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Design of Small-Scale Movable Charging Unit and Reducing Charge Time using Fuzzy Logic for Electric Vehicle

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Abstract: Now-a-days Electric Vehicles (EV) are drawing attention due to its enormous advantages subduing its setbacks. Lots of research is going on to overcome the prevailing drawbacks, out of which the increased charge time is a highlighted one. Though lots of Fixed Charging Stations have been installed, mobile charging stations are gaining popularity, due to less installation cost and increased customer satisfaction. The development of self -sustainable Small-Scale movable charging unit i.e., mobile charging station, to charge EV, is discussed in this paper. In addition, the charge time for EV is reduced by using Fuzzy Logic. The survey was conducted among EV users to find out the acceptance ratio. The small-scale movable charging unit has been designed and discussed using simulation in MATLAB R2021a. Also, the mathematical model used in designing SSMCU and verification of design along with charge time is discussed. The fuzzy logic was employed to reduce charge time to 2hrs 45 mins for State of Charge from 20% to 100%. The simulation results with fuzzy logic and using conventional method was compared. It was shown that the charge time was reduced by 30.4% with fuzzy logic, when compared with conventional controller for SOC from 20% to 100%. The charging behavior of EV with local load, was also studied using simulation. The Small-Scale Movable Charge Unit was designed as a feasible option to local vendors, with the reduced charge time being an additional feature. Also, the paper aims to satisfy United Nations Sustainable development goals UNSDG-7(affordable and clean energy) and UNSDG- 13(climate action).

Keywords: Electric Vehicle, Movable Charging Unit, Fuzzy Logic Controller, Charge time, Mobile Charging Station, Model of SSMCU.

1. Introduction

Now-a-days there is an increasing necessity to decarbonize the transportation sector with a promising solution. The increasing penetration of Electric vehicles (EV) turns to be a lucid answer, which provides pollution-free, noiseless environment and good mileage when compared with traditional fossil-fueled vehicles [1] Two- and three-wheelers (2/3Ws) remained the most electrified segment of road transport in 2024, with over 9% of the global fleet now electric. Electric models accounted for around 15% of total 2/3W sales globally, with total sales reaching 10 million. [2] In 2023, the global public charging infrastructure grew by approximately 40%, with fast chargers making up 35% of the total and expanding at a quicker pace than slow chargers. China led the market in both categories, installing over 85% of the world's fast chargers and 60% of the slow chargers during the year. [3] In India, EV sales rise to 41% in April 2023 to around 109000 units. Among this, Electric Vehicle 2 wheelers account for 65730 units. Electric passenger vehicles account for 5147 units with Tata motors being the leader. 79 units of Electric buses were sold. [4] According to data on dec 2024, from the Ministry of Power, a total of 25,202 electric vehicle public charging stations have been installed across India.

The steady rise in EV adoption demands an efficient charging infrastructure which includes charging at home or public charging stations. There are various EV charging stations employed in developed countries to satisfy the charging need of EVs. The fixed charging stations consume the power from power grids, solar panels, wind turbine based on applicability. The solar panels and wind turbine depend on Renewable Energy Resources like sun and wind, for production of power. [5] categorizes and compares various energy management schemes employed in EV charging stations, including PV-grid integration and standard grid charging, providing insights into their operational efficiencies and challenges.

The lack of space, money demands, congestion problem, lengthy ques necessitate the introduction of moving charging stations (MCS) with less installation cost. The authors of [6] found that there are various complications in selection of location of a public charging station, mainly the location - dependent installation costs in addition to other constraints. [7] Foresee the number of EV charging stations and also the high costs (installation and operating cost) involved, in the required road path taking into account the road patterns, driver behavior and other environmental complications. [8] Reviews the state -of -art of MCS and market solutions. They present MCS a complementary solution to FCS in terms of range-anxiety reduction and cost reduction.

In various developed countries MCS are being used where a moving vehicle is provided with solar panels, small wind turbines or battery. A specific FCS has a manageable number of MCS. Otherwise MCS is also maintained and charged independently. The battery of MCS, is charged in FCS or powered from pantograph. The pantograph is an overhead charging system which supplies power to the moving charging station. If solar panels or wind turbine is placed in MCS, the renewable energy resources play a vital role in delivering energy. [9] Introduces a new concept that fuses the integrated energy system with MCS, thereby improving the efficiency and reducing the operation cost. Also, [10] emphasize the usage of community energy storage system, which improves flexibility, reduce CO2 emissions and achieve waiting time at FCS to zero.

The challenging issues that need to be addressed in charging EV are range anxiety, lesser public charging points, more charging time and lesser safety. Among these, the significant issues are lesser public charging points and more time for charging. As an aiding solution to address these issues, a small-scale movable charging unit (SSMCU) which is mobile and charge EV (Electric two-wheeler only), is presented. The fuzzy logic has been implemented in this paper, to reduce charge time of EV. The proposed SSMCU i.e., mobile charging station, includes charging from renewable energy sources like solar or wind. Solar panels would be mounted on top of the vehicle and small wind turbine (if the environment is windy) can be placed in the vehicle. A hand generator is also included. Thus, the movable charging unit is self-sustainable which charges the EV (EV two- wheeler only). The fuzzy logic has been simulated, with constant current charging circuit of EV and the charging time has been reduced to 2 hrs. 45 mins for SOC (State of Charge) increase from 20% to 100%. The study [11] presents the design of solar photovoltaic- fed charging station and ensures safe and efficient charging with fuzzy logic controller with constant current charging.

A multi-charger optimization framework was proposed by [12], where a combination of different types of Fixed Charging Stations (FCS) and Mobile Charging Stations (MCS) was analyzed to minimize both cost and charging time for EV users. The framework was implemented in Chattanooga, TN, USA, and the findings revealed that MCS provided the most optimal solution. Similarly, [13] presented a cost-effective and optimized design for a wireless charging station using inverter configurations tailored for electric scooters. The system was benchmarked against conventional small-scale scooter charging setups and demonstrated notable advantages—such as user-friendliness, compactness, misalignment tolerance, and high efficiency (85%–92%). These studies indicate a growing interest in MCS among EV users due to their flexibility and practicality, for particularly electric 2 wheelers. In this context, we propose a small-scale movable charging unit that integrates solar, wind, and mechanical (hand-generator) energy sources to charge electric two-wheelers. This system is first integration of hand-generator backup with multi-source energy harvesting into a small-scale movable charging unit, with fuzzy control.

The key sections of the manuscript are as followed. The section 2 explains the Case study and Literature Review of Movable Charging Unit. The section 3 explains the proposed architecture of Small-Scale Movable Charging Unit (SSMCU) and the EV model. The Section 4 elaborates the simulation results of SSMCU. The conclusion is given in section 5.

2. Case Study and Literature Review of Movable Charging Unit (MCU)

Current research and analysis in EV and charging station, is in preliminary stage in India. There is no active implementation of charging station due to various reasons, mainly lack of installation space. Hence a ‘MCU users EV opinion survey’ was conducted for movable charging units in Chennai, Tamil Nadu, India with the aim to prove the benefits and improve the awareness of mobile charging station. A total of five teams of two members each were assigned to conduct survey in Chennai's south, east, north, and west. Each team talked to movable charging unit users in person, and collected the survey data, as most of the roadside vendors lack proper education. The surveyed data were inputted in google forms by the teams and graph was collected. The survey was conducted with population size being 4646732, confidence level 99.9%, margin error 5% and sample size 1083. The survey results are considered to be appropriate to represent the total population size with the responses being 2300.The important questions of survey results are shown below and discussed. It was found that most of the movable charge unit users use lead acid battery to utilize electrical appliances in the movable charge unit.

