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Integrated on Board Battery Charger using Fuzzy Logic Controller for Plug-in Electrical Vehicles'

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ABSTRACT

Expanding usage of PHEV has certain considerations like high charging time, low range of driving and less number of stations for charging. PHEV chargers are known for two types as off board and on-board chargers. In this, 1-phase integrated on-board charger utilizing Fuzzy Logic based PEV 3-phase ac machine (PMSM) with its converter for traction, is proposed. The process for charging enables Power Factor Correction (PFC) in the source end. The 3-phase windings of the machine are used in the place of inductors to act as interleaved boost converter. A circuit utilizing 3-phase PMSM is built in MATLAB SIMULINK as well as verified the execution by using Fuzzy Logic Controller (FLC). An approximately unified power factor (PF) with less amount of THD of input current is obtained.

Keywords: *MPPT; Wind energy conversion system (WECS); Optimum relation based (ORB); Growing neural gas (GNG); Perturb and observe method (P&O); Particle swarm optimization (PSO).*

1.0 Introduction

Three-phase machine and battery charger are primary pieces of the module for Off-board and On-board charger interfaces as displayed in Fig-1. Customary on-board chargers used to devour single stage controlling for charging. By this power impediment, it consumes around 5 to 25 hrs to completely charge a PEV [1], [2]. Battery charger mostly comprises of the stages like ac-dc conversion and dc-dc conversion to control the voltage and current. Off-board charger is 3-phase more power chargers which require less than an hour for complete charging. Though apart from time consumption they are lourd and call for huge infrastructure. In 3-phase ac machine-driven framework, 3-phase bidirectional converter is utilized, permits battery power flow into machine in driving and charging while regenerative braking.

To accomplish the need for more efficiency, dc voltage of converter is required to be more than listed hench machine voltage (mostly around 360 V or 720 V) [3]-[5]. In addition to that a 3-phase ac machine's converter is used for regulating the voltage in a large scope of battery voltage. In integrated quick chargers, cost, size and weight of on-board chargers is decreased which likewise gives on-board quick charging without generous included expense and weight, which additionally expands the driving scope of PEV[6]. Specialists have concentrated coordinated non-confined single-phase charger that consolidate rectifiers as well as the drive machine's dc-dc bidirectional converters [7]-[9]. In an examination of 2-phase and single-arrange converter, topology diminish the number as well as size related to cumbersome reserved parts, for example, inductors. Massive inductors and capacitors include the weight and size of on-board charger [10]. For ac power factor amendment activity, with added transistors as well as diodes are required, that makes circuit confused. Where the expansion of segments may expand control and lead to bring down unwavering quality because of the expansion of all the more exchanging segments. The three stage ac machine's dc-dc bidirectional converter is appraised on behalf of high power as it is three stage machine. Here a new single-organize coordinated charging technique is proposed, using three phase ac motor of PEVs. The method proposed in this paper has no need of access to internal details for the three phase ac motor [11]. Improvement of the affiliations is similarly not required during the change from the charging mode to the driving mode.

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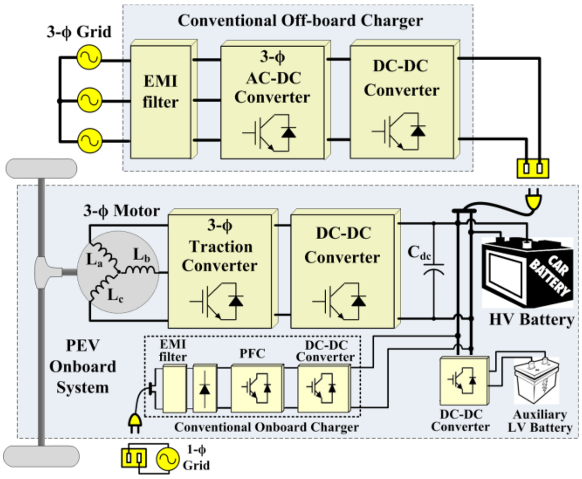
Figure 1: Plug-in EV Conventional Interfaces [1]



2.0 Integrated on board charger

3. On-board charger works irrespective of the 3-phase motor, as shown in Fig-1. The proposed on-board charger in this is obtained by linking a PFC bridgeless converter amid one of the machine and the negative terminal of bidirectional traction converter, as shown in Fig-2. In this structure, only viable access to motor phase terminal [a, b, c] in the three phase ac machine is utilized [1].

