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Research Article

Fuzzy Logic Approach Based Demand Side Management For Maximizing The Penetration Of Electric Vehicle

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Abstract-
This article provides a demand side management for the efficient adoption of electric vehicles in utility grid. The proposed framework includes two separate areas: the technological activities of the distribution network and the nature of the energy markets. All the players involved in all these procedures are described in detail, as well as their operations. In addition, multiple simulations are provided to demonstrate the possible impacts/benefits coming from the integration of the network of electric vehicles with the distribution network under the referred system, comprising steady-state and complex analysis of behaviour. This paper finds the opportunities to integrate the electric vehicle and power system sectors for the demand side management with the help of fuzzy logic approach.
Keywords: Distribution network, electric vehicle, integration, vehicle-to-distribution network, Fuzzy logic.

1. INTRODUCTION

In many parts of the world, the adoption of plug-in EVs (including two and three-wheelers, cars, vans, trucks and buses) is increasing exponentially, powered by policies to minimize transport emissions and rapidly reduce battery prices. EV Charging results in new demand for electricity, introducing both integration problems and electricity system benefits. It has to accommodate the shares of variable renewable energy (VRE) generation and decentralized resources, such as Energy storage and photovoltaic rooftops (PV). On the demand side, more electrified loads are experienced and customer participation in electricity markets is more involved.

The future solution to the shortage of fossil fuels, as well as the environmental issues associated with their widespread use, would most likely involve the massive use of EVs. The battery and fuel cell EVs are driven only by electricity, while current hybrid EVs available also have an internal combustion engine. Since these vehicles would require the use of batteries with high energy storage capacity and large electric load charging requirements, a large implementation of this concept would have a significant impact on the design and operation of the electric power system but would also allow and benefit the use of green energy resources.

EVs can consume energy and store it when parked and connected to the electricity network, being able to deliver electricity back to the grid as well. The latter is the distinctive feature of the concept of V2G, enabling many ancillary facilities, such as peak power and spinning reserves, to be offered. In order to be able to provide these services, each EV must have some additional facilities, such as an electronic network interface to allow regulated electricity exchanges, a metering system and a bidirectional communication interface to connect with the aggregator, which is responsible for handling a large number of EVs.

A major EVs deployment will involve:

- Assessment of the effects that battery charging may have on system operation.
- Identification of effective operational monitoring and control methods surrounding the charging time of batteries.
- Identification of the right methods to be implemented to use RES to charge EVs preferentially.
- Assessment of the ability of EVs to engage in the procurement of services for power systems, including the provision of reserves and power delivery within the scope of a concept of V2G.

EVs could be able to provide extra power to the peak loads, conducting load shifting at the distribution level or supplying the system with either spinning reserves or regulations, if island operation is envisaged for certain areas of the distribution network. Several implementation cases need to be analysed to reliably determine the effect of these new load/storage systems, taking into account several variables such as the type of vehicles (fleet or individual), the technology used (electric, hybrid, or fuel cell), the behaviour of the owners, the traffic patterns, the locations where cars are parked and connected to the utility grid, the type of communication between the EV and the network, as well as the network control architecture.

Relevant local charging infrastructures would also require the replacement of conventional vehicles by EVs. Several solutions can emerge to fit the requirements of various EV owners, namely:

- Charge stations devoted to EV fleets;
- Stations for fast charging;
- swap stations for batteries;
- Specific domestic or public charging points for slower charging.

Large-scale penetration of EVs will increase energy demand during charging times. Power flows, network losses, and patterns of the voltage profile around the network would also change considerably. In addition, the network flows would also be affected by providing the supply from EV. The combination of all these effects may oblige the network to be reinforced in some areas. Nonetheless, reinforcement postponements may be achieved, depending on the EV charging strategy to be adopted. It is also expected that, due to EV storage capacity, the amount of intermittent RES that can be safely integrated into the electrical network may increase. This would allow the reduction of emissions of pollution and the cost of producing energy, which will also have a strong impact on the behaviour of electricity markets.