The survey outcome in Figure 1(a) showed that 52.2% of users charged the battery at home and 47.8% charged with rent. In Figure 1(b) about 61%of users charged the battery daily and 27% charged 2 days once, which showed that users preferred low-cost battery and low maintenance cost. From Figure 1(c) around 38% of users have idea about solar energy and 46% of users were aware about solar panels, which is a positive aspect towards using solar panels in movable charging unit. From Figure 1(d) the average charging amount/month is illustrated where 84.8% of users spent lesser than 1000Rs and about 13% spent between 1000Rs and 3000Rs.From Figure 1(e), about 83.8% of users preferred the addition of EV charging facility in movable charging unit, since it would be a cheaper and beneficial option and an aid to increase the monthly income.

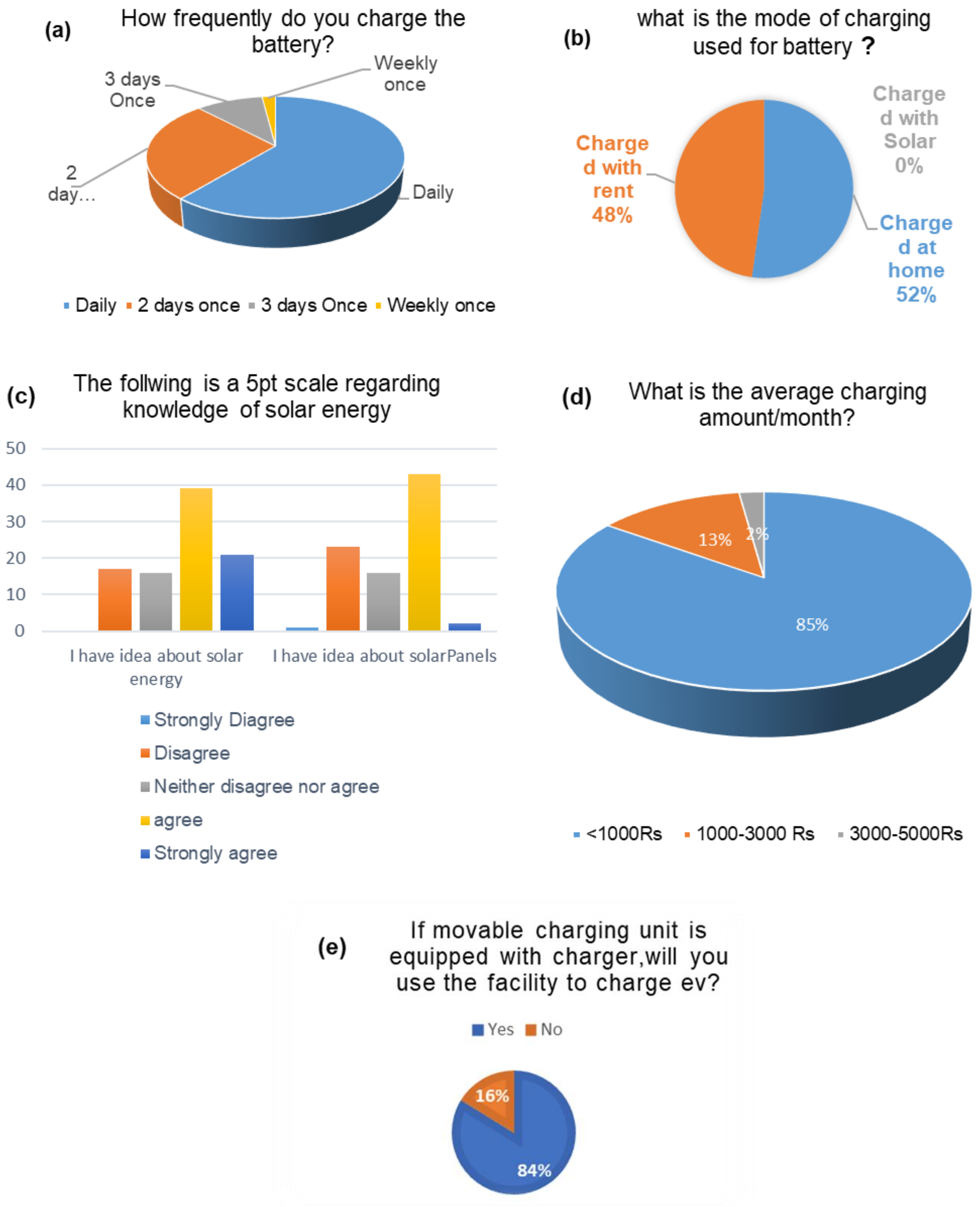

Figure 1. MCU users EV opinion survey **(a)** and **(b)** Responses set1, **(c)** Responses set 2, **(d)** And **(e)** Responses set3 related to SSMCU acceptance.

Around 52.2% of users charged the battery at home and 47.8% charged with rent. Also, the survey results showed that 61% of users charged the battery daily and 27% charged 2 days once, which conveyed that they used low-cost battery at low maintenance cost. 38% of users have idea about solar energy and 46% of users were aware about solar panels, which gave an idea that most of users would welcome usage of solar panels in movable charging unit. About 83.8% of total users accepted that they would charge their EV in the movable charging unit if it is was equipped with EV charger. Thus, we can conclude that most of the EV users welcomed the option of equipping the movable charging unit with EV charger.

[14] Have showed that the DC nano grid, which is powered by solar energy and wind energy, uses buck and boost converter to charge EV. The Mobile Charging Station (MCS) provides battery swapping and utilizes V2G facility during overloading of nano grid. The six dispatch algorithms were formulated by [15] to charge EV from MCS when Fixed Charging Station (FCS) is overloaded or when EV is outside FCS. Thus, the waiting time of EV was improved when FCS was overloaded or when request comes from EV directly to MCS.[16] Showed that when the MCS is operating in off grid, the MCS takes charge from energy storage units like ultracapacitor and charges the Electric Vehicle. When connected online with grid, the MCS charges energy storage unit with the help of pantograph. The 75kw mobile charging system is designed, developed and implemented with 400kwhr storage system by [17] to charge high power EVs. Interleaved Cascaded buck boost converter is utilized to get power from grid and energy is stored using Lithium-ion battery thermal model storage system. A novel approach has been suggested in [18] where queue based analytical approach has been utilized to use mobile charging (MC) i.e., Mobile plug in (MP) configuration or Mobile swapping (MS) configuration to charge nearest EV in the service area. The approach uses the Poissson distribution for charging requests and nearest-job-next (NJN) service strategy is used to find out its next request.

