Photo-voltaic Powered Electric Vehicle Fast Charger

C P Y Lai¹, K H Law², K H Lim³

¹ Department of Electrical and Computer Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia
² Department of Electrical and Computer Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia
³ Department of Electrical and Computer Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia

E-mail:

Abstract. In the last years, dominant usage of petroleum-based transportation and consumption of fossil fuels results in greenhouse gas (GHGs) emissions into the atmosphere which causes negative impacts across the globe. As the situation worsens, more people are motivated towards opting for electrified transportation. However, there are still a lot of challenges to be overcome with one of the main issues concerning the development and availability of fast charging technologies in electric vehicles (EVs). To decrease high energy demand from the grid, usage of renewable energy systems (i.e., photo-voltaic) to fast charge EVs are preferred. In this paper, high performance DC-DC boost converter controlled by PI controller is proposed with the objective to mitigate the current state of fast charging and environmental problems. The proposed converter is able to generate different output power level based on the desired preset reference voltage value. All simulation results are documented to verify the proposed photo-voltaic (PV) powered EV fast charger. For simplicity, EV batteries are being replaced with one resistor as the load whereas PV panels are used to generate input power for the converter.

1. Introduction

Vehicles have been shaping human civilization for centuries and in the past few decades. However, increasing usage of petroleum-based vehicles produce harmful exhaust components namely carbon dioxide (CO₂), oxides of nitrogen, and sulphur dioxide (SO₂). The United States Environmental Protection Agency analyzes that the transportation sector for more than a quarter of GHG emissions [1]. Fortunately, there has been a significant evolution from the usage of fossil fuel to electric based transportation in all sectors. The aforementioned transition is expected to accelerate exponentially, especially in EVs, through government support, technology advancement, increasing involvement of private sectors and reductions in prices due to large-scale production as it plays a huge role in aiding the market [2–4]. In addition, there will only be sufficient crude oil supply until about the year 2050 [5], it is clear that fossil fuels substitutes needs to be generated for all sectors, particularly in transportation. Furthermore, the global stock of EVs passed 5 million in 2018 which is a significant increase of 63% compared to the previous year [6]. EVs boosts energy saving (efficiency) through improved fuel economy, helps provide a wider range of fuel choices for transportation and decreases pollution/emissions especially with the integration of renewable energy sources (RES), such as wind and PV in electricity generation. These RES in the power systems have since matured. Although their
forecast is quite erratic, penetration of the RES into the power market has significantly increased to fulfill strict energy policies and energy security issues.

Despite the advancement in electrified transportation technologies, the charging times are still the chink in the armour of EVs as it has been quicker and handier to refuel from petroleum-based sources. As of 2018, publicly available fast chargers are still low at 0.14 million [6] globally. EV charger can be categories into AC and DC types. These are further categorised into three bodies; namely the IEC, Society of Automotive Engineers (SAE), and CHAdeMO, that are strive to elected as the standard for EV battery charging. Table 1 shows various charging levels and standards in Europe, Japan and North America.

| Charging Level | Voltage Level | Maximum Power (kW) | Charging Time (h) | Standards |
|----------------|---------------|-------------------|------------------|-----------|
| Level 1 (Slow) | 120 VAC       | 3.7               | 10-15            | Private Outlets       |
|                |               |                   |                  | SAE J1772 (Type 1)    |
| Level 2 (Slow) | 220 VAC       | 3.7-22            | 3.5-7            | IEC 62196 SAE J1772 (Type 2) |
|                |               |                   |                  | SAE J1772 (Type 1)    |
| Level 3 (Fast) | 480 VAC       | 22-43.5           | 0.17-0.5         | IEC 62196 SAE J3068 (Type 2) |
|                | 200-600 VDC   | <200              |                  | CCS Combo 2 CHAdeMO   |
|                |               |                   |                  | CES Combo 1 CHAdeMO   |
|                | <150          |                   |                  | CHAdeMO               |

The classified EV chargers from [6] are as: Level 1 with charge power less than 5 kW, Level 2 charges between 5 kW to 50 kW through three-phase outlets, and Level 3 is DC fast charge which is characterized using 480 V AC input with charging power greater than 50 kW. However, the power conversion and control stage becomes more expensive and bulky due to higher power capability. Due to size constraints, the required power electronics for Level 3 charging are not carried on board. Hence, to decrease the mass of on-board electronics, the power transferred to the vehicle for Level 3 charging is in DC while AC energy transfer is allowed in Level 1 and Level 2 chargers as they contain on-board electronic converters.

