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Asian Resonance

Implementation of Charging Circuit for Electric Vehicle

Abstract

Electric Vehicles (EVs) are the latest development in the transport industry. The objective is to develop eco-friendly form of transport at the same time economical feasibility is also required. The Infrastructure required for charging and battery maintenance is key issues in commercialising EVs. This paper addresses one of the issues which is charging infrastructure for the EVs. This paper in accordance with IEC 15118 proposes a structure for DC Fast Charging Station (DCFCS). DCFCS is an AC/DC converter coupled with DC/DC converter meant to supply electricity from grid to EV which consists of two lithium batteries. This proposed circuit reduces the EVs' charging time which encourages the integration of fast chargers in existing low voltage (LV) network. The infrastructure required for the charging station can be made economically viable by involving it as an ancillary service provider for utilities.

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Introduction

Even though the significance of electric vehicle research has multiplied, the absence of a fast charging station is the key hindrance in large scale deployment.[1] This limits the distance that could be travelled by the EV. But, air contamination in urban areas forces the government to implement vehicle rationing schemes such as the odd-even scheme implemented in Delhi. The drawback of these schemes is that it creates public hindrance due to the absence of required public transport infrastructure. Moreover, the batteries for the e-vehicles are becoming cheaper but does not compensate with lifetime and reliability [2]. An additional reason for the e-vehicles is not yet competing with IC engine based vehicle because of the charging time. Longer charging time causes it to be less reliable due to the unavailability of the vehicle for a longer period. This has been observed in european countries [3]. The paper [4] confirms that delivered power is in the range of (7 - 43) kW in AC for charging stations which means that 1 or 2 hours of charging can help in travelling a distance of 110 to 150 km.

Paper [5] proposes a battery swapping method at charging stations to reduce the charging time. But this again requires additional infrastructure such as storage and stock administration of batteries. Fast charging (FC) method is a viable alternative for battery swapping method. This can be done through dedicated connections to the medium voltage (MV) grid. Despite the fact that as of now effectively actualized, producers despite everything show a preservationist mentality with regards to permitting batteries to be charged faster because this method has the probability of overheating and quicker debasement of battery. The limitations of quick charging stations involve

1. higher connection expenses to the grid operators to counterbalance the expense of bigger transformers and electrical gears
2. increased losses just as potential lines over-burdens and system get congested

Base on these limitations, some papers came up with innovative tariff frameworks that help in peak clipping the demand for charging during the day [6]. Another study [7] proposed to interface batteries as back up devices between the grid and the charging stations. This battery also acts as a buffer to lessen their impact on peak loads.

This research specifically focuses on proposing a dual battery energy system (BES) that decouples the LV distribution network and the DC fast charging station (DCFCS) as shown in Figure 1. The twin battery system (BES1 and BES2) works in such a manner that one battery gets charged from the network while the other powers the EV. This helps in creating flexibility in charging the batteries. Due to this flexibility the peak demand diminishes.

Sections II introduces the best in class charging modes and the section III proposes the integration of quick charging in LV grid. The section IV proposes a design for charging station and the section V explains the operation of the proposed structure. Results for the simulations battery usage optimisation are presented in Section VI. Section VII discusses the possible ramifications because of the practical usage of the proposed framework thereby giving a lead to the scope of future research.

EVs Charging Modes: State of The Art

Global standard IEC 61851 "electric vehicle conductive charging framework, "indicates that there are distinctive charging modes named mode 1, mode 2, mode 3 and mode 4.Section 1 and 2 of IEC 61851 are applicable for on-board and off-board hardware's that are meant for charging EVs and additional electric power to value additions in EVs. The strategies for charging EVs are

1. Interfacing the grid to an on-board charger
2. Utilizing an off-board charger for supplying DC power for charging.

The charging modes for EVs are as follows:

Charging Mode	Uses	Rating
1	Home chargers	16A, 11kW
2	Private offices	32A, 22kW
3	Open charging stations	63A, 43 kW
4	Off-board chargers	50 to 120 kW

Table I. Profile Of Charging Conditions And Modes

Charging Mode	Vehicle Battery charger	Max. current
Mode 1	4-8 h	16 A
Mode 2	2-4 h	32 A
Mode 3	1-2 h	63 A
Mode 4	5-30 min	400 A DC

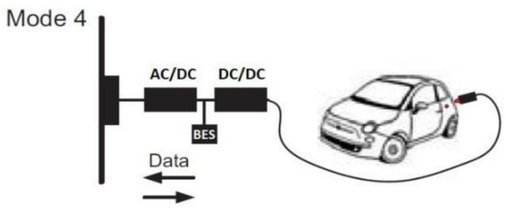
The IEC 61851 section 23 and 24 give the general prerequisites for controlling the communication between a DC-charger and an Electric Vehicle, as indicated by IEC 15118 [8].

The IEC 62196 applies to attachment outlets, connectors and plugs which utilize conductive charging [9]. The standard permits to energizing in DC with the power of 50 kW to 240kW and current. 400A in Chademo and Combined Charging System (Combo). In most of the urban communities, mode 2 and mode 3 charging are prevalent for the accompanying reasons: low costs and available international standards. These days, inspite of having robust AC charging architecture, power constraints are a limitation. Additionally, the charging rate to arrive at 80% of the EV battery with 22kW will roughly take 1 hour for a vehicle of 20kWh while operating in mode 3. This creates issues like parking congestions and charges; moreover, AC recharging involves more conversion losses on the EV side. The efficiency of an onboard converter is approximately 85%, and this means there will be an additional energy demand for the EV to arrive at 80% of SoC. Also, the Huge losses occurring in the onboard charging is reflected in the total energy consumed, which means that extra cost per kWh of energy for users. Mode 4: DC quick charging station and specifically their incorporation in the LV grid is the only other option available. Cutting edge technology that is available are: 50kW by ABB with the combo in LV, 120kW by Tesla associated in MV, 62.5kW by Chademo system in LV. Mode 4 reduces the charging time and increases the conversion efficiency on the EV side. These charging stations when rated at 100/150kW, require a solid grid infrastructure with in turn demands high venture cost. Such enormous installed capacities usually require MV lines and a suitable transformer which increases the expense and is further hurdled by space limitations. Installation in urban communities multiplies this problem.

DC Fast Charging Stations' Integration with LV Grid

The DCFCS along with the BES can be an effective answer for mitigating adverse consequences for the network, since the decrease of the maximum demand from the EVs decreases the losses that occur while dispatching electric energy. Additionally grid regulation and support are provided by the charging stations [10]-[11]. Besides, the charger has various advantages, for example, power decoupling and power level increase and congestion management. In addition, it can offer ancillary services like frequency and voltage control for the grid. [12]-[13].

Figure 1. DCFCS in mode 4 with BES



The DC Fast Charging Station is a significant component for recharging EVs; which creates a need for the smart grid which interconnects various types of sustainable power sources and stationary storage with the main grid [14]. A significant angle to consider is the low cost of the lithium-ion battery which is an opportunity for EV to penetrate the markets and helps in setting up the smart charging stations. The Lithium-ion battery for electric vehicle (BEV) consumes 25% of the total expenditure of the EV which means that, a significant cost reduction in batteries would dramatically reduce the total cost of EVs.

DCFCS Modelling and Control

The objective is to control the power flow between the batteries BES1, BES2and the converter The SOCs of the batteries (BESSoC1 and BESSoC2) is determined by measuring the voltage on the battery terminals V_{BES}(Figure 3). Figure 2 shows discharge characteristics obtained through a simulink model.

The reference voltage V_{BES} creates a discharge curve of the BES inside the nominal operating zone. Figure 3 shows the operation limits about three levels: normal-level, low-level and high-level SoC.

