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Constant Current Fuzzy Logic Controller for Grid Connected Electric Vehicle Charging

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***Abstract*— The increase in demand for clean sources of energy is getting more attention in recent time. Electric vehicle (EV) is an important area to fulfil this demand. However, one of the major obstacles in the growth of EV is the longer charging time. Therefore, there is a definite need for the reduction of charging time in EVs. Constant current charging of EV can help to solve this problem. That's why, the role of DC-DC converter is very important. DC-DC converters are commonly utilized in electronic devices such as mobile phones, computers etc. This paper presents the possibility of grid connected constant current charging of EV with buck DC-DC converter through fuzzy logic control (FLC). FLC is easy to implement without the requirement of intensive mathematical modelling. The complete model of the considered system has been developed in MATLAB/Simulink. The achieved simulation results show the viability and capability of the proposed scheme.**

Keywords*— *DC-DC converter, fuzzy logic controller, electric vehicle.

I. INTRODUCTION

According to International Energy Agency, about 64% of global oil utilization originates from transport sector. The increase in fossil fuel demand, coupled with the upsurge in climate change, has led to control in the release of CO_2 and NO_x emissions [1]. Eventually, there is an increase in the demand for clean sources of energy. Electric vehicles (EV) [2] can help to reduce the menace related to climate change. Presently, a lot of research work is going on regrading EV [3] and viability of designing the charging process through power grid connection [4]. However, the charging system of EV needs to be improved considerably. Decrease in charging time is an important requirement in making EV easy to use [5]. As a result of this, fast DC and constant current (CC) charging systems offer a fascinating opportunity [6].

The author in [7] describes the two levels of DC fast charging according to the international standard of IEC 61851-1. The DC-DC bus connection is more desirable because it requires lesser switching process which facilitates higher efficiency [8]. Moreover, according to algorithm developed in [9], the CC charging can also be used to determine the charging power requirement, based on the battery capacity, departure time, arrival time and the battery state of charge.

A comprehensive review of fast charging process with required charging current and voltage is discussed in [10]. Power grid and photovoltaic connected EV charging is developed in [9] but the detail design of the EV charging process is not illustrated. In [11], a fast DC charging of EV is implemented with a proportional integral (PI) controller but generally PI are often subjected to tuning. In [2], a voltage sensing smart charging is used for the energy management with a PI controller for buck converter charging of the EV. In [12], DC voltage source is used as the PV panel and the battery is modelled as a simple resistor with a bang-bang fuzzy logic controller for the EV charging implementation.

In contrast to previous works, this paper focuses on buck DC-DC converter charging of grid connected electric vehicles with a constant current fuzzy logic controller (FLC). In this paper, the actual models of the grid connection as well as battery have been used in MATLAB/Simulink for the analysis of the complete EV charging system. FLC can be used in various home and industrial applications [13]. FLC is easy to implement than the classical proportional integral (PI) controller and it easily adjusts to changes in operating conditions [14]. It can be computed with linguistic variables rather than numbers. Membership functions (MF) are used in describing fuzzy sets. MF denotes degree of accuracy in fuzzy logic and it is mapped between 0 to 1. A MF value of 0.2 denotes 20% degree of accuracy in a fuzzy logic. The control algorithm for fuzzy set can be implemented through fuzzy rules by operators for difficult and non-linear systems without the requirement for intensive numerical modelling. It is also highly reliable and robust to change in circuit parameters and transient conditions [15].

This paper is organized as follows: Section 2 of this paper presents the design of buck converter and the grid connection. Section 3 describes the constant current fuzzy logic controller for EV charging. Section 4 presents the simulation results. Finally, Section 5 concludes this paper.

II. BUCK CONVERTER AND GRID CONNECTION DESIGN

The complete simulation diagram of the EV charging system is developed in MATLAB/Simulink as presented in Fig. 1. In this figure, voltage source is modeled as a three phase source and the transformer as a Star-Delta connection. A three-level bridge inverter is used for AC to DC conversion. The adjustment of the DC bus voltage and reactive current of the grid are done by the control system, DC regulator, as shown in Fig. 2. This comprises of a DC voltage control and a current control. A d-q transformation process is employed with phase loop. The current reference Id_{ref} is the output of the DC voltage regulator. The magnitude and voltage phase generated by the current regulator is used to regulate the converter as presented in [16].