In recent literature, environmental consequences, integration issues, optimization, technological aspects, and the impact on the grid such as peak load demand and voltage malfunctions [8] are covered in existing PV-EV charging papers. In addition, combination of RES and the grid is considered appealing in regards of future smart grid framework. However, there are still limited amount of papers regarding the methodology of PV-EV fast charging. For example, in [9; 10], the design of a high efficient battery charger and control technique for EV fast charger is proposed but no RES is implemented. Not only that, in [11], a solar grid-connected charger for EV is designed but there is no fast charging.

This paper proposes a design and implements a PV-powered fast charger to produce different output power level from the source to the load. To achieve the aforementioned task, DC-DC
boost converter topology is chosen. MATLAB/Simulink is utilized to carry out simulation to develop the model. For simplicity, the EV batteries are replaced by a resistive load during the modelling phase to incorporate the control of the charge current into the battery.

2. Battery
The main energy resource for EVs is rechargeable battery. There are several types of rechargeable battery integrated in EVs including lead-acid battery and lithium-ion battery. Lead-acid battery was the first battery technology being used in transportation. However, the downsides of utilizing it are heavy, low energy density, and not environmental friendly when compared with lithium-ion battery. There are several methods to charge an EV battery. For instance, constant current (CC), constant voltage (CV), constant power (CP), taper charging, and trickle charging [12]. The combination of these traditional charging techniques leads to the advance development of rapid battery charging methods such as CC-CV, pulse and negative pulse [13] charging [14].

2.1. Slow Charging Techniques
The following are the conventional methods used for charging and recharging of EV batteries.

2.1.1. Constant Voltage (CV). The charging voltage is maintained at the maximum voltage depending on the type of battery. As the battery is approaching full charge, the charging current slowly decreases. This method is suitable for lower voltages due to temperature control. However, long charging periods are of main concern [15].

2.1.2. Constant Current (CC). A CC is outputted to charge the battery. However, the reliability of the battery can still be affected due to overheating even if the charging current is not exceeding the rated current of the battery [15].

2.1.3. Constant Power (CP), Taper Charging, and Trickle Charging. For CP method, the battery is charged with constant regulated power. Taper charging method is performed with an unregulated voltage source, which increases the chance of damaging the battery due to overcharge [16]. Trickle charging charges the battery with small currents to atone for self-discharge in batteries.

2.2. Fast Charging Techniques
The following describes the rapid charging techniques in rechargeable batteries utilized in EVs.

2.2.1. Constant Current-Constant Voltage (CC-CV). CC-CV charging method as shown in Figure 1, is used in the majority of commercial chargers to charge lithium-ion batteries as they

![Figure 1. CC-CV charging.](image)
have higher output power and energy densities when compared to other battery types. Several benefits of CC-CV technique include controlled charging voltage and current to prevent overvoltages and reduce thermal stress. With this method, the charger outputted CC until the predefined voltage potential of the battery has reached. Then, the battery voltage will be held constant while decreasing the charging current until reaching full charge [17]. The charging period is almost similar or more than the CC method due to its capability of reducing the charging current upon completed the charging process [18; 19].

**Figure 2.** Pulse charging and negative pulse charging.

### 2.2.2. Pulse Charging and Negative Pulse Charging.

Pulses from the charging current is applied through the battery. The charging rate can be approximately controlled by varying the pulse width. This method optimizes the charging time while taking into consideration of polarization, temperature, State-of-Charge (SoC) and variable battery impedance [20]. The charging impedance of the battery varies with frequency which in turn affects the charging current due to the battery’s capacitive nature during charging. Hence, charging impedance can be minimized to maximize the charging current by selecting the suitable pulse frequency to achieve shorter charging times.

In [13], a duty-varied voltage pulse charging strategy was proposed to increase charge speed and efficiency to the battery. In [21], another pulse charging technique using optimal frequency and duty searching modes was proposed. The finding of this method proves that pulse charging speed is twice the rate when compared with CC-CV charging method.

Negative pulse charging, which initially being developed to increase the charging efficiency of converters for lead acid batteries, has been extended to lithium ion batteries [15]. This method helps to lower the stresses of the battery’s cell through temperature monitoring. A faster charging period can be achieved through continuation of high currents pumped into the battery by depolarizing the cell periodically. Figure 2 illustrates the charging profile for pulse charging and negative pulse charging. Negative pulse charging is part and parcel of pulse charging which has been claimed to enhance overall charging process and prolong the battery life.