Figure 2. SoC Determination with Discharge Voltage at 5C and 135A

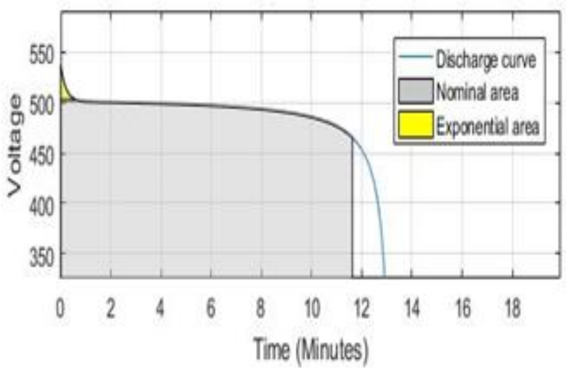


Figure 3. SoC level determination through the V_{BES}

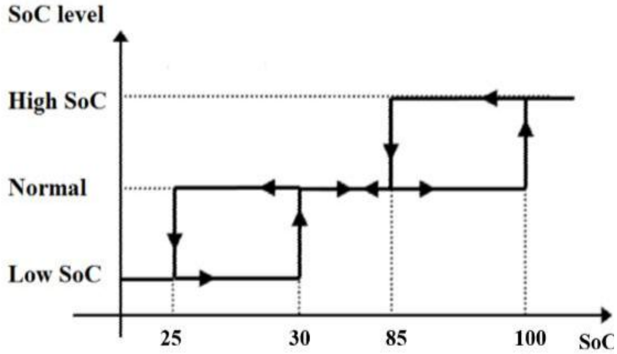
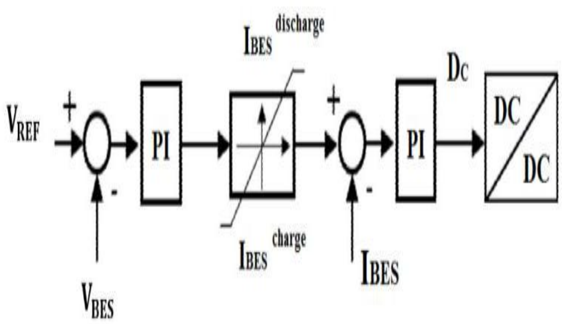


Figure 4 represents the dynamic control system used between BES and EV. In the BES control system V_{REF} is used as a reference voltage for the input V_{BES}. The I_{BES} is the BES current. The current limiters are used to determine the discharging and charging limits. A closed loop is formed for self control of BES to not deviate away from its operating range.

Figure 4. BES Control System



The I_{BES} is a current reference of the BES for controlling the transferred power through EV using a PI controller. The I_{BES} is restricted in capacity to the releasing rate 5C. The PI controls the duty cycle of the thyristors used in BES DC/DC converter within the set parameters. The power transfer to the vehicle is stopped when, the SOCBES arrives at 25%. The AC/DC converter will recharge every BES with 50kW and charge them at the rate of 4.62C.

Simulation Results

The DCFCS is simulated in Matlab/Simulink to assess its reliability and performance. A PI controller is used in boost converter for controlling the DC/DC converter. A constant voltage is necessary for maintaining the system stability for each SoC of the EVs using a boost converter. To assess the stability of the converter, an EV with 20 kWh and an SoC of 25% has been analysed. Furthermore, investigations have been performed considering the capability of DCFCS with various EVs and SoCs under different situations.