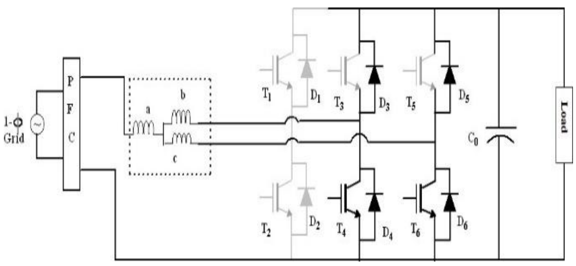
4. In driving mode, the battery provide driving power via 3-phase bidirectional traction converter, in Fig-2(a), as well as the added diode bridge converter has no effect on inverting (traction) converter operation [4]. In the charging mode, as Fig-2(b), the grid voltage converted with the diode bridge converter as well as three phase ac machine winding and bidirectional power (traction) converter improve a 2-channel of interleaved boost converter.

5. In this event, the T1/T2 bridge is deactivated, whereas the other two bridges T3/T4 and T5/T6 are used to realize an interleaved boost converter [9]. The IGBTs T1, T2 are constantly open circuited in battery charging condition. The positive o/p voltage from diode rectifier will make the anti-parallel diode D2 to be in reverse bias condition.

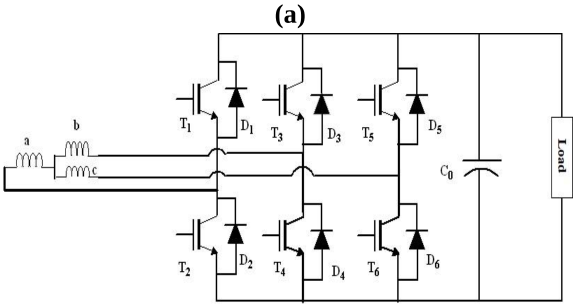
6. To attain less THD of the grid, the converter is designed to operate in continuous conduction mode (CCM). Choice of traditional onboard charging or high power level integrated charging depends on the available supply level.

The ac machine aids as a 3-winding coupled inductor in lieu of energy storing as well as ripple cancellation. One among the 3-phase traction converter bridges linked to the positive terminal of the PFC rectifier [2]. In this situation, the T1/T2 bridge is deactivated, whereas the remaining bridges T3/T4 and T5/T6 are utilized for building an IBC [8].

Figure 2: Operating Modes Integrated Charger Including Machine Windings: (a) Propulsion Mode; (b) Charging Mode



(a)

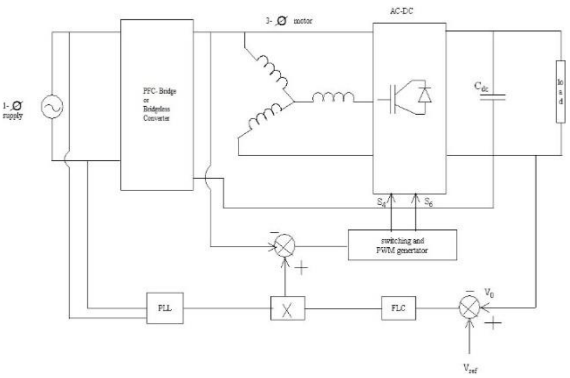


(b)

3.0 Charging Operation

The ability of attaining unity PF as well as reducing THD less than 2%. The regulator compose the double closed loops, i) if input current of the inward loop shape is a sinusoidal input line current; ii) if output current/voltage of outward loop to control the output current/voltage, as shows the Fig. 3. The inner loop is to endure current in the phase-b as well as in phase-c flows (I_b as well as I_c) over the Phase Locked Loop (PLL) to pursue direction with respect to line voltage. The outer loop to regulate the currents with respect to the output voltages. The PWM generation to be applied in 180 degree out of phase to both. If those dual PWM signals are applied to switches S4 as well as S6 in addition to 180 degree stage move [9]. The fuzzy controller is utilized to tune the PI- Controller. Because of similarity of the 2-channel IBC is enduring state flows in stage b as well as stage c windings be there part similarly (I_b = I_c=1/2|I_a|), despite the fact that their instant values probably won't be equivalent.

