

SWITCH MODE POWER SUPPLY (SMPS) SYSTEMS AND CONTROL TECHNIQUES: A REVIEW OF APPLICATIONS IN ELECTRIC VEHICLES

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ABSTRACT

Switch mode power supply (SMPS) system has prominently featured in many power system applications. It is a critical component of electric vehicle (EV), providing reliable and efficient voltage link to drive electric motor. In direct current to direct current (DC-DC) SMPS, the duty cycle can be adjusted to control the amount of power flow between the input and output. There are different DC-DC power converters that have been implemented for SMPS operation in EV, with its advantages and disadvantages. This work presents SMPS and the control techniques used to ensure efficient power train operation in EVs. The study shows that the application of control systems in the operation of SMPS ensures good dynamic response by generating a control signal that is applied to pulse width modulator which triggers a semiconductor device such as insulated gate bipolar transistor for efficient switching mode/ power transfer. Despite the promising results offered by the various control methods, the issue of ineffectiveness in the event of parameter variation and nonlinearity is still common, especially for proportional integral derivative (PID) controllers. Also, intelligent based control systems like fuzzy logic controller and fuzzy-PID are prone to steady-state error and subpar effect. Machine learning models and other advanced methods are subjected to design and computational complexity. These gaps have been addressed by SMPS system for driving EV. Most systems employ single-loop control strategy. To explore the benefits of these control methods and for improved switching and dynamic response performance for SMPS and the EV, composite controllers and multi-loop control methods can be leveraged.

Keywords: Electric motor, Electric vehicle, Switch mode power supply, control systems, PID.

1.0 INTRODUCTION

SMPS is a power electronic converter that incorporates switching regulators for efficient conversion of electrical power. Power can be transferred by SMPS such as a battery to a load for example, electric motor, just like every other supply system but in regulated manner using switching regulators. The switching regulator can be pulse width modulator (PWM) or even proportional integral and derivative (PID) Controller that triggers a power electronic component such as insulated gate bipolar transistor (IGBT) at regulated time interval (or period) in order to regulate either output voltage or current by switching ideal storage elements such as inductor and capacitor into and out of different electrical mode (ON/OFF). In contrast to linear power supply, the transistor (or IGBT) of SMPS, continuously switches between low-dissipation, full-on and full-off states, and with very little time spent during high-dissipation transitions, resulting in minimized dissipated energy. There is no power dissipated by an SMPS when ideally considered (Indira & Valarmathy, 2017). In

SMPS, voltage regulation (or power transfer) is achieved by varying ON-to-OFF time ratio unlike in linear power supply, where output voltage is regulated by continuous power dissipation through transistor. The importance of SMPS in future power systems has been intensified particularly due to move toward achieving one hundred per cent renewable energies (Peyghami *et al.*, 2020). Switch Mode Power Supplies or power electronic converters, can be classified in to six categories namely, diode rectifier (uncontrolled rectifier), alternating current to direct current. (AC-DC) converter (controlled rectification), DC-DC converter (DC chopper), alternating current to alternating current (AC-AC) converter (AC voltage regulator), direct current to alternating current converter (DC-AC) converter (inverter), and static switches. The common types of conversion are DC-DC, AC-DC, DC-AC, and AC-AC (Ned Mow *et al.*, 2003). The proper functioning of these converters includes high output quality, long lifetime, and less consumption of energy (Mohammadi *et al.*, 2018). SMPSs are largely employed in wide range of applications, with very high reliability required in some applications such as military and commercial aircrafts, space applications (Alamand & Khan, 2014). Other areas of applications include distributed generations especially, in renewable energies, medium voltage distribution systems, ultra/high voltage transmission systems, electric vehicles (e-mobility), and microgrids (Peyghami *et al.*, 2019). Power electronic converters are becoming the foundational technology in the modernization of future power system (Hohan *et al.*, 2019). This can be attributed to high power conversion efficiency which serves as an important advantage of a SMPS in electric motor drive of electric vehicles (EVs). In electric vehicle design, incorporating linear power (energy) supply or energy storage devices with a traction (or motor) drive causes major challenges because their output voltage vary with load or state of charge including the high voltage of the DC-link. DC-DC converter (or SMPS) can be employed to interface the elements in electric power train by boosting or chopping the voltage levels (Al Sakka *et al.*, 2011). The structure of the SMPS has to be of lightweight, small size, reliable, and very efficient (Al Sakka *et al.*, 2011). Generally, the addition of SMPS with appropriate controller will help in choosing the voltage variation of the devices and also control the power of energy storage or power supply device.