A numerous papers have been presented with the aim to minimize the charging time of EV which is an alarming issue that demands attention. [19] Discussed new steps to charge lithium-ion battery with multistage constant heating optimization method with Genetic Algorithm. He revealed that proposed method can decrease time of charging and increase in temperature. Compared to CCCV charging at ambient temperature, 10°C, 25°C, and 40°C, the proposed method reduced time of charging by 1.9%, 5.3%, 8.56%, and 9.54%, respectively, while the temperature rise was lowered by 48.6%, 28.3%, 67.3% and 17.9%, respectively. [20] P.H.L. Notten introduced boost charging concept to reduce charge time to 5 mins to charge one-third of its rated capacity. [21] G. Madhuri implemented buck boost converter, PID controller along with Fuzzy logic controller for fast charging of the Electric vehicle. The simulations showed that electric vehicle can be charged within half a minute. [22] Jiuchun Jiang, proposed constant-polarization-fuzzy control charging method, to reduce the time of charging with not much temperature rise. He compared the results with CC-CV charging method, which had issues with the battery life and charging speed. [23] The optimized Fuzzy Logic Controller using Genetic Algorithm was introduced to show minimal charge time and lesser temperature rise. [24] In their paper, discussed about multistage CCCV method to reduce time of charging and lessen ageing of battery. They optimized charging current using PSO and reduced charging time from 6105 sec to 3846 sec. According to Liang-Rui Chen [25], the proposed grey method increased the charging time by more than 23% but improved charging efficiency by over 1.6% compared to the conventional CC-CV method. In [26] the authors proposed Dynamic Programming method showed better results like charging time 0.23% increase and charging loss 0.79% increase as against conventional Dynamic Programming method.

The authors in [27] has compared Teaching–learning-based optimization- Fuzzy (TLBO-F) and Particle swarm optimization Fuzzy (PSO -F) and non-optimisation-fuzzy (NO-F) in a hybrid energy storage system (HESS) paired with ultracapacitor where it aims to prolong the battery life time. The battery's state of charge reached excess by 14%, which results in increased charging speed, when TLBO-F was implemented relative to PSO-F and raised by 30% compared to NO-F algorithm.

Despite being less expensive to install than fixed charging stations, the Mobile Charging Unit is still not cost effective. In order to address this research gap, a Small-Scale Movable Charging Unit (SSMCU) has been designed, which require less financial aid to charge electric vehicles (electric two-wheelers only). With the solar panels mounted on top, and/or small wind turbine placed in SSMCU, there is an advantage of utilizing Renewable energy, which results in less expenditure. Additionally, a hand generator is placed which serves as a source of power and an economic tool. Furthermore, fuzzy logic has been implemented with constant current charging circuit of Electric Vehicle, which reduced the charge time to 2hr 45 mins.

3. Materials and Methods

The proposed architecture of SSMCU is shown in Figure 2. The key components are solar panel, wind turbine, hand generator, dc-dc boost converter, constant current charging circuit, fuzzy logic circuit and Electric vehicle battery. The source of generation is solar, wind and/or hand generator which is connected to a hybrid controller. The hybrid controller combines the sources and is connected to an energy storage battery which output 12v.

Initially, on the top of the SSMCU with conventional controller, solar panels are positioned, which is step-up by a DC-DC boost converter. This is finally connected to constant current charging circuit. The wind turbine and hand generator may also be employed as the source. The Constant Current (CC) charging method is employed where the current is fixed at -6Amps and the circuit finally charges EV. The lithium-ion battery (as a substitute for EV) is simulated, with the voltage 12v for test purpose as a prototype model. The SOC of EV battery increased from 20% to 100%, and the charge time took 3hrs 56 mins. The proposed architecture of SSMCU includes fuzzy logic along with conventional controller, where fuzzy logic circuit was added as the feedback loop to CC charging circuit. The charging circuit in figure 2 comprises of fuzzy logic circuit serving as feed- back loop to the CC charging circuit.

Fuzzy logic is a form of logic in which the variables have truth values between 0 and 1. There is a concept of partial truth, where the truth value may range from 100% true to 100% false. A fuzzy logic is based on the observation that decisions are made based on inaccurate and vague information. By using fuzzy rules and fuzzy sets, fuzzy logic can make computers guess to form decisions that are more similar to those of humans. Symbolic logic is dependent on fuzzy sets. Fuzzy sets connect us to the imprecise situations. Fuzzy sets and fuzzy rules are used to represent symbolic logic. The table 1 describes the fuzzy rules implemented in this paper. A fuzzy set consists of a collection of items that are related to one another but are set in different degrees. Fuzzy rules are justified for showing information in “fuzzy logic” as it is the key tool. Using symbolic logic, fuzzy inference is used to develop a mapping from an input to an output. In the FIS (Fuzzy Inference System), fuzzy membership functions are employed to form logical meanings.

Fuzzification: In this rule-based system, FLC (Fuzzy Logic Controller) employs fuzzification inference along with complex algorithms to assess the if-then rules. There is a tendency for them to produce fuzzy results, which should be converted into crisp results.

Defuzzification: In relation to a fuzzy set, it refers to the conversion of a fuzzified output into a crisp value. A defuzzied value identifies the appropriate action to be taken to control the process.

In [28], an optimal charging pattern was achieved using a fuzzy approach. Compared to the traditional CC-CV method, this approach resulted in a reduction of charging time by over 56.8%, an increase in battery life cycles by 21%, and a 0.4% improvement in charging efficiency. A fuzzy-controlled active state-of-charge controller (FC-ASCC) for reducing the battery time of charging was proposed by [29]. The FC-ASCC reduced the charge time to 243 mins as against 280 mins by general charger. The FC-ASCC replaced the CV mode which improved the performance by 23%.

The Fuzzy logic was implemented with EV load in the proposed SSMCU. The above Table 1 shows the rules used in Fuzzy Logic Controller.

