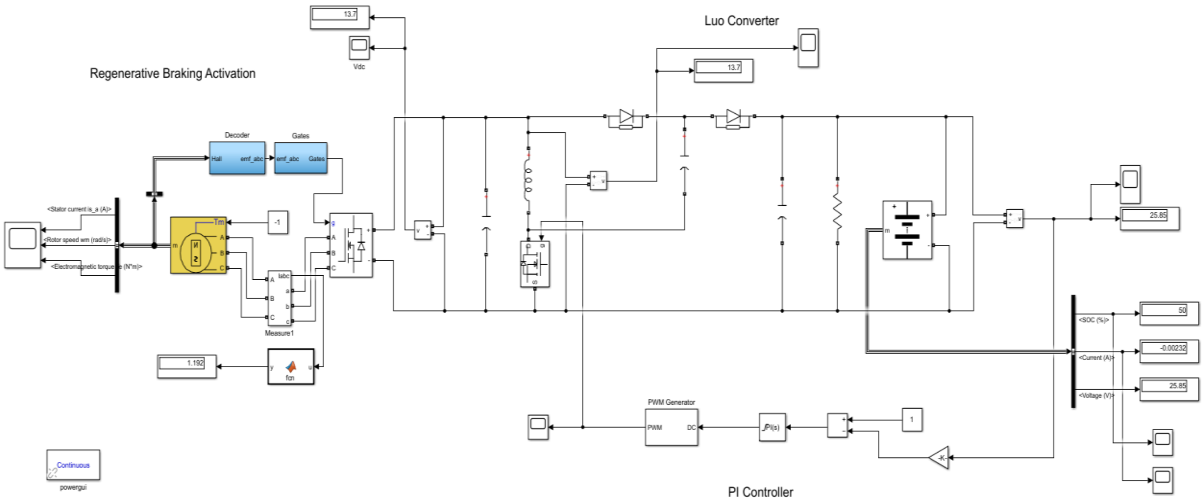

Fig 4. Simulation of proposed Luo converter Integration.

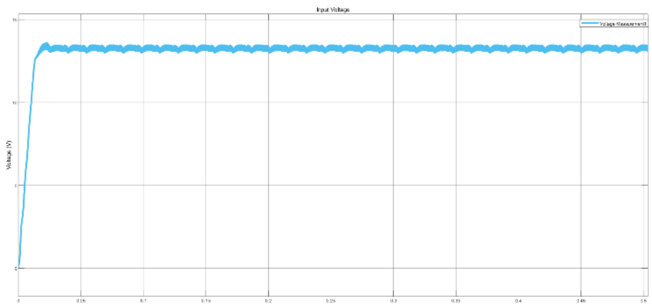

Fig 5. Input voltage obtained from regenerative braking activation

The above Fig 5. shows the input voltage obtained from regenerative braking activation of the proposed simulation.

To simulate the regenerative braking activation, here an PMSM motor drive is employed from the MATLAB tools. It is shown in the Fig 5. that we can get an average of 12V input from the regenerative braking for our proposed system.

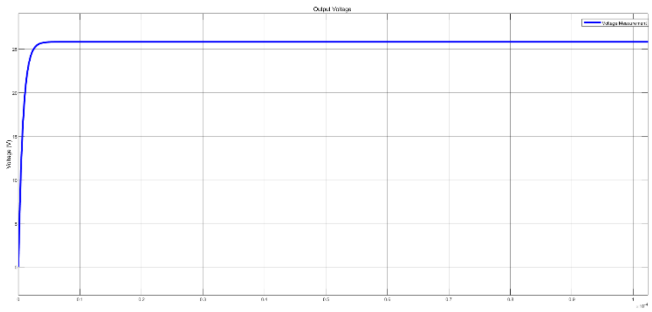

Fig 6. Output of Luo Converter

Fig 6. presents the boosted voltage from Luo Converter after boosting operation i.e., average of 25V. And it evidently shows that unlike the buck-boost converters, here there are no prominent voltage spikes in the output. Thus, the Luo converter improves the efficiency of the system.

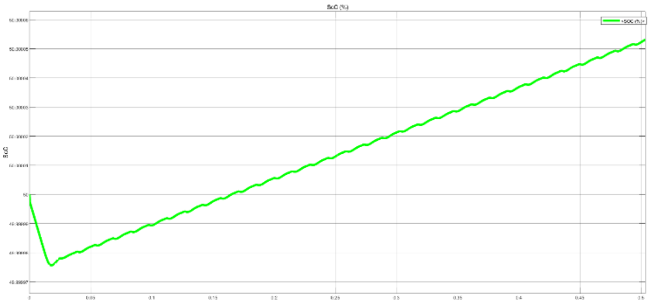

Fig 7. SoC level of Battery while charging

Output of the Luo converter with the average of 25V is then fed to the EV Battery which is of 24V for charging it. The simulation has been done with having the SoC level of the battery as 50 percent. Fig 7. shows that the SoC of the battery increases while charging and Fig 8. represents the charging current applied to charge the battery from the converter according to the PI controller [5-6].

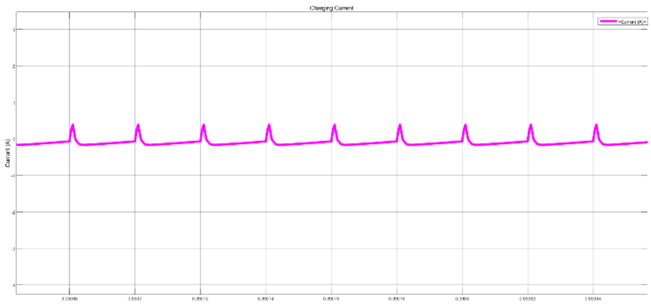

Fig 8. Charging current

The following Fig 9. shows the Stator current, Speed and the Torque of the PMSM drive employed for regenerative braking activation [7-8].

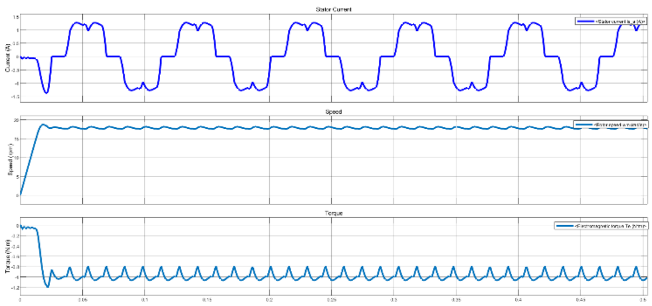

Fig 9. Stator current, Speed and Torque of PMSM drive

VI. CONCLUSION

A perfectly suitable Luo converter design to boost-up the energy harvested from regenerative braking is obtained also the performance parameters were analysed, the results are attached. The proposed Luo converter integration system represents a significant stride towards sustainable and efficient transportation. The regenerative braking approach contributes to enhanced EV efficiency and notable reduction in energy consumption. Luo converter and the charging mechanisms ensure stable power output, facilitating optimal utilization of regenerated energy for charging the EV Battery.

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