2.0 POWER ELECTRONIC CONVERTERS

The processing and control of electrical energy flow by delivering voltages and currents in a form that is optimally suited for the user loads is basically the task of power converter (Bordy, n.d.; Electronic Hub, 2015). Power electronic converters exist in different types and are used to carry out different tasks such as rectification, inversion, and others. In order to process and convert electrical energy, a power electronic converter employs power electronic devices such as silicon control rectifiers (SCRs), Triacs, insulated gate bipolar transistor (IGBT), diodes and others. The major aim of a convert circuit is to produce conditioning power according to design application (Electronic Hub, 2015). The block diagram of a power electronic converter is shown in Figure 1.

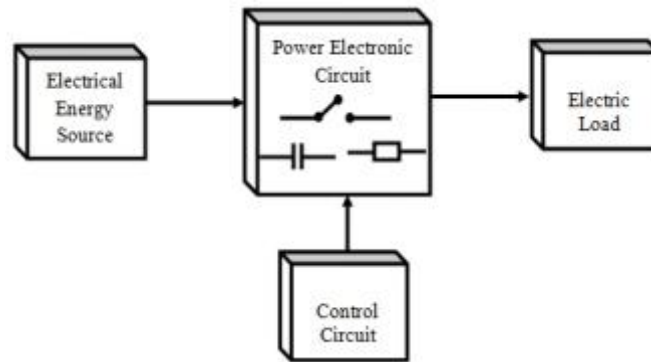


Figure 1: Typical block diagram of power electronic converter

In Figure 1, a power electronic converter basically comprises an electrical energy source, a control circuit, power electronic circuit, and an electric load. In the power electronic converter, the transfer of energy from the source to load is performed by the power electronic circuit, while the control circuit regulates the components in the power section of the converter. This circuit is built with a complex low power electronic circuit that comprises either analog or digital circuit assembly (Electronic Hub, 2015).

There are different basic power conversion functions that are performed by power electronic converters. A converter has a power conversion stage that can carry out any of the functions in AC and DC power conversion systems. Power converters are classified according to the type of function performed as discussed in the following subsections.

2.1 AC-DC Converters

In AC-DC converter, AC supply from main lines is converted to DC supply for the load. It is also called rectifier. Figure 2 is a block diagram of an AC-DC converter. The essential elements in this converter are the transformer, switching circuit, filter, and control circuit. The transformer alters the input AC supply voltage at the primary and fed to the input of the rectifier (AC-DC converter) stage. The transformer is usually a step down and reduces the operating range of the supply voltage (Electronic Hub, 2015).

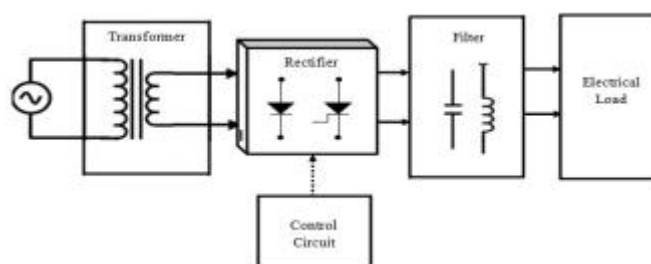


Figure 2: Block diagram of AC to DC converter circuit

The low voltage AC supply available at the secondary terminals of the transformer is converted into DC supply by the rectifier, which consists of diode and/or thyristors depending on the type used. The resulting output from the rectifier is a pulsating DC electric energy, which is fed into a filter circuit that filters or removes associated pulse in the DC. The filter is usually made with a choke or a capacitor. The control circuit or element controls the thyristor firing angle for phase-controlled rectifiers. However, for diode rectifiers, no control block is required. Thus, rectifiers are majorly classified into uncontrolled diode rectifier and controlled rectifiers.