Figure 3: Block Diagram of Integrated Charger with Dual Closed-loop Control



On the other hand, in comparing the traditional interleaved boost converters, in this converter inductors are 120º spatially out of phase dispersed windings (a, b, c) of an AC machine is dissimilar steady state equal inductances. If switching process distributed to four switching states (I)-(IV), as shows the Fig. 4. In accordance with switching of the duty cycle (D), if steady state procedure has considered to two distinct cases, [1] 0<D<0.5, in which Vo<2Vac<2Vo ; and [2] 0.5<D<1, where Vo>2Vac. The duty cycles mean the duty cycles of the lower level switches, T4 as well as T6, as shows Fig. 5. Here, CCM action takes place because of inductor currents, meanwhile DCM process takes the high current stresses to inductors [3], [6], the switches as well as diodes are not suitable to the power applications with high level.

3.1 Switching states

If 0<D<0.5, the circuit process takes a periodical switching order of (I)-(III)-(II)-(III)-(I). For 0.5<D<1, the switching order changing to (I)-(IV)-(II)-(IV)-(I). In State I if the first leg of transistor S4, should on turned on; along with diode of the second channel, D5, conducts.

$$V_a - V_b = V_{in} \quad \ldots(1)$$

$$V_a - V_c = V_{in} - V_o \quad \ldots(2)$$

Where, Vac as well as Vo are the input as well as output voltages are interleaved boost converter. Use the $V_a + V_b + V_c = 0$, Eq. (1) as well as Eq. (2), if stator phase voltages of State I can be stated such as,

$$V_a^1 = \frac{2V_{in} - V_o}{3} \quad \ldots(3)$$

$$V_b^1 = -\frac{V_{in} + V_o}{3} \quad \ldots(4)$$

$$V_c^1 = -\frac{V_{in} - 2V_o}{3} \quad \ldots(5)$$

Conferring the Eq. (3)-(5) along with the ignoring stator resistance (Rs=0); then stator phase-currents should characterized such as,

$$i_a^I = \frac{2V_{in} - V_o}{3(L_{aa} + M_t)} \quad \ldots(6)$$

$$-i_b^I = \frac{V_{in} + V_o}{3(L_{aa} + M_t)} \quad \ldots(7)$$

$$-i_c^I = \frac{V_{in} - 2V_o}{3(L_{aa} + M_t)} \quad \ldots(8)$$

In the State II transistor of the second leg, T6, is turned on as well as diode of the first leg, D3, conducting. In this state:

$$V_a^{II} = V_a^I, V_b^{II} = V_b^I, V_c^{II} = V_c^I$$

The phase-currents stated such as,

$$i_a^{II} = \frac{2V_{in} - V_o}{3(L_{aa} + M_t)} \quad \ldots(9)$$

$$-i_b^{II} = \frac{V_{in} - 2V_o}{3(L_{aa} + M_t)} \quad \ldots(10)$$

$$-i_c^{II} = \frac{V_{in} + V_o}{3(L_{aa} + M_t)} \quad \ldots(11)$$

State III individual happens while 0<D<0.5. It ensues in between the State I as well as State II. In view of this state, both the transistors of two legs, T4 as well as T6 should be turned off; along with the diodes D3 as well as D5 are in conduction.

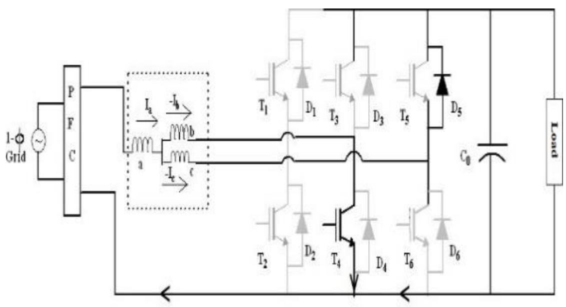
$$V_a - V_b = V_{in} - V_o \quad \ldots(12)$$

$$V_a - V_c = V_{in} - V_o \quad \ldots(13)$$

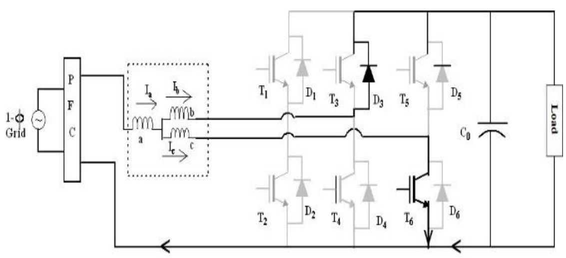
$$V_a^{III} = \frac{2(V_{in} - V_o)}{3} \quad \ldots(14)$$

