BIDIRECTIONAL CONVERTER–DRIVEN MODE CONTROL TECHNIQUE FOR ELECTRIC VEHICLE CHARGING SYSTEMS

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Abstract:-
Power electronic converters, particularly DC–DC converters, function as variable-structure systems due to the presence of power electronic switches that create multiple structural configurations corresponding to their ON and OFF states. Mode controllers (MCs), which are inherently nonlinear, are well suited for regulating such systems. In operation, once the output reaches and slightly exceeds the reference value, the switching pulses are temporarily suspended. As the output voltage gradually declines below the set point, the pulses are reapplied. Thus, the switching action is governed solely by whether the actual output voltage is above or below the desired threshold. Accurate evaluation of battery internal conditions is essential to ensure reliable operation and prolonged service life, both of which are critical for achieving extended driving ranges— although this may increase vehicle weight and cost. To address this, researchers have proposed a dual-battery approach for electric vehicles (EVs). A smaller, permanently installed battery supports short-distance travel while reducing overall vehicle mass. Meanwhile, a larger, swappable battery provides extended driving range. Because this larger battery is used less frequently, it exhibits longer lifespan and its cost can be distributed over the entire operational life of the vehicle.

Keywords:
Battery Management, Electric Vehicle, Charge, Control Algorithm

I. INTRODUCTION

In nearly all engineering domains—including civil construction, electromechanical systems, industrial and chemical processing, medical and surgical equipment, robotics, and automotive applications—electronic systems play an essential role. These systems commonly incorporate power electronic converters to supply subsystems with electrical power in various required forms. While some applications demand a regulated DC supply, others require variable-frequency AC, pulsed power, or different voltage and current levels. Consequently, modern engineering systems rely extensively on power-conversion stages to meet these diverse electrical requirements [1, 2].

Contemporary engineering technologies that depend on electricity as the primary driving force require it in multiple forms with varying attributes. Moreover, emerging solutions in renewable energy generation also involve several stages of power processing, as renewable sources may inherently produce either DC or AC power in their primary form [3]. Therefore, depending on the end-use application, the primary electrical output must be converted into a suitable and usable form [4].

Global energy demand continues to rise with sustained economic growth. According to estimates, CO_2 emissions due to energy use are projected to increase by nearly 10% by 2040 [5]. At the same time, the economic value of fossil fuels is decreasing due to resource depletion. Hence, the global energy sector faces the dual challenge of delivering "more energy with less carbon." Concerns related to the global energy crisis, limited availability and declining quality of conventional energy resources, increasing greenhouse gas (GHG) emissions, and the abundant potential of renewable energy sources have accelerated the integration of distributed energy resources (DER) into modern distribution systems.

Typical DER include shunt capacitors (SC), supercapacitors, battery energy storage systems (BESS), distributed generation (DG), and superconducting magnetic energy storage (SMES). Recently, electric vehicles (EVs) have emerged as a promising alternative in the energy sector, given that the transportation segment accounts for approximately 23% of global energy-related GHG emissions. Powered by electricity, EVs offer a viable solution to the challenges of depleting fossil fuel reserves and rising emissions. Additionally, EV batteries can function as distributed energy resources capable of supplying power back to the grid. Thus, EVs can be regarded as DER assets within the distribution network, albeit with time-dependent availability.

However, EV charging introduces additional load on the distribution system. Uncoordinated and random charging patterns may cause undesirable load peaks, transformer overloading, increased system losses, voltage deviations, and higher operational costs [6, 7]. Therefore, coordinated charging strategies are necessary to ensure that EV integration does not adversely affect the distribution network.

Studies indicate that nearly 95% of EVs remain plugged into the grid while parked or idle [8]. This parking duration provides an opportunity to adjust charging rates and allocate charging time slots. If the system experiences overload conditions or voltage limit violations, the charging schedule can be shifted within the available parking window. Furthermore, if the EV battery is not fully discharged, the remaining stored energy can be utilized for grid support during peak demand periods [9]. Consequently, EV batteries can provide ancillary services, and their charging impact can be minimized through coordinated charge–discharge scheduling. This has led to significant interest in developing intelligent scheduling strategies to fully harness the benefits of EV integration.