2.2 DC-DC Converter

In several DC operated applications, different levels of DC voltage from a given DC source are required. Examples of these applications include DC traction system, subway cars, battery operated motors, control of large DC motors, trolley buses, and others. In these applications, variable DC voltages are required to produce variable speed, and as such a power conversion device is needed.

As a static device, a DC chopper converts a fixed input DC voltage to variable DC output or a fixed DC output of different magnitude that may be lower or higher than the fixed input value. Generally, static converter is a meshed network of electrical devices that operates as a linking, adapting or transforming stage between two sources, usually between generator and a load. The block diagrams of a DC chopper and a typical static converter are shown in Figures 3 and 4.

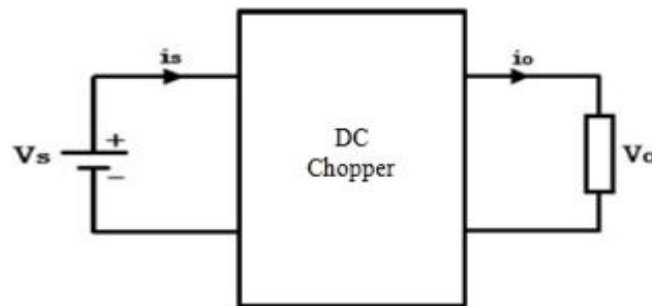


Figure 3: Block diagram of DC chopper

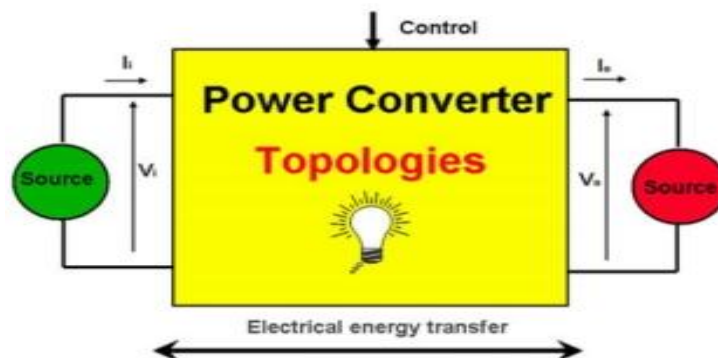


Figure 4: Description of static converter (Bordy, n.d.)

In Figure 3, the chopper circuit is tied to the DC input source one side while a DC load is tied to its other end. A typical chopper comprises semiconductor modules (power electronic switching devices) such as SCRs, which are connected in a manner to produce expected DC load voltage. Control is provided for the output voltage by adjusting the thyristor (or switch) ON time that in turn changes the DC voltage pulse width at the output. This switching method is called pulse width modulation (PWM) control. The resulting DC chopper output can be low or higher than the input and can be varying or fixed value. Depending on the application the DC chopper is intended for, it can be unidirectional or bidirectional (Electronic Hub, 2015).

DC choppers are largely employed in DC drives such as in electric vehicles (EVs) and hybrid electric vehicles (HEVs). They are basically classified into three types depending on the input and the output voltage levels and are described as follows.

2.2.1 Buck Converter

A buck converter also called step-down chopper produces an average output voltage that is lower than the input DC voltage. The circuit diagram of a buck converter is shown in Figure 5. The switching device is a thyristor. The input voltage is switch to the load at particular instant the thyristor is triggered. The diode operates as a freewheeling diode that permits the flow of load current through it when thyristor is turned OFF. The absence of this diode will cause high induced voltage (electromotive force, EMF) in inductor may result in damage to the switching component.