$$V_b^{III} = v_c^{III} = -\frac{V_{in} - V_o}{3} \quad \ldots(15)$$

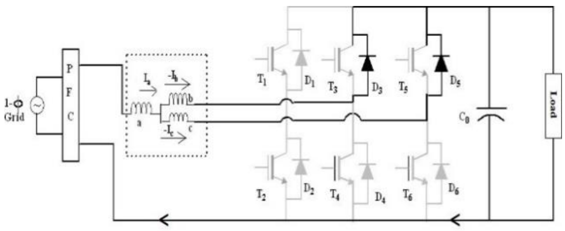
Figure 4: States of Switching (I)-(IV) While Battery Charging



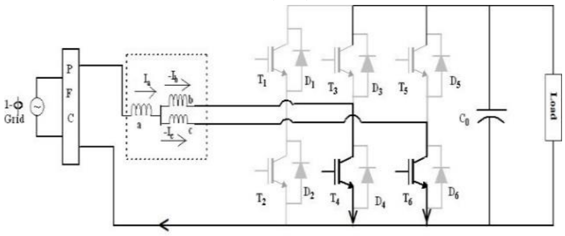
(I)



(II)



(III)



(IV)

Regarding this condition, the value of slope of ia is two times to that of –ib as well as –ic and is expressed as,

$$i_a^{III} = \frac{2(V_{in} - V_o)}{3(L_{aa} + M_t)} \quad \ldots(16)$$

$$-i_b^{III} = -i_c^{III} = \frac{V_{in} - V_o}{3(L_{aa} + M_t)} \quad \ldots(17)$$

During the operation of State IV only occurs when 0.5<D<1. It transpires among Mode I as well as Mode II. In this state, two transistors of two legs, T4 and T6, are on; diodes of two legs, D3 and D5, are reverse biased. The identical voltage, Vac, appears through the windings of the stator.

$$V_a - V_b = V_{in} \quad \ldots(18)$$

$$V_a - V_c = V_{in} \quad \ldots(19)$$

Thus, one could existing phase voltages such as,

$$V_a^{IV} = \frac{2V_{in}}{3} \quad \ldots(20)$$

$$V_b^{IV} = v_c^{IV} = -\frac{V_{in}}{3} \quad \ldots(21)$$

In this specific case the round rotor of currents could be written such as,

$$i_a^{IV} = \frac{2V_{in}}{3(L_{aa} + M_t)} \quad \ldots(22)$$

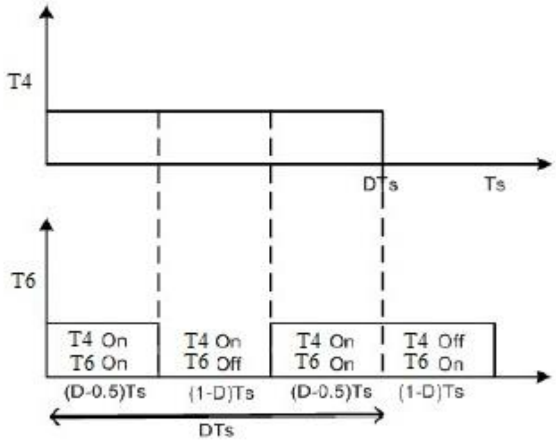
$$-i_b^{IV} = -i_c^{IV} = \frac{V_{in}}{3(L_{aa} + M_t)} \quad \ldots(23)$$

Hence, this steady-state output-to-input voltage gain Av for 0<D<1 could be attained such as,

$$A_v = \frac{V_o}{V_{in}} = \frac{1}{1-D} \quad \ldots(24)$$

Which is equal towards the conventional interleaved boost converter. Here this steady state, consider as an ideal converter, whether the input power is equivalent to the response i.e.output power corresponding to load R, formula for input current is as follows,

Figure 5: Gating Sequence for the Switches 0.5<D<1 [1]



$$I_{in} = \frac{V_o^2}{R_L V_{in}} = \frac{V_{in}}{(1-D)^2 R_L} \quad (25)$$

3.2 Fuzzy logic controller

Fuzzy logic utilizes fuzzy set theory with a defined degree of membership in this the variable has associate with the one else more sets. Fuzzy logic allows us to compete with the process of human reasoning in computers [11], to enumerate imprecisely data, to make decisions based on imprecise as well as complete information, however to attain clear values by implementing a "defuzzification" method. For the operation of the fuzzy controller rule base is required and the rule base is to be load in the inference engine.

