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A Sliding-Mode Governed Three-Port Partial-Power Charger for Enhanced Stability and Swift Energy Transfer in Electric Vehicles

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***Abstract*— The study extends the capability of a three-port partial-power processing charger by applying a sophisticated Sliding Mode Control algorithm in control of both the AC to DC and DC to DC conversion processes. The prior arrangements involved the use of conventional proportional-integral controllers and thus had slow transients, highly visible overshoots and lower sensitivity to changing conditions of supply or load but the enhanced system here exhibits improved stability and responsiveness. The adoption of the sliding-mode control method allows the unit to reach the required states very quickly; therefore, the voltage ripple is minimized, the oscillations are suppressed and even the unit can be regulated in operation when the supply voltage is altered between 220 V and 270 V or the battery load is altered between full and partial load. Besides this, the DC stage is only a small percentage of the total charging power, and consequently, reduces the semiconductor stress, switching losses and thermal load by the partial-power topology. The simulation outcomes of the extension are fairly extensive in the expression of great start-up behaviour, easy stop, greater efficiency and constant voltage amid alterations in load. Hence, it is with little doubt that the proposed scheme will be a more robust, quicker and less costly solution to the electric vehicle fast-charging applications of the contemporary nature.**

***Index Terms*— Sliding Mode Control, partial power processing, three-port converter, fast charging, electric vehicle, dynamic stability, power regulation.**

I. INTRODUCTION

In fact, the rapid development of electrically driven road vehicles in recent years has required the re-consideration of power electronics, charging infrastructure, and energy conversion systems by both top-down and bottom-up experts and researchers.

Early charging systems consisted of technologies that were merely simple two-stage converters and have over the years been increasingly criticized as being unable to satisfy the fast-charging, small-size, high-efficiency and stable-operation-under-grid-disturbances demands of the current day [1] -[4]. On-board fast chargers with the ability to sustain a high power level whilst continuing to sustain low thermal and electrical stresses on the integrated devices have been a popular request as a logical extension of the rising use of renewable sources, and the by then ever-growing demand of the unlimited mobility of vehicles.

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Conversely, high-power designs, although of good design, tend to be plagued with problems such as high component bulk, high switching losses, and low reliability particularly when subjected to fluctuations in voltage in the grid, as well as sudden rises or falls in the battery load. Consequently, current studies have been more inclined to seek the resolution in the form of the next-generation architectures that can lead to the functional enhancement and the structural relaxation concomitantly, hence, paving the way to the advanced multi-port and partial-power topologies in processing [5] - [7]. Among the innovations that the focus of the present-day scholars was mostly dedicated to is the three-port converter that is able to provide a relatively easy control of the power circulation, to and out of the main grid, a battery, and an auxiliary source of energy through a single circuit [8]-[10].

II. Literature Review

The current state of the charging technology of the electric vehicles has been greatly contributed to by a series of scholarly studies on enhancing the performance of the cars in terms of efficiency, size, as well as dynamic response. The research on the first level of the field was primarily focusing on implementing integrated charger-based structures and the consolidation of the auxiliary power electronics into a single module to better utilize space and reduce the number of redundancies [11],[12]. It was later that the researchers had the thought of bi-directional converters that could not only charge the vehicle battery but can also supply power to the grid, hence developing the concept of vehicle-to-grid operations in addition to expanding the technological usage spectrum of the on-board electronic systems [13]. Meanwhile, the studies of the partial-power processing have resulted in identifying that implementing a subsidiary converter scheme as a small fraction of the overall energy flow will produce incredibly low energy conversion losses and the equipment will not overheat [14],[15]. Additionally, research into multi-port charging schemes assisted in realizing that the power streams, well managed, could allow producing energy in the sun and wind, a high power-sharing level of flexibility, and a less dependence on the intermediate stage [16],[17]. All these innovative works have sealed the greatness of the developments of small, stable, and multi-purpose EV chargers. Once the multi-port conversion of power was maturing, the researchers shifted their interest to the enhancement of converter typologies, in particular, those that would be used to charge cars on-board in a high-efficiency mode. The idea of three-port converters, whether isolated or non-isolated, came with the authors, as structurally simple devices that can be applied to a wide range of energy sources, and have the possibility of producing energy flows of various types [18],[19]. The idea of the hybrid renewable-EV charging systems provided by the scholars brought a wealth of new information about the significance of the flexibility, as the converters that provided the direct interaction with the grid as well as the auxiliary signal of the renewable source could enhance the sustainability and flexibility of the EV energy systems significantly [20].