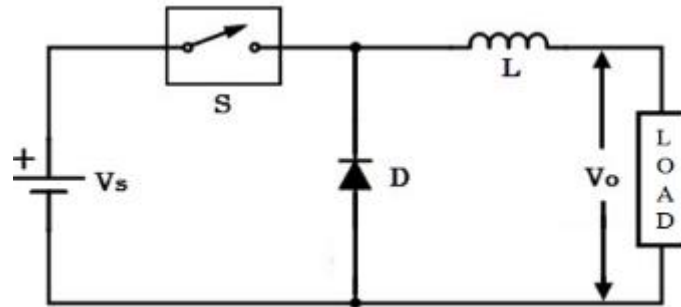


Figure 5: Circuit diagram of buck converter

In order to vary the average output voltage of the converter, the turn ON/OFF period of the thyristor is controlled. The output voltage is the same as the input voltage when the thyristor is turn ON, but becomes zero when the thyristor is turn OFF. The output voltage is equal to the product of duty ratio k and the input voltage V_s given by (Electronic Hub, 2015):

$$V_o = \left(\frac{T_{ON}}{T} \right) \times V_s \quad (1)$$

where T_{ON} and T are the turn on period and duty period respectively, their ratio is called duty ratio. Thus, by increasing the duty ratio, the output voltage will be increased.

2.2.2 Boost Converter

Boost converter also called step-up converter provides an output voltage that is always higher than the input voltage. The circuit diagram of a boost converter is shown in Figure 6. In this case a thyristor (or SCR) is used as a switch and is connected in parallel with the load. Just like the buck converter, a diode is connected in series with the load. The diode permits the flow of load current when the thyristor is in OFF state.

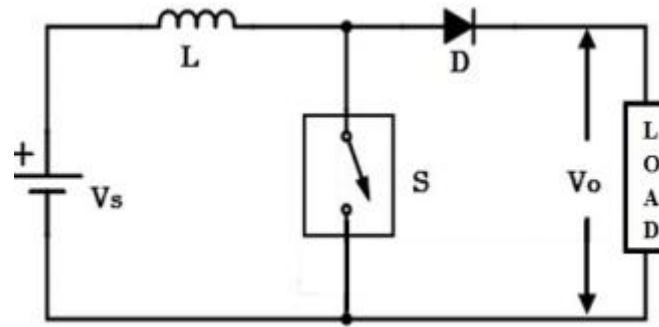


Figure 6: Circuit diagram of boost converter

In turn ON state of the thyristor, the diode will be reverse-biased and thus isolates the load circuit from the source thereby making the inductor to charge to the maximum input voltage source. During the OFF state of the thyristor, the input voltage reaches the load including from the inductor. This, therefore, makes the output voltage of the converter higher than the input voltage. The output voltage of the boost converter is given by (Electronic Hub, 2015):

$$V_o = \frac{1}{1 - \left(\frac{T_{ON}}{T}\right)} \times V_s \quad (2)$$

Varying the duty ratio ($k = T_{ON}/T$) results in the output voltage varying the load gets the desired voltage (Electronic Hub, 2015).

2.2.2 Buck-Boost Converter

The buck-boost converter is a type of DC chopper whereby continuous adjustment of its duty cycle makes operate either in step-down and step-up modes. Figure 7 shows a circuit diagram of buck-boost DC chopper. The circuit comprises only one switching device (a thyristor), an inductor, a diode, and a capacitor connected in with the circuit.

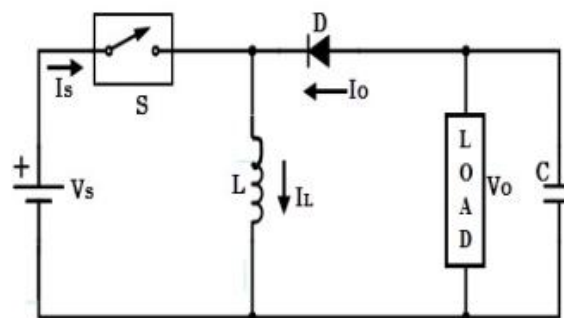


Figure 7: Circuit diagram of a buck-boost converter

The operation of the circuit is such that at any time the thyristor is turned ON, supply current goes to the inductor through the thyristor and as such, the voltage is induced in the inductor. At turn OFF state of the thyristor, the current in the inductor seems to decrease with the polarity of the induced voltage reversed. The converter's output voltage will be constant as capacitor is connected across the load. However, by varying the

duty ratio to a typical range of $0 < k \leq 0.5$, the output voltage is lower than the input voltage such that the chopper is buck converter, and for a range $0.5 < k \leq 1$ it behaves as a boost converter.