The FLC mainly consists of three blocks

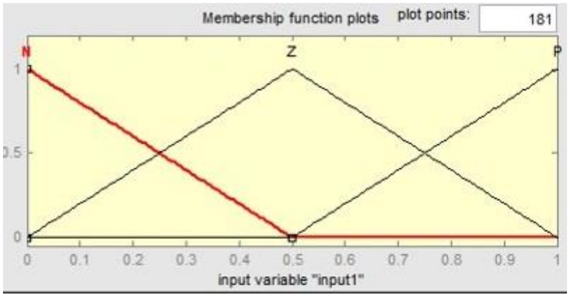
- Fuzzification
- Inference
- Defuzzification

For simulation of the circuit, Mamdani inference is considered and the rules are loaded into the block using triangular membership function. The parameters considered for the tuning are error in the output voltage and change in the error in the output voltage [11]. Fuzzy rule set for the fuzzy block is defined in the Table 1 as follows,

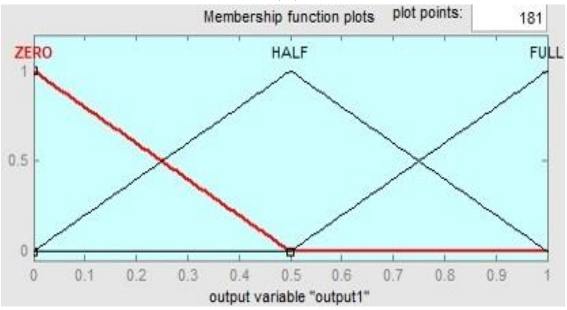
Table 1: Fuzzy Base Rules Utilized in the Design

		Error in the Voltage		
Change in the Error in the voltage		**N**	**Z**	**P**
	N	N	Z	Z
	Z	P	Z	N
	P	Z	Z	P

Figure 6: (a) Fuzzy Inputs; (b) Outputs



(a)

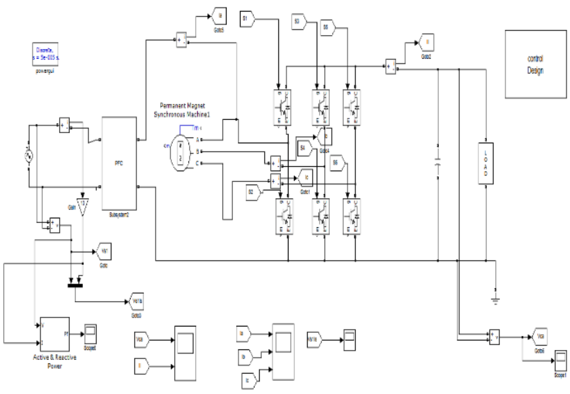


(b)

From the above Fig. 6(a), it is the input variable membership function. For the evaluation purpose, error and change in error are considered. Fig. 6(a) represents the input membership function, i.e. error. The range of the error function if from [-0.01] to [0.01]. The range of change in error is from [-0.0001] to [0.0001]. From the Fig. 6(b), the output membership function is displayed and the range of the function is [0] to [1].

4.0 MATLAB Simulink Results

Figure 7: Simulink Model for the Proposed Bridgeless PF Corrected FLC Based Single Phase On Board Charger



The proposed model, simulated in MATLAB-Simulink and this circuit of simulation is as shows the Fig. 7.

Table 2: Test Values for the Circuit

Criterion	Symbols	Magnitude	Units
I/P Voltage	V_{in-rms}	230	V
I/P Current	I_{in-rms}	8	A
I/P Frequency	f_{in}	50	Hz
Switch Frequency	f_s	20	kHz
O/P Voltage	V_o(avg)	420	V
Equivalent Resistive load	R_L	300	Ohms
Max o/p power	P_o	3.3	kW
Power Factor	pf	0.98	
THD(for I/P current)		1.6	

The integrated charger is much economical compared to 1-phase conventional chargers as the circuitry is reduced in the charger.