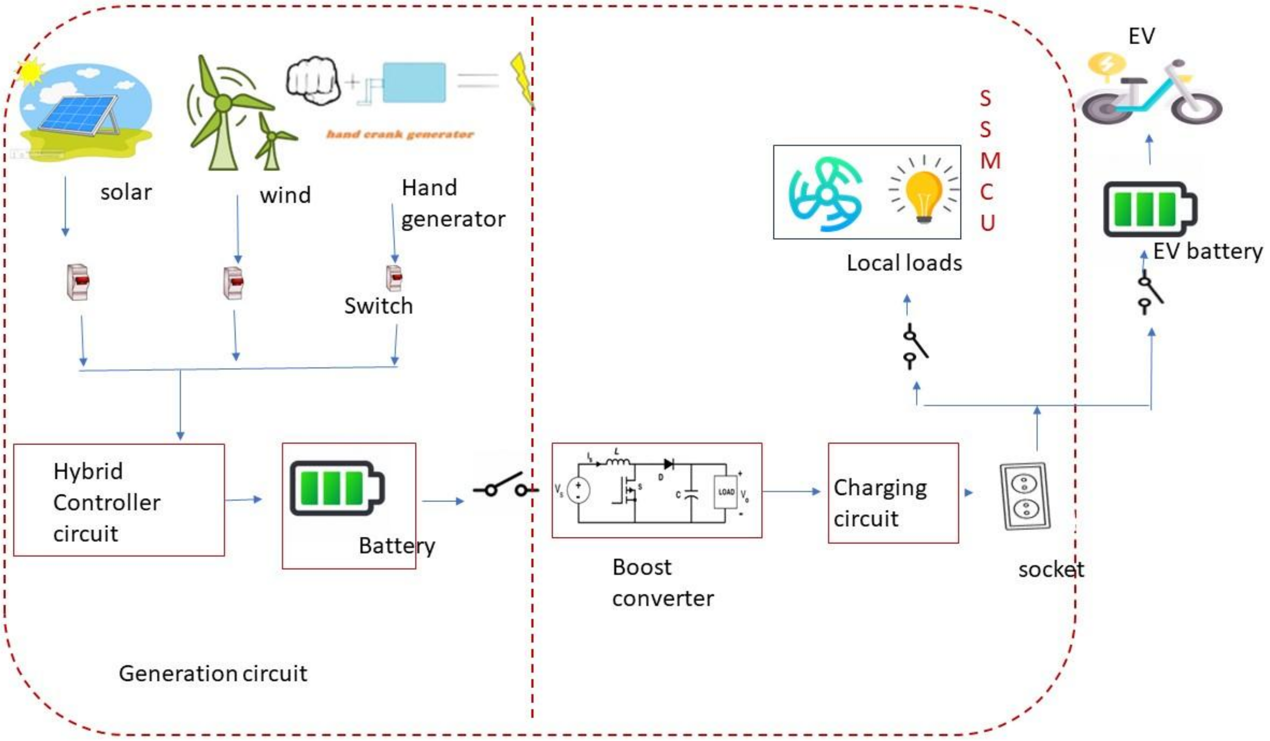

Figure 2. Design of Small-Scale Movable Charging Unit

The linguistic variables ΔSOC and ΔI follow fuzzy iF THEN rules which decides the output linguistic variable Δu. The input variables ΔSOC represents the change in State of Charge and ΔI represent the change in current. The output variable Δu denotes the duty ratio. The term set {NB, NS, ZE, PS, PB} uses standard names with the typical abbreviations S(small), B (big), N (negative), P (positive) and, ZE (zero). For example, NB represents Negative Big and so on. For example, IF (ΔSOC is NB AND ΔI is NB) THEN Δu is NS. The membership functions are assumed to possess values from 0 to 1. The range of ΔSOC lies between -50 to +50, ΔI between -20 and +20 and Δu between -1 and +1.

Table 1. Fuzzy Rules in SSMCU

ΔSOC	ΔI					
	Δu	NB	NS	ZE	PS	PB
	NB	NS	ZE	ZE	PB	PB
	NS	NS	ZE	ZE	ZE	PS
	ZE	NS	NS	ZE	PB	PB
	PS	ZE	ZE	ZE	NS	NB
	PB	ZE	ZE	ZE	NS	NB

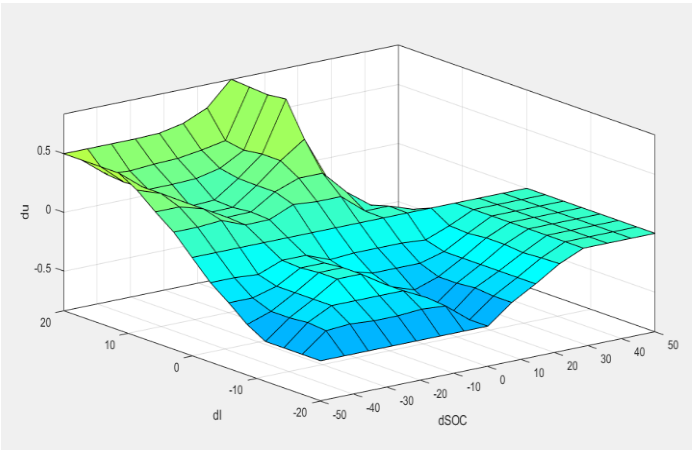

Figure 3. Surface control behavior

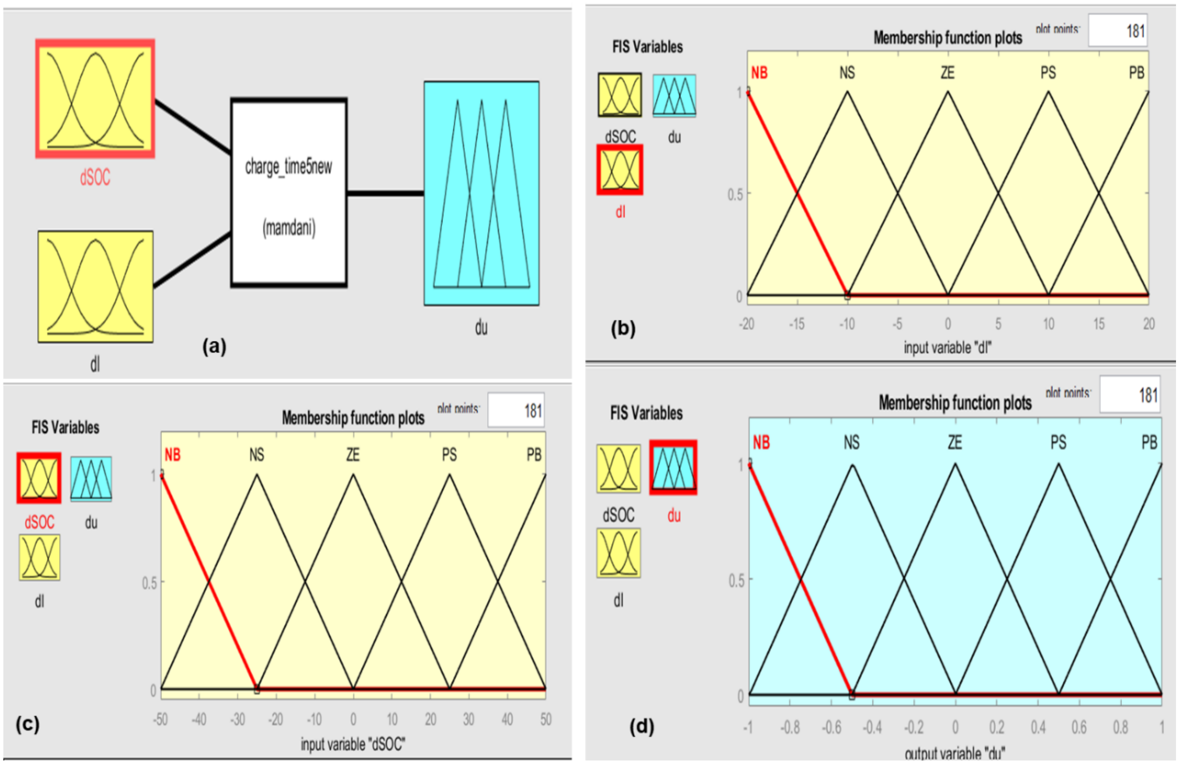

Figure 4. **(a)** Membership functions, **(b)** Membership function plot for ΔI, **(c)** Membership function plot for ΔSOC, **(d)** Membership function plot for Δu

The Figure 3 depicts the nonlinear relationship between the linguistic input variables ΔI, ΔSOC and output variable Δu. The Figure 4(a) reveals the membership functions using Mamdani approach. The Figure 4(b) shows the membership plot for the input variable ΔI. The Figure 4(c) membership plot for the input variable ΔSOC.The Figure 4(d) shows the membership plot the output variable Δu.

3.1 Model of SSMCU

In this section the model used in the architecture of proposed SSMCU is discussed. There are various factors assumed while designing the proposed architecture. They are:

- If Solar and wind energy is not available, the battery provides the charge to the boost converter.
- SSMCU charges only one EV (Electric 2-wheeler only) at a time.

3.1.1 EV Battery

In the recent days, the run time-based models combined with Thevenin model is widely used as in [30]. The same method is deployed in this paper. Figure 5 illustrates the electrical circuit of the Thevenin model. The U_{OCV} represents the open-circuit voltage, which depends on the state of charge (SOC), while the open-circuit behavior is characterized by the series resistance Ro. The parallel RC denotes the transient response of the battery.

