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doi:10.15199/48.2023.08.44

Design and analysis performances of a 3.6 kW new three-phase charger based on synchronous buck converter with low harmonic distortion for urban cars

***Abstract**. This paper deals with design and simulation of a proposed charger topology based on a three-phase PWM rectifier, to ensure a good power transfer, and in the same time, guarantee a reduced battery recharging time comparing to the conventional charger based on a single-phase charger with a diode bridge rectifier. To achieve this goal, a simulation of this proposed charger was carried out under Matlab/Simulink and a linear control was implemented in the AC side to maximize the transfer of active power using a PWM rectifier. And a control battery charging using the constant current constant voltage algorithm was used in a synchronous buck converter in the DC side. To improve its performances, a comparison was made between the two topologies in term of the quality of input electrical energy and in term of recharging time.*

***Streszczenie.** Artykuł dotyczy zaprojektowania i symulacji proponowanej topologii ładowarki opartej na prostowniku trójfazowym PWM, aby zapewnić dobry transfer mocy, a jednocześnie zagwarantować skrócony czas ładowania baterii w porównaniu z konwencjonalną ładowarką opartą na jedno- ładowarka fazowa z diodowym mostkiem prostowniczym. Aby osiągnąć ten cel, przeprowadzono symulację proponowanej ładowarki w środowisku Matlab/Simulink i zaimplementowano sterowanie liniowe po stronie prądu przemiennego, aby zmaksymalizować transfer mocy czynnej za pomocą prostownika PWM. Natomiast w przekształtniku synchronicznym po stronie DC zastosowano sterowanie ładowaniem akumulatora algorytmem stałoprądowym i stałonapięciowym. Aby poprawić jego wydajność, dokonano porównania między dwiema topologiami pod względem jakości wejściowej energii elektrycznej i czasu ładowania. (**Projektowanie i analiza wydajności nowej trójfazowej ładowarki o mocy 3,6 kW opartej na synchronicznej przetwornicy buck z niskimi zniekształceniami harmonicznymi do samochodów miejskich**)*

Keywords: Urban car, Fast charging, Li-ion battery, DC-DC converter, PWM rectifier, Linear control.
Słowa kluczowe: Samochód miejski, Szybkie ładowanie, Akumulator litowo-jonowy, Przetwornica DC-DC, Prostownik PWM, Sterowanie liniowe

1. Introduction

Transportation system electrification could effectively relieve the energy dependence on fossil fuels and gradually reduce the greenhouse gasemissions [1].

The large-scale penetration of EVs represents an opportunity for growing business, but at the same timea challenge in terms of power quality [2]-[3]. Promising first steps by the Citroën AMI, the 100% electric urban vehic le developed by Citroën and produced in Kenitra, Morocco in the factory of the Stellantis group, owner of the Peugeot, Citroën , Opel, and Fiat brands.

In the same context, Barid Al-Maghrib launches the circulation of 225 electric vehicles exclusively dedicated to the modernization and expansion of its mail-parcel distribution network. Designed by Stellantis Kenitra, Morocco especially for Barid Al-Maghrib office, following an agreement signed in October 2020. These electric vehicles of the Citroën Ami type are suitable for daily distribution activity. They have a range of 75 km, while the full charge does not exceed a duration of 3 hours. A real springboard to a new era, these vehicles meet Barid Al-Maghrib's objective of adopting eco-mobility in order to help reduce transport-related CO2 emissions and ensure clean and sustainable mobility.

To follow the development of the marketing of electric vehicles, it is imperative to think about further developing the power of the electrical network and in particular the establishment of fast charging points for more fluidity. To follow the development of the marketing of electric vehicles, it is imperative to think about further developing the power of the electrical network and in particular the establishment of fast charging points for more fluidity. the charging points can be a charging station with single-phase or three-phase alternating current outlets or a high-power station with an integrated charger but with a direct current outlet.

AC charging technologies do not directly charge the battery EVs, but instead charge the battery via the on-board charger (OBC) that feeds the battery. In these technologies, the conversion unit is placed inside the vehicle, which increases the weight of the overall system. They arecommonly charged in either single-phase (1φ) on-board (OB) slow charging [4]-[5] or three-phase (3φ) OB fast charging systems [6]. One of the most common 1ϕ OB slow charging technologies, i.e., level 1 with an output power of about 2 kW. Compared to the 1ϕ OB slow charging technologies, the 3ϕ OB fast charging technologies [7] can provide a faster charging capability because of their medium power rating about 20 kW [8]. This urban vehicle recharges via a single-phase AC source and takes more than 3 hours of recharges for the total recharge of the battery. On-board battery charging is one such technology that can reduce end user range anxiety by allowing for the vehicle's battery to be charged from any available power outlet. [9]. There are several types of connector which are adapted with the type of charger, current profile and station power. Two types of charging connector protocols are CHArge de MOve (CHAdeMO) and Combined Charging System (CCS), and they have different ranges of battery voltage. [10].