Figure 3 shows DC-DC buck converter system with output Vo. The converter allows the lowering of input voltage magnitude to a desirable level in order to charge the EV. The input of the DC-DC buck converter is connected to the output of the grid supply and the output of the converter is connected to the battery. The duty cycle of the buck converter, which is the ratio of two voltages, can be determined as:

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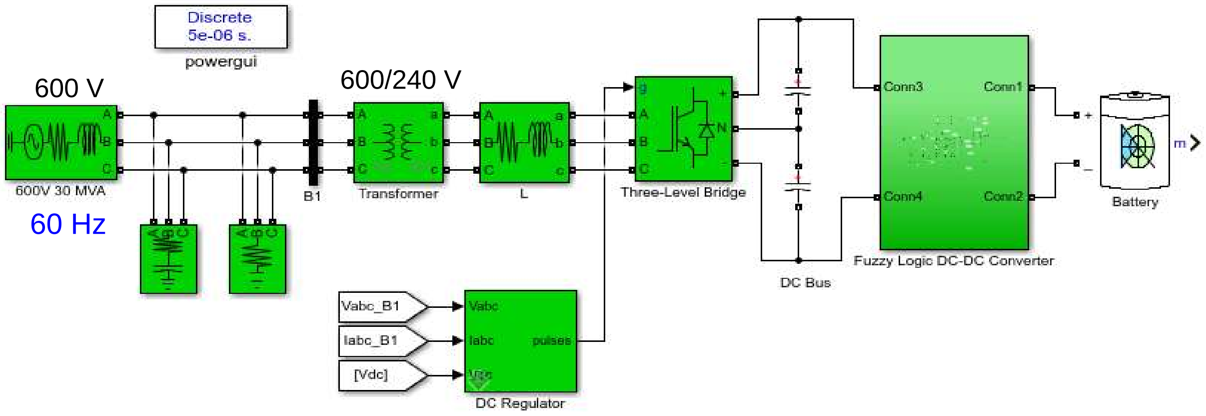

Fig. 1. EV charging system developed in MATLAB/Simulink.

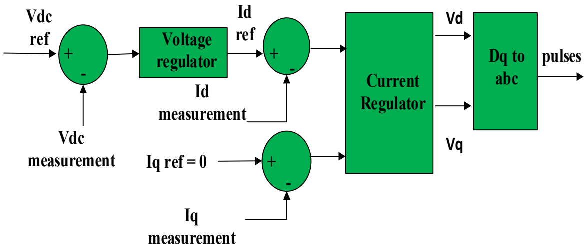

Fig. 2. DC regulator.

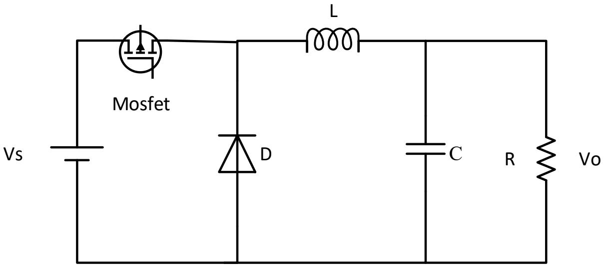

Fig. 3. DC-DC Buck converter.

$$D = \frac{V_O}{V_S} \tag{1}$$

where, D is duty cycle, Vo output voltage and V_S is the source voltage. Duty cycle determines the on/off stages of the converter. For continuous-current operation of buck converter, proper switching frequency and inductor size must be selected. The minimum inductor size L_{min} can be determined from:

$$L_{min} = \frac{(1-D)(R)}{2f} \tag{2}$$

where, R and f are the resistance and switching frequency respectively. The inductor size (L) can be 25 percent larger than the minimum to ensure that the inductor current is continuous. That's why:

$$L = 1.25L_{min} \tag{3}$$

Average inductor current (I_L) is the ratio of the output voltage (Vo) to the resistance (R). For a steady state operation, the average capacitor current must be zero. Therefore, the current through the load is the average inductor current, which can be calculated as:

$$I_L = \frac{V_o}{R} \tag{4}$$

Proper selection of capacitor is required to maintain very low output ripple voltage. The required capacitance with respect to specified output ripple voltage can be calculated as:

$$C = \frac{(1-D)}{8L\left(\frac{\Delta V_O}{V_O}\right)f^2} \tag{5}$$

where, $\Delta V0$ is the peak-to-peak ripple voltage at the output.