### 3. State-of-the-art DC Fast Chargers

Conventional state-of-the-art DC fast charger consists of two power conversion stage from three-phase AC to DC which includes Power Factor Correction (PFC) circuit and a DC-DC stage with galvanic isolation [7]. AC voltage is rectified into immediate DC voltage during AC-DC rectification stage while the immediate DC voltage is controlled to the desired charging voltage and current levels, as defined by EV battery whilst providing galvanic isolation. PFC functions by ensuring the grid power quality adheres with the grid codes while the galvanic isolation enables the charger output stages to be connected in parallel plus separating EVs from the grid [22]. The DC-DC conversion stage implements a dynamic control method to reduce temperature and battery polarization for fast-charging applications [23]. A typical DC fast charger will also utilize an active pulse width-modulated (PWM) rectifier whereby the pulse generator would be implemented for pulse and negative pulse fast charging [20].
Commercially available DC fast chargers typically utilize CC-CV technique. The battery voltage rises proportionally with the state-of-charge (SOC) when the battery charges in the CC region. Upon reaching CV phase, the power delivered to the battery decreases. Table 2 shows the technical specifications of commercially available DC fast charger.

| Manufacturer Model | ABB Terra 53 | ABB Terra HP | Tritium Veefil-RT | Tesla Supercharger | EVTEC espresso&charge |
|--------------------|-------------|-------------|------------------|-------------------|----------------------|
| Rated Power (kW)   | 50          | 350         | 50               | 135               | 150                  |
| Supported standards| CCS Type 1 CHAdeMO 1.0 | SAE Combo 1 CHAdeMO 1.2 | CCS Type 1 & 2 CHAdeMO 1.0 | Supercharger | SAE Combo 1 CHAdeMO 1.0 |
| Input voltage      | 480 VAC     | 400 VAC ±10%| 380-480 VAC 600-900 VDC | 200-480 VAC     | 400 VAC ±10%          |
| Output DC voltage  | 200-500     | 50-500      | 150-920          | 200-500          | 50-410               | 170-500               |
| Output DC current  | 120         | 375         | 125              | 330              | 300                  |
| Peak efficiency    | 94%         | 95%         | <92%             | 92%              | 93%                  |
| Volume (L)         | 758         | 1,894       | 495              | 1,047            | 1,581                |
| Weight (kg)        | 400         | 1,340       | 165              | 600              | 400                  |

4. Methodology
The future concept and perception of EV fast charging is shown in Figure 3 and Figure 4 below.

**Figure 3.** General Scheme of the power system for EV.

**Figure 4.** Pipeline of fast charging for EVs.
The proposed fast charger will be installed at designated areas nearby the available PV power allowing consumers to charge their EVs for a short period of time. Figure 5 below illustrates the pipeline to design the PV-powered fast charger. This project is carried out in four phases with different approach.

**Figure 5.** Phases of Project

In Phase 1, EV battery specification and its charging characteristic is identified and investigated. A review on the usage of PV energy to fast charge EV in terms of power level competency were also carried out. For Phase 2, the transfer function and state-space equations for the design of the DC-DC boost converter are derived [24–30]. The selection of the size of passive components are then carried out. After that, the development and selection of appropriate controller (Proportional Integral (PI) controller) is administered to conclude its gain values through root locus diagram. The conceptual design of the proposed PV-powered fast charger established for this work is shown in Figure 6.

**Figure 6.** Boost converter with PV array for EV charging.

To make sure that power regulation and DC-link voltage stabilization can be achieved by the proposed PV-powered fast charger according to the desired predefined reference voltage value, MATLAB/Simulink is utilized. MATLAB/Simulink is also used to examine and measure the performance of the proposed topology based on the dynamic and transient response as well as the conversion efficiency. Last but not least, to verify the optimization and real-time behaviour of the aforementioned works, a prototype of the proposed topology will be developed in the future works. The prototype will also be used to identify the discretization issues, modelling issues, and the accuracy of data supplied to the model.