To overcome the drawback of single-phase charger in term of recharging time, a three-phase charger with PWM rectifier is proposed to make it more competitive in the market. However, some adaptations are necessary in terms of the car connector to receive a three-phase source, size of the onboard charger, and more efficient thermal management. The proposed charger is composed of an AC-DC stage of PWM rectifier with which used in various applications, such as telecommunication power systems and wind turbine systems. [11]. While the DC-DC conversion stage based on synchronous buck topology piloted by the constant current constant voltage algorithm to recharge the vehicle battery.

The "constant-current and constant-voltage" charging mode is a widely used charging profile, in which a battery is charged with a constant current until a voltage limit is reached and then a constant-amplitude voltage is applied until the current reduces to a certain value, to charge the battery as fully as possible [12]. The back-end DC-DC converter is usually used to realize CC and CV [13].

However, the main challenge with such a control structure is to provide a smooth transition between the modes [14].

So, using appropriate control strategies and PWM modulation technology, it could realize that AC side current real-time track AC side voltage, the power factor can reach close to unity, and it can overcome the impact that the traditional rectifier circuit on the power grid and other equipment. [15]- [16]. For battery charging applications greater than 400 W, the dominant architecture is a two-stage approach with cascaded PFC switching ac-dc and isolated dc-dc converters [17]. PFC converters can operate in discontinuous conduction mode (DCM) [18]-[19], boundary conduction mode (BCM) [20]- [21], or continuous conduction mode (CCM) [22]. Thus, PFC technique impact on the voltage besides current waveforms are sinusoidal by adjusting circuits to allow advanced techniques. [23]. And to make the charging process more safe, it is important to mention that high voltage systems should be isolated (that is the power disconnected and secured In such way that it cannot be inadvertently switched back on).[24].

This article is structured as follows: Section 2 presents the general description of the system and the block diagram. design of the power stages part and the control of the whole system. Section 3 presents the results of the simulation and the comparison between the two chargers subject of this study.

2. Design and control of the system

2.1. Overview of the proposed topology

In this article, we propose a three-phase charger with a controlled bridge rectifier to ensure low harmonic distortion, maximize power factor and reduce the recharging time as mentionned in synoptic scheme in the Figure 1 below.

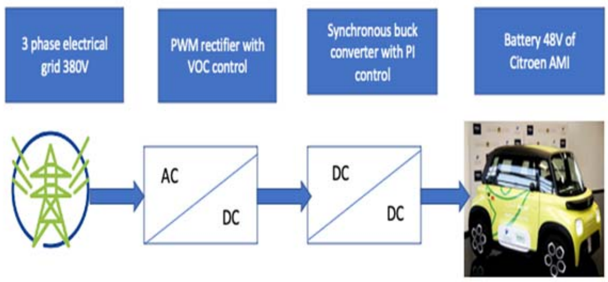

Fig 1.Overview synoptic of the proposed topology based on three phase charger

The proposed charger is composed by two parts. The first part is AC/DC conversion based on a three phase PWM rectifier, with input current and DC bus output voltage regulation. As for the second, it is composed by a DC/DC converter stage to step down the DC bus voltage to the level of the battery voltage. This DC/DC stage is a synchronous buck converter topology which used in order to slightly reduce the voltage drop caused by the switching diode in the ordinary buck converter topology. And in term of regulation in this DC/DC side, it is ensured by two loops using the constant current constant voltage algorithm (CC-CV). One to maximize the charging current and the other to maintain the battery voltage once the nomial voltage of the battery is reached. While the other is for the output voltage to maintain it at the level of the load.

2.2. Design and control of the AC-DC stage

As known, the three phase rectifiers have become widely used lately due to its effective control of active and reactive power to ensure a high-power transfer from the grid to the load. In fact, this technique consists of supplying the load through a controlled PWM three-phase bridge with high efficiency and a high-power factor as well as low distortion in term of harmonics. The working principle is based on controlling the switches, over two loops, in such a way as to have a sinusoidal current and with an almost zero phase shift with line voltage. The first one, is for the input current, to control the shape of the signal and phase shift with the input voltage and the other is for the output voltage in order to maintain it at the level of the load.