This article identifies a strategic structure capable of dealing with demand side management with the integration of EV and business activities in the future, in order to successfully manage EV charging.

2. ELECTRIC VEHICLE

A vehicle that uses one or more electric motors or traction motors for propulsion is an electric vehicle (EV), also called electrics. An electric vehicle may be powered by electricity from off-vehicle supplies by a collector system or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel into electricity. Electric vehicles (EVs) operate on electricity only. Many have 80 to 100 Km of all-electric range, while a few premium versions have ranges of up to 300 kilometres. Depending on the form of charger and device, when the battery is drained, it will take from 30 minutes (with quick charging) to almost a whole day (with Level 1 charging) to recharge it. Battery operated electric vehicles have nearly 99% less moving parts that require less maintenance as compared to an internal combustion engine.

2.1 Advantage of Electric Vehicle

- Less noise pollution
- Eco-friendly
- Easy to Recharge
- Cost effective
- Less maintenance

- easy to drive
- More Popular

2.2 Disadvantage of Electric Vehicle

- Initial Cost is high
- Less rechargeable points
- More recharge time
- Less driving range
- More rechargeable time
- Less battery life

2.3 Mathematical Modelling of Electric Vehicle

There are six parts of the electric vehicle: the electric motor, the power circuit, the battery, controller of motor, the battery controller, and the interface of the vehicle. The vehicle interface provides an interface for the sensors and controls that interface with the controller of the motor and the controller of the battery.

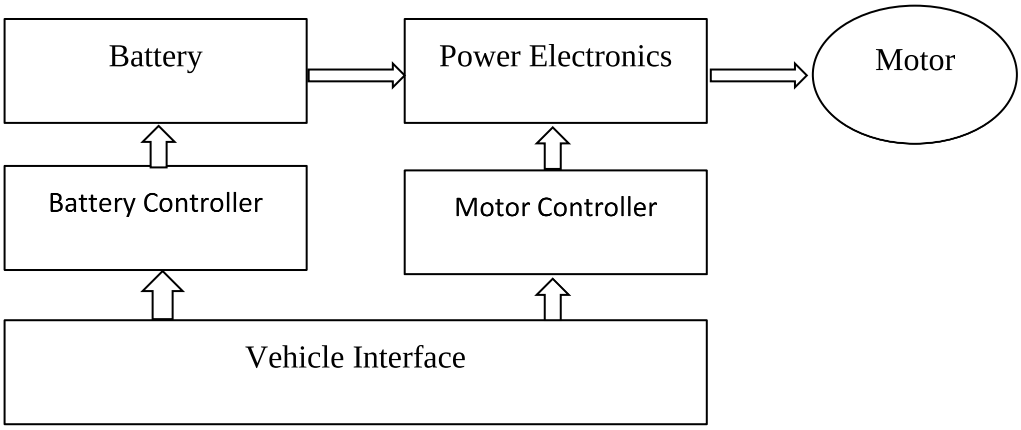


Fig. 2.1 Block diagram of Electric Vehicle

All mathematical equations to represent each component in the EV drive train were determined in order to model an EV. On the Algorithms based, the motor, battery, motor controller and proportional-integral (P-I) controller have been modelled into individual block diagrams to form an EV drive system using the following equations.

The torque produced in the motor for a DC motor, T_p is proportional to the current of the armature I_a;

$$T_p = K_m I_a$$

Based on its winding configuration, K_m is the motor constant.

The voltage produced in the motor, Vp is proportional to the speed of the armature N_a;

$$V_p = K_m N_a$$

Voltage at terminal 1 of the motor (terminal voltage), V_1 is given by;

$$V_1 = I_1 Ra + L_1 di(t)/dt + V_p$$

where, I_1 is the current at terminal 1 (terminal current), Ra is the resistance of armature, and L_1 is the inductor value at terminal 1.