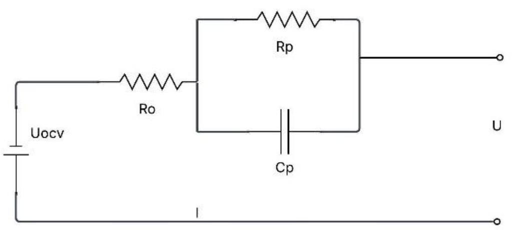

Figure 5. Thevenin model of EV battery.Adapted from Reference [31] Licensed under CC BY 4.0

The calculation of charge time is found using the formula:

Charge time= (Battery capacity) / (Charge current) (1)

Where

- Charge time is the time needed to charge battery from current SOC to desired SOC
- Battery capacity is the total battery capacity in Ampere hours (Ah)
- Charge current is the rate in which current is given to the battery during charging in Amperes(A)

The equation 1 calculates the charge time as mentioned in [32].

3.1.2 Solar Panel

An equivalent circuit of solar cell from Figure 6, use an ideal current source with diode parallel to it. Rsh and Rs are added to account for resistive losses. I_L is photogenerated current, I_D is diode current and Ish is the current through shunt resistor. The resulting output current Io is given by

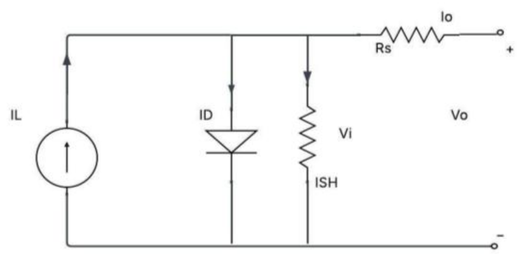

Figure 6. Circuit configuration of solar cell. Adapted with permission from Reference [33].

$I_{out} = I_L - I_D - I_{SH}$ (2)

as the cell current expressed in [34].

The junction voltage V_i

$V_i = V_o + I_o R_s$ (3)

$I_{SH} = V_i / R_{SH}$ (4)

3.1.3 Boost Converter

The authors [35] have designed the fast-charging station with energy storage devices like fly wheels and supercapacitors with the electronic converters like DC-DC converter or AC-DC converter between sources and charging station. The authors [36] have developed fast charging station for EV in which feedback is given to dc-dc converter, taking SOC into account, by utilizing battery pack controller module and also tuning the PI controller. The Figure 7 shows the circuit configuration of dc-dc boost converter which boosts the input voltage to an increased output voltage. During the switch on phase, energy is stored in the inductor, and during the off phase, this energy is released to the load. The input voltage Vin(12V) is across the inductor L (L = 0.148 H) during the switch-on period, which causes the inductor's current to increase linearly. The reverse biased diode D, restricts the current to pass through the load. The inductor current is

$\Delta I_L = (V_{in} \cdot t_{on}) / L$ (5)

Where t_{on} is the time taken of the switch in on period.

During the switch-off phase, diode D becomes forward-biased, allowing the inductor to release its stored energy to the load and capacitor C (0.0264 F). At this point, the voltage across the inductor equals the difference between the output voltage (Vout) and the input voltage (Vin). The inductor current becomes,

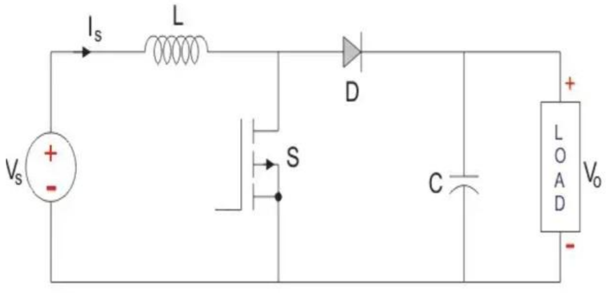

Figure 7. Boost converter circuit. Adapted with permission from Reference [37].

$$\Delta I_{L} = ((V_{out} - V_{in}) / L).\ t_{off} \quad (6)$$

Where t_{off} is the time of the switch off period.

Finally, we get

$$V_{out} = V_{in} / (1 - D) \quad (7)$$

Where D is the duty cycle given by

$$D = t_{on} / (t_{on} + T_{off}) \quad (8)$$

3.1.4 Constant Current Charging Circuit

Constant current (CC) charging circuit in Figure 8, is powered by dc source which has voltage greater than battery voltage and maintains the constant current. The circuit regulates the output current through duty cycle modulation of the MOSFETs. The voltage across R_{sense} represents the I_{out}.

$$V_{sense} = I_{out} \cdot R_{sense}$$

Where $I_{out}$is the output constant current. A feedback loop adjusts the PWM signal, to control the MOSFETs and maintains the constant current for EV. The current in the battery increases while EV is charged. The CC circuit adjust the voltage and maintains the steady current. The Rsense value includes 1e-300 Ω and inductance 0.176e-2 H. The I out is maintained at -6A. The Vsense is maintained at 12.8V.[38] The Voltage-based Multistage Constant Current (VMCC) charging strategy was implemented in conjunction with Multi-Objective Particle Swarm Optimization (MOPSO) to achieve a balanced trade-off among charging time, charged capacity, and energy loss. In [39] revealed a multi stage CC charging method with fuzzy logic which gave the charging time 9.76% reduced in comparison to the conventional CC-CV method.

3.1.5 Fuzzy Circuit:

The feedback loop from battery consists of fuzzy logic circuit which adjust the PWM signal to the MOSFETs. The Fuzzy Logic Controller (FLC) makes precise decisions based on fuzzy rule sets and maintains constant current in EV battery by adjusting the signals to MOSFETs.

