International Journal of Scientific Research in Computer Science, Engineering and Information Technology
ISSN : 2456-3307 (www.ijsrcseit.com)
doi : https://doi.org/10.32628/IJSRCSEIT

A Novel ANFIS controller-based Grid connected EV charging system with constant current control topology

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ARTICLEINFO

Article History:
Accepted: 01 April 2023
Published: 14 April 2023

Publication Issue
Volume 10, Issue 2
March-April-2023

Page Number
342-349

ABSTRACT

This project proposes a novel approach to grid-connected electric vehicle (EV) charging systems using an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. The objective is to achieve constant current control and minimize the gap between the reference and measured output parameters. The proposed system employs a buck converter with a DC-DC topology to regulate the voltage and current for EV charging. The system also integrates a bang-bang control mechanism and a fuzzy logic controller to ensure accurate and efficient operation. Simulation results show that the proposed ANFIS-based system performs better than traditional control systems, providing higher accuracy and stability. The proposed system can be a promising solution for future grid-connected EV charging systems.

Keywords : ANFIS controller, smart Grid, Electric vehicle, Charging station, Renewable energy, Battery management, Power quality

I. INTRODUCTION

The International Energy Agency estimates that the transportation sector accounts for around 64% of global oil consumption. CO2 and NOx emissions have been controlled as a result of the rise in demand for fossil fuels and the acceleration of climate change [1]. In time, there will be a rise in the need for clean energy. Electric vehicles (EV) [2] can contribute to reducing the risk posed by climate change. Substantial research is currently being done on EVs [3] and the practicality of designing the charging process through a power grid link [4]. However, there is a clear need for significant improvement in the EV charging system enabling electric vehicles (EVs) to be user-friendly requires careful consideration of the charging duration [5]. The development of rapid DC and continuous current (CC) charging systems, which are currently in existence [6], has resulted from this.

As outlined by the writer in [7], the two levels of rapid DC charging are defined in accordance with the international standard IEC 61851-1. The DC-DC bus connection is the preferred option [8] as it involves less switching and enables higher efficiency. In addition, [9] outlines a method for estimating the required charging power by taking into account factors such as the battery capacity, departure and arrival times, and the battery's state of charge. Meanwhile, [10] provides a comprehensive discussion on fast charging, including the required voltage and

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current for charging. Although [9] develops photovoltaic and power grid connected EV charging, the detailed architecture of the process is not displayed. Although fast DC charging for EVs is provided by a proportional integral (PI) controller in [11], PI controllers are frequently modified. In [2], the buck converter charging for the EV is taken care of by an energy management system with a PI controller In [12], a simple resistor are used to model the battery as a DC voltage source, which is used as a PV panel for the implementation of EV charging.

This study focuses on charging buck DC-DC converters for grid-connected electric vehicles employing a (FLC). In order to analyses the entire EV charging system in this work, MATLAB/Simulink was utilized in combination with actual models of the grid connection and battery. Applications for FLC can be found in both domestic and commercial settings [13]. The FLC is simpler to set up than the traditional proportional integral (PI) controller, and it is also more flexible as operating conditions change [14]. Instead of using numbers to calculate it, someone may use linguistic variables. Fuzzy sets are described using membership functions (MF). In fuzzy logic, MF stands for degree of accuracy and is mapped from 0 to 1. In fuzzy logic, a 20% accuracy level is indicated by an MF value of 0.2. Operates for difficult, nonlinear systems can perform the fuzzy set control algorithm with fuzzy rules without the need for extensive numerical modelling. Moreover, it is extremely dependable and resistant to changes in circuit characteristics and transient circumstances [15].

The ANFIS is regarded as the most beneficial algorithm in artificial intelligence-based algorithms. Both effective controllers, such as neural networks and FLC, are used in this. By using the identical functions in both inputs, the membership functions (MFs) utilised to implement the ANFIS algorithm (error and change in error). 49 rules were applied in order to provide greater accuracy and produce good results. Also, these guidelines were selected in consideration of past performance, subject-matter expertise, and process dynamics. The ANFIS combines neural networks and (FLC) (NN). Next sections explore the proposed ANFIS controller's specifics in more detail.