5. **Mathematical Modelling**

Figure 7 shows the principle of operation of the proposed PV-powered fast charger based on DC-DC boost converter. From Figure 7(a), when the switch is on, the input source $V_{SO}$ causes inductor $L$ to charge and capacitor $C$ to discharge to the load. However, as from Figure 7(b), when the switch is off, the energy stored in the inductor $L$ discharges. A much higher DC output voltage $V_{DC}$ when compared to $V_{SO}$ is produced due to the summation of the input source $V_{SO}$ with the energy. This simultaneously charge the capacitor $C$ and drive the load.
The overall power rating of the converter together with the voltage and current ripple content produced by the converter can be determined by the size of the capacitor $C$ and inductor $L$. The size of inductor $L$ and capacitor $C$ can be calculated using the equations defined in (1) and (2) as follows:

\[
L = \frac{V_{SO}}{\Delta I_{L_{\text{max}}}} DT_{SW} \quad (1)
\]

\[
C = \frac{V_{DC}}{\Delta V_{DC_{\text{max}}}} RDT_{SW} \quad (2)
\]

where $V_{SO}$ signifies the input voltage source, $V_{DC}$ signifies the output voltage, $\Delta I_{L_{\text{max}}}$ signifies the maximum ripple current flowing through the inductor $L$, $\Delta V_{DC_{\text{max}}}$ signifies the maximum voltage ripple measured across the capacitor $C$, $R$ signifies the resistance of the load, $D$ signifies the steady-state duty cycle generated from the PI controller and $T_{SW}$ signifies the switching period.

The equations for $\Delta I_{L_{\text{max}}}$ and $\Delta V_{DC_{\text{max}}}$ used in this work can be seen in 3 and 4 respectively, as follows:

\[
\Delta I_{L_{\text{max}}} = 1\% \times I_L \quad (3)
\]

\[
\Delta V_{DC_{\text{max}}} = 1\% \times V_{DC} \quad (4)
\]

where $I_L$ signifies the input current flowing through the inductor $L$.

Using the state-space averaging modeling technique, the voltage loop controller of the proposed DC-DC boost converter operating in continuous conduction mode (CCM) is designed. Two states of operations (i.e., when the switch is on ($D$)(see Figure 7(a)) and when the switch is off ($1-D$)(see Figure 7(b)) for the DC-DC boost converter are derived in 5 and 6 from figure 7 respectively as follows:

\[
\left( \frac{dI_L}{DT_{SW}} \right) = \left( \begin{array}{cc} 0 & -\frac{1}{RC} \\ \frac{1}{L} & 0 \end{array} \right) \left( \begin{array}{c} I_L \\ V_{DC} \end{array} \right) + \left( \begin{array}{c} \frac{1}{L} \\ 0 \end{array} \right) V_{SO} \quad (5)
\]

\[
\left( \frac{dI_L}{(1-D)T_{SW}} \right) = \left( \begin{array}{cc} 0 & -\frac{1}{RC} \\ \frac{1}{L} & 0 \end{array} \right) \left( \begin{array}{c} I_L \\ V_{DC} \end{array} \right) + \left( \begin{array}{c} \frac{1}{L} \\ 0 \end{array} \right) V_{SO} \quad (6)
\]

The linear time invariant state-space average equations over the switching period $T_{SW}$ are then derived by taking into consideration of the small deviation from the steady-state operating point of the boost converter for inductor current $i_L$ and capacitor voltage $v_C$ are derived in 7 and 8 respectively as follows [31]:

\[
\left( \frac{dV_{DC}}{dT_{SW}} \right) = \left( \begin{array}{cc} 0 & -\frac{1}{RC} \\ \frac{1}{L} & 0 \end{array} \right) \left( \begin{array}{c} i_L \\ V_{DC} \end{array} \right) + \left( \begin{array}{c} \frac{1}{L} \\ 0 \end{array} \right) V_{SO} \quad (7)
\]

\[
\left( \frac{dC}{dV_{DC}} \right) = \left( \begin{array}{cc} 0 & -\frac{1}{RC} \\ \frac{1}{L} & 0 \end{array} \right) \left( \begin{array}{c} i_L \\ V_{DC} \end{array} \right) + \left( \begin{array}{c} \frac{1}{L} \\ 0 \end{array} \right) V_{SO} \quad (8)
\]
\[
\frac{di_L}{dt} = -v_{DC}\left(1 - \frac{D_O}{L}\right) + v_{SO}\left(1 \frac{1}{L}\right) + V_{DC}\left(\frac{d}{L}\right) + v_{SO}\left(1 \frac{1}{L}\right)
\]  
\(7\)

\[
\frac{dv_{DC}}{dt} = i_L\left(1 - \frac{D_O}{C}\right) - V_{DC}\left(\frac{1}{RC}\right) - I_L\left(\frac{d}{C}\right)
\]  
\(8\)

where the uppercase letters (i.e., \(D_O\), \(V_{DC}\), and \(I_L\)) represents the steady-state parameters whereas the lowercase letters (i.e., \(v_{DC}\), \(d\), \(v_{SO}\), and \(i_L\)) represents the deviations or small perturbations from the steady-state parameters.