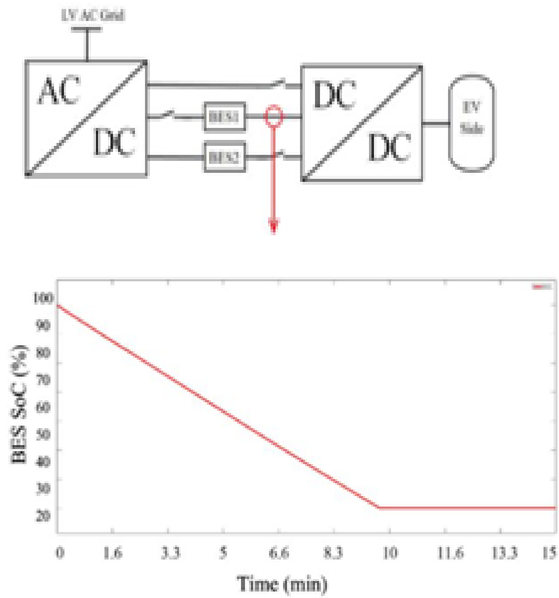
EV Charging Process

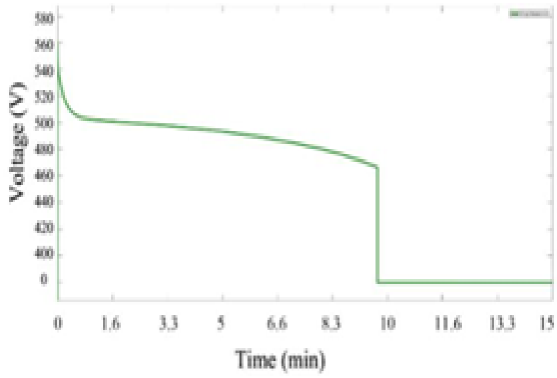
Each EV has certain driving conditions as mentioned in the user's guide by the manufacturers as indicated by the tests acted in the EV research center. As per the guidance 90% of the ostensible limit is utilized as work limit. The other 10% will be proportional to the battery debasement. This system encourages the client to utilise the EV in a reliable manner. The charger can charge 11.4 kWh with a 5C discharging pace. An EV with 20 kWh and an SoC of 25%, 18 kWh could be utilized to energize. This result has been obtained after a brief analysis.

The EV will communicate to the DC charger when it arrives at 80% of the SoC due to communication between DCFCS and EV following the IEC 15118 rules. The delivered energy from the BES, right now, be 10 kWh, enough to arrive at 80% EV SoC in 10-minutes.

The diagrams in Figure 5 and Figure 6 show the BES1 discharging process and the power consumed by the electric vehicle.

Figure 5. BES_{SoC1}, discharging voltage at 5C and current delivered by the BES





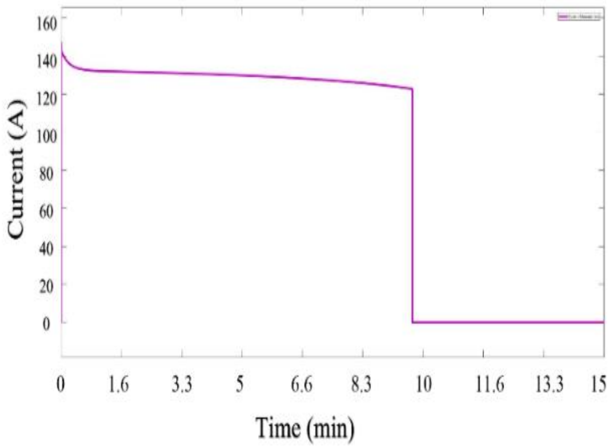
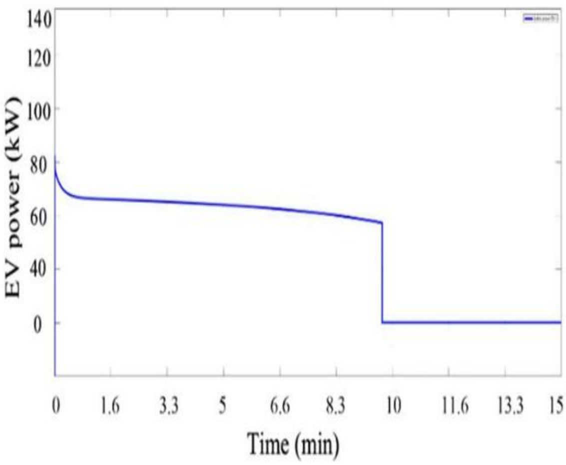


Figure 5 (a) produces diminishing characteristics of the SoC_{BES1}, the voltage drops in Figure 5 (b), and the steady current is 135 A. Figure 6 shows the EV's active power intake.