III. FUZZY LOGIC CONTROLLER

Controllers are primarily employed to bridge the gap between the measured output parameter and the reference value. The fuzzy logic controller in this paper is based on the bang-bang control [15],[12]. Bang-bang control system automatically turns on/off in order to keep the measured output close to the reference value. It is basically known as a two-step controller. Fig. 4 shows the design for the control system where the fuzzy controller is implemented as a current regulator. The difference between the reference and the actual voltage measurement serves as the input for the fuzzy controller. This determines the reference current to charge the EV battery. In Fig. 4, L,C,R_1 and R_2 represent the inductor, capacitor and resistors respectively. The source in Fig. 4. represents the grid connection, which was described in Fig 1. The pulse width modulation (PWM) block in Fig. 4 generates the switching frequency for the MOSFET. The input, output membership functions as well as crisp output function are presented in Fig. 5, 6 and 7 respectively.

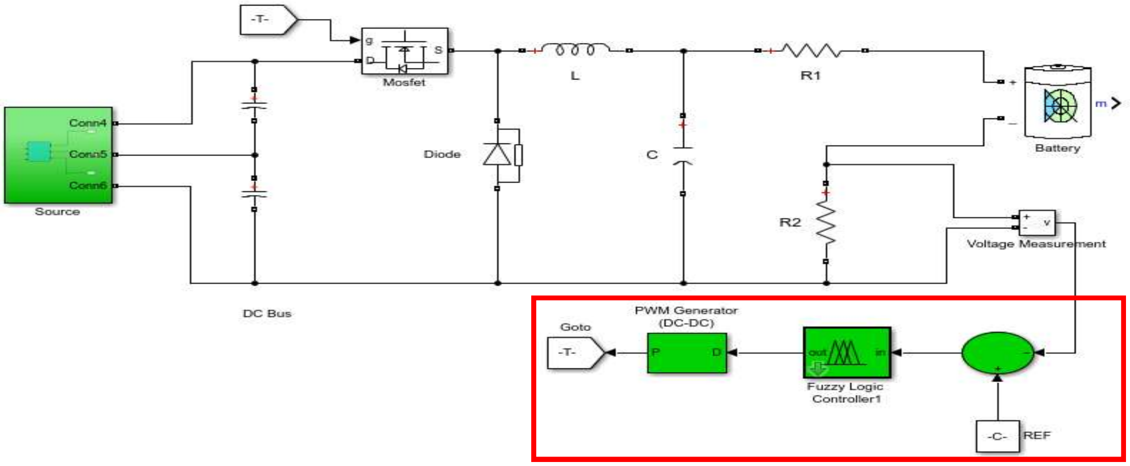

Fig. 4. Fuzzy logic controller with DC-DC converter.

Centroid defuzzification or center of gravity (COG) approach was employed between the input and output membership functions (MF). This is center of gravity where all points intersect. This procedure produces an output value based on the COG of the fuzzy set. The overall control is obtained from smaller division of membership function's total area. The COG and the area of each smaller division are computed and the total sum of all these smaller divisions is used to calculate the defuzzified output for a non-continuous fuzzy set. The defuzzified value, x^*, with centroid defuzzification approach is represented as:

$$x^* = \frac{\sum_{i=1}^{n} x_i.\mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \qquad (6)$$

where x_i , $\mu(x_i)$ and n denote the sample elements, membership function and number of elements in the sample respectively.

The rules are as follows:

- If input MF is high input (HI) then the output MF is also high (HO)
- If the input MF is low input (LI) then the output MF is also low (LO)

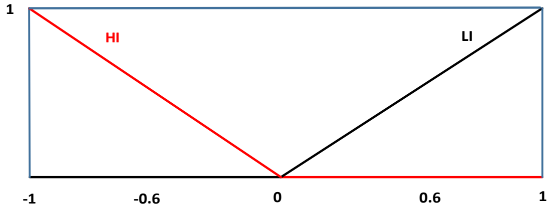

Fig. 5. Input membership function.