2.2.4 Interleaved Four-Channel DC-DC Boost Converter

The interleaved boost converter comprises a parallel connection of boost or step-up converters, as depicted in by the Simulink model in Figure 8. The current is divided due to a parallel connection. So, current stresses are decreased as the power losses are minimized (Faraj & Hussein, 2020). The interleaved (or multichannel) boost DC–DC converter (IBC) comprises four similar inductors (L_1, L_2, L_3, L_4) in four step-up levels to reduce the conductor weight and input current ripples, four parallel power-switching devices for successive phase shifting, diodes, and a filtering capacitor to eliminate the output voltage ripples. All these inductors contain individual magnetic cores for better energy storing and release. As a result, the IBC topology can increase the voltage level by more than four times (Al Sakka *et al.*, 2011).

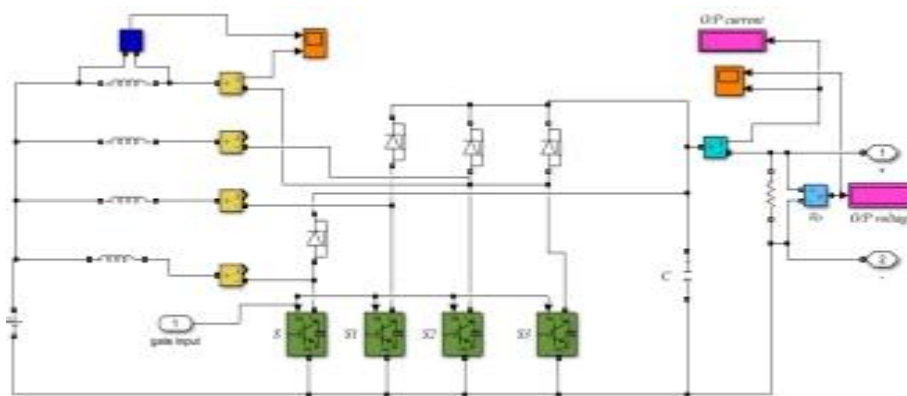


Figure 8: Four-channel interleaved DC–DC boost converter

The 4-channel interleaved boost DC–DC converter has been chosen for EVs for its several compatible reasons, such as a reduction in inductor size and output capacitor size, a more significant reduction in input current and output voltage ripples, and higher overall system efficiency (Chakraborty *et al.*, 2019; 2017). Nevertheless, the IBC is sensitive to any changes in the duty cycle, high cost, and impact on the magnetic core due to any changes in load (Islam *et al.*, 2023).

2.3 Gaps in some Reviewed Literatures

Bahadir and Aydoğdu (2023) developed a high power (75 kW) novel driver and control algorithm for an electric passenger vehicle whose features can be used practically. It was observed that some problems occur in the operation of the developed control algorithms in traction systems operating at high power. The study then proposed a scheme as the solution methods to addressing the problems. The simulation model of an electrical vehicle was obtained by determining the basic parameters for a passenger electric vehicle. Then a brushless DC motor and drive system was determined for the electric vehicle and an original 75 kW DC-AC Converter (Inverter) in accordance with automotive standards has been designed and tested for the Brushless DC motor. Also, in the design and implementation phase, PID and Fuzzy control-based vehicle control software was developed in MATLAB/Simulink environment on the purpose of rapid prototyping and loaded on the DS1401 dSPACE based control system. It has been seen that through rapid prototyping, the appropriate controller development cycle time for the vehicle drastically reduced, which significantly has reduced the research and development costs. In the vehicle control algorithm, the authors used speed information as a

reference input and brake information is used as feedback. The control signal generated by the controller is converted into PWM pulses for each phase and applied to the IGBT driver. These PWM pulses were used to switch the six IGBT power components used in the three-phase full-bridge DC-AC converter. Driving performance at the design stage was studied for cases of starting, speed, reversal and load failure. Simulation and experimental results demonstrated the effectiveness of the driver and drive control system that were originally developed. When the system response was examined, it was revealed that the fuzzy logic control algorithm provided much improved performance than the Proportional Integral (PI) and the PID control algorithms. Simulation results and application results were consistent with each other and the system performance was successfully tested. Despite the effectiveness of the proposed system, the sudden change in load (disturbance still) affects the controller output voltage especially with fuzzy logic controller.

Nemes and Hajdu (2023) developed and simulated a BLDC motor drive system for EV in MTALB/Simulink environment. The structure and complexity of the dynamics was determined. The model discussed was developed so that an optimization task could be defined more precisely by inserting it as a sub-model into a vehicle dynamics model. In order to increase the accuracy of the model with measured data in the future, as well as to be able to validate it, scalability was considered. A BLDC motor efficiency map generation program was created during the study including environment for testing the generated data. The authors asserted that the developed system offers the opportunity to use a shape-correct efficiency model when simulating a BLDC motor even without measured data, which makes it possible to discover real relationships between model parameters when performing optimization. The authors were able to develop a DC motor drive but this was not validated with direct application in an EV, though it was meant for that purpose.

Vighneswaran and Nair (2018) implemented speed control of EV driven by permanent magnet synchronous motor (PMSM) with PI and sliding mode control (SMC). The dynamic model of bicycle was substituted for the EV model. A sinusoidal PWM was employed to generate pulses for the inverter. A gear factor is used to convert the motor's speed to the speed required to drive the wheels. The simulation results showed the vehicle tracks the input speed. An obvious problem with the SMC is that it is prone to chattering. The authors used a PI and sliding mode control method, but the problem with the SMC is that it is prone to chattering, and this was not taken care of.

Akgül *et al.* (2023) designed, analyzed and provided application details of electrical vehicle battery charge device based on half bridge DC-DC converter. Half bridge DC-DC converter in the study has 620 W power at full load, 25 kHz switching frequency and input DC voltage is obtained by uncontrolled bridge rectifier. In addition, information about the battery that is charged, and battery pack are given. In addition, a protection structure of battery is added by measuring both current and voltage of battery. Firstly, equations required for half bridge DC-DC converter were derived and simulation of battery charge circuit is realized by using PSIM and MATLAB/Simulink. Then, the results of the experimental study and the simulation results are given comparatively. The experimental results prove the accuracy of the simulation studies. One limitation in this work is that a closed loop control application was not considered for the converter circuit so as to keep the output voltage in check.

Doko *et al.* (2020) presented design and construction of switch mode power supply (SMPS) for an off-grid application using spent electric bike (e-bike) battery. The circuit comprises passive, active components, and with LM2586 Adjustable as the controller. It was designed purposely to use spent Lithium –ion battery from

e-bike/vehicle. It was intended to abide by all relevant standards (regulation) including protection against electromagnetic interference (EMI), and electric shock. The designed SMPS provided a multiple output power supply with input voltage range of 36V to 48V dc, output voltages of 5V, 12V, 24V dc with an output current of 0.1A, 1A and 1A respectively. The authors reported an efficiency of 93%. The authors designed and constructed SMPS, but the effectiveness of the proposed system was not demonstrated in an application with e-bike/vehicle as the authors claimed.

Manikandan and Vadivel (2023) stated that the essence of DC-DC converter in most devices such as EV controller is to attenuate high voltage ripples irrespective of change in load voltage. The authors proposed a Luo converter to replace a buck DC-DC converter because of the problem of not being able to meet load requirement containing more ripples on the output voltage and parasitic effects. A DC-DC Luo-converter technology was introduced to overcome this problem. The Luo converter is an enhanced buck-boost converter. In this proposed model the additional filter elements in the Luo-converter eliminate the output ripples and effectively enhance the output voltage level. Simulations were conducted using MATLAB/SIMULINK. The results indicated that the Luo converter reduced the output ripple and parasitic effects. However, despite the fact that the converter was proposed for electric vehicles, it was not implemented or applied to any EV in the work.

