

Modular Fast Charger Station for Electric Vehicles with Energy Storage Element

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Abstract

This paper describes one off-board fast charge station for electric vehicles. The proposed station is modular and expandable with and integrated energy storage unity. The expansible feature allows a reduced up-front investment and permits the site owner to add more charge points when the demand for fast charge increases. In addition, the proposed off board has an energy storage system which allows shaping the power demanded from the grid, reducing power peaks and possibly the total energy cost, since battery bank is used to store energy when few vehicles are connected. The proposed off board fast charge station is comprised of the following blocks: i) transformer operating from a medium voltage grid followed by a twelve pulse non-controlled rectifier with a small active filter; ii) energy storage system; iii) a 600V DC distribution bus; iv) charging end-points composed of buck interleaved converters. Each end-point, which has potentially low cost, complexity and footprint, gives up to 60 kW charge to an electric vehicle. Simulations results are given to demonstrate the feasibility of the proposed off board fast charging. Also, results from current harmonics at the grid side and analysis of converters responses are presented. Moreover, a viability study shows how the battery bank can help the fast charge system to reduce the use of energy from grid during peak hours, making it profitable.

Keywords: off-board, fast charge, EV (electric vehicle), lithium battery, simulation

1 Introduction

The constant use of fossil fuel in transportation leads to many overcomes. Among them, it contributes to climate changes and deteriorates the air quality in urban areas. Reducing vehicles pollutants emission in atmosphere is a sound alternative to these challenges. In this scenario, the substitution of fossil fuel to electric vehicles

(EVs) is key and its success depends on important factors as infrastructure of charging stations. A massive insertion of EVs in streets will demand an increase number of charge stations to be spread over work places, parking lots and mall centers, etc. A large number of electric vehicle recharge points can motivate car users to bet in this new technology, reducing anxious range. A slow charge, Level 1, can take at least 6 to 8 hours to recharge a car battery that will run 200km on

average. Other battery recharge way is using a Level 2, for 4 to 6 hours, using a specific AC charger installed in a garage, for example. Though, times when a driver are with no energy during a ride, a fast charge can be used during 30 minutes to recharge a vehicle from 20% to 80% of state of charge (SOC). Quickly charges are ideal for users that run many kilometres during a day, however, the mainly problem of a fast station system for one end-point is high up-front investment in equipment, that can move away investors. In other to find a solution for commercial fast charger investments, the proposed work shows an idea of a modular and expandable system for fast charger. A desired model for a fast charge station must have galvanic isolation and standard connectors, like CHAdeMO, SAE J1772 Combo or IEC 62196-2 [1]. In addition, network connectivity, reliability, low cost, low footprint and modularity are among desired features of a charge station for EVs. An internet connection with smartphones and site owner is essential, in order to notice available charging points, charge cost plans and promotions. Furthermore, expandable charge stations have benefits as low up-front investment and new end-points can add in future as a request by site owner. This paper describes in details a modular fast charge system that has low up-front investment, end-points with low footprint and a grid friendly thanks to its internal energy storage system. Moreover, a viability study shows the gains that a modular storage system can provide in the reduction of electric bill consumption during peak hours.

2 Proposed Modular Fast Charger Station for EVs

With crescent demand for EVs, the design of a modular system should be considered, in which an

up-front investment in the first stage of the system is required, followed by an end-point. As usage and necessity for fast charge increases, the site owner can only add end-points in his fast charging station. Consequently, his future investment will be lower compared to install all desired end-points at once [2].

In this way, the initial system will have a galvanic low frequency isolated transformer, a 12 pulse rectifier and only one recharging end-point. The energy costs can be reduced and the power peaks generated on the grid can be regulated, using an energy storage expandable module. When no vehicle is charging, the storage unity stores energy and later gives it back to charging cars. In addition, with growing necessity of fast charges, another energy storage module could be added in the modular fast charge system as needed. This whole system is presented in a block diagram on Figure 1.

The proposed fast charge end-point is projected at maximum power of 60kW with 480V and 125A in each end-point [3]. This power limit is adopted considering the most common PEV available in the cities e.g. Nissan LEAF. Voltage ripple equals to 5% and current ripple to 1% [4]. The power comes from 13.8kV grid to a 3 phase Y: Δ , Y transformer, which is connected to a non-controlled 12 pulses rectifier. An input of 13.8kV is chosen because it is a nominal medium distribution voltage used in the country, than a higher current can be drain and the energy cost can be negotiated with a power distribution company. Furthermore, the phase shifted transformer with a 12 pulse rectifier is chosen to cancels harmonic currents as 3th, 5th and 7th. The first expressive harmonic currents will be in the 11th, 13th and 23th harmonics.