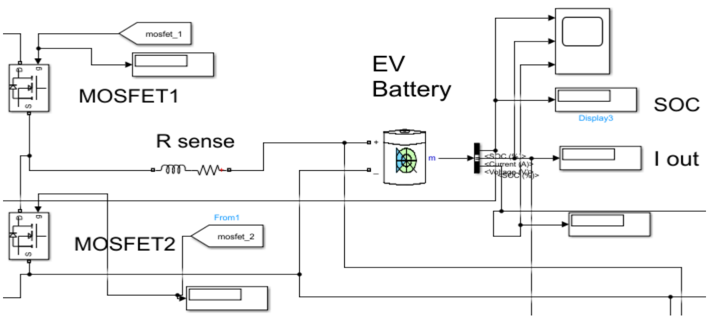

Figure 8. Constant current charging circuit

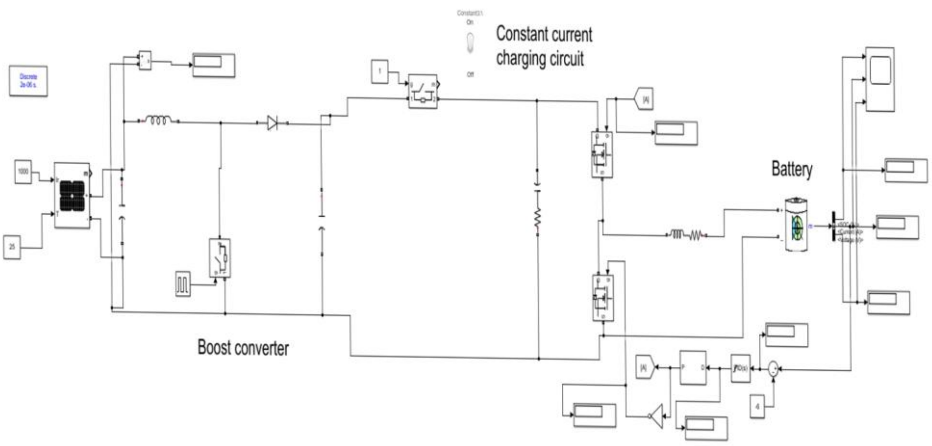

Figure 9. SSMCU with conventional controller

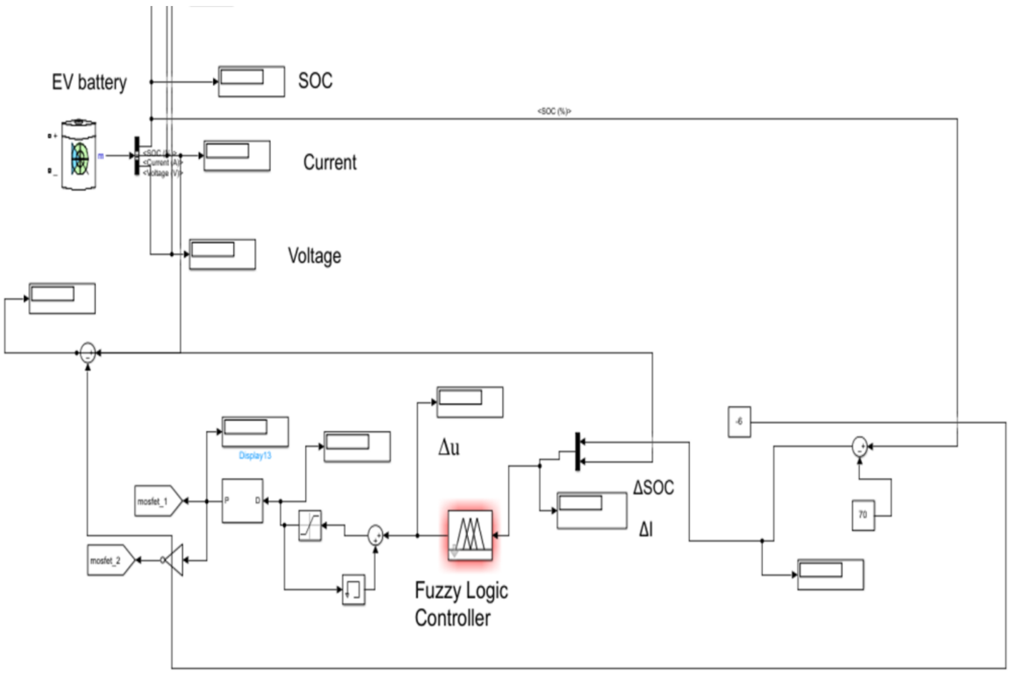

Figure 10. Advanced FLC circuit in SSMCU with EV

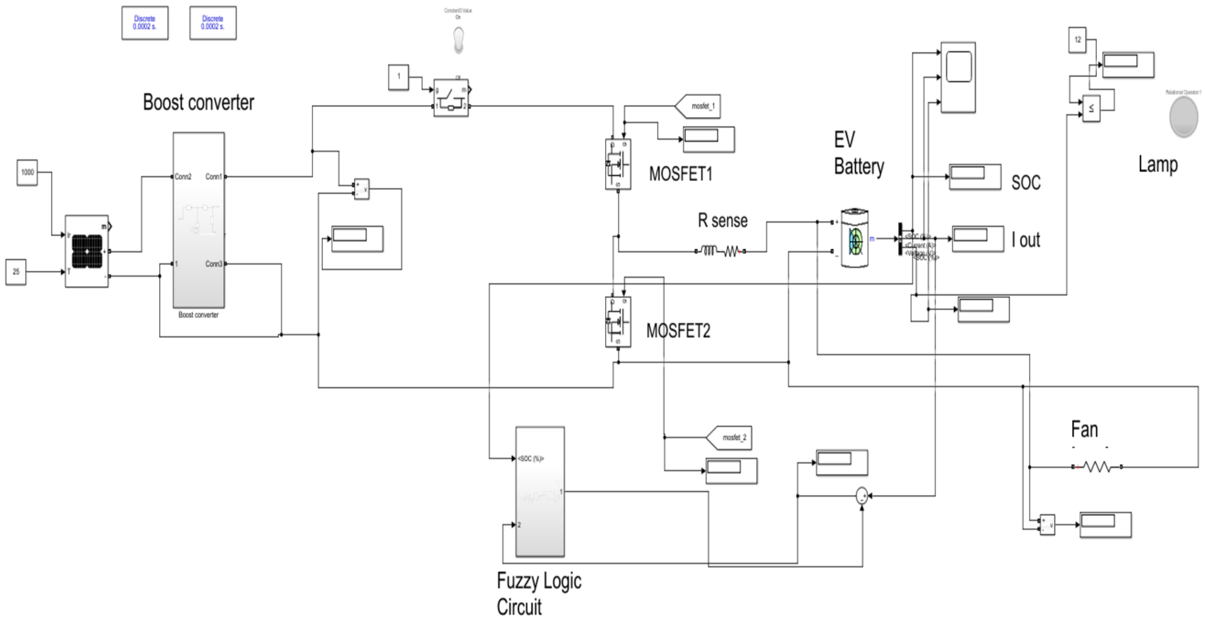

Figure 11. SSMCU with EV and local load

The Figure 9 shows the design of SSMCU with conventional controller in MATLAB. The Figure 10 shows the advanced FLC circuit connected with the constant current charging circuit of EV. The range of controller inputs ΔSOC (change in SOC) lies between -50 to +50, ΔI (change in current) lie between -20 and +20 and Δu (duty cycle) lies between -1 and +1. The Figure 11 shows the SSMCU with EV and local loads. The fuzzy circuit was loaded along with local loads i.e. a lamp and a fan. The lamp will be ON i.e. it will show blue indicator if the voltage across lamp is 12v, else it would be green.

4. Results and Discussion

The design procedure of the presented model is implemented and the SSMCU is simulated in MATLAB Simulink R2021a with the input parameters from Table 2 while Table 3 gives the resulting parameters. The EV battery is selected based on the model specified in Figure 5 and is implemented by using 'battery' block from MATLAB/Simulink. The solar panels are positioned in SSMCU as in section with the input parameters from Table 2. Likewise, wind turbine may also be used based on inputs from Table 2.

The charge time can be calculated according to equation (1). The rated capacity being 16Ahr and charge current -6A. The charge time calculated mathematically comes to around 162 mins. The charge time obtained by simulation, is found to be 165 mins. The results are approximately closer. The charge time for SSMCU simulation with conventional controller is 237 mins. The charge time was reduced by 30.4% by using fuzzy logic in SSMCU. The results are obtained along with the resulting parameters from table 3.

