MODELLING AN IMPROVED POWER FACTOR OF A SINGLE PHASE RECTIFIER FOR ELECTRIC CAR BATTERY CHARGING APPLICATION

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Abstract— **The awareness of cleaner environment has lead to the intensity use of electric machine and battery has been developed to be used intensely in motor vehicle. For this situation, a paper for modeling a high power factor (PF) and low ripple factor (RF) for electric vehicle battery charging application has been proposed. The single stage high power factor converter will be proposed in this paper. The modeling parameters are inductance (L), capacitance (C), load resistance (R), load reactance (X_C) and power factor correction circuit (PFC).– It shown that ripple factor can reduced less than 10% by varied the parameters and power factor also can be improved by using the PFC circuit.**

Keywords-Rectifier, boost converter, power factor (PF), ripple factor (RF),power factor correction(PFC)

I. INTRODUCTION

The electric vehicle battery is low energy density, limited range and lifetime causes high cost [1]. Another important factor, is the period of recharge and discharge life cycle. If the life cycle is short, the battery is needed to replace more frequent. Electric vehicle charger is a potential for power quality problems such as power factor degradation and ripple factor. The power factor of an AC electric power system is defined as the ratio of the real power flowing to the load to the apparent power, and is a number between 0 and 1.

In an electric power system, a load with low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

Linear loads with low power factor can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise power factor. The devices for correction of power factor may be at a central substation, or spread out over a distribution system, or built into power-consuming equipment.

Many power factor correction converters have been presented in some papers. They usually can be divided into two categories: the two stages and single stage approach [2]. The single stage approach combines the power factor correction stage with a DC to DC converter into one switch with sharing one switch. In order to get tight output regulation, an internal energy source capacitor is needed so the output voltage is free of the line ripple. The high power factor is usually obtained by operating the power factor correction stage like a boost converter in the discontinuous current mode with constant duty cycle control [3].

$$PF = \cos\theta \quad (1)$$

Where;

$PF = Power\ Factor$
$\theta = Phase\ angle\ between\ current\ and\ voltage$

Ripple factor can be defined as the variation of the amplitude of DC due to improper filtering of AC power supply. Based on Fig. 1, ripple factor can be measured by:

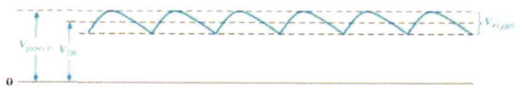

Fig. 1: Concept of ripple factor

$$RF = \frac{V_{o(max)} - V_{o(min)}}{V_{o(ave)}} \quad (2)$$

$$RF = \frac{1}{2fR_LC-1} \tag{3}$$

$$RF = \frac{\sqrt{2}}{3}\frac{1}{4\omega^2CL} \tag{4}$$

Where;

$RF = ripple\ factor$
$V_{r(pp)} = peak\ to\ peak\ ripple\ voltage$
$V_{DC} = average\ output\ voltage$
$R_L = load\ resistance$
$C = capacitance\ filter$
$L = inductance\ filter$

Although rectified waveforms contain many harmonics of the input voltage frequency, it is generally satisfactory to determine the ripple factor at the fundamental frequency only [4]. A simple filter consists of a capacitor connected in parallel with the load resistance. If the reactance of the capacitor at the power line frequency is small compared with the load resistance R_L, the ac component is shorted out and only DC current remains in the load resistor.

Characteristics of the capacitor filter are determined by examining the waveforms in the circuit. The capacitor is charged to the peak value of the rectified voltage V_p and begins to discharge through R_LC time constant and the period of input voltage.

Ripple is reduced by increasing the value of the filter capacitor. When the load current is equal to zero ($R_L \rightarrow \infty$) ripple factor becomes zero, which means the output voltage is pure DC[5]. Also note that ripple voltage of a full wave rectifier is approximately one half of the half wave circuit, because the frequency of the rectified component is twice as great. The constancy in output voltage with current is called the regulation of the power supply. Simple capacitor filter provides very good filtering action at low currents and is used in high voltage and low current power supplies.