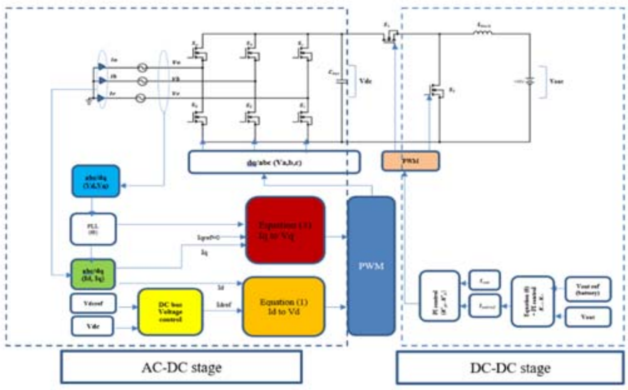

Fig 2.Overview scheme of the proposed three phase charger

To control three phase PWM rectifiers, two parameters must be controlled. It is about the quadratic and direct components of input current, to align it with the network voltage. Thus to cancel the phase shift between them. While the second parameter, is controlling the DC bus voltage, to maintain a constant voltage at the input of the DC-DC converter. In fact, to avoid a disturbance at the level of the battery voltage.

The control in the regulation loops is based on the park and Clark transformation techniques to facilitate the control of a three-phase system by using only two-phase system. The quadratic and direct components of line voltages, respectively, V_d and V_q are obtained from the Park transform while the angle between line current and line voltage is obtained from the phase locked loop (PLL) technique as shown in Figure 3. And the same technique is used to get the quadratic and direct components of line current respectively I_d and I_q form line currents. To cancel the phase difference between the current and the voltage, it is necessary to cancel the reactive power in grid side. Thus, the quadratic component of current must be canceled. After calculating V_d and V_q through equations (1), (2) and (3), it is necessary to use the inverse transformation of Clark and Park to reconstruct the three-phase voltage signals. These signals plays as references for the PWM block in order to generate the control pulses of the 6 switches to the three phase rectifier mentioned in the Figure 2. The numerical values of all PI controllers are obtained by acting on response time. Thus, their values are mentioned in Table 2 below.

$$V_q^* = I_q.\left(K_{pi} + \frac{K_{ii}}{s}\right)$$

$$I_d^* = \left(V_{dcref} - V_{dc}\right).\left(K_p + \frac{K_i}{s}\right)$$

$$V_d^* = I_d^*.\left(K_{pi} + \frac{K_{ii}}{s}\right)$$

This stage recharges the battery of the electric car through the synchronous buck converter. The synchronous buck is a DC/DC converter which adapts the AC-DC bus voltage of the first stage to the battery voltage of the urban electric car. The regulation of this converter is ensured by two loops for controlling the load current and maintaining the voltage as mentioned in Figure 4. In the first phase, the current is at its maximum level until the battery approaches its nominal voltage, the current begins to drop and the voltage is maintained until the end of the recharging operation. The advantage of using the synchronous buck converter is the two switches, with a frequency commutation of 20kHz to reduce the losses, instead of one switch in the classic topology. This stage is powered through a DC bus from the controlled three-phase rectifier bridge. the stage must ensure a power transfer of 3.6kW at a battery output voltage of 48V. Therefore, the definition of the parameters of the inductance, the capacitance, the duty cycle of the converter is based on these latter parameters mentioned above.

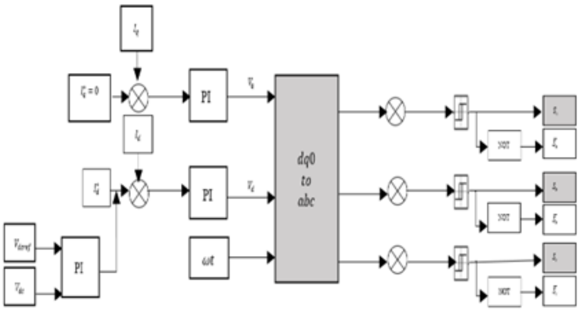

Fig 3. Control blocks of AC-DC side

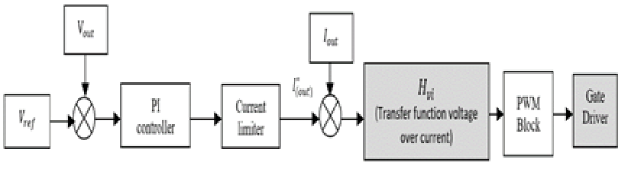

Fig 4. Control blocks of DC-DC side

a. Inductor calculation

The calculation of the inductor is crucial. its definition depends on the input voltage, output voltage, switching frequency and ripple current. Its formula is given by the following equation (1).