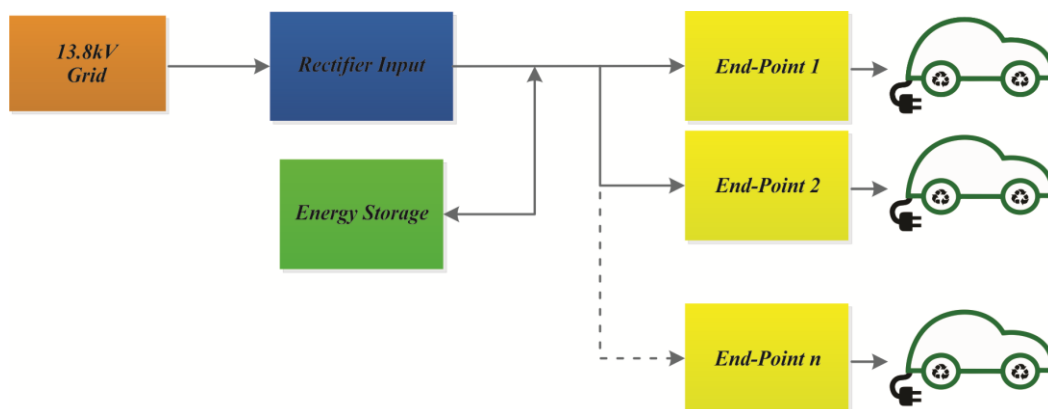


Figure 1 - Fast charger system block diagram.

Table 1 – Current harmonic limits by IEEE 1547. [5]

Individual harmonic order h (odd harmonics)	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	Total demand distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

High current distortions degrade the power factor of the load, causing unnecessary heating in supply cables and transmission lines. In addition, for a three phase system, a neutral current appears due to current harmonics. For this reason, there are standards limits for voltage and current harmonic inserted in grid for medium voltages. The IEEE 519 and IEC 61000-3-6 standards limit harmonic emission for customers connected in medium voltage. In the IEC standard the limits are presented in percentage of each harmonic order, e.g. for 3rd harmonic is tolerated until 5% of fundamental, for 5th harmonic 6%, for 7th harmonic 5%, for 9th harmonic 1.5%, for 11th harmonic 3.5% and for 13th harmonic 3% [6]. Other important standard is the IEEE 1547 that regulates maximum level to current harmonics is described in Table 1 [5].

The harmonics are verified in simulations results, the 11th and 13th that are about 6% and 5.5%. For this case a small active filter should be added in a transformer winding in order to reduce this harmonics.

After the rectifier input stage, the energy goes to a DC bus and it can be delivered to the end-points or to the battery bank. The interface converter will control slow charge to storage

element and fast discharge to provide energy for vehicle fast charge. The AC-DC converter stage is projected based on [7], which brings a THD equals to 14% and a PF=0.99.

Other vital part of this system is the Buck Interleaved PWM Phase-Shift converters responsible to charge the EV batteries, they are projected based on [8]–[14] and are better explained in [15]. These buck converters are feed by a DC 600V bus. An interleaved converter is chosen to do this job because it divides the output in each inductor branch [16]. Moreover, it works very well for high power, presenting fewer losses in semiconductors, smaller output capacitor, lower EMI generation and simpler control system. Each outlet added in the system will increment another end-point, in this case, a simple totem with the buck DC-DC. Operational stages and design is based on [12], [14]. In addition, a PI controller with current control was used to provide the necessary power as desired by the vehicle battery management system, reaching a maximum of 125A to the battery. In addition, two control meshes were used in PI controller to avoid circulation and unbalancing current in inductor branches. Without a balance control, all current could be drained to one inductor branch, causing overload, overheating and permanent damages.