\[
v_{DC}(s) = \left(\frac{v_{SO}(s)}{V_{SO}(s)^2(1 - D_O)} + \frac{d(s)}{(1 - D_O)^2} \left(1 - sL(1 - D_O)^2R\right)\right) \ast \left(\frac{V_{SO}(s)}{\left(\frac{s^2LC}{(1 - D_O)^2} + \frac{bL}{(1 - D_O)^2R} + 1\right)}\right)
\]  
\(9\)

where the first bracket of 9 represents the input voltage deviation during an operating point and the second bracket represents the transfer function of the boost converter \(G_{conv}(s)\) (see Figure 8) which are required to calculate the gains of PI controller.

\[
PI = K_P + \frac{K_I}{s}
\]  
\(10\)

where \(K_P\) signifies the proportional gain whereas \(K_I\) signifies the integral gain.
With the objective to increase the input voltage by 5 times, the desired output voltage $V_{DC}$, of 60 V is set in accordance to the output DC voltage, $V_{DC}$, from Table 2 (i.e. Tesla Supercharger and ABB Terra 53). Upon determining the intended output voltage, $V_{DC}$, the input voltage, $V_{SO}$, of 12 V can now be calculated using (11).

$$V_{SO} = \frac{1}{5}V_{DC}$$

Once the desired input and output voltage is determined, the duty cycle of 0.8 can now be calculated using (12)

$$\frac{V_{DC}}{V_{SO}} = \frac{1}{1 - D}$$

The value for inductor, $L$, and capacitor, $C$, is chosen based on the availability of the components. As for the resistance, $R$, the value of 60 Ω is selected according to the desired output voltage (i.e. 60 V) and current (i.e. 1 A) using (13)

$$R = \frac{V}{I}$$

6. Results and Discussion
Using MATLAB/Simulink software package [32], the proposed PV-powered fast charger designed based on DC-DC boost converter is analysed to examine and study its dynamic and transient performances. For load, the EV batteries (load) are replaced by a resistor whereas the input source of the converter is retrieved from PV panels.

6.1. Simulation Results
The system parameters used to carry out simulation study of the proposed PV-powered fast charger designed based on DC-DC boost converter is listed in Table 3. The total simulation period is 15 s. Figure 9 shows the simulation result obtained from Figure 8 in regards to two different DC output voltage references $v_{DC}^*$ (i.e, from 0 V to 60 V) which step changes at 5 s.

| Table 3. System Parameters Used In Computer Simulation |
|------------------------------------------------------|
| **Boost Converter Steady State Parameters** | **Value** |
| Input voltage source, $V_{SO}$ | 12 V |
| Rated input current, $I_L$ | 5 A |
| Input power rating, $P_{SO}$ | 60 W |
| Rated output voltage, $V_{DC}$ | 60 V |
| Rated output current, $I_{DC}$ | 1 A |
| Switching frequency, $f_{SW}$ | 10 kHz |
| Filter inductance, $L$ | 100 μH |
| Filter capacitance, $C$ | 1000 μH |
| Load resistance, $R$ | 60 Ω |
| Steady-state duty cycle, $D$ | 0.8 |
| Proportional gain, $K_P$ | 0 |
| Integral gain, $K_I$ | 0.0280411089392773 |
Based on Figure 9, it can be observed that although the boost converter plant is unsteady, it is still able to remain stable and continue tracking with the preset DC output voltage references $v_{DC}^*$ until it reaches steady-state at 0.46 s. Besides, undershoot and overshoot behaviours are mitigated during the changes of DC output voltage $V_{DC}$ due to care and experience when designing the DC-DC boost converter.

Figure 10 depicted the measurement result of four parameters obtained from the circuitry of boost converter (see Figure 7) after the schematic circuit is replaced by the boost converter transfer function $G_{CONV}$.