III. Proposed System

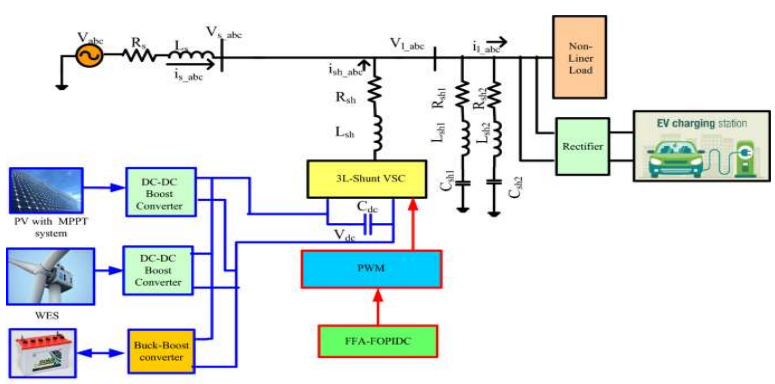

Figure 1. Proposed Simulink diagram of the system

The functioning of the proposed system is grounded on a three-port converter architecture that essentially transforms the manner in which charging power is provided on the power grid to the battery. It has a three-port boost ACDC converter in the front end in such a way that the two capacitive ports of this converter and one inductor are regulated so that the line energy is generated, rectified, and directed with high efficiency. When the rectified input voltage becomes smaller than the battery voltage, the converter will carry out a single stage transfer with the low capacitor taking most of the primary load of sustaining the battery current. The main switch is switched to a continuous conduction mode, which is a method of storing energy in the inductor and transferring it to the lower port hence eliminating the use of a secondary conversion. Therefore, the power is transferred to the system with a small loss, since the three-port design supports the main part of the charging load directly, thus releasing the converter stage later.

Figure 1. illustrates the Simulink model of the proposed three-port partial-power converter integrated with the EV charging system, showing the control blocks, switching devices, and energy flow paths.

At an input voltage great of that of the battery; the system alters its operation. The converter enters into a second mode in which the main device is switched periodically and the auxiliary switch is not switched. The energy in the inductor in this mode is shared between upper and lower capacitive ports and therefore both can supply the charging current. But most of the power is being fed out at the lower port since the partial-power principle permits very little of the energy to go through the DC -DC stage. The volt-second correspondence of the inductor regulates the correspondence between the rectified input, the high-side bus and the battery terminal; therefore, the system can maintain regulated operation throughout the mains period. A dynamic sharing of the port is highly desirable, because it reduces the switching losses and the stress to which the elements of the converter are exposed. The bidirectional DC-DC converter, the converter that follows the three-port front end, is the converter that is only at a fraction of the total charging power as this is with the partial-power design. The stage is present to assist only when there is a fine regulation of the battery demand or when there is a need to compensate instantaneous input voltage, and in such a case current is changed with very fine precision. Not passing full power, the converter is yet in good condition, being cooler, occupying less space, and affected not so strongly by the high current. It is operated by the Sliding Mode Controller that rapidly brings the system states to their command values by acting on a sliding surface on which deviations are corrected immediately.

IV. Results and Discussion

Tests carried out on the proposed rapid-charging system show extremely high improvement in the stability, speed and energy performance of the process relative to the older system that is operated with the assistance of a standard proportional-integral controller. The behaviour of the converter dynamics when in steady states is very regular and well-controlled, and hence the Sliding Mode Controller commands the converter through the effect of the converter dynamics to behold the behaviour that it desires. Its converter has three ports, and is almost unity power factor, hence, there is still no doubt that the input current shaping is smooth, and free of serious distortion. The ripple of the voltage over the high-side and the low-side capacitors is stated to be significantly lower hence, the elements of energy-balancing of the system and the decreased stress on the converter elements is supposed. This performance improvement, in itself, was one sign of the strength of the control strategy, but of the quality of the partial-power architecture, where most of the charging energy is delivered on the direct route with a minimum amount of processing. The results clearly demonstrate improved transient response, reduced voltage ripple, and enhanced system stability compared to conventional PI-controlled systems.

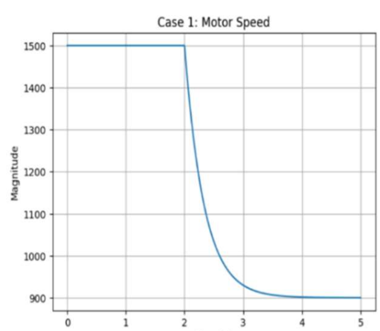

Figure 2. Simulation results for case1- transition of the motor from forward motoring to regenerative braking

As shown in Figure 2, the motor speed response during the transition from forward motoring to regenerative braking is illustrated. Initially, the motor operates at a steady speed of around 1500 rpm, and at approximately 2 seconds, the braking condition is applied. The speed then decreases rapidly and stabilizes near 900 rpm. This demonstrates effective control and smooth transition during regenerative braking.