After thorough review of several related literatures on EV, its charging system, its power storage system, power electronic converters, the implementation of SMPS on EV, the following summarizes the gaps;

- i. In the implementation of SMPS for electric vehicles, the reviewed works did not consider the effect of electronic noise associated with the power electronic components used for the converters. This electronic noise affected the performance of the controllers due to the perturbation it introduced into the system and as such adversely impacted the stability of the DC-DC link.
- ii. Also, most of the DC-DC converters implemented in the reviewed works were the conventional type which utilized only a single IGBT. In this work, multiple IGBT is suggested for improved stability of the system.
- iii. The reviewed literature showed that thorough work was not done on the type of electric motor drive used to provide the power train required to move the vehicle in the development of the EV. This should be significantly viewed as several factors should be thoroughly considered regarding the components of the system before a particular one will be selected.
- iv. Moreso, the control strategy used is important in order to provide reliable DC-DC link. In the study done by Bahadir and Aydoğdu (2023), a brushless DC motor was used as the driver while a continuous time PID and fuzzy logic controllers were implemented as the control methods. For Vighneswaran and Nair (2018), permanent magnet synchronous motor (PMSM) with a continuous time PI and sliding mode control (SMC) techniques were implemented. The continuous time PI and PID controllers were largely affected by mismatch in system parameters, while fuzzy logic controller was prone to steady state error. In addition, the SMC was prone to chattering caused by non-linear dynamic equations of the system (Eze *et al.*, 2018; 2024). Chattering is an undesirable occurrence in the implementation of SMC which is usually associated with irritating high frequency oscillation. The PI controllers have been largely implemented in continuous time form (analogue state) in the existing EV. However, there are associated problems such as poor long-term stability, bad temperature performance, and susceptibility to environmental conditions associated with analogue

circuit such that the integrating component cannot achieve high stability (Luo *et al.*, 2014). Thus, in this work, the study done by Vighneswaran and Nair (2018) should be modified using a two-loop digital PI controller with filtering component and with multichannel interleaved DC-DC converter (i.e., more than one IGBT) to improve the DC-DC link of the electric vehicle. The presence of the filter ensures that chattering was removed and steady state error associated with fuzzy logic was also eliminated.

These gaps are what this research should address for an improved switch mode power supply system for driving EV.

3.0 IMPLEMENTED SMPS IN ELECTRIC VEHICLE WITH CONTROLLER

Since the emergence of electric vehicles, there has been rapid growth in demand because it is environment friendly, and are replacement for the less friendly fuel/diesel powered internal combustion engine of automobiles. It was reported that 27% of the total greenhouse emission was caused by the transportation sector in the United States in 2020 (Poorfakhraei *et al.*, 2021; Islam *et al.*, 2023). Also, the fact that electric vehicles have less moving parts for maintenance, they are considered to have low running costs. Electric vehicles use energy storage devices. However, the output voltage of energy storage devices changes based on load and as such the high voltage direct current link imposes challenge to vehicle engineers when energy storage devices are being configured with traction drive (or electric motor). Hence, the use of SMPS addresses this problem and at the same time provides reliable and efficient power transmission link for electric vehicle operations. Thus, several SMPSs have been implemented in EVs with control systems for efficient electrical energy conversion.