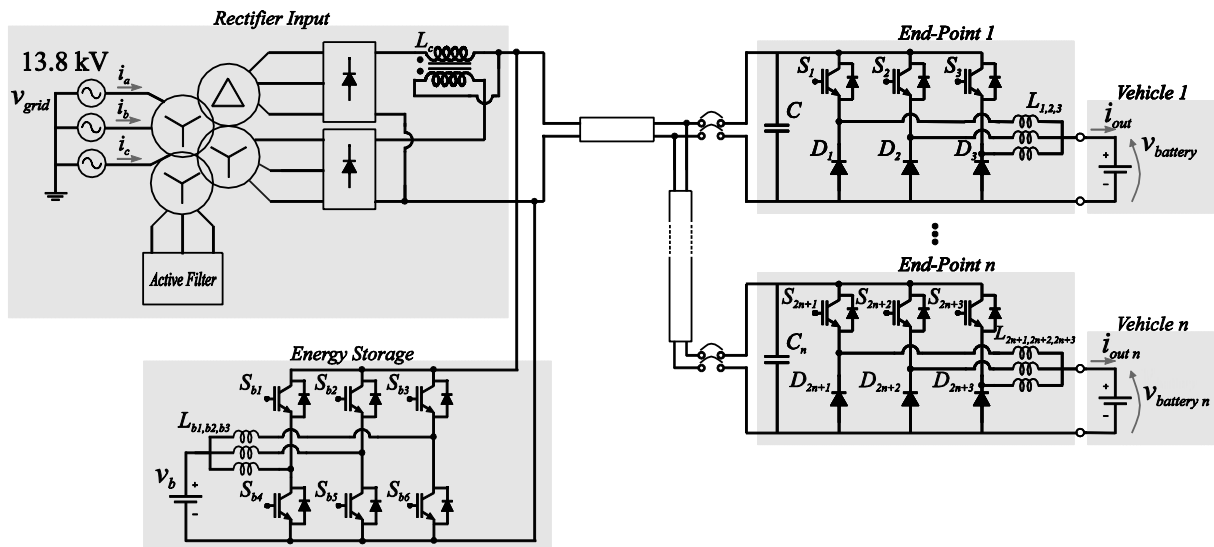


Figure 2: Proposed Modular Fast Charger Station Circuit.

Table 2 - System proposed parameters.

Parameters	Values
Input Voltage (V_{in})	13.80KVac
Max. Output Voltage (V_{out})	480 Vdc
Max. Output Current (I_{out})	125 A
Output Power (P_{out})	60 kW
Grid Frequency (f)	60 Hz
Swiching Frequency (f_s)	20 kHz

3 System Designed Simulations and Results

The modular fast charger system was simulated for different number of charging profiles. An LiFePO₄ cell model [17], [18] was used to simulate an vehicle battery pack as shown in figure 3. The equations about battery comportment were used in software PSIM to simulate a battery response. The reached response

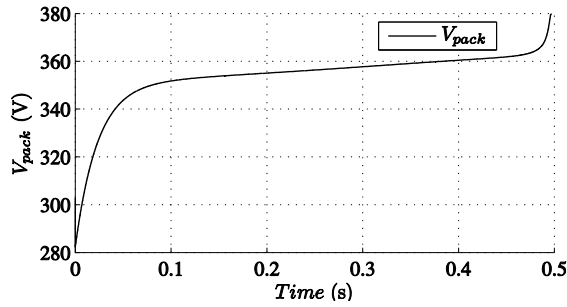


Figure 3: Battery pack model using 2C (C = 66.2 Ah).

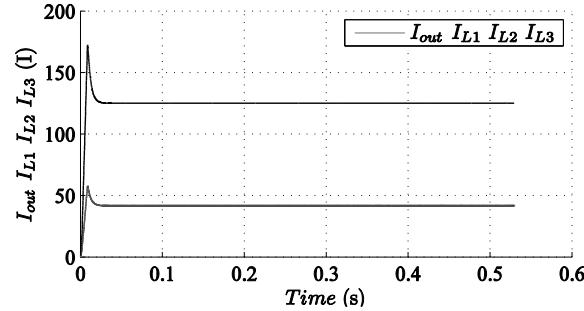


Figure 4: Total current I_{out} in buck interleaved output and the current in each buck interleaved inductor.
 $V_{out} = 479.30$ (V), $I_{out} = 124.81$ (A)

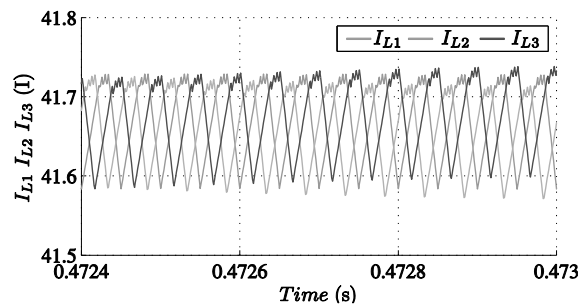


Figure 5: Currents in buck interleaved inductors.