Figure 6. Active power absorbed by the EV

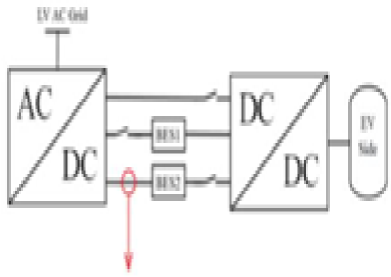


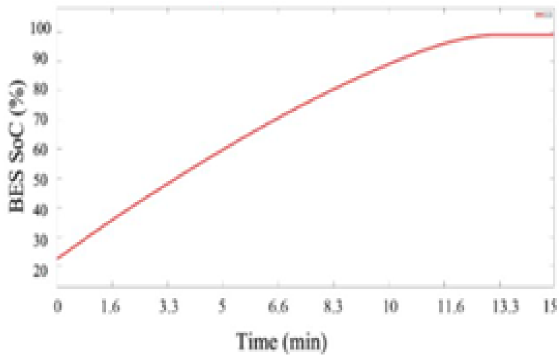
B. Charging process of the BESs

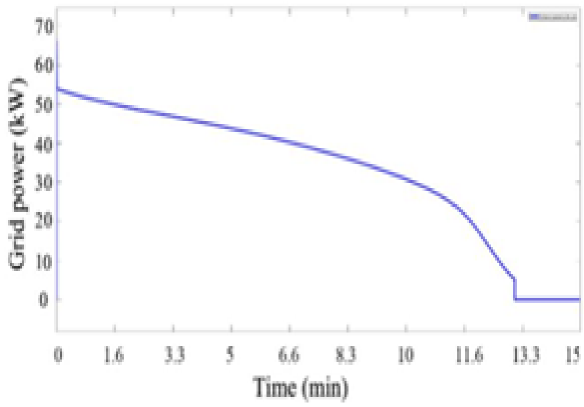
At the point when the BES1 and BES2 require simultaneous charging, the grid with the 50 kW AC/DC converter charges at a pace of 4.63C for BES2 and 5C for BES1. This is shown in fig.7.

Charging every BES will be longer and for storing 11.4 kWh. BES with 25% SoC requires around 13 minutes due to grid power constraint which is 50kW. As recently referenced, the DCFCS has been intended to be utilized for the most part in the urban areas by connecting them to LV grids. It can energize every vehicle up to 80% of their SoC in 10-13 minutes, contingent upon the SoC of every EV.

Figure 7. Active power delivered by the LV grid







VI. CASE STUDY

Different Scenarios of the DCFCS

The comparison of distinctive commercial EVs has helped in the evaluation of the functionality of the charging system. The case studies consider a few models from 2015 to 2017 with the battery pack between 16 kWh and 60 kWh. The calculations depend upon two situations:

EVs SoC at the beginning = 25%, as shown in Figure 8

EVs SoC at the beginning = 35%, as shown in Figure 9

The DCFCS of 70 kW through the BESs charges the EVs. The outcomes related to the ability of the DCFCS and its limits to supply energy to the end-clients appear in Figure 8 and Figure 9.