II. METHODOLOGY

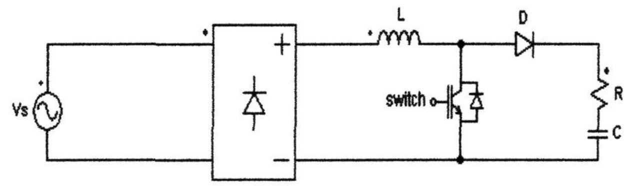

Fig. 2: A rectifier with boost converter

Fig. 2 shows the proposed rectifier circuit with boost converter [6]. This circuit is combination of full wave rectifier, boost DC-DC converter and shunt output filter. Full wave rectifier used to convert AC to DC. Then, the rectifier is connected to the boost DC-DC converter to step up the output from the rectifier to the desired DC output. Shunt capacitor is connected at the output of DC-DC converter to reduce the variation of the output voltage rectifier. Since the DC-DC converter is used controlled switch, therefore it can improve the power factor from the supply.

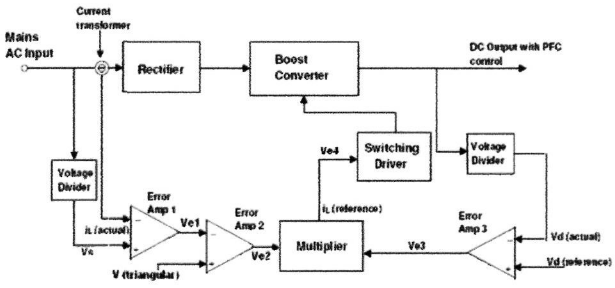

Fig 3: Block diagram of PFC circuit

Fig. 3 shows the block diagram of the proposed circuit. The mains AC input voltage is rectified and supplied to the boost converter, which mainly consists of an inductor, a power IGBT, a power diode and a bulk capacitor. The Error Amp 3 with predetermined reference voltage senses the DC output voltage across the bulk capacitor. The error voltage V_{e3} from the amplifier then is fed to the multiplier and multiplied with the template sinusoidal input voltage to get the reference current, i_L(reference). The error V_{e2} that is the output of Error Amp 2, as the difference of i_L(actual) and i_L(reference) provides the correct timing logic for the switching driver circuit to turn on and off the IGBT in the boost converter. Hence, this method ensures continuous conduction of current flow for the full cycle of the input voltage. The simulation was done by using PSIM 7.1.2 as shown in Fig. 4.

The first task of the power factor correction circuit is to use the boost converter to convert the varying input voltage up and down the half sinusoids to a constant, fairly well regulated DC voltage somewhat higher than the input sine wave peak. It does this by turning on the IGBT for a time Ton out of period T and storing energy in inductor L. When IGBT turns off, the polarity across L reverses, and the dot end of L rises to a voltage (Vo) higher than the input voltage (Vin). Energy stored in L during Ton is transferred via diode to the load and Co during IGBT off time. It can be shown that the input output voltage relation by [3]:

$$V_o = \frac{V_{in}}{1-\frac{T_{on}}{T}} \tag{5}$$

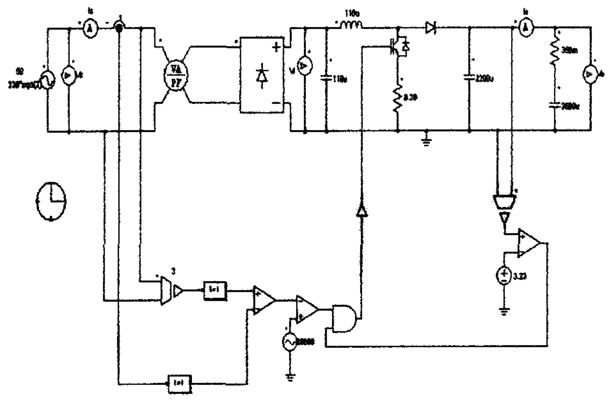

Fig. 4: Schematic of the proposed converter using PSIM

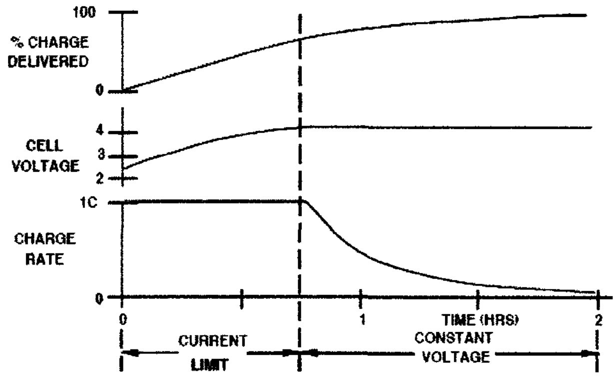

Fig. 5: Typical CV charge profile

During the simulation in capacitor, the load used is RC load. That is because of RC load will be super- capacitor. Super-capacitor power supply and the former is mainly used for large industrial equipment and consumer power, and today in a variety of sizes of products, especially in portable devices have also found unnecessary rechargeable laptop battery up to several thousand farad ultra capacitor capacity value and fast charge and discharge of the known.

As long as it can store a lot of power, performance super-capacitor more likes a battery, rather than a standard capacitor. In fact, technological progress, they will replace a number of products in rechargeable batteries, computers, digital cameras, mobile phones and other handheld devices [8]. In principle, people can be super-capacitor as a rechargeable battery. It can store the charge is proportional to its capacity, and demand the release of charge-discharge. Super-capacitor and electrolytic capacitor is the difference between the largest two-tier structures for its electronics, it can achieve a higher capacity.

A prototype of battery is set up to verify the proposed fast charging technique to realize the internal resistance compensation design. The value of R_L is set to 350mΩ and C_{BAT} equal to 3500uF [9].

A constant voltage charger sources current into the battery in an attempt to force the battery voltage up to a pre-set value. Once this voltage is reached, the charger will source only enough current to hold the voltage of the battery at this constant voltage. Hence, the reason it is called constant voltage charging as shown in Fig. 5 [10].

III. RESULTS

The single phase boost rectifier was simulated by using PSIM with input voltage is $230V_{ac}$. The ripple factor has been observed first to obtain the lowest ripple voltage for the output. The parameters have been varied and the results obtained have been plotted in Fig 6, 7, 8, and 9. Based from the results, the equations (3) and (4) have been approved. To continue with the battery charger application, large value of capacitor and inductor will be used. The output for the converter can be defined by using some equations as shown below [11]:

$$L = \frac{V_{IN}(V_{OUT} - V_{IN})}{\Delta I_L f_S V_{OUT}} \qquad (6)$$

$$\Delta I_L = \frac{V_{IN(min)} D}{f_S L} \qquad (7)$$

$$D = \frac{1 - V_{IN(min)} x \eta}{V_{OUT}} \qquad (8)$$

$$C_O = \frac{I_{OUT}(1-D)}{f_S \Delta V_{OUT}} \qquad (9)$$

Simulation with Power Factor Correction (PFC) circuit.

A. Verifying the value of capacitor from 1mF to 10mF and value of inductor and resistor are fixed which are 5mH and 100Ω respectively.

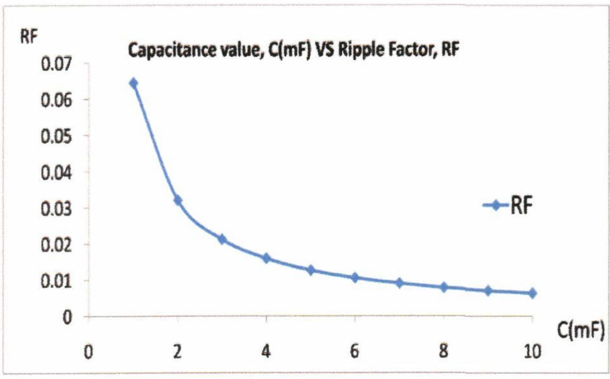

Fig. 6: Relationship between C and RF

B. Verifying the value of inductor from 1mH to 10mH and value of capacitor and resistor are fixed which are 10mF and 100Ω respectively.