The essay is organized in the following manner: Section 2 provides a description of the system. Section 3 outlines the proposed method. Section 4 presents the Results and Discussion. Chapter 5 concludes the conclusion.

II. SYSTEM DISCREPTION

A. the design of the buck converter and grid connection

Using MATLAB/Simulink, the simulation for the electric vehicle charging system was developed, as shown in Figure 1. The diagram demonstrates the implementation of a Star-Delta connection for the transformer and a three-phase voltage supply. A three-level bridge inverter is employed to convert AC to DC. The control system, or DC regulator, as depicted in Fig. 2, makes adjustments to the reactive current and voltage of the grid's DC bus. Included in this are two controls: both for current and DC voltage, respectively. In d-q transformation techniques, a phase loop is employed, as indicated in [16], the output of the DC voltage regulator serves as the basis for determining the current reference. The current regulator's role is to generate the appropriate magnitude and voltage phase required to regulate the converter.

A DC-DC buck converter configuration with an output voltage of Vo is depicted in Figure 3, which is used to charge the electric vehicle (EV) by reducing the input voltage magnitude to a specific level. The converter is connected to the grid supply output at its input and to the battery at its output. The duty cycle of the buck converter, which indicates the voltage difference, is calculated using the following equation.

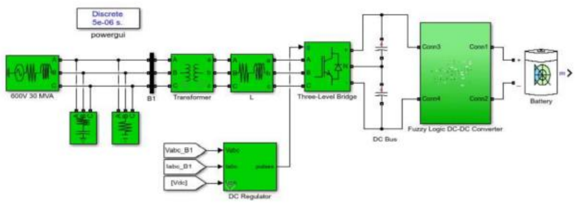

Fig. 1. EV charging system developed in MATLAB/Simulink

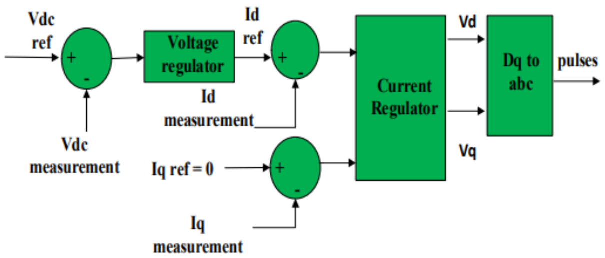

Fig. 2. DC regulator

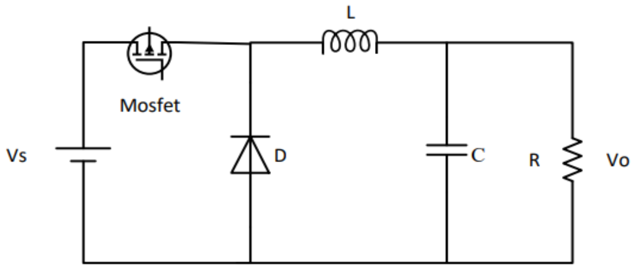

Fig. 3. DC-DC Buck converter

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

The duty cycle, denoted by D, regulates the on/off periods of the converter, with Vo representing the output voltage of the source voltage. To maintain continuous current in a buck converter, to ensure optimal performance, it is important to carefully choose the appropriate switching frequency and size of the inductor. It is possible to determine the minimum size of the inductor by applying the following equation:

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

In the above equation, R represents resistance while f stands for switching frequency. In order to maintain a constant current in the inductor, it is recommended to choose an inductor size (L) that is at least 25% larger than the minimum required size. This will result in the following outcome:

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

The ratio of output voltage to resistance (R) is proportional to achieve stable functioning, it is necessary to maintain an average of zero for the capacitor current. In order to calculate the average current that passes through the load, also known as the average inductor current (IL), the following equations can be utilized:

$$I_L = \frac{V_O}{R} \quad 4$$

In order to attain an extremely low output ripple voltage, the selection of the capacitor must be approached with great care. To calculate the necessary capacitance based on the targeted output ripple voltage, the following equations can be utilized:

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

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

B. Fuzzy logic controller

The main objective of utilizing controllers is to minimize the difference between the measured output parameter and the desired reference value. This paper adopts a Fuzzy Logic Controller (FLC) that is built upon the principles of bang-bang control, which have been detailed in references [15] and [12]. The bang-bang control approach's automatic on/off switching mechanism aids in maintaining the measured output in proximity to the reference value, operating essentially as a two-step controller. The control system's arrangement is depicted in Figure 4, wherein a (FLC) is integrated as a current regulator. The input to the FLC is the discrepancy between the measured voltage and the reference voltage, which determines the charging reference current for the electric vehicle (EV) battery. In Figure 4, the inductor, capacitor, and resistors are represented by the letters L, C, R, and R, respectively, while the grid connection discussed in Figure 1 is symbolized by the source. The pulse width modulation (PWM) block, as shown in Figure 4, generates the MOSFET's switching frequency. Figure 5 presents the input and output membership functions, while Figure 6 displays the crisp output function.

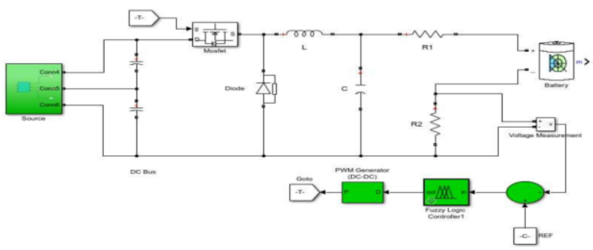

Fig. 4. The DC-DC converter with a Fuzzy Logic Controller.

The centroid defuzzification method, also known as the center of gravity (COG) technique (MF), was employed to defuzzify the input and output membership functions. The COG is located at the convergence of all points, and the output value of this method is determined by the COG of the fuzzy set. To achieve greater accuracy in controlling the COG and the area of each sub-division, which are summed up to determine the output of a non-continuous fuzzy set, the entire functional region of the membership function can be partitioned more finely. By applying the centroid defuzzification method, the defuzzifier value x* can be computed using the following equation.

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

In the formula, xi represents the individual elements of a sample, (xi) represents their corresponding membership values, and n is the total number of elements. The following rules apply:

• If the input membership function is categorized as high (HI), then the output membership function will also be categorized as high (HO).

• Conversely, when the input membership function is categorized as low (LI), the output membership function will also be categorized as low (LO).

Fuzzy logic controller with DC-DC converter

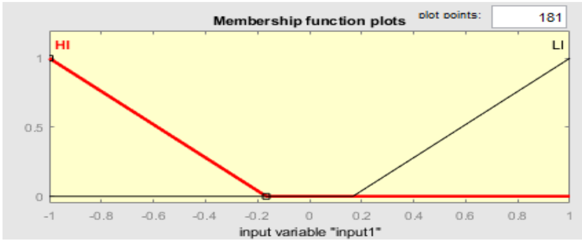

Fig. 5 Current error

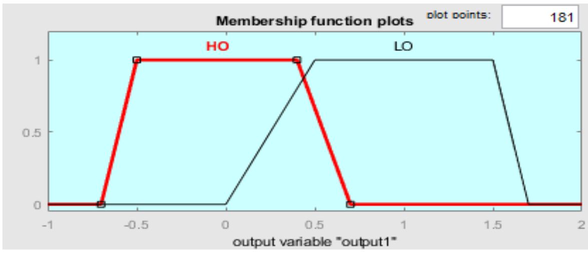

Fig. 6 Duty cycle

Rules table

INPUT	OUTPUT
HI	HO
LI	LO

III. PROPOSED METHOD

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a type of artificial neural network that is used for modeling and controlling complex systems. ANFIS is based on the integration of two powerful tools: fuzzy logic and neural networks. Fuzzy logic provides a mathematical framework for dealing with uncertain and imprecise information, while neural networks can learn from data to make predictions and control decisions.

ANFIS uses a set of rules and membership functions to represent the fuzzy logic part of the system. These rules and membership functions are generated by a clustering algorithm that groups the input data into fuzzy sets. The neural network part of ANFIS is used to adjust the parameters of the fuzzy logic rules and membership functions based on the input-output data.

The ANFIS architecture consists of five layers: input layer, Fuzzification layer, rule layer, defuzzification layer, and output layer. The input layer receives the input data, which is then transformed into fuzzy sets by the Fuzzification layer. The rule layer applies the fuzzy rules to the input data and produces the output of each rule. The defuzzification layer combines the outputs of the rules to produce a crisp output. Finally, the output layer produces the final output of the system.

ANFIS has several advantages over other control systems, such as the ability to handle non-linear and complex systems, the ability to learn from data, and the ability to adapt to changes in the system. ANFIS is widely used in many different fields, including control systems, robotics, and engineering.

ANFIS controller:

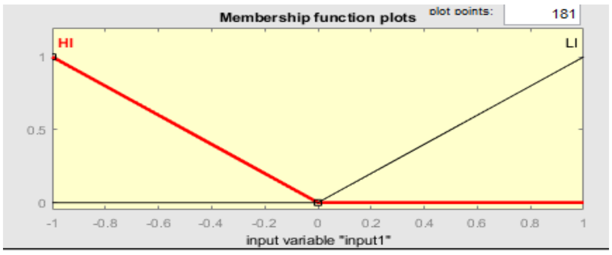

Fig. 7 Input

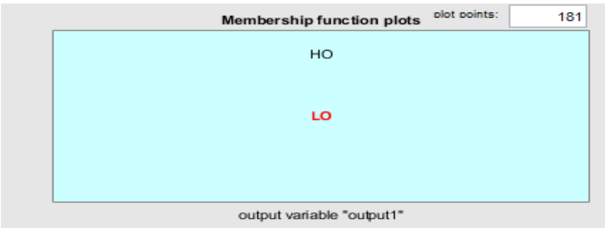

Fig. 8 Output

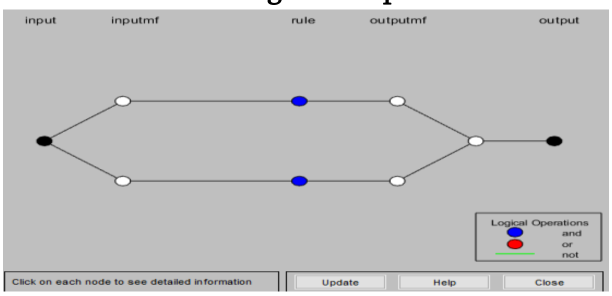

Fig. 9 Anfis structure

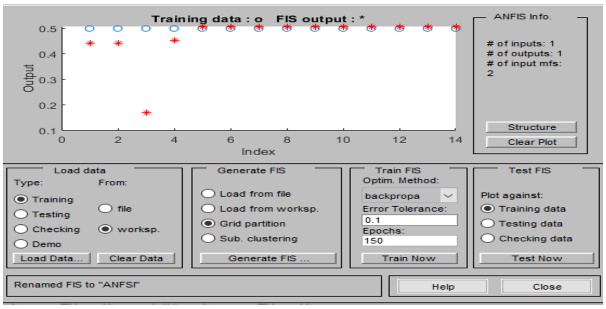

Fig. 10 Error

INPUT	OUTPUT
HI	HO
LI	LO

Rules table

Fig. 11 Rules viewer

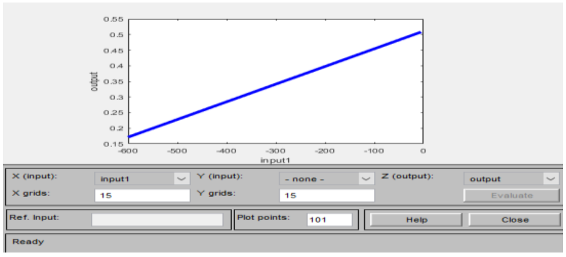

Fig. 12 ANFIS surface

IV. Results and Discussion

Simulation results:

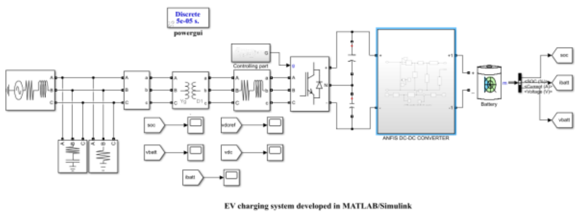

Fig. 13 Schematic diagram

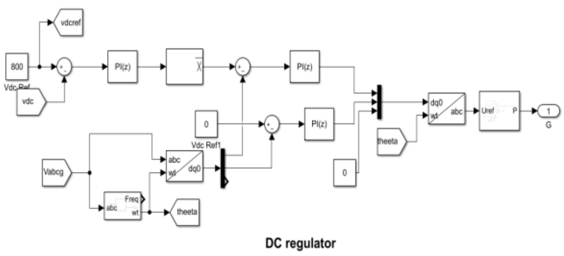

Fig. 14 Dc regulator

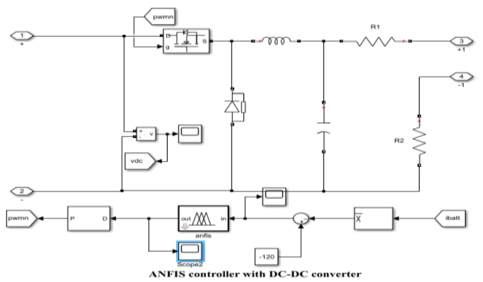

Fig. 15 ANFIS controller based dc-dc converter

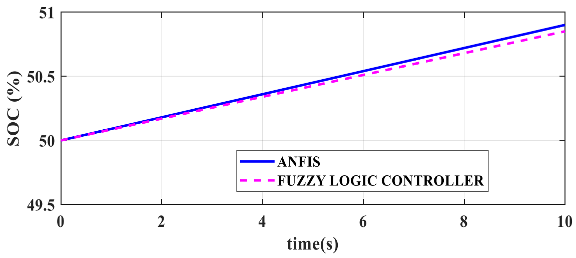

Fig. 16 Soc

As demonstrated in Figs. 16 and 19, the battery state of charge (SOC) steadily increases after reaching 50% while the DC bus voltage remains constant.

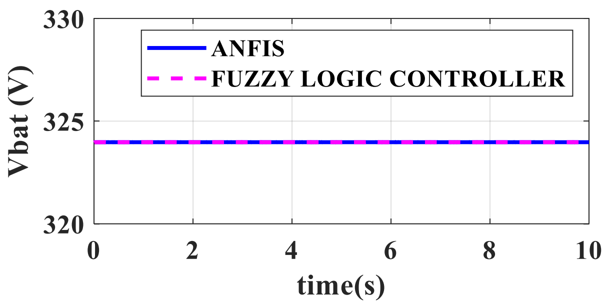

Fig. 17 Vbat

The charging voltage is more than the 324V open circuit voltage (OCV). According to Fig. 17, the charging voltage for a battery charging at CC is always higher than the OCV.

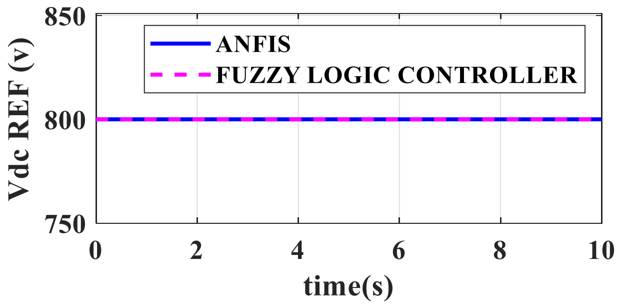

Fig. 18 Vdc ref

Fig. 18 shows the transient behavior of the DC bus voltage when a battery is connected for charging. There is a brief settling phase of approximately 0.2 seconds before reaching the ultimate value of 800V.

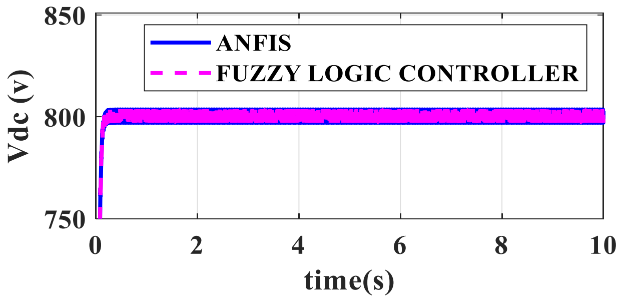

Fig. 19 Vdc

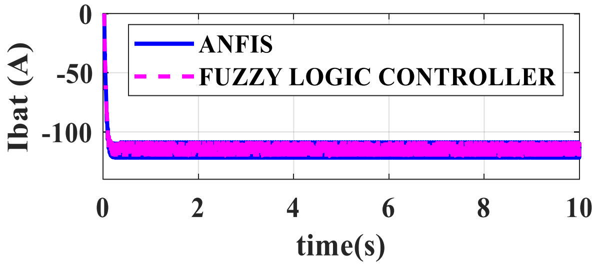

Fig. 20 Ibat

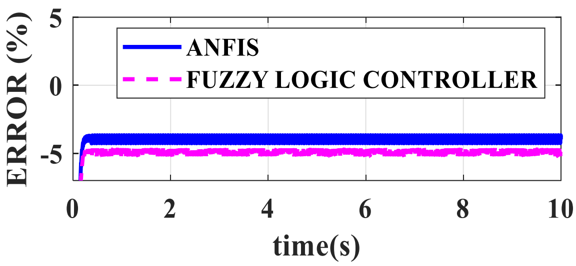

Fig. 21 Error

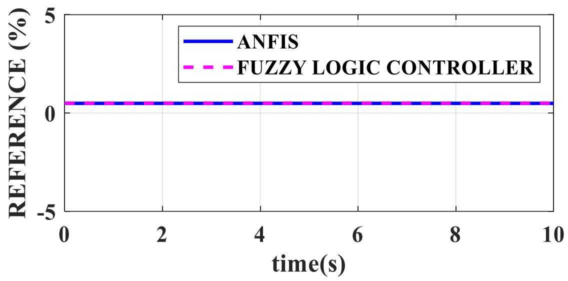

Fig. 22 Reference

The outcome of the 120A constant current (CC) charging for the 12 kWh EV battery is shown in Fig. 20. The ANFIS controller keeps the current flowing continuously while the EV battery is being charged. This outcome shows the value of the ANFIS controller for EV fast DC charging.

V. CONCLUSION

It proposed a new method for controlling the charging process of electric vehicles. The use of Adaptive Neuro-Fuzzy Inference System (ANFIS) has provided a solution for accurately maintaining a constant current level during the charging process, which can help to extend the lifespan of the battery and improve the overall efficiency of the charging process. This has also demonstrated the feasibility of implementing this system in a real-world setting by building a prototype and testing it in a lab environment. The results showed that the ANFIS controller was able to maintain a constant current level despite variations in the input voltage, temperature, and other factors that can affect the charging process.

Overall, this project has contributed to the development of more efficient and reliable electric vehicle charging systems. With the increasing demand for electric vehicles, such systems are becoming increasingly important for reducing carbon emissions and promoting sustainability.

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Cite this article as :

P. Ramesh, A. Yamini, M. Siva Ram, V. Bhargavi, P. Bala Sujith, N. Jyothish, "A Novel ANFIS controller-based Grid connected EV charging system with constant current control topology", International Journal of Scientific Research in Computer Science, Engineering and Information Technology (IJSRCSEIT), ISSN : 2456-3307, Volume 9, Issue 2, pp.342-349, March-April-2023.