Table II. Different Commercial Evs Comparison

Models (2015-2017)	Range [km]	Battery [kWh]	Usable battery [kWh]
Mitsbuishi i-MiEV	100	16	14.4
Smart Electric	110	17	15.3
Chevy Spark EV	130	20	18
BMW i3	130	22	19.8
Ford Focus EV	130	23	20.7
Fiat 500e	140	24	21.6
Nissan Leaf 24kWh	130	24	21.6
Nissan Leaf 30kWh	165	30	27
Kia Soul EV	150	30	27
Mercedes B-Class ED	170	36	32.4
eGolf	300	37	33.3
Tesla S 60	340	60	54
Tesla model 3	350	60	54

Figure 8. EVs SoC and km available at the end of the charging process with SoC 25%

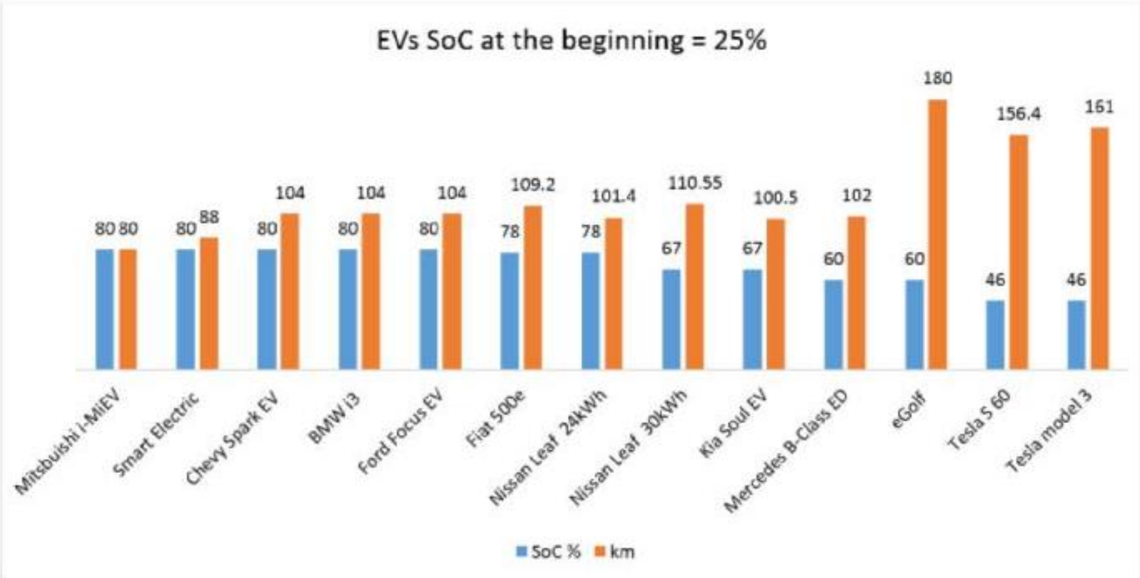


Figure 9. EVs SoC and kilometres available at the end of the charging process with SoC at 35% in the beginning