represents a vehicle battery pack. Moreover, the DC-DC converter current response with a battery model connected can be seen on figure 4 and 5. In figure 5 is showing the current control system maintaining all branches on balance. Also, total distortion on input current for one end-point (figure 6) and for three end-points (figure 7) can be seen on the simulations results. Figure 7 shows each current harmonic present the system input. It is possible to see the 11th at 660Hz with 36A (9%), 13th at 780Hz with 21A (5.3%) and 23th at 1380Hz with 12A (3%). Comparing these magnitudes with table 1, the values of each one still higher than allowed by grid standards IEEE 1547, which require lower THD on input currents. Looking forward to solve this problem a small active filter module should be included in a quaternary transformer output to reduce harmonics levels.

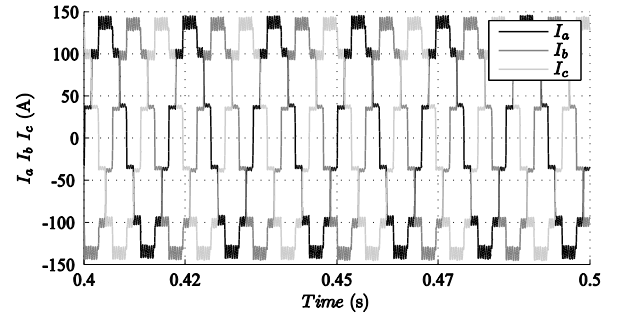


Figure 6: Input currents for one end-point charging.

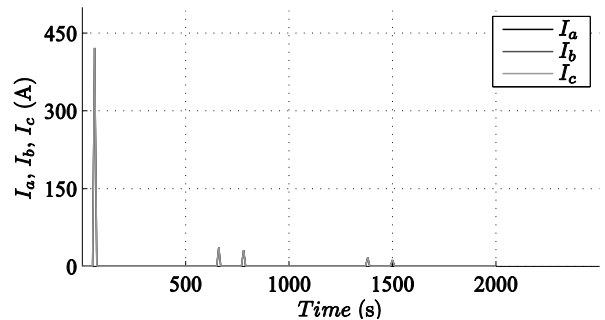
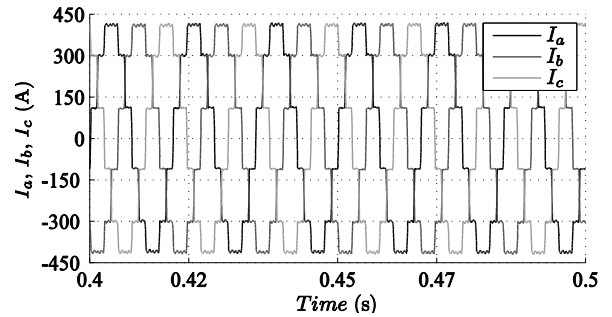


Figure 7: Input currents for three fast charge end-points charging at same time (a), and its harmonics (b).

4 Energy Storage Element Viability Study

In a modular system with more than one end-point for fast charge, which consumes high power from the distribution grid, the presence of an energy storage element is important to reduce the energy consumption during peak hours.

There are some points to be considered in order to make an analysis in order to install or not a battery bank element. The first one is how electricity will be charged, because each electricity company has his rules. Other point to be considered is where the system will be installed. In addition, a third point to be considered is the battery bank costs and number of cycles.

4.1 Electricity Tariff Plans

The power billing is basically performed in Brazil according to consumer group voltage range [19]. For a fast charge station with an input voltage of 13.8 kV, it is categorized in sub group A4 (voltages from 2.3kV to 35kV). For this voltage level, the electricity can be billed in three different plans, as chosen by the electricity consumer. Each electricity plan should be analysed in a scenario of consumption, demand and climate season. The most detailed and complete electricity plan is the *blue tariff plan*. This tariff plan is composed by a sum of: electric power consumed in peak hours, electric power consumed off-peak, contracted demand on peak, contracted demand off-peak, exceeded demand on peak hours plus exceeded demand off-peak. Peak hours correspond 3 hours of national maximum energy utilization, between 18h and 21h (6p.m. to 9 p.m.). Further, the concept of demand is the drained active power from the grid in an instating measurement. For example: a house has 25kW of equipment, in every 15 minutes, the company performs a power measurement, if all the electronics are turned on, the demand will be

25kW. In this billing type, a value of maximum month demand is contracted. In this case, if a user connects more power than the demand determined by the contract, he will pay the exceeded demand. The exceeded demand tariff is 3 times more than normal demand tariff. Simplifying, total electricity bill will be equals to the sum of $P_{CONSUMPTION} + P_{DEMAND} + P_{EXCEED}$, that each term is explained in equations (1),(2) and (3).