II. BATTERY MODELING

A battery management approach is required to accurately predict the internal states of the battery. When selecting an appropriate battery model, operating conditions constitute the most critical factor to consider [10]. Additionally, it may be necessary to interconnect all bus bars through suitable power electronic converters to enable flexible power transfer among them, depending on source availability and varying load demands. In contrast to microgrids—which integrate multiple sources to supply numerous loads—simple power electronic converters with multiple input and multiple output ports, designed for specific applications, are increasingly being developed. These systems typically accommodate a limited number of input sources and serve a small set of loads.

The chosen battery model should also be computationally efficient and easily implementable within the battery management system. Battery models are generally categorized into three main types: electrochemical models, data-driven models, and equivalent circuit models. This section outlines the current state of battery modeling and discusses the advantages and limitations associated with each model type [11, 12].
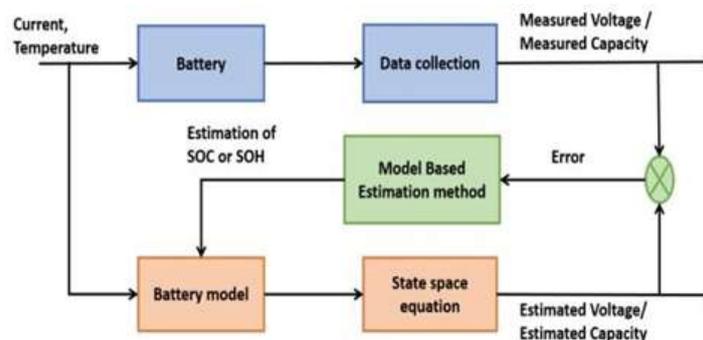

Figure 1: Model based internal states estimation

When it comes to SOC estimation, if battery SOC is not accurately estimated becomes erroneous, which in turn causes the battery terminal voltage prediction error to increase. As a result, precise battery state of charge (SOC) estimate reduces forecast error for battery terminal voltage. The battery terminal voltage prediction error serves as the feedback compensation for SOC estimation. Therefore,

the technique is necessary to determine the feedback gain value in order to compensate for the variability in battery SOC measurement. Comparing the measured and estimated battery capacity yields feedback benefit in the capacity deterioration estimation situation as well [13].

III. SIMULATION MODEL

Owners of electric vehicles also stand to benefit financially, as they can potentially recover part of their costs by selling the unused energy stored in their batteries. Vehicle-to-Grid (V2G) technology offers significant advantages to EV users by enabling revenue generation while simultaneously contributing to climate-change mitigation. V2G operation reduces dependence on fossil fuels and can support overall grid stability. By utilizing a coordinated set of power converters, the stored energy in EV batteries can be supplied back to the grid, particularly during periods of peak demand.

The Battery Management System (BMS) plays a crucial role in regulating battery charging and discharging processes. The proposed model in this work primarily relies on effective battery charge control, as illustrated in Figure 2.
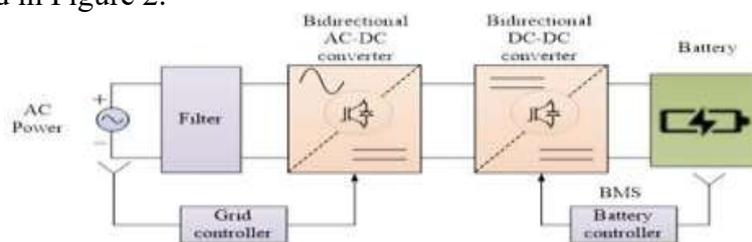

Figure 2: Proposed Model

A. Bidirectional Power Converters

In general, bi-directional converters can be used for both G2V and V2G operations. These facilitate power exchanges between the electric car and the grid. In general when a power electronic converter is designed the primary requirements are the power quality and power conversion efficiency [14]. The upkeep of the power quality on the source side as well as the load side are to be considered with due care. The designed power electronic converter should be capable of delivering the required voltage and power levels to the load while satisfying the given power quality constraints like minimal ripple in the case of a DC load. If a load connected to a source through a power electronic converter affects the source then the other loads connected to the same source will be affected. When a power electronic converter is expected to deliver power to the load at the required power quality it is also expected not to disturb and degrade the quality of the source. The V2G Technology makes use of the three converters listed below:

B. DC-AC Inverter

AC does not always mean the inverter depicted in figure 3 with a perfect sinusoidal waveform block diagram. Sinusoidal AC outputs' dimensions and frequency are it should be possible to control both phase and frequency. Depending on the kind of AC power waveform, inverters can have either of the two basic topologies.
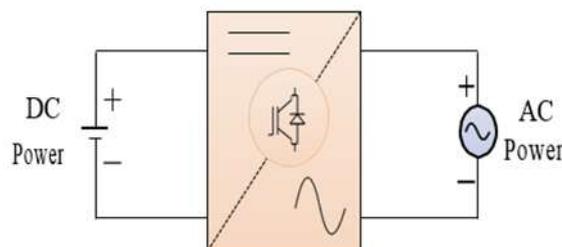

Figure 3: Basic diagram of DC-AC Inverter

C. AC-DC Rectifier

Half wave and full wave rectifiers are two types of rectifiers that are required to supply the load with DC voltage or DC current that is free of ripple. Figure 4 displays a block diagram of an AC-DC rectifier. Single- phase diode rectifiers are suitable for low power applications up to 15kW.
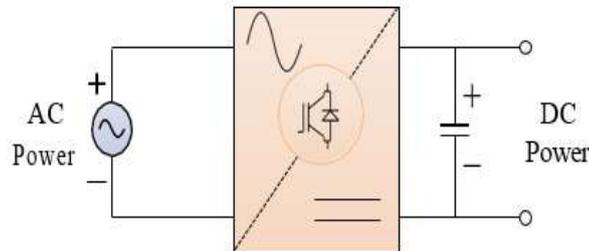

Figure 4: AC-DC Rectifier

D.DC-DC Converter

DC-DC converters, sometimes referred to as choppers, are used to modify the level of DC V. This DC-DC converter, depicted in figure 5, is called a booster step- up converter. Medical equipment with the exception of military applications invariably uses the utility AC source from where the required DC voltages sources are made of. An uncontrolled rectifier with power factor correction front end or an active front end rectifier is used for producing a common DC source. From the common DC source using multiple output DC to DC converters the various required DC levels are produced.
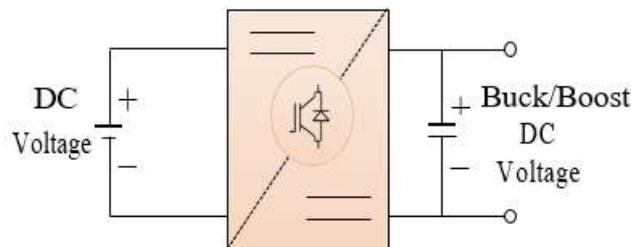

Figure 5: DC-DC converter

For this, about six battery states of charge ranges are taken into account. The Soc is 0 to 10% and the extraction of current from the grid case is significant if the battery is fully degradable or depleted. As indicated, the power is 2.5 kW. Likewise, in a different instance of SOC ranging from 10% to 30%, power is assumed to be 2.4 kW and decreases further as SOC increases. This entire process is carried out in BMS. The SOC is normally monitored in BMS, and current and power reference are computed appropriately.
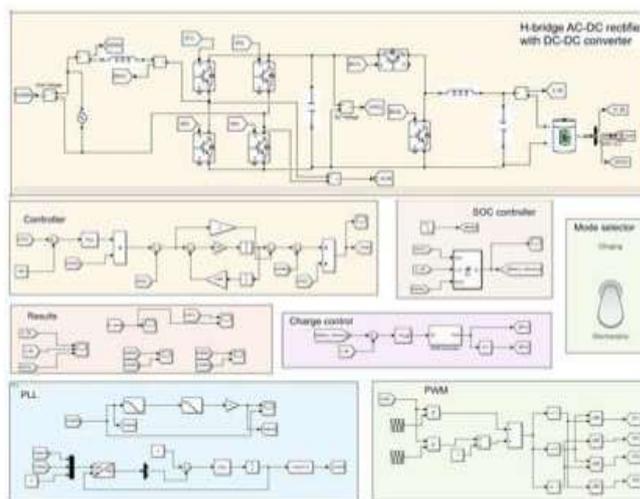

Figure 6: MATLAB simulation battery charge control

Electronic industry is undergoing drastic growth due to two major aspects; they are low voltage and high power density. In the world market the production of DC-DC converter is much higher than AC-DC converter. The market comprise of low, medium and high power application. Out of all DC-DC converters, boost converter has gained lot of attention due to its voltage boost capability which comprise of only three components; an inductor, a switch, and a diode. The voltage boosting ability of boost converter and its derived converter can be customized to produce multiple outputs.The multiple output DC to DC converters are special converters that are used some specific applications. Automobiles, satellites, medical equipment like the ultrasonic scanner and so on require multiple DC outputs with different voltage levels.

IV. SIMULATION RESULT

To verify the feasibility of the innovative topology as a bidirectional AC-DC converter, a simulation model is developed using the MATLAB platform. Three modes are used to verify the MATLAB simulation:

•   The discharging mode benefits from a DC-AC inverter.

•   AC-DC rectifier with resistive load, which is suitable for verifying voltage regulation and power factor correction;

•   • AC-DC rectifier with a bidirectional DC-DC buck-boost converter, which is used for verifying an electric vehicle's charging (G2V) and discharge (V2G) modes.

Table 1: Parameters to validate the proposed work

Parameters	Value
Grid voltage (v_s)	230 VRMS
Filter inductor (L_s)	4.5 mH
Filter capacitor (C_o)	2200 uF
Resistive load (R_o)	20 Ohm
Switching frequency (F_{sw})	10 kHz
Grid frequency (f_g)	50 Hz
EV battery load	Lithium ion (72V)

The output voltage (V) is regulated to 200V DC, or less than 325V peak voltage, as seen in Figure 7. In other words, the suggested converter functions as a buck rectifier.
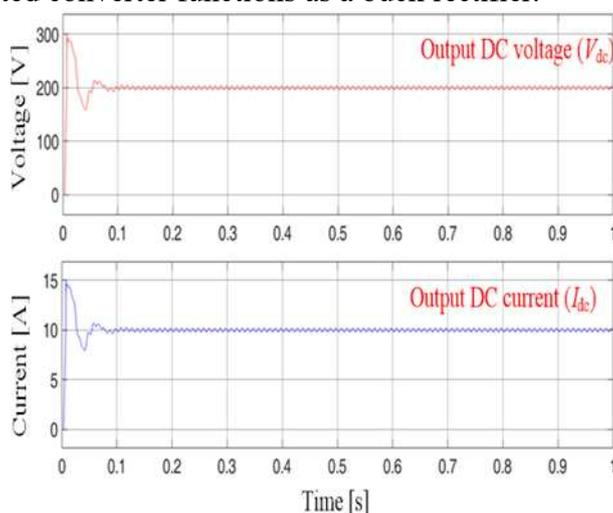