(1) $$L_{buck} = \frac{V_{out} \cdot (V_{dc} - V_{out})}{\Delta I_{out} \cdot f_s \cdot V_{dc}}$$

Where: L_{buck} – the inductance of the primary inductor of the dc/dc converter [H], V_{out} – the output voltage of battery [V], V_{dc} – the dc bus or input voltage [V], f_s – the switching frequency of the dc – dc converter [Hz], ΔI_{out} – the ripple of inductor current [A]

b. Duty cycle calculation

The duty cycle makes it possible to determine the duty cycle to be applied in order to have the desired voltage at the output. Its formula is given by the following equation.

(2) $$D_{buck} = \frac{V_{out}}{V_{dc}}$$

c. Control parameters calculation

Thus, the power stage is established, the definition of the parameters of the regulation loop depends on the small signals model of the synchronous buck converter [25]-[26]. Since the battery is a voltage source, the model becomes a first-order low-pass filter. the parameters of the two current and voltage loops are calculated on the basis of the frequency response for a cut-off frequency of 2 kHz for the external voltage loop and 200 Hz for the internal current loop.

To realize the regulation of the dc-dc converter. We need two control loops. An inner current loop and an outer voltage loop. The inner current loop maintains the current in the battery while the outer voltage loop maintains a constant voltage as the current decreases until the battery reaches its nominal voltage. The first current loop is a transfer function between voltage and current while the second is a transfer function between current and duty cycle. since the switching frequency is 20kHz, the cut-off frequency of the current loop is 2kHz and it is equal to 200Hz for the second voltage loop. These values of cut-off frequencies which help us to choose the coefficients of correction of the static gain and the static error to have a stability of the two loops shown in Figure 5. To realize the control of the control loop of the dc-dc converter, two loops to control the current and the voltage are needed. The first loop begins with a comparison between the measured voltage and the reference voltage through, the resultant enters a PI-based control block. Which contains the transfer function between the output voltage and generates a reference current. This reference current is also compared with the measured current and passed through a PI-based transfer function.

(3) $$\boldsymbol{H_{vd} = H_{vd_0} \cdot \frac{1}{sL_{buck}/r_{L_{buck}} + 1}}$$

(4) $$H_{id} = H_{id_0} \cdot \frac{1}{sL_{buck}/r_{L_{buck}} + 1}$$

Where: H_{vdo} – static gain of Hvd which equal to V_{out}/D; L_{buck} - - the inductance of the primary inductor of the dc – dc converter [H]; r_{Lbuck} – series resistance of primary inductor [Ω]

(5) $$H_{vi} = \frac{H_{vd}}{H_{id}}$$

Where: H_{vi} – the transfer function of voltage over current; H_{vd} – the transfer function of voltage over duty cycle; H_{id} – the treansfer function of current over duty cycler

To determine the parameters of the PI correctors of the two regulation loops, it is necessary to establish the small signal model of the dc-dc converter in order to define the transfer function which links the current to the voltage. Thus deduce, according to the chosen cut-off frequency and the phase margin, the stable response.

2. Simulation results and discussion

To defend our proposition, we made a comparison between the two charger topologies. Single-phase charger with diode bridge shown in Figure 5 and three-phase charger with PWM rectifier controlled by voltage-oriented control technique in Figure 6. The objective behind this comparison is to show the rapidity of recharging of the battery of the urban vehicle, and in the same time, with a maximum transfer of active power. The discussion of the results be-tween the two charger configurations is made based on the recharge time factor and the harmonic distortion factor (THD). The single-phase charger, currently used, for the urban vehicle is composed by an uncontrolled rectifier based on diodes with a controlled DC-DC converter. The objective behind this simulation, is to simulate the battery recharge time on a single-phase socket while looking at the same time the quality of electrical energy absorbed on the electrical grid. To achieve this goal, a Matlab /Simulink model was established as mentioned in Figure 5.

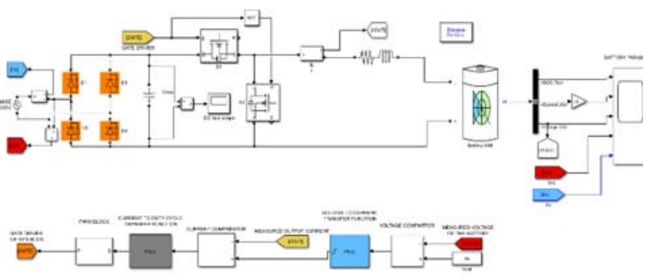

Fig 5. Matlab/Simulink model of single phase charger

The parameters of the various components of the charger as well as the parameters of the regulation loop are specified in Table 1 below.

Tab 1. Parameters of single-phase charger model

Parameters of single-phase charger	Symbol	Value
RMS Grid Voltage	V_{sp}	220 V
Output voltage	$V_{sp_{out}}$	48 V
Output power	$P_{sp_{out}}$	1.8 kW
Duty cycle	D	21%
Buck inductor DC side	$L_{sp_{buck}}$	0.5 mH
Series resistance of Buck inductor DC side	$r_{L_{buck}}$	0.25 mΩ
Proportional gain of voltage loop DC side	K_{pvs}	0.53
Integral gain of voltage loop DC side	K_{ivs}	0.17
Proportional gain of current loop DC side	K_{pis}	11.89
Integral gain of current loop DC side	K_{iis}	3.89

In the following Figure 6, the proposed charger is made under Matlab/Simulink. The charger is composed by three phase bridge rectifier controlled by the voltage oriented control method. And associted with synchronous dc-dc converter controlled with two PI controllers for the inner current loop and outer volatge loop.

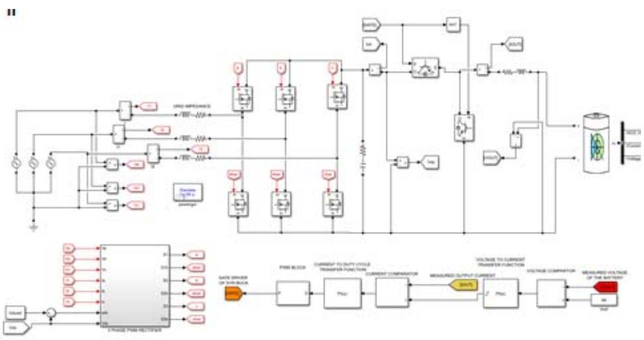

Fig 6. Matlab/Simulink model of the proposed three phase charger with PWM rectifier

The parameters of the various components of the three phase charger as well as the parameters of the regulation loop are specified in Table 2 below.

Tab 2. Parameters of three phase charger model

Parameters of three phase charger	Symbol	Value
RMS Grid line to line Voltage	V_{abc}	380 V
Output voltage	$V'_{sp_{out}}$	48 V
Output power	$P'_{sp_{out}}$	3.6 kW
Duty cycle	D'	11%
Proportional gain components of current loop AC side	K_p	0.27
Integral gain of components of currents loop AC side	K_i	1.48
Proportional gain of voltage loop AC side	K_{pi}	6
Proportional gain of voltage loop AC side	K_{ii}	128.5
Buck inductor DC side	$L'_{sp_{buck}}$	9.3 mH
Series resistance of Buck inductor DC side	$r_{L_{buck}}$	0.25 mΩ
Proportional gain of voltage loop DC side	K_{pvs}	0.53
Integral gain of voltage loop DC side	K_{ivs}	0.21
Proportional gain of current loop DC side	K_{pis}	11.58
Integral gain of current loop DC side	K_{iis}	2.98

According to Figure 7and Figure 8, we can observe in simulation response, that the total harmonic distortion(THD) of current exceeds 37% in the single phase topology, comparing to the three-phase charger in Figure 9 and Figure 10, which does not exceed 2% on the low voltage electrical grid. The presence of high rates at level of 37%, exceeding the threshold of 5% according to EN 50160 standard, of odd order harmonics makes the single phase charger less competitive comparing to the level of 2% shown in the proposed PWM rectifier three phase charger.