The tariff prices are determined by a Brazilian regulatory institution (ANEEL) [20], of each tariff are presented on

Table 3 and Table 4 in American dollars. In recent days, 1 dollar is about to 4 reals. In addition, these tariffs do not include federal and state taxes.

Table 3 – Demand Tariff.

Blue – Demand Tariff (US\$/kW)			
Peak	Exceed Peak	Off-Peak	Exceed Off-Peak
5.29	15.87	3.65	10.95

Table 4 – Consume Tariff

Blue – Consume Tariff (US\$/kWh)	
Peak	Off-Peak
0.12087	0.08202

In resume, the demand and consume tariff price on peak is higher than in other hours, reducing the necessity of energy from the grid on peak gives a cheaper bill. The exceeded demand tariff is 3 times more expensive than the normal tariff, so it is better to do not connect more power on the grid on peak hours.

$$P_{CONSUMPTION} = \text{Peak Hours Consumption Tariff} \cdot \text{Peak Hours Consumption Measured} + \text{Off-Peak Hours Consumption Tariff} \cdot \text{Off-Peak Hours Consumption Measured} \quad (1)$$

$$P_{DEMAND} = \text{Peak Demand Tariff} \cdot \text{Peak Contracted Demand} + \text{Off-Peak Demand Tariff} \cdot \text{Off-Peak Contracted Demand} \quad (2)$$

$$P_{EXCEED} = \text{Peak Exceed Tariff} \cdot (\text{Peak Measured Demand} - \text{Peak Contracted Demand}) + \text{Off-Peak Exceed Tariff} \cdot (\text{Off-Peak Measured Demand} - \text{Off-Peak Contracted Demand}) \quad (3)$$

4.2 People and Vehicles Flux in a Center Mall

A modular fast charge system is proposed to be installed in places that have a great flux of vehicles and people. For example, parking lots of a mall center, working centers and electric taxis places. In this study, a parking lot a shopping center is considered, because it has a great movement of cars and people. Accordingly to a study that counted the number of vehicles that entered and left in a mall parking lot, during a day, the highest occupation is from 18h to 21h [21].

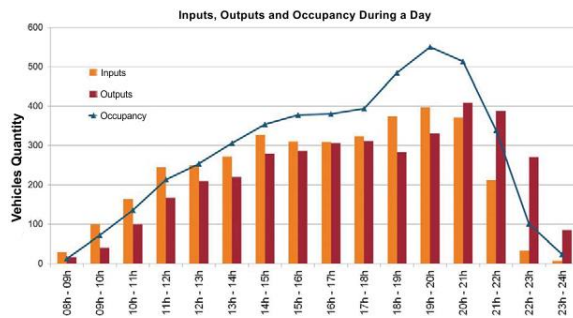


Figure 8 – Occupancy rate in a mall [21].

4.3 Battery Number of Cycles

In order to receive back the initial investment in a battery pack, it should have a large number of cycles. Recent model of lithium batteries LiFePO_4 presents a maximum number of cycles that depends on factors as temperature, charge and discharge rate, and charging profile. A slow charge can influence for a highest number of cycles. Many research studies try to explain and predict the number of cycles for lithium batteries [22], [23]. Anseán, D. et al. presents in [24], [25] an study about number of cycles that a LiFePO_4 can have until it reaches a depth of discharge (80% of SOC). He shows that this type of battery can achieve about 5000 cycles, either for 0.25C charge rate or for 4C charge rate, as shown in figure 9.