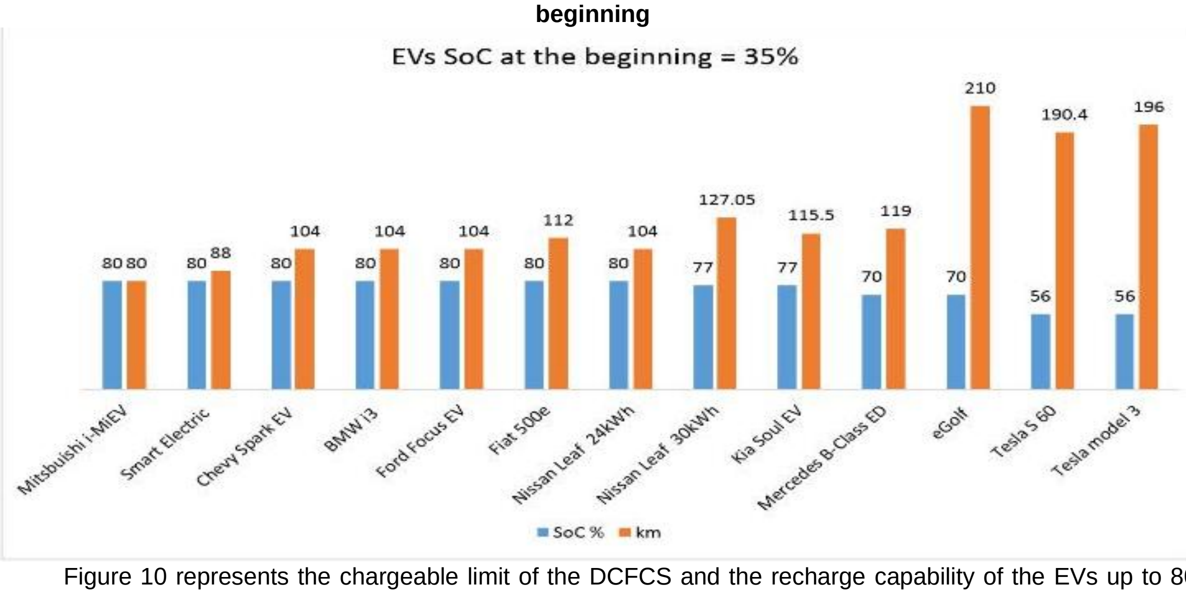
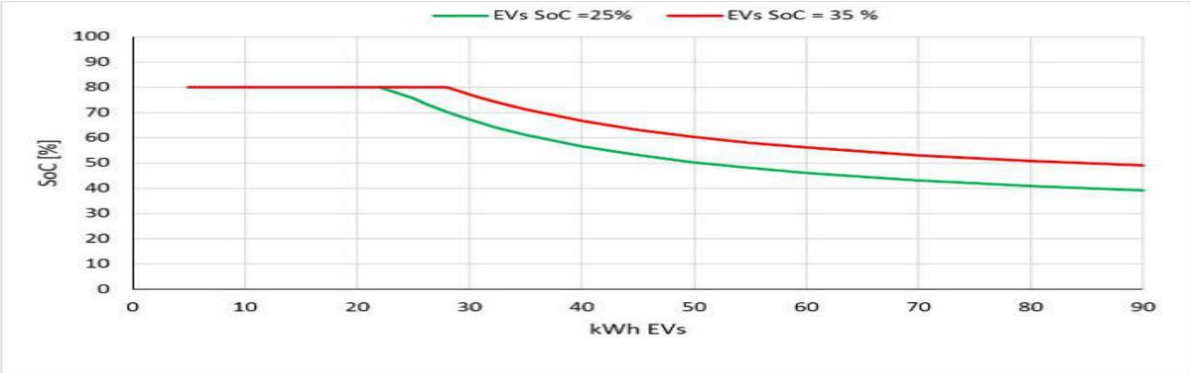


Figure 10 represents the chargeable limit of the DCFCS and the recharge capability of the EVs up to 80% SoC as per the EV_{SoC} and the battery pack. The characteristics are plotted when EVs SoC are at 25% and 35%

Figure 10. Charging limit of the DCFCS with EVs at 25% SoC and 35% SoC



Conclusion

This article dealt with the configuration and ideal design of BESs which are available inside quick charging stations. The DCFCS could be partly decoupled from the LV network with the upside of limiting the grid impact and the congestion during the peak power demand as indicated in the outcome. We can conclude that

1. The EV market development depends on the 'smartness' of the electrical grid. The DCFCS helps in keeping steady charging power during peak requirements.
2. The intermediate battery assists in scaling back the required limit in the LV grid.
3. The DCFCS provides a possibility of just 10 minutes charge for driving a distance of 100 km.

The trade-off is necessary between the grid constraint and charging time for BESS in a charging station. As a conclusion, dynamic estimation of the SoC of the BES is possible through an ideal control for DC/DC converter. The charging procedure could be automatically updated. As an extension, it is possible to research on a quick charging station of BES, fit for recharging an enormous number of EVs in LV networks by including load control adaptability

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