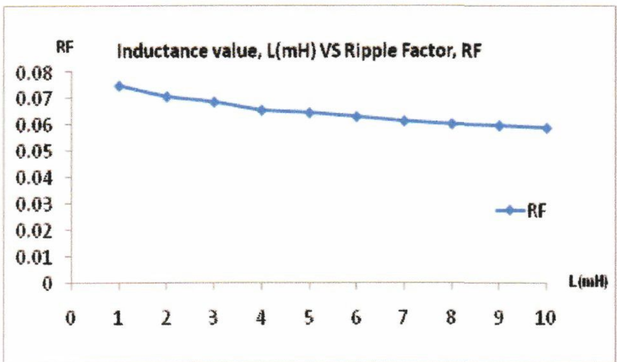

Fig. 7: Relationship between L and RF

C. Verifying the value of load from 100Ω to 1000Ω and value of inductor and capacitor are fixed which are 10mH and 10mF respectively.

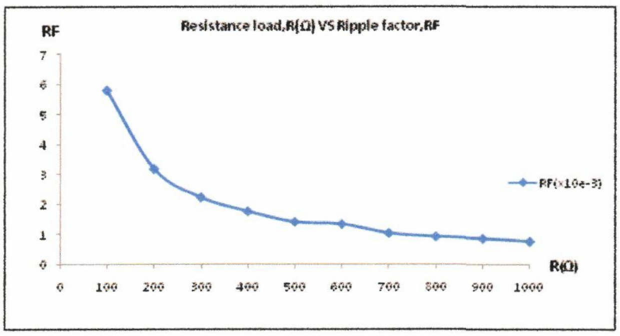

Fig. 8: Relationship between R and RF

D. Verifying the value of load capacitance from 100uF to 1000uF and value of inductor, capacitor and load resistance are fixed which are 10mH, 10mF and 10Ω respectively.

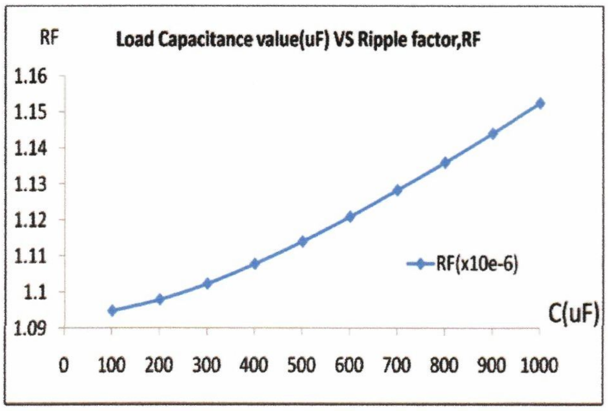

Fig. 9: Relationship between C and RF

The graphs plotted in Fig. 6, 7, 8, and 9 showed the relationship between all the parameters with RF. They showed the parameters are inversly proportional with the RF. When all the parameters increased, RF also increased.

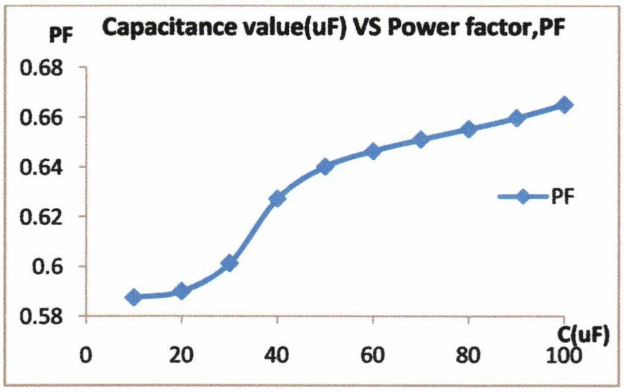

Fig. 10: Relationship between C and PF without PFC circuit

From the result in Fig. 10, it shows that the PF value is lower than the circuit with PFC circuit as shown in Fig. 11. The average value of the power factor for the circuit with PFC circuit is 0.8288 and without using PFC circuit is 0.6324. From there, it showed that PFC has improved the power factor up to 76.30 %.