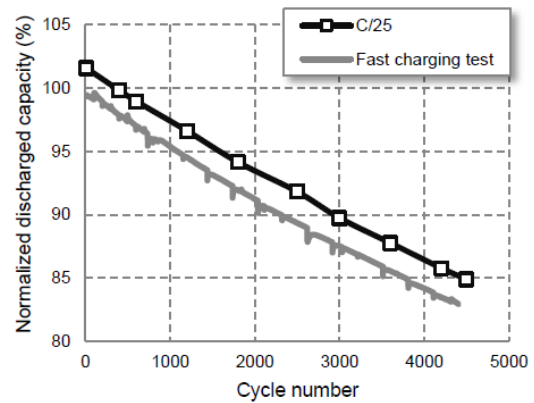


Figure 9 - Number of cycles for a fast and a slow charge[25].

4.4 Viability Study

After a brief explanation about tariffs and vehicle frequency in a mall, it is ease to realize that peak hours considered by the electricity company are the same maximum occupation hours of a mall. Therefore, it is possible to use energy storage element to reduce consumption in peak hours. In this analysis, it is considered vehicles fast charging during 3 hours (from 18h to 21h) in 10 end-points simultaneously. Considering that each end-node drains 60kW, these vehicles will uses a maximum power expected of 600kW during 3 hours, 1800kWh. For this case, an instantaneous power will be 600kW, so the contracted demand should be 600kW, if the demand goes further than 600kW, the exceeded demand cost will be 3 times higher. Consequently, an energy storage system can supply energy to the vehicles during peak hours, and recharge after mid-night when no vehicle is connected, reducing contracted demand on peak hours.

In a first analysis, the energy storage element is not used, the contracted demand is decreased in steps of 60kW (one end-point) from 600kW to 540kW, to 480kW and so on until reaches 0kW. Reducing contracted demand, the energy costs will be higher due to exceeded demand price. A month cost is calculated for each situation in table 5. The second part of this study is inserting a battery pack of an equivalent capacity necessary to supply during 3 hours one end-point and so on. For example, in the second case of table 5 the contracted demand is reduced from 600 to 540 kW, so one end-point should be supplied by a battery pack in order to avoid exceeded demand. In addition, this battery pack should be design to provide enough energy during 3 hours, having capacity of 180kWh.

Table 5 - Month electricity cost with no energy storage element.

Contracted Demand	Peak Demand	Pymnt Peak (US\$)		Month (3h*30d)	Pay. Cons. (US\$)	Month
Demand	Peak	Demand	Exceeded Demand	Consume (kWh)	Peak	Total (US\$)
600	600	3,174.00	-	54000	6,526.98	9,700.98
540	600	2,856.60	952.20	54000	6,526.98	10,335.78
480	600	2,539.20	1,904.40	54000	6,526.98	10,970.58
420	600	2,221.80	2,856.60	54000	6,526.98	11,605.38
360	600	1,904.40	3,808.80	54000	6,526.98	12,240.18
300	600	1,587.00	4,761.00	54000	6,526.98	12,874.98
240	600	1,269.60	5,713.20	54000	6,526.98	13,509.78
180	600	952.20	6,665.40	54000	6,526.98	14,144.58
120	600	634.80	7,617.60	54000	6,526.98	14,779.38
60	600	317.40	8,569.80	54000	6,526.98	15,414.18
0	600	-	9,522.00	54000	6,526.98	16,048.98

It was calculated the total electricity cost in a month, for each case until all battery pack substitute grid energy during peak hours.

There is a significant difference in the electricity bill, in each case, between a system without energy storage and with energy storage. This difference is presented in table 7, and using the amount saved for one year with a battery bank, it will be possible to invest in this battery system.

In this part of analysis, a battery pack is recharged in slow charge after mid-night and on peak hours it gives energy back for a vehicle fast charge. Doing this cycle once a day, a battery will work at least 3650 cycles for 10 years, less than the necessary to reach DoD. As a result, it is considered that a battery stay in a good life for ten years doing one cycle a day. Therefore, based on commercial battery packs a 24kWh battery costs about US\$ 7,000, or 1kWh = 292US\$ [26][27]. Hence, a basic investment in an 180kWh will be approximately US\$ 50,400, using the annual difference from exceeded demand (case 2 from table 7) this investment becomes rentable after 4 years. In other words, payback time will be in 4 years. In addition, an investment in a modular energy storage system of 180kWh will have a net present value of US\$ 77,524.44 after 10 years, with a 33% internal rate of return.

The simulation of a bigger battery bank capable to supply 5 end-points during peak hours (900kWh capacity) brings an investment of US\$252,000, a net present value of US\$ 387,622.19, with a 33% internal rate of return. For this analysis, the does not matter the size of the battery pack, the internal rate of return will be the same for all cases, the only change will be in the net present value which depends on the initial investment amount in a battery pack.