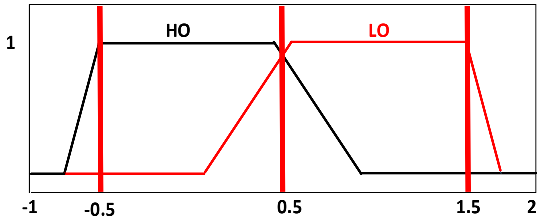

Fig. 6. Output membership function.

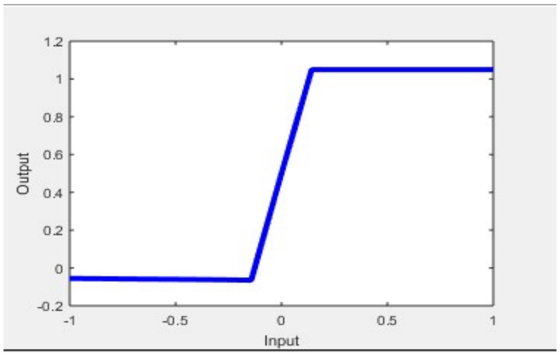

Fig. 7. Crisp output function.

IV. SIMULATION RESULTS

The values of the parameters used for simulation are presented in TABLE I. DC fast charging mode with $400V$, $120A$ and $48kW$ are used for simulation. The complete simulation block diagram is presented in Fig. 1.

Fig. 8 shows the result for the $120A$ constant current (CC) charging for the $12\ kWh$ EV battery. The fuzzy logic controller maintains a constant current for charging of the EV battery. This result shows the applicability of the fuzzy logic controller for fast DC charging of EV.

The charging voltage is greater than the open circuit voltage (OCV) of $324V$. When battery charges at CC, the charging voltage is always greater than the OCV as shown in Fig. 9.

Furthermore, there is a steady rise in battery state of charge (SOC) from 50% while maintaining a constant DC bus voltage as shown in Fig. 10 and Fig. 11 respectively.

Fig. 12 shows the transient behavior of DC bus voltage when battery is connected for charging. The small settling time of around 0.2 second can be observed before reaching the final value of 800V.

All these presented simulation results show that the fuzzy logic controller can be utilized for large scale deployment of EV charging.

TABLE I. DESIGN PARAMETERS.

Parameters	Values
DC bus voltage	800 V
Inductance	21μH
Grid voltage	600 V
Transformer	600/240 V
Grid frequency	60 Hz
Battery SOC	50 %
Battery nominal voltage	300 V
Battery time constant	2 sec
Battery capacity	12 kWh
Short circuit level	30 MVA
X/R ratio	8
EV charging current	120 A

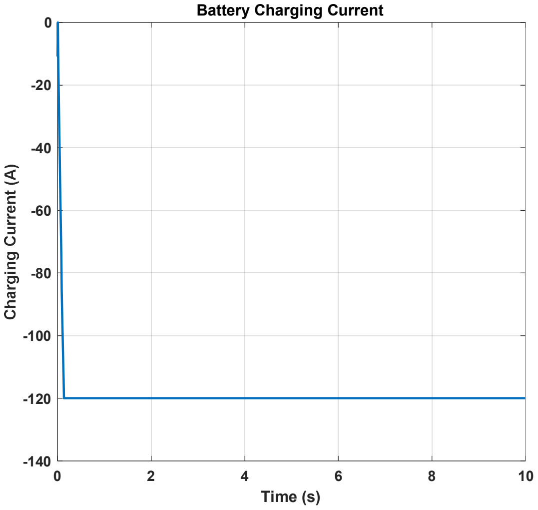

Fig. 8. Battery charging current.