Figure 8: Obtained Waveform of the Input Voltage & Current (gain) in Simulation

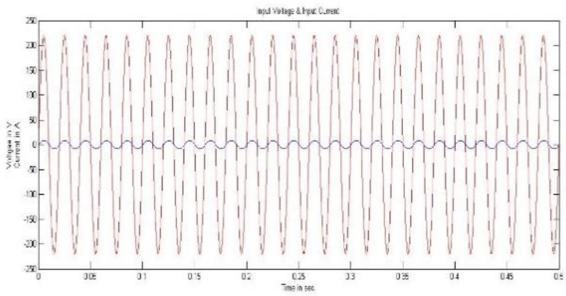
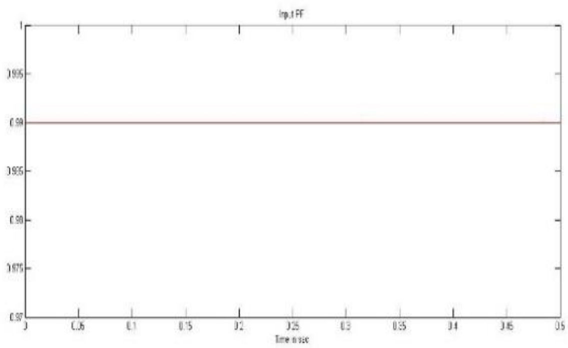
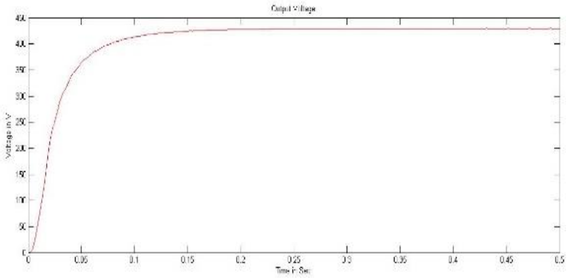


Figure 9: Obtained Waveform of Power Factor in simulation

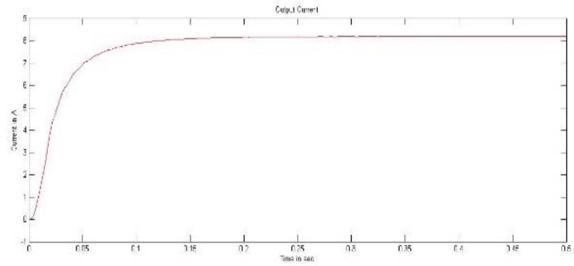


As in Fig. 9, power factor on the input side is 0.98.

Figure 10: Obtained (a). Output Voltage & (b). Output Current in Simulation



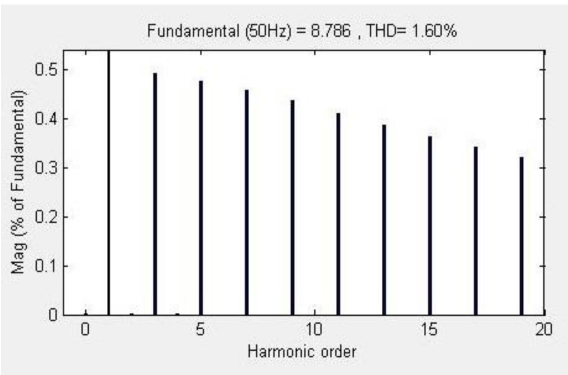
(a)



(b)

The output voltage as well as output current obtained in the simulation are as shown in Fig. 10. The output voltage is shown in Fig. 10(a), the magnitude is 420V. The output current is as in Fig. 10(b), with magnitude of 8A.

Figure 11: Input Current THD in %



From Fig. 11, the THD on input side is around 1.60%.

5.0 Conclusion

An integrated on board battery charger dealing with 3-phase propulsion system is anticipated for plug-in electric vehicles is described. The charging circuit uses propulsion system of the electric vehicle as interleaved boost converter with PFC control and controlling with FLC. The integrated charging approach is realized through a 3-phase PMSM motor using a $230V_{rms}$ input using Fuzzy Logic Controller. An approximately unity PF and THD with less than 2% for input ac current is attained. For further development, unused bridge in the propulsion circuit can be utilized and the efficiency of the charger can be increased by creating a 3-channel interleaved boost converter.

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