As seen from Figure 9, not only was the proposed voltage loop feedback control able to ensure zero tracking performance. The calculated values in 3 were also similar to the magnitude of the parameters obtained from Figure 10.

![Figure 9. Proposed voltage loop feedback control for boost converter simulation result.](image)

![Figure 10. Simulation results of boost converter for (a) input voltage $V_{SO}$, (b) input current $I_L$, (c) output voltage $V_{DC}$, and (d) output current $I_{DC}$ when nominal input source voltage-level is deviated.](image)

![Figure 11. Simulation results of boost converter for (a) input voltage $V_{SO}$, (b) input current $I_L$, (c) output voltage $V_{DC}$, and (d) output current $I_{DC}$ when nominal input source voltage-level is deviated.](image)

Figure 11 illustrates the precedence of the proposed voltage loop feedback control as the nominal input source voltage level is varied from 12 V to 9 V under similar loading condition. It is observed from Figure 11 that the proposed controller has the ability to control and retain the desired DC output voltage-level of the boost converter to 60 V although the input source voltage $V_{SO}$ is lower than 12 V.

Figure 12 shows the resultant duty cycle $D$ obtained from the proposed voltage loop feedback controller throughout the 15 s simulation period. This results proves that the proposed boost controller is able to regulate its DC output voltage based on the DC output voltage references $v_{DC}^*$ despite changes in input source voltage as well as loading conditions.
Figure 12. Resultant duty cycle from the proposed voltage loop feedback controller simulation result.

Figure 13. Simulation results of PV panel with (a) constant irradiance variable temperature and (b) variable irradiance constant temperature.

Simulation for the proposed PV-powered fast charger designed based on DC-DC boost converter with PV panel (i.e., Suntech power STP180S-24-Ad+) is carried out. Figure 13 illustrates the results obtained when two set of irradiance and temperature characteristics are employed for a simulation period of 6 s. For Figure 13(a), the irradiance was maintained constant at 1000 W/m$^2$ whereas the temperature was increased from 25°C to 45°C at 2 s. Then 45°C to 50°C at 3 s after which it was decreased to 32°C at 5 s. For Figure 13(b), the temperature was maintained constant at at 32°C whereas the irradiance was increased from 1000 W/m$^2$ to 4500 W/m$^2$.

Figure 14. Simulation results of boost converter for (a) input voltage $V_{SO}$, (b) input current $I_L$, (c) output voltage $V_{DC}$, and (d) output current $I_{DC}$ at constant irradiance variable temperature.

Figure 15. Simulation results of boost converter for (a) input voltage $V_{SO}$, (b) input current $I_L$, (c) output voltage $V_{DC}$, and (d) output current $I_{DC}$ at constant temperature variable irradiance.

Figure 14 depicts the simulation results obtained from the proposed converter controlled by
the proposed controller when subjected to the weather condition described in Figure 13(a). Figure 15 illustrates the simulation results obtained from the proposed system when subjected to the weather condition described in Figure 13(b).

From Figure 14 and Figure 15, it is observed that the proposed system are still able to regulate its output voltage to 60 V although change in temperature of the PV panel results in a non-constant DC voltage output.

Figure 16(a) and Figure 16(b) illustrates the resultant duty cycle $D$ of the proposed system when it is subjected to the weather conditions described in Figure 13(a) and Figure 13(b) respectively.

![Figure 16](image)

Figure 16. Resultant duty cycle from the proposed voltage loop feedback controller simulation result.

7. Conclusion
This paper presents the design of a PV-powered fast charger for electrical vehicles. PI controller is used to control provide automatic control of the system. To ensure that the design proposed meets the required specifications and needs, various values for various parameters were calculated, derived and chosen. Before proceeding to the next phase (i.e. hardware implementation), MATLAB/Simulink was utilised to carry out simulations for the proposed design to make sure that expected results are achieved. Simulation results obtained show the expected results which demonstrated the ability to generate different output power level based on the desired preset reference voltage value. Hardware implementations will be carried out in future works to ensure the usability of the designed fast charger and potential maximization of system efficiency and performance. In addition, analysis will be carried out to distinguish areas of improvement to reduce charging period through RES. This includes identifying better matching values and tool dynamics of capacitor used. Finally, implementation and integration of PV power for direct fast charging of EVs to increase efficiency during power conversion will be carried out in future works.