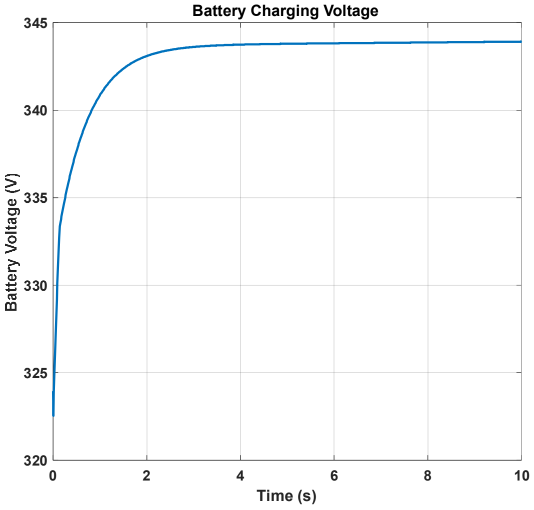

Fig. 9. Battery charging voltage.

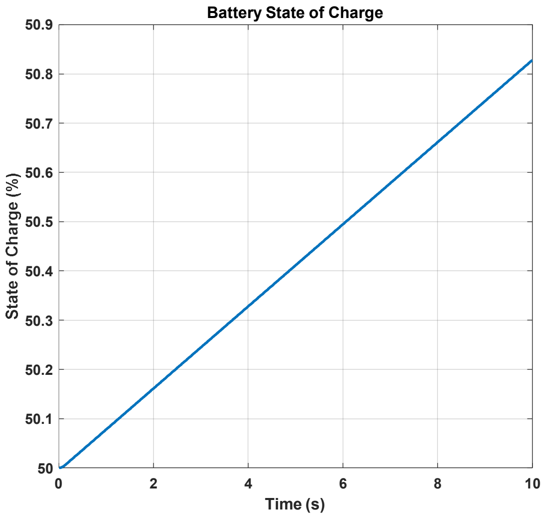

Fig.10. Battery state of charge (SOC).

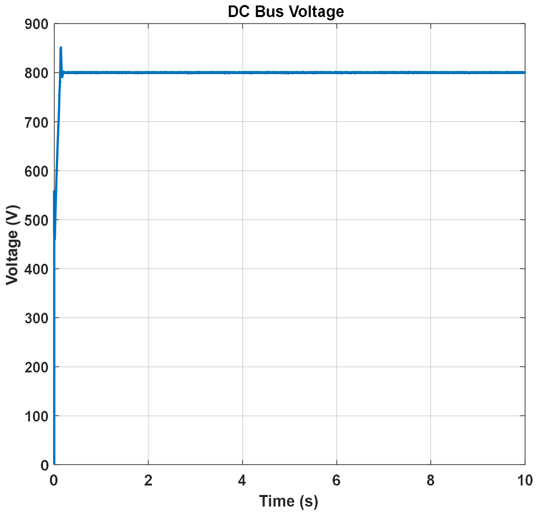

Fig. 11. DC bus voltage.

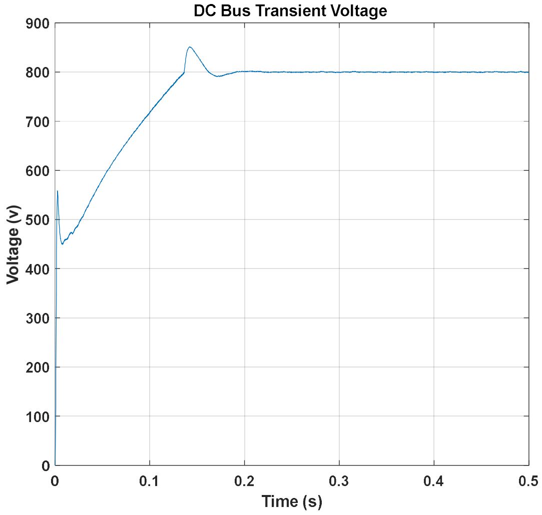

Fig. 12. DC Bus transient voltage.

CONCLUSION

In this paper, the complete model of EV charging system with the utilization of fuzzy logic controller is presented. The complete simulation model has been developed in MATLAB /Simulink. The achieved simulation results show how easy FLC can be used in EV charging without the requirement for any tuning like with PI controller.

In perspective of this work, experimental validation of the proposed scheme can be performed.

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