Table 6 - Electricity costs with energy storage element.

Energy Storage	Total	Contracted	Used Demand	Pymnt Peak (US\$)		Month
Capacity (kWh)	Cost (US\$)	Demand Peak (kW)	Peak (kW)	Demand	Exceeded Demand	Total (US\$)
0	0	600	600	3,174.00	0	9,700.98
180	50,400.00	540	540	2,856.60	0	9,255.92
360	100,800.00	480	480	2,539.20	0	8,810.85
540	151,200.00	420	420	2,221.80	0	8,365.79
720	201,600.00	360	360	1,904.40	0	7,920.72
900	252,000.00	300	300	1,587.00	0	7,475.66
1080	302,400.00	240	240	1,269.60	0	7,030.59
1260	352,800.00	180	180	952.20	0	6,585.53
1440	403,200.00	120	120	634.80	0	6,140.46
1620	453,600.00	60	60	317.40	0	5,695.40
1800	504,000.00	0	0	0.00	0	5,250.33

For all analysis, it was considered an annual increase of 12% in power tariff and an interest rate of 10%.

Table 7 – Difference in monthly electricity bill with and without an energy storage element.

Month Energy Cost (US\$)			
Case	Without Energy Storage	With Energy Storage	Difference (US\$)
1	9,700.98	9,700.98	0
2	10,335.78	9,255.92	1,079.87
3	10,970.58	8,810.85	2,159.73
4	11,605.38	8,365.79	3,239.60
5	12,240.18	7,920.72	4,319.46
6	12,874.98	7,475.66	5,399.33
7	13,509.78	7,030.59	6,479.19

5 Conclusion

The proposed system can help site owner to invest in a fast charger station with a low up-front investment and with possibilities to add end-points as needed. The modular system is based in a twelve pulse non-controlled rectifier giving a DC bus, a PWM buck interleaved converter controlling the fast charge in end-nodes and an energy storage element composed with lithium batteries to reduce energy demand on peak hours. The system can be used in urban areas such as mall, working centers and parking lots.

A battery pack model was used in simulations to give better results on converter responses. A current balance in buck inductors was shown using a PI current control. Moreover, input current was shown with a high PF and low THD, however, it should be added an active filter in the first stage to reduce high order harmonics as required by international standards.

Furthermore, a study about the viability of energy storage element was presented giving an idea that it could reduce energy demand in peak hours. With all the analysis it is possible to conclude that the element gives a 33% internal rate of return and it does not depend on the size of the batteries. In other words, it is viable to be inserted in a modular fast charge station system on conditions of a higher electricity price on peak hours than off-peak. Moreover, the payback time of this storage element is 4 years.

In addition, future studies should be done to determine how will be the converter to control the energy storage element (only one or modular) and the viability including all electronic converters costs.