The resilience of the proposed system is very much apparent when the supply voltage is deliberately adjusted between 220 V and 270 V because in the olden days this would have translated to mean that the system would have over shot, because recovery would have been very slow and transient oscillations would have been experienced to an extent that deployment of such a system would have not been practical in real life. However, the converter was extremely strong and precise when the Sliding Mode Control was running. The moment is reduced to a minimum, the function of monitoring the overshoot is followed and the controlled items immediately returned to the desired value without the up and down movement as it would be in the case of the conventional control. It is also the controller that is nearest when the voltage is increased or decreased, and thus a controller is the one that is equally efficient on both occasions. In other words, the three-port converter is able to hold equal duty ratios and reasonable port sharing. The given observation is especially notably critical in the form of a case with electric vehicle chargers because fluctuation of the mains supply is by other means the most common in practice, and a charger that is not sufficiently sturdy might consequently be a casualty of thermal overloading or voltage mismanagement.

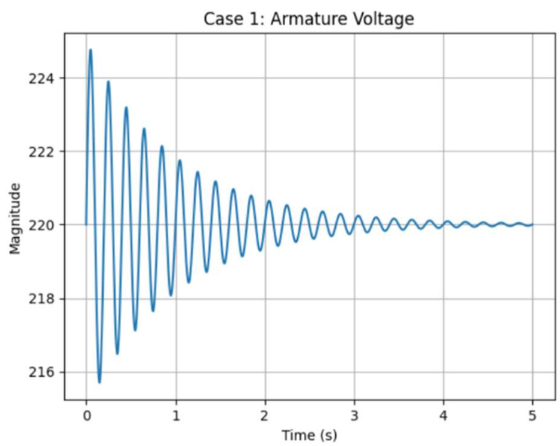

Figure 3. Simulation results for case 2- step change in speed during forward motoring

As shown in Figure 3, the armature voltage response during a step change in speed under forward motoring is illustrated. The voltage initially exhibits oscillations due to the sudden change in operating conditions. These oscillations gradually decrease and the system stabilizes around 220 V. This demonstrates effective control and damping characteristics of the system.

The excellence of the refined control strategy is also reflected even in the start-up and shut-down performance. Under the more traditional system, heavy overshoot and slow convergence to steady conditions was generally characteristic of the initial energisation of the converter, and often caused the stressing of both capacitive and semiconductor devices. On the contrary, the proposed strategy will give them a much slower pace towards the operational balance, the Sliding Mode Controller will therefore guarantee that the states are not only closely followed towards their corresponding targets, but also gently so. The shut-down action also was carried out more regulated without the abrupt lowering in voltage or oscillatory decay that was previously a frequent and annoying failure of the system. These upgrades are more efficient besides being superior in regard to the life of the components as much as the less transient the components the lesser the wear and hence the system will be more suitable in terms of long-time utilization of the vehicle. The step changes in the behaviour of the battery loaded make a new dimension of the enhanced performance of the system. There the charging demand is cut to half its former value; the former system seemed to have been unsound and the output temporarily cut down and the converter hard at work to bring order back to the modified working. Sliding Mode controlled, the proposed system, in full control and composure at such an abrupt change, consequently exerted its power on the changes in a very smooth and self-assured way. Power flow between the battery and the charger was maintained to fine limits and the DC-DC stage is concurrently slightly and promptly performing the required adjustments, and performing it without any unnecessary load. The controller regarded the real path as the most priority and made it immediately, thus there will be no chance to notice the big error deviations. This behaviour ensured that the chargers can undergo unpredictable change of battery states or they can have manipulation of charging rate by the user without any sign of unreliability and as such provides a well-polished and reliable charging experience.

V. Conclusion

The present work has demonstrated that a three-port partial power converter together with a Sliding Mode Controller in combination leads to a charging system so robust, efficient and stable that it surpasses the previous proportional-integral controlled system designs. The suggested design will greatly reduce the load on the DC-DC stage since the greater part of the power is switched by the grid to the battery, which will decrease the losses, heat dissipation, and degradation of the parts. With high-speed correction and imperviousness to disturbance, the controller ensures a well-organized operation even in the conditions of variations in the supply, sudden changes in loads, and dynamic charging. According to the simulations, the start-up is softer, accurate shut-down, reduced ripple, and significantly increased transient response. Thus, the new charger can be enumerated as a massive step towards the future of the electric vehicles as a source of stability, speed and long-term performance as per the stringent conditions of the electrified transport of the present day.

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