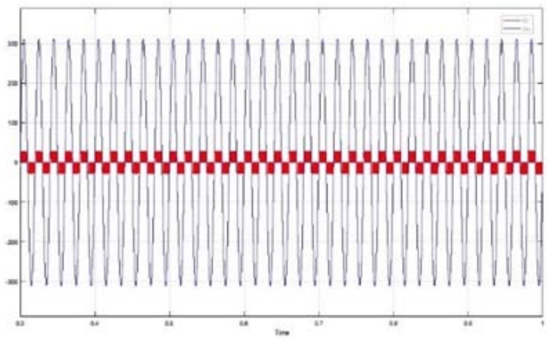

Fig 7. Input current and input voltage in single phase charger

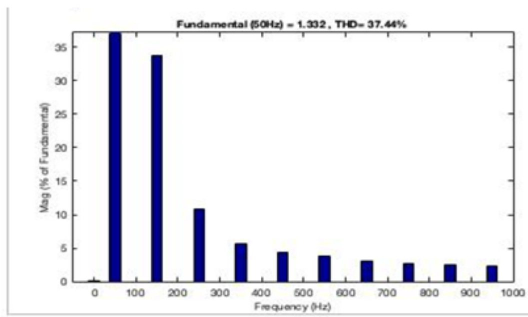

Fig 8. FFT analysis of input current in single phase charger

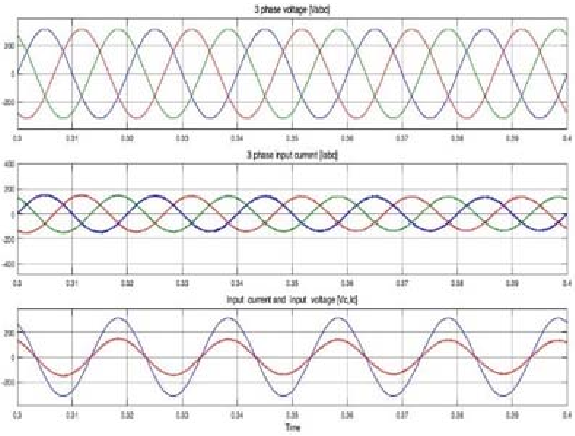

Fig 9. Input current and input voltage in the three phase charger

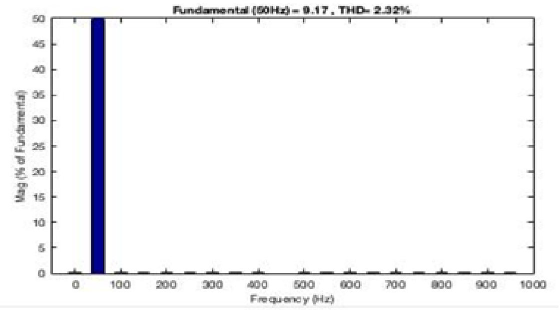

Fig10. FFT analysis of input current in three phase charger

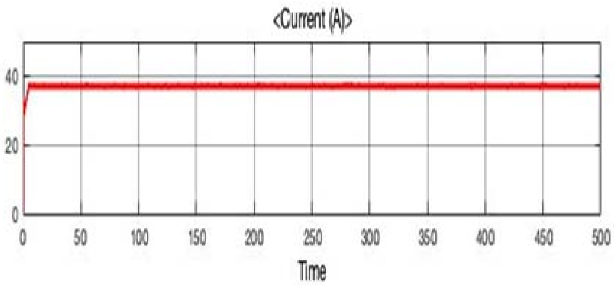

Fig 11. Output current under single phase charger

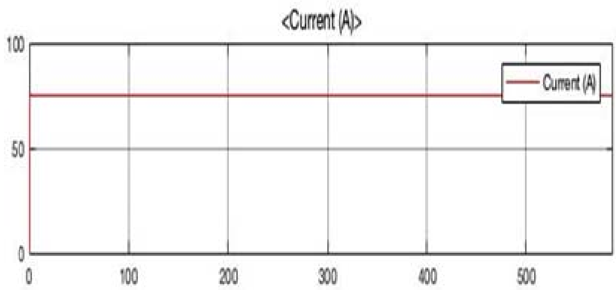

Fig 12. Output current under three phase charger

Otherwise, we launch the simulation for 10min at battery's state of charge of 90%. We observe that, the state of charger of the battery does not exceed 95%(Figure 14) under 37A (Figure 11) in conventional 1.8 kW single-phase charger comparing to the 3.6kW PWM three phase rectifier, under 74A (Figure 12) which reaches 100% and completely charge the battery (Figure 13). Then, we can deduce, using theoretical extrapolation, on the total capacity of the battery of 115Ah, that the single-phase 1.8kW charger takes more than 3 hours while the three-phase charger with PWM rectifier only takes less than 1h30min. Thus a gain of 50% comparing to the conventional topology under single phase.

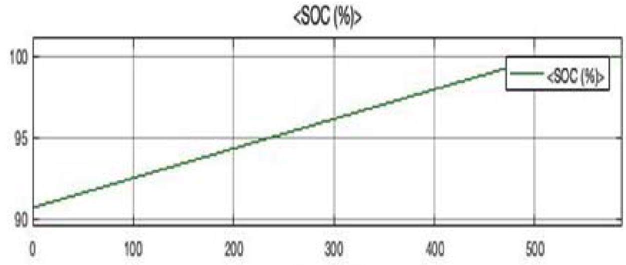

Fig 13. State of charge in three phase charger

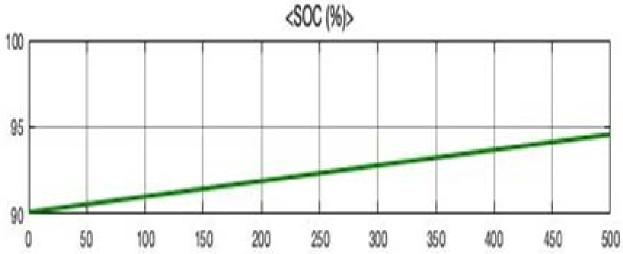

Fig 14. state of charger in single phase charger

Moreover, the voltage in the DC bus on the three-phase charger is smoother (Figure 15). Thus, showing the good regulation mode in the control of the DC bus in the three phase charger.