By assuming that there is no loss of friction and no loss of inertia, The produced electric torque, T_p is equivalent to the mechanical torque output $T_{m..}$ Hence, the electrical power produced is equivalent to the mechanical power developed. To maintain the input power equal to the output power, a basic motor controller is used. With zero loss and no time lag, the controller is assumed to be optimal.

Voltage at terminal 1 (input)

$$V_1=k.V_2$$

Current at terminal 1 (input)

$I_1=(1/k).I_2$

Where, K is the gain value of the controller, V2 is the voltage at terminal-2 (output) and I2 is the current at terminat-2 (output).

The battery is modeled as the source of voltage, EB and internal power loss In the battery resistance, R_B,

$$V_2=I_2+R_B+E_B$$

The internal voltage of the required battery is calculated using the motor controller's current and voltage. The difference between the measured E_B ($E_{B(measured)}$) and the actual E_B ($E_{B(actual)}$) is the error of the battery voltage, B_{Error} to be used for gain controller by the P-I controller.

$$B_{Error}= E_{B(actual)}- E_{B(measured)}$$

The P-I controller uses the proportional gain, KP and integral gain quantities, KI to calculate the output of the motor controller, K value.

$$K=(K_p+s.K_i).\ B_{Error}$$

In the drive cycle, the road in the virtual simulation was modeled to assist reduced expensive for on-road monitoring. Vehicle speed values were set for a drive interval of 100s for driving test and simulation purposes. The torque value is usually obtained from the value of the speed and the dynamics of the vehicle. However, since vehicle dynamics are not used in the model, it is assumed that the torque values are known for the simulation. The developed drive cycle consisting of the values of speed and torque is as shown in Fig. 2.2.