Figure 7: DC output V & C

When charging (prior to time t< 1) is inverted in the discharging mode, causing both to be 180 degrees out of phase. This indicates that the car is currently moving toward the grid is displayed in Figures 8 and 9.
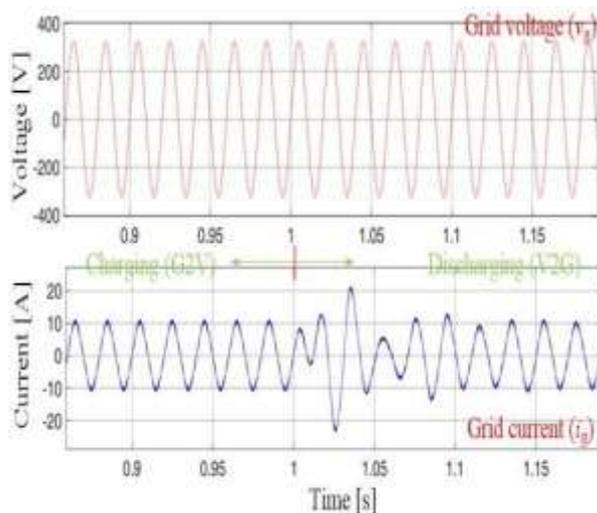
Figure 8: Grid V and grid C

In all situations, the rectifier-regulated DC output voltage is balanced to 200V. Additionally, when the discharging mode operates, the battery voltage varies. In the fraction of time, voltages and currents are balanced, demonstrating the accuracy of the controller tracking. The battery voltage, battery current, and rectifier- regulated voltage for charging and discharging modes of operation are displayed in Figure 10.
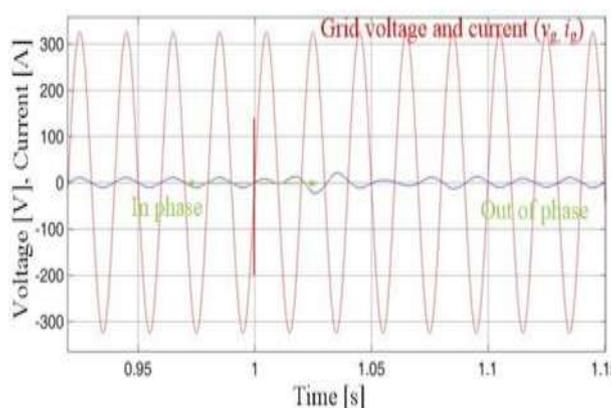

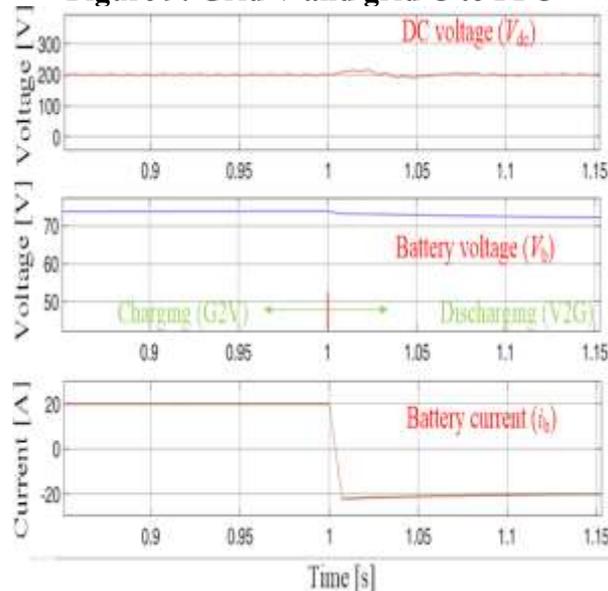**Figure 9: Grid V and grid C to PFC**

Figure 10: V2G operation

V. CONCLUSION

By distributing the load uniformly across two batteries and ensuring identical charging and discharging rates, the power management system prevents any single battery from being overstressed over long durations. Operating each battery at reduced charge–discharge rates, compared to using a single battery, enhances overall battery lifespan. An effective power management strategy also enables extended driving range and increases the feasibility of deploying multiple battery-powered electric vehicles. Additionally, the bidirectional power flow to and from the battery— supporting both charging and discharging modes—has been demonstrated.

Although some studies have explored adapting conventional boost converters for dual-output applications, the novelty of this research lies in employing a Quadratic Boost Converter (QBC) to achieve higher voltage gain, making it particularly suitable for solar photovoltaic (SPV) and electric vehicle applications.

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