References

- [1] T. W. Ng, J. F. Liu, and K. W. E. Cheng, "A Review of International charging coupler Standards and its availability in Hong Kong."
- [2] C. Wheelock and J. Gartner, "Electric Vehicle Charging Equipment," 2010.
- [3] T. Aneqawa, "Green Car Congress: Tokyo Electric Power Licenses Aker Wade to Build Level III Fast Chargers." [Online]. Available: <http://www.greencarcongress.com/2010/01/akerwade-20100115.html>. [Accessed: 24-Mar-2016].
- [4] D. Aggeler, F. Canales, H. Zelaya - De La Parra, A. Coccia, N. Butcher, and O. Apeldoorn, "Ultra-fast DC-charge infrastructures for EV-mobility and future smart grids," *IEEE PES Innov. Smart Grid Technol. Conf. Eur. ISGT Eur.*, pp. 1–8, 2010.
- [5] Standards Coordinating Committee 21, "IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems," 2004.
- [6] M. Mcgranaghan, S. Member, G. Beaulieu, and S. Member, "Update on IEC 61000-3-6 : Harmonic Emission Limits for Customers Connected to MV , HV , and EHV," pp. 1–4.
- [7] I. Barbi, *Power Electronics*, 6th ed. Florianópolis, BR, 2006.
- [8] I. Barbi, *Design of Switching Power Supplies*, 1st ed. Florianópolis, BR.
- [9] R. R. Duarte, M. M. Jacques, A. J. Bombardieri, and M. A. DallaCosta, "Development of a design methodology for buck converters," *XXV Congr. Reg. INICIAÇÃO CIENTÍFICA E TECNOLÓGICA EM Eng. – CRICTE 2013*, pp. 11–14, 2013.
- [10] B. T. Hegarty, "Benefits of multi-phasing buck converters," *Semiconductors*, no. November, pp. 1–4, 2007.
- [11] A. C. Schittler, D. Pappis, A. Campos, and M. a. D. Costa, "High power HID lamps electronic ballast based on the interleaved buck converter," *XI Brazilian Power Electron. Conf.*, pp. 997–1003, 2011.
- [12] A. C. Schittler, "Analysis and Design of a Buck Interleaved Converter for High Power Pressure discharge lamps," Federal University of Santa Maria, 2012.
- [13] Y. Zhang, P. E. Bagnoli, and E. Franchi, "Theoretical Design of Compact Multi-phase Interleaved Buck DC-DC Converter for Automotive Power Applications," *Int. Symp. Power Electron. Electr. Drives, Autom. Motion*, pp. 1324–1329, 2012.
- [14] J. Zhang, "Bidirectional DC-DC Power Converter Design Optimization , Modeling and Control," Virginia Polytechnic Institute and State University, 2008.
- [15] H. Pinheiro, G. Balen, and L. Schuch, "Modular Fast Charger for Electric Vehicles," no. December, pp. 1–7, 2015.
- [16] S. Dusmez, A. Cook, and A. Khaligh, "Comprehensive analysis of high quality power converters for level 3 off-board chargers," *Veh. Power Propuls. Conf. (VPPC), 2011 IEEE*, pp. 1–10, 2011.
- [17] M. Chen and G. a. Rincón-Mora, "Accurate electrical battery model capable of predicting runtime and I-V performance," *IEEE Trans. Energy Convers.*, vol. 21, no. 2, pp. 504–511, 2006.
- [18] L. Lam, "A Practical Circuit-based Model for Li-ion Battery Cells in Electric Vehicle Applications," *INTELEC, Int. Telecommun. Energy Conf.*, pp. 1–9, 2011.
- [19] J. C. de S. Guedes and J. C. R. Aguiar, "Electricity Tariff Manual," Rio de Janeiro, RJ, 2011.
- [20] ANEEL, "Homologatory Resolution nº 1.879, April 14, 2015," 2015.
- [21] G. G. Pereira, "Mall Center Car Attraction Model," São Paulo, 2011.
- [22] N. Omar, M. Abdel, Y. Firouz, J. Salminen, J. Smekens, O. Hegazy, H. Gaulous, G. Mulder, P. Van Den Bossche, and T. Coosemans, "Lithium iron phosphate based battery – Assessment of the aging parameters and development of cycle life model," *Appl. Energy*, vol. 113, pp. 1575–1585, 2014.
- [23] S. Surampudi, S. R. Narayanan, and E. P.

- Plichta, "High Power, Gel Polymer Lithium-Ion Cells with Improved Low Temperature Performance for NASA and," pp. 3–6.
- [24] D. Anseán, M. González, J. C. Viera, V. M. García, C. Blanco, and M. Valledor, "Fast charging technique for high power lithium iron phosphate batteries: A cycle life analysis," *J. Power Sources*, vol. 239, pp. 9–15, 2013.
- [25] D. Anseán, J. C. Viera, M. González, V. M. García, J. C. Álvarez, and J. L. Antuña, "High power LiFePO 4 cell evaluation: fast charge, depth of discharge and fast discharge dependency," vol. 6, pp. 1–10, 2013.
- [26] J. O'Dell, "Nissan Prices Leaf Battery Replacement at \$5,500 | Edmunds.com." [Online]. Available: <http://www.edmunds.com/car-news/nissan-prices-leaf-battery-replacement-at-5500.html?SID=ikg4609qdk0115i0001ol&kw=flexibletexttool&PID=6160237&AID=10364102&mktid=cj260233&mktcat=affiliates>. [Accessed: 25-Mar-2016].
- [27] J. Cole, "Nissan Prices LEAF Battery Replacement at \$5,499, New Packs More Heat Durable." [Online]. Available: <http://insideevs.com/breaking-nissan-prices-leaf-battery-replacement-5499-new-packs-heat-durable/>. [Accessed: 25-Mar-2016].

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