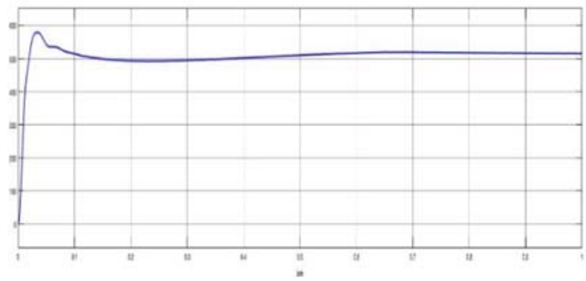

Fig 15. DC bus voltage in three phase charger

Coclusion

This article presents a proposal for fast charging of the Citroen AMI urban car which became an alternative for the Post staff in Morocco. And a real alternative for transportation in the city for the rest of users to encourage the green mobility. The proposed charger is a three-phase charger with a power level of 3.6 kW which recharges the battery in almost 85min due to an extrapolation of the results obtained to compete with the existing single-phase charger of 1.8 kW which requires 180min, i.e. a gain of 47%. This charger is composed of an AC-DC stage based on PWM rectifier to improve the quality of electrical energy whose distortion rate in current harmonics does not exceed 2% comparing the conventional single-phase charger which exceeds 37%. And to ensure charger regulation, we adopted linear PI-based control for the PWM rectifier, DC bus voltage and the synchronous buck converter. The choice of this r topology comes from its simple structure, its high power and its simple linear control. It remains to be noted that to duplicate this solution on the vehicles subject of our application some adaptations are recommended. So, an adaptation in terms of the connectors of the car, reinforcement of the cooling system and of course a three-phase source in the urban charging stations.

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REFERENCES

[1] Z. Wei, Y. Li and L. Cai, "Electric Vehicle Charging Scheme for a Park-and-Charge System Considering Battery Degradation Costs," in *IEEE Transactions on Intelligent Vehicles*, vol. 3, no. 3, pp. 361-373, Sept. 2018, doi: 10.1109/TIV.2018. 2843126.
[2 Jia Ying Yong, Vigna K. Ramachandaramurthy, Kang Miao Tan, N. Mithulananthan, A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects, Renewable and Sustainable Energy Reviews, Volume 49, 2015, Pages 365-385, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2015.04.130.
[3] L. Caro, G. Ramos, D. Montenegro, and D. Celeita, “Variable harmonic distortion in electric vehicle charging stations,” in Proc. IEEE Ind. Appl.
[4] Subotic, N. Bodo, and E. Levi, ‘‘Single-phase on-board integrated battery chargers for EVs based on multiphase machines,’’ IEEE Trans. Power Electron., vol. 31, no. 9, pp. 6511–6523, Sep. 2016.
[5] C. Shi, Y. Tang, and A. Khaligh, ‘‘A single-phase integrated onboard battery charger using propulsion system for plug-in electric vehicles,’’ IEEE Trans. Veh. Technol., vol. 66, no. 12, pp. 10899–10910, Dec. 2017.
[6] L. A. D. Ta, N. D. Dao, and D.-C. Lee, ‘‘High-efficiency hybrid LLC resonant converter for on-board chargers of plug-in electric vehicles,’’ IEEE Trans. Power Electron., vol. 35, no. 8, pp. 8324–8334, Aug. 2020.
[7] S. A. Q. Mohammed and J. -W. Jung, "A Comprehensive State-of-the-Art Review of Wired/Wireless Charging Technologies for Battery Electric Vehicles: Classification/Common Topologies/Future Research Issues," in IEEE Access, vol. 9, pp. 19572-19585, 2021, doi: 10.1109/ACCESS.2021.3055027.
[8] B. Whitaker et al., "A High-Density, High-Efficiency, Isolated On-Board Vehicle Battery Charger Utilizing Silicon Carbide Power Devices," in IEEE Transactions on Power Electronics, vol. 29, no. 5, pp. 2606-2617, May 2014, doi: 10.1109/TPEL.2013.2279950
[9] J. -W. Kim and P. Barbosa, "PWM-Controlled Series Resonant Converter for Universal Electric Vehicle Charger," in IEEE Transactions on Power Electronics, vol. 36, no. 12, pp. 13578-13588, Dec. 2021, doi: 10.1109/TPEL.2021.3072991.
[10] J. -S. Lee and K. -B. Lee, "Carrier-Based Discontinuous PWM Method for Vienna Rectifiers," in IEEE Transactions on Power Electronics, vol. 30, no. 6, pp. 2896-2900, June 2015, doi: 10.1109/TPEL.2014.2365014.
[11] J. -H. Ahn and B. K. Lee, "High-Efficiency Adaptive-Current Charging Strategy for Electric Vehicles Considering Variation of Internal Resistance of Lithium-Ion Battery," in IEEE Transactions on Power Electronics, vol. 34, no. 4, pp. 3041-3052, April 2019, doi: 10.1109/TPEL.2018.2848550.
[12] N. Heng, and Q. Yu, Enhanced control technique of PWM converter under harmonically distorted voltage conditions, Proceedings of the CSEE, vol. 32, no. 9, pp. 41-48, 2012.
[13] Praneeth Ammanamanchi Venkata, J.S. and Williamson, S.S. (2020), Analysis and design of single-stage, two-mode AC/DC converters for on-board battery charging applications. IET Power Electronics, 13: 830-843. https://doi.org/10.1049/iet-pel.2019.0777
[14] Z. W. Zhang, and X. Zhang, PWM controller and its control. Mechanical Industry Press, Beijing, China, 2003.
[15] J. Lu, G. Zhu, D. Lin, Y. Zhang, H. Wang and C. C. Mi, "Realizing Constant Current and Constant Voltage Outputs and Input Zero Phase Angle of Wireless Power Transfer Systems With Minimum Component Counts," in IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 1, pp. 600-610, Jan. 2021, doi: 10.1109/TITS.2020.2985658.
[16] M. Alam, W. Eberle, D. S. Gautam, C. Botting, N. Dohmeier and F. Musavi, "A Hybrid Resonant Pulse-Width Modulation Bridgeless AC–DC Power Factor Correction Converter," in IEEE Transactions on Industry Applications, vol. 53, no. 2, pp. 1406-1415, March-April 2017, doi: 10.1109/TIA.2016.2638806.
[17] K. Yao, X. Ruan, X. Mao and Z. Ye, "Reducing storage capacitor of a DCM boost PFC converter," IEEE Trans. Power Electron., vol. 27, no. 1, pp. 151-160, Jan. 2012.
[18] D. –H. Kim, G. –Y. Choe and B. –K. Lee, “DCM analysis and inductance design method of interleaved boost converters,” IEEE Trans. Power Electron., vol. 28, no. 10, pp. 4700-4711, Oct. 2013.
[19] H. Choi and L. Balogh, "A cross-coupled master–slave interleaving method for boundary conduction mode (BCM) PFC converters," IEEE Trans. Power Electron., vol. 27, no. 10, pp. 4202-4211, Oct. 2012.
[20] D. W. Clark, F. Musavi and W. Eberle, “Digital DCM detection and mixed conduction mode control for boost PFC converters,” IEEE Trans. Power Electron., vol. 29, no. 1, pp. 347-355, Jan. 2014.
[21] H. Kim, G. Seo, B. Cho and H. Choi, “A simple average current control with on-time doubler for multiphase CCM PFC converter” IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1683-1693, Mar. 2015.
[22] S. Heckford, "Design of an onboard battery charger for an electric vehicle", Sweden, vol. 66, pp. 1, Oct. 2001.
[23] Ahmed R, Yunis M, Dawood B, “Utilizing the power controller, enhance the operation of a single-phase AC to DC converter” Indonesian Journal of Electrical Engineering and Computer Science (2023) 29(3) 1224-1232. http://doi.org/10.11591/ijeecs.v29.i3.pp1224-1232.
[24] Krzysztof POLAKOWSKI, “Dangers to which electric vehicle users may be exposed and ways to prevent them”, PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 94 NR 11/2018 doi:10.15199/48.2018.11.33.
[25] A. Mohamed, C. Khalid and L. Abdesslam, "Modeling and Control of a Synchronous Buck Converter Fed by Single Phase System For Charging The Urban Electrical Vehicles," 2021 IEEE PES/IAS PowerAfrica, 2021, pp. 1-5, doi: 10.1109/PowerAfrica52236.2021.9543323.
[26] Arrach, M., Chikh, K., Lokriti, A. (2022). Modeling and Control of a PFC Forward Converter with Linear Control for Charging the Urban Cars. In: Bendaoud, M., Wolfgang, B., Chikh, K. (eds) The Proceedings of the International Conference on Electrical Systems & Automation. ICESA 2021. Springer, Singapore. https://doi.org/10.1007/978-981-19-0039-6_9