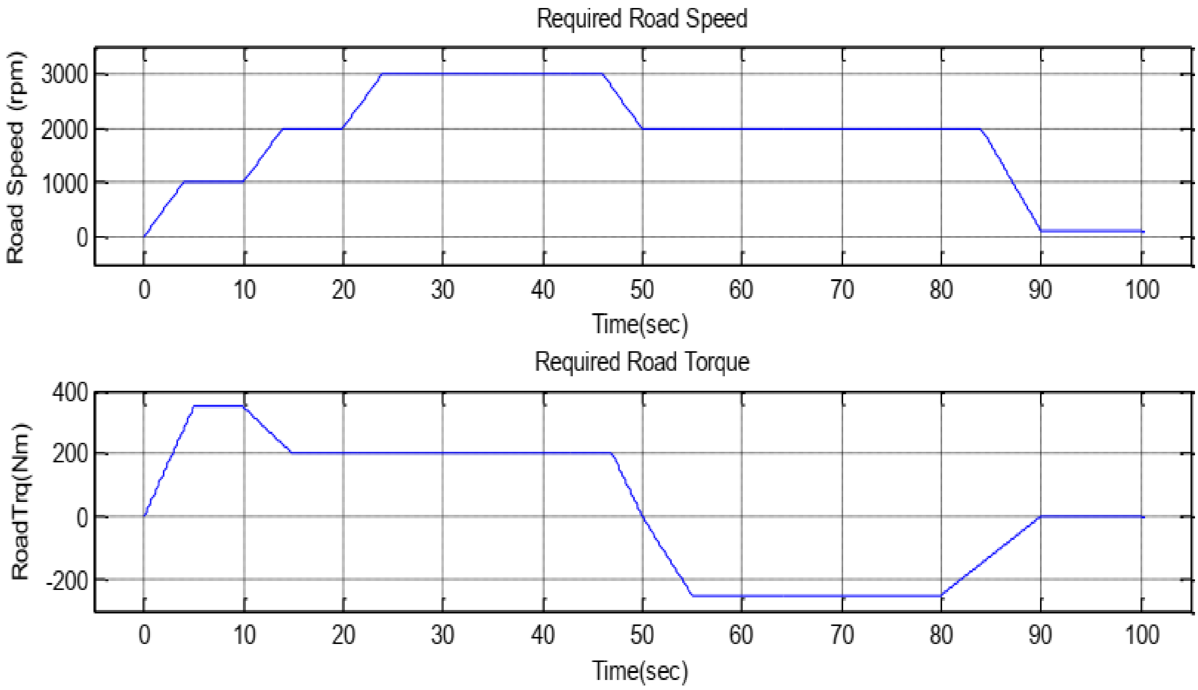


Fig. 2.2 Values of speed and torque for the simulation

The required road speed is a plot of a combination of step by step increases and decreases with a partly constant positive speed, whereas the required road torque comprises of the positive and negative side plots.

3. FUZZY LOGIC APPROACH

The utility grid has been designed without integration of electric vehicle like most distribution system. EVs would also have an expanded effect on the distribution network. From the distribution network point of view, the aim is to analyse the maximum amount of EVs that can be charged by stopping the irregular activity of the distribution network (bus voltages and capacity of lines must be within the limits). The maximum number of EVs that can be charged from the closest to the furthest charging points by increasing the number of EVs connected to the distribution network in an ascending proportion to the distance from the substation of each load.

3.1 Fuzzy Logic Based Controllers

Fuzzy logic is a mathematical framework which is commonly used in many control applications. In complex control systems, defining the precise objectives of the controllers utilising conventional control methods is a difficult task. One of them is the management of EV charging in distribution networks. The logic of fuzzy-based controllers overcomes the limitations that historically existed. Fig. 3.1 illustrates the architecture of a standard fuzzy dependent controller.

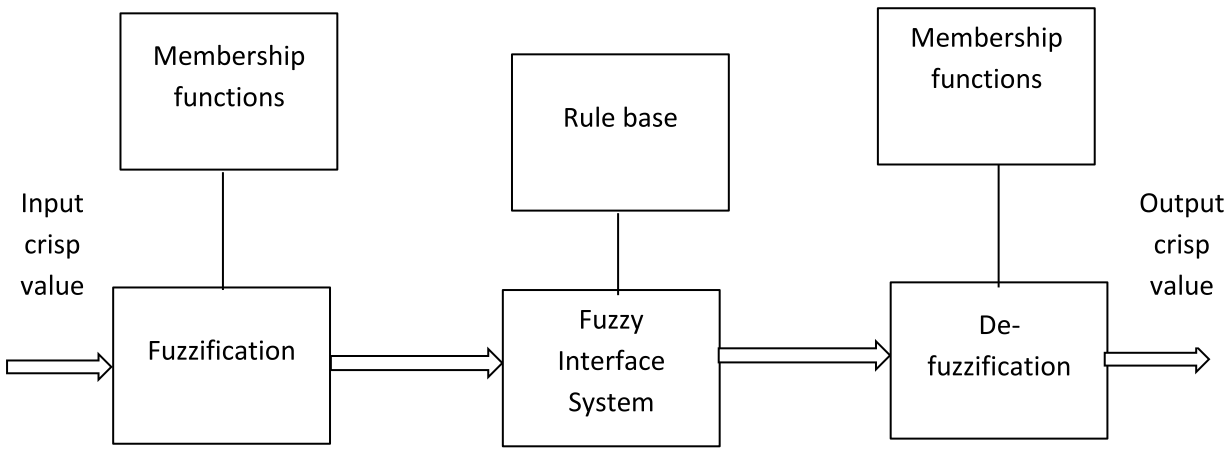


Fig. 3.1 Block diagram of a fuzzy logic controller

The fuzzification of the fuzzy controller by using membership functions includes the conversation the controller's crisp input values into a set of fuzzy linguistic values. The most commonly used membership functions for fuzzy sets are the Gaussian