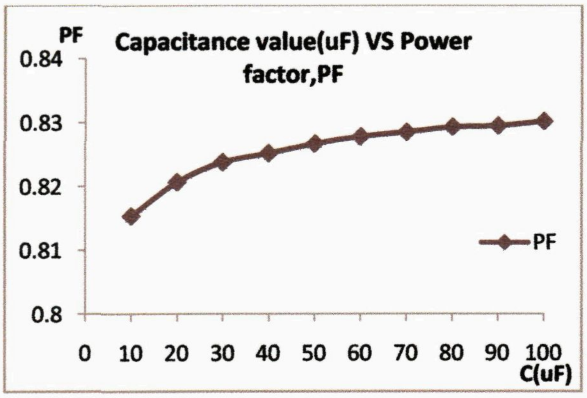

Fig. 11: Relationship between C and PF with PFC circuit

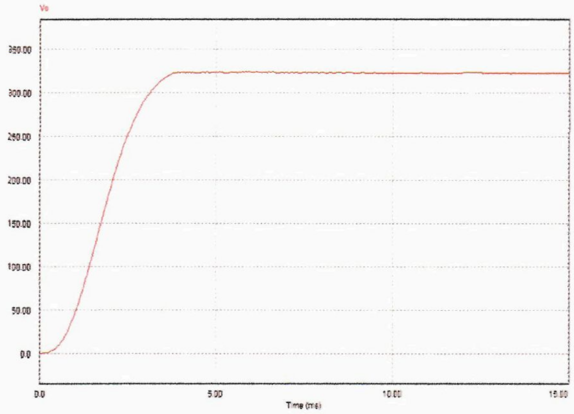

Fig. 14: Output voltage for battery charger

Simulation by using PSIM for 330V battery charger without PFC circuit.

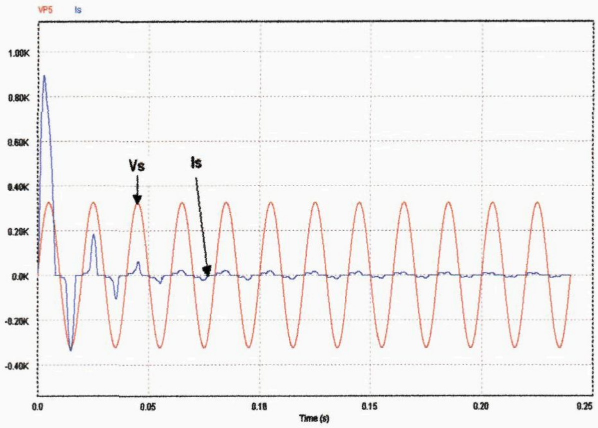

Fig. 12: Input voltage and input current of the circuit

Simulation by using PSIM for 330V battery charger with PFC circuit.

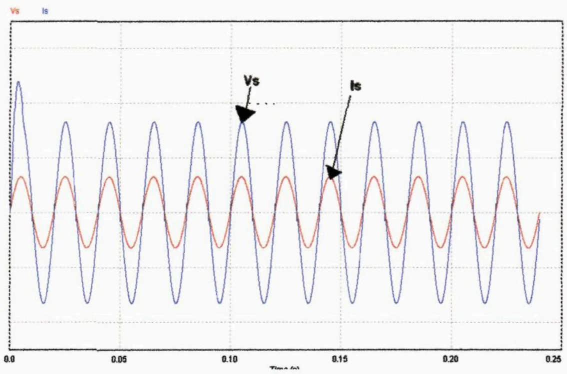

Fig. 13: Input voltage and input current of the circuit

Fig. 11 shows the results for the battery charger application without PFC circuit. It shows that the power factor of the circuit is low. From the power factor meter the reading is 0.7452. Then it was improved by inserting PFC circuit.

Fig. 13 and Fig. 14 show the results for the battery charger application. The desired output which is 330V was obtained and the power factor is close to unity. The parameters used came from the results of varied parameter and equations (6), (7), (8) and (9). The value of PF for the battery charger also close to unity by measured the phase angle between input current and input voltage in Fig. 13. From the power factor meter, it shows the value of power factor is 0.9975.

IV. CONCLUSION

This paper presented the simulation result for high power factor and low ripple factor for electric vehicle battery charging application. The circuit proposed a PFC circuit in order to improve the power factor for reduce power quality problems. From the results, we can see the different power factor values between using PFC and without using PFC. The changes in PF value is up to 25.29% with PFC circuit. The ripple factor also has been reduced to avoid the overvoltage supplied to the battery. The ripple factor is inversely proportional with the R_L, L, C and X_c values. The large values of L also will improve both values of RF and PF in the simulation circuit. The results also satisfied with the desired output which is 330V to supply to the battery and charging characteristics also showed in the simulation.

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