Table 2. Input Parameters of SSMCU

Nominal voltage	14V
Initial SOC	20%
Battery response time	1sec
Vin	12V
Solar panels parallel strings	3
Series connected modules/string	10
R sense	1e-300 ohms

Table 3. Resulting parameters of SSMCU

L_{boost}	27e-6mH
C_{boost}	1.78e-6mF
V_{out}	13.2V
I_{out}	6A
D	0.8
Charge time T	165 mins

4.1 Case 1- Load application with EV load only

The various results have been obtained and analyzed. When the solar panel acts as a source of generation, the irradiance is 1000 and temperature is 25ºC. The solar panels are positioned at the top of SSMCU. In the SSMCU circuit with the conventional controller, the 12v to 18v dc-dc boost converter is utilized. The CC charging circuit maintains the current to be at -6A and voltage 13.2V. The rated capacity of the EV battery is chosen to be 16 Ahr. The initial SOC is set to 20%. Once it starts to charge EV, the SOC increases from 20% to 100% which took 3hrs 57mins. In the SSMCU circuit with fuzzy logic, the fuzzy circuit was built with constant current charging circuit of EV battery. The input membership functions were ΔI and ΔSOC and the output membership function was Δu. The input membership function ΔI referred to the change in current values between constant current -6A and battery current. The input membership function ΔSOC referred to change in SOC values between reference SOC i.e. 100% and the battery SOC. The output membership function was the duty ratio Δu, which was given to MOSFET1 and MOSFET2 depending on output value from PWM generator. The initial SOC is set to 20%. Once it starts to charge EV, the SOC took 2hrs 45 mins to increase from 20% to 100%.

Similarly, the fuzzy logic was implemented with CC circuit in both buck and boost modes and compared with CC-CV method in [40]. The CC-fuzzy method outperformed the conventional method, by charging by 25% and 12.5% faster, in buck and boost modes respectively. In addition, the temperature in buck mode was 0.5ºC and in boost mode both the methods had the same temperature. The PWM duty is activated by controlling voltage and current in [41] while charging 2C. The charge time has been improved by 37.8% and reached efficiency up to 82%, compared to conventional CC-CV method.[42] propose a DC micro-grid setup energized by photovoltaic powered EV charging station with fuzzy with constant current charging control, where it provides efficient bidirectional charging and increased efficiency by 95%. Though grid supply is not in context in this paper, power from grid can be extended in future for SSMCU.

The figure 12(a) shows the SOC increase from 50%. SOC with fuzzy logic proved that it increased by 0.05% faster when compared to SOC with conventional controller. This can be shown with the SOC data for SSMCU with the initial SOC 50% in table 4.

Table 4. SOC comparison for SSMCU

Time(Secs)	SOC for SSMCU with conventional controller	SOC for SMCU with Fuzzy Logic
30	50.025	50.05
60	50.06	50.1
90	50.09	50.15
120	50.15	50.23
150	50.21	50.28
180	50.25	50.32
210	50.33	50.38
240	50.38	50.42
270	50.42	50.48
300	50.45	50.52
330	50.47	50.59
360	50.5	50.64
390	50.58	50.7
420	50.64	50.75
450	50.7	50.8
480	50.75	50.82
510	50.8	50.9
540	50.88	50.94
570	50.9	51.05
600	51	51.1

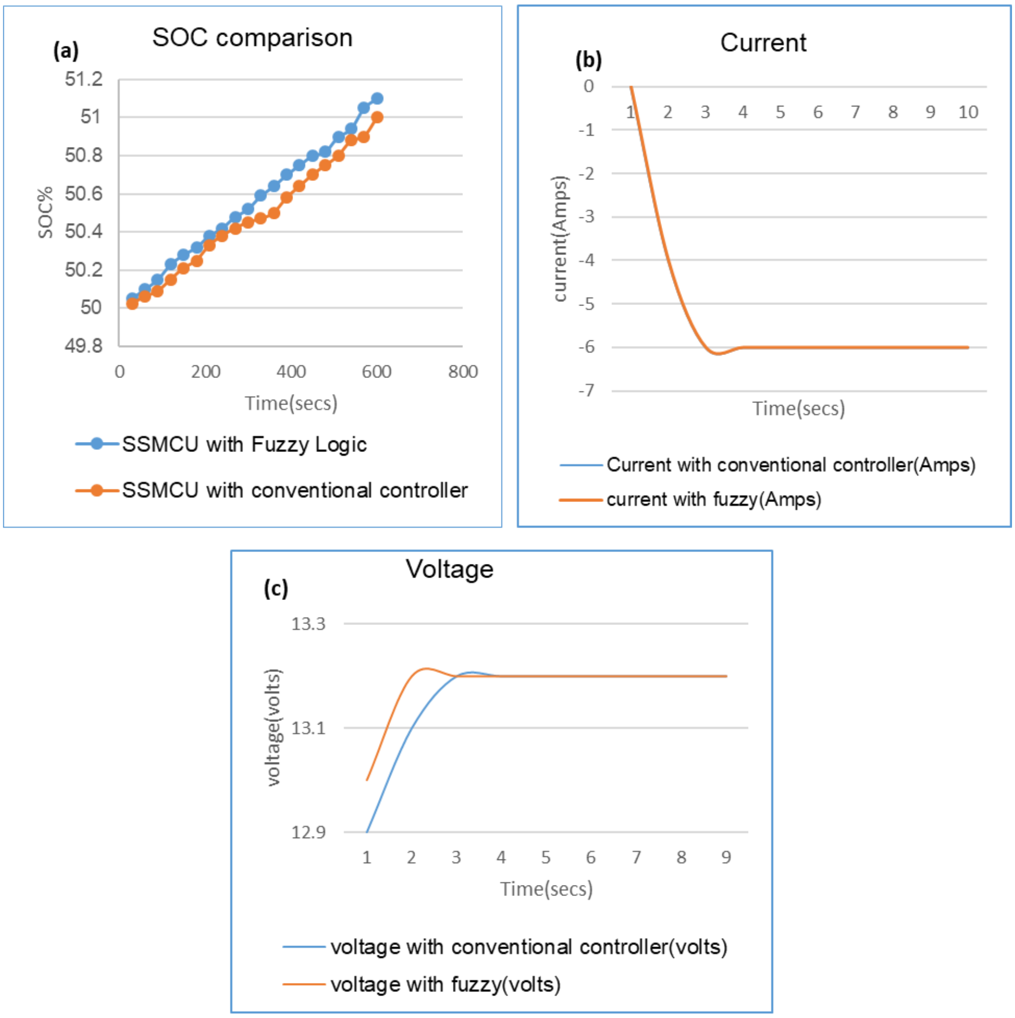

Figure 12. (a) SOC graph with EV only, **(b)** Current graph with EV only, **(c)** voltage graph with EV only

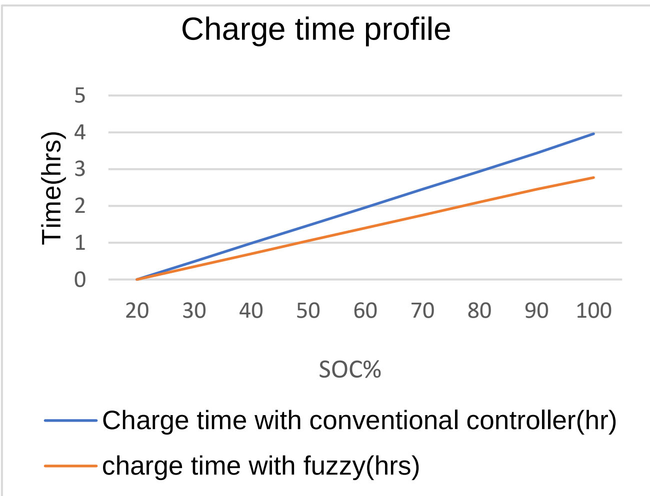

Figure 13. Charge time profile

The figure 12(b) show the constant current at -6 Amps for current with conventional controller and as well with fuzzy logic. The figure 12(c) shows the voltage constant at 13.2 volts for Voltage with conventional controller and with fuzzy logic. The figure 13 shows the charge time profile with various SOC for charge time with fuzzy and with conventional controller. Thus, the comparative study of SOC, with fuzzy and conventional controller is studied. The charge time with conventional controller took 3hrs 57 mins for SOC, which increased from 20% to 100%, whereas the charge time with fuzzy logic took 2 hrs. 45 mins for the same rise in SOC. Thus, the implementation of fuzzy logic reduced charge time by 30. 4% and increased SOC by 0.05% when compared with conventional controller.