References
[1] Sources of greenhouse gas emissions URL https://www.epa.gov/ghgemissions/
[2] Blanning B 2013 2013 World Electric Vehicle Symposium and Exhibition (EVS27) pp 1–6
[3] Pillot C 2013 2013 World Electric Vehicle Symposium and Exhibition (EVS27) pp 1–6
[4] Hannisdahl O H, Malvik H V and Wensaas G B 2013 2013 World Electric Vehicle Symposium and Exhibition (EVS27) pp 1–13
[5] U.S. energy information administration - eia - international energy outlook 2017 URL https://www.eia.gov/ieo
[6] Global ev outlook 2019 URL https://www.iea.org/gevo2019/
[7] Ronanki D, Kellkar A and Williamson S S 2019 Energies 12 3721
[8] Lai C P Y, Law K H and Lim K H 2019 2019 7th International Conference on Smart Computing Communications (ICSCC) pp 1–6
[9] Kim J M, Lee J, Eom T H, Bae K H, Shin M H and Won C Y 2018 2018 21st International Conference on Electrical Machines and Systems (ICEMS) (IEEE) pp 2603–2607
[10] Lee J H, Moon J S, Lee Y S, Kim Y R and Won C Y 2011 IECON 2011-37th Annual Conference of the IEEE Industrial Electronics Society (IEEE) pp 4577–4582
[11] Akmal M, Jawad A and Al Tarabsheh A 2018 2018 UKSim-AMSS 20th International Conference on Computer Modelling and Simulation (UKSim) (IEEE) pp 108–113
[12] Yong J Y, Ramachandaramurthy V K, Tan K M and Mithulananthan N 2015 Renewable and Sustainable Energy Reviews 49 365–385
[13] Chen L R 2008 IEEE Transactions on Industrial Electronics 56 480–487
[14] Shareef H, Islam M M and Mohamed A 2016 Renewable and Sustainable Energy Reviews 64 403–420
[15] Trivedi N, Gujar N S, Sarkar S and Pundir S 2018 2018 IEEMA Engineer Infinite Conference (eTechNxT) (IEEE) pp 1–5
[16] Lynch W and Salameh Z 2007 2007 IEEE Power Engineering Society General Meeting (IEEE) pp 1–5
[17] Zhang S S 2006 Journal of power sources 161 1385–1391
[18] Dharmakeerthi C, Mithulananthan N and Saha T 2012 2012 IEEE Power and Energy Society General Meeting (IEEE) pp 1–8
[19] Electropaedia Battery chargers and charging methods URL http://www.mpoweruk.com/chargers.htm
[20] Collin R, Miao Y, Yokochi A, Enjeti P and von Jouanne A 2019 Energies 12 1839
[21] Di Yin M, Youn J, Park D and Cho J 2015 2015 Ninth International Conference on Frontier of Computer Science and Technology (IEEE) pp 40–45
[22] Srdic S and Lukic S 2019 IEEE Electrification Magazine 7 22–31
[23] Law K H, Ng W P Q and An P I 2019 IOP Conference Series: Materials Science and Engineering (IOPSCIENCE) pp 1–11
[24] Law K H, Dahidah M S, Konstantinou G S and Agelidis V G 2012 Proceedings of The 7th International Power Electronics and Motion Control Conference vol 1 (IEEE) pp 330–334
[25] Law K H and Dahidah M S 2014 2014 IEEE 5th International Symposium on Power Electronics for Distributed Generation Systems (PEDG) (IEEE) pp 1–7
[26] Law K H, Dahidah M S and Almurib H A 2014 IEEE Transactions on Power Electronics 29 6433–6444
[27] Law K H, Ng W P Q and Wong W K 2017 International Journal of Power Electronics and Drive Systems 8 100–108
[28] Law K H, Dahidah M S, Sim S Y, Ng W P Q, Masaoud A and Abu-Siada A 2018 TENCON 2018-2018 IEEE Region 10 Conference (IEEE) pp 0020–0025
[29] Law K H and Ng W P Q 2018 2018 IEEE 7th International Conference on Power and Energy (PECon) (IEEE) pp 56–61
[30] Yong S K, Law K H, Ng W P Q and Dahidah M S 2018 Journal of Telecommunication, Electronic and Computer Engineering 10 39–44

[31] Law K H and Dahidah M S 2014 2014 International Power Electronics Conference (IPEC-Hiroshima 2014-ECCE ASIA) (IEEE) pp 1283–1290

[32] Mathworks URL https://www.mathworks.com/