Bahadir and Aydoğdu (2023) developed a brushless DC motor driven EV in which control signals generated by PI, PID, and fuzzy logic control (FLC) schemes were converted into PWM pulses applied to six IGBT drivers used in enhancing the performance of 75 kW three-phase full-bridge DC-AC converter. Simulation analysis in MATLAB/Simulink revealed that FLC outperformed PI and PID controllers. A permanent magnet synchronous motor (PMSM) driven EV model using PI and sliding mode control (SMC) triggered PWM that generates pulses for AC-DC converter was implemented in Vighneswaran and Nair (2018). A half-bridge DC-DC converter of 620W power capacity at full with 25kHz switching frequency was implemented for EV battery charging device (Akgül *et al.*, 2023). SMPS for an off-grid application using spent electric bike (e-bike) battery that was controlled with LM2586 Adjustable (as the controller) was developed in Doko *et al.* (2020). The speed and torque of squirrel cage induction motor has been improved with less power loss in EV using a constant V/F controller implemented on the Texas Instruments TM320F2812 digital signal processor (DSP) to generate space vector PWM model required to drive the gates of IGBT DC-AC converter. Filter and control system integrations in electric power system involving different SMPS methods such as AC-DC and DC-DC have shown to exhibit more stable characteristics (Güven & Akbaşak, 2021). Dual FLC system that consisted of initial PWM's duty cycle control and the charging rate of the PWM's duty cycle control was implemented as a technique for driving mode switches of plug-in hybrid EVs (Zeng *et al.*, 2018). PID and RST controllers were implemented as digital controllers for buck SMPS with RST offering better load transient response than PID in terms of reduced rise time and smaller undershoot (Lin-Shi *et al.*, 2006). A buck converter was implemented to achieve switch mode power supply function with speed and current PI controllers to achieve efficient power-train action in a DC motor. The speed and mechanical torque of permanent magnet synchronous motor (PMSM) driven EV was separately simulated using PI and SMC (as

control unit) to generate control signal to trigger the gates of DC-AC, which was supplied by a battery to realize the driving action (Cherif *et al.*, 2024). In an effort to address any disturbance in the speed of separately excited DC motor driven EV, a PI controller was used to generate PWM triggering signal that controls the switching mode of a boost converter via its IGBT so to achieve real-time voltage regulation and speed control for DC motor (Al-Othman *et al.*, 2016). Bi-directional IGBTs converter triggered by PWM via PI control system for good dynamic response was designed, simulated and implemented for EV charger by Mapari *et al.* (2019). Despite the fact that multi-channel boost converter has shown a huge switching mode process, some techniques such as mode predictive control (MPC), FLC, SMC, hybrid PI controller, high order SMC, and active disturbance rejection control (ADRC) have been used to make it stable in the presence of significant disturbance (Islam *et al.*, 2023).

4.0 CONCLUSION

One area of application of SMPS is in electric vehicle, where different sources of energy such as batteries, fuel cells and super-capacitors are combined to power an electric motor. EVs are either fully or partially powered on electric power, and are run at low cost because they have less moving parts requiring maintenance and are also environment friendly. The emergence of electric vehicle can be attributed to the increasing demand for renewable sources of energy as substitutes for decreasing non-renewable sources of energy (fossil fuel such as petrol or diesel) and their adverse effects on human health and the ecosystem due to climate change, increase in the rate of carbon (IV) oxide emission, declining oxygen in the atmosphere, air pollution, and global warming. This work has considered some of the most recently implemented SMPS in power system especially in EV. Also, various control techniques that have been designed, applied and implemented to ensure stability in SMPS and improve the overall switching performance have been considered also. Thus, in this study, various control methods critical to the efficient performance of EVs have been evaluated, including classical controllers such as proportional integral derivative (PID) and advanced controllers like artificial intelligence systems, machine learning models, and predictive controllers. Despite the promising results offered by the various control methods, the issue of ineffectiveness in the presence of parameter variation and nonlinearity is still common especially for PID controllers. Also, intelligent based control systems such as fuzzy logic controller (FLC) and fuzzy-PID are prone to steady-state error and subpar effect. Machine learning models and other advanced methods are design and computational complexity. These gaps are among the issues that have been addressed by switch mode power supply system for driving EV. In most cases, the methods of control are usually based on single-loop strategy. Thus, to explore the benefits of these control methods and for improved switching and dynamic response performance for SMPS and the EV, composite controllers and multi-loop methods can be leveraged.

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