4.2 Case 2-Load Application with EV and Local Loads

The fuzzy circuit was loaded along with local load i.e. a lamp and a fan in SSMCU. The Figure 14(a) shows the SOC increase with EV and local loads – a lamp and a fan with 12v. The Fuzzy logic implementation shows a 0.05% increase in SOC performance compared to conventional controllers. Figure 14(b) shows the current graph with EV and local loads. The current graph shows the same behavior, as the circuit with EV only. The Figure 14(c) shows the voltage with EV and local loads. The voltage graph shows the same behavior, as the circuit with EV only.

The results demonstrate that fuzzy logic provides a smoother response in relation to voltage, current, and state of charge variables. Also, fuzzy logic is capable of handling uncertainty, rigidity, and vague conditions using simple fuzzy rules. When compared to methods such as Cuckoo optimization, as described in [43], where results are obtained by Hierarchical Technique (HT) and Conditional Random Technique (CRT), this method is less complex and more suitable for real-time applications. The fuzzy controller is implemented along with Genetic Algorithm (GA) in [44] and results have been compared with the conventional cccv method. The model predictive control (MPC) is applied with Genetic Algorithm and hence the adaptivity is more with the model updates. When compared to system optimized with GA, the fuzzy controlled system with constant current logic is semi-intelligent with fixed current profile. Also, the controller uses predefined current level and is simple to implement. The FLC uses heuristic-based adaptation to parameters like SOC, temperature etc. Another paper [45] points out the importance of FLC. It reiterates that the FLC system can be implemented with lower computational requirements and thus making it suitable for limited resources, while MPC needs more computational requirements. Multi Stage Constant Current method (MSCC) was implemented by [46], where the optimal charge pattern was found. The charge time was increased by 12% and charge efficiency by 0.54%. They had compared MSCC with Fuzzy Logic stating that Fuzzy improves efficiency by 0.4% and reduce charge time by 56.8%.

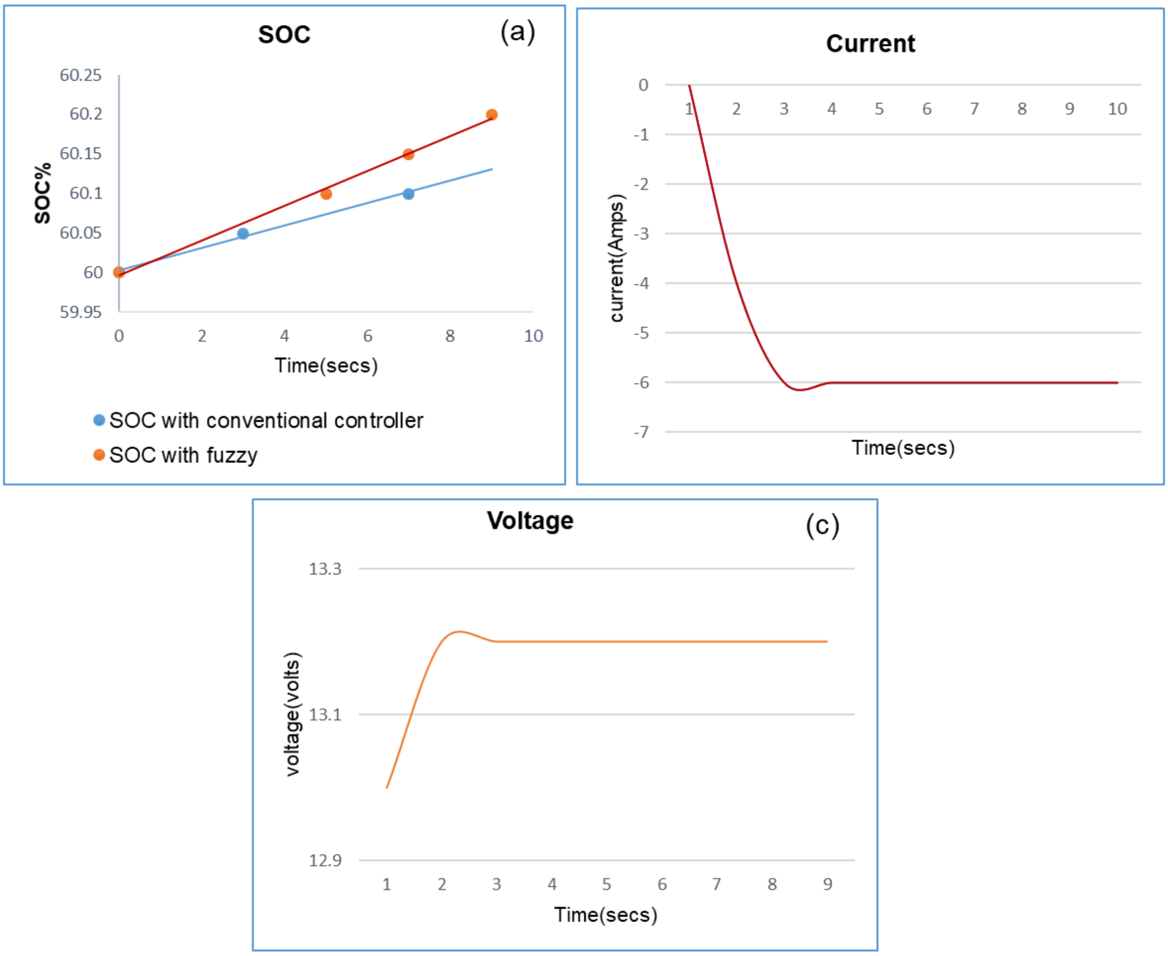

Figure 14. (a) SOC graph with EV and local load, **(b)** Current graph with EV and local load, **(c)** Voltage graph with EV and local load

5. Conclusion

The Fixed charging stations for EV, are few in India due to enormous factors. The SSMCU i.e. a mobile charging station, has been introduced as a feasible option at low cost. Also, the roadside vendors would get benefitted as it would be a source of additional income. Thus, the SSMCU has been simulated and results are discussed in detail. A mathematical model and verification procedure are presented for the design of the SSMCU and for reducing the charge time for EVs.

The benefits of the SSMCU have also been validated and justified by a 'MCU users EV opinion survey'. As a result of employing fuzzy logic over conventional controllers, the charge time was decreased by 30.4% and the SOC % increased by 0.05%. By reducing charging time, more electric vehicles can be charged, which leads to an increase in income for SSMCU vendors. But SSMCU has been designed to charge only electric two-wheelers. In the future, the unit will be designed to charge electric four-wheelers and also to obtain power from the grid. Also, load balancing algorithms will be implemented in future to distribute the workloads.

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Authors Contribution Statement

P.S. Mahitha: Visualization, Data curation, Investigation, software, Writing - Original Draft, Writing - Review & Editing. L. Ramesh: Conceptualization, Methodology, Formal analysis, Supervision, Validation, Project Administration, Funding acquisition. Both the authors have read and agreed to the published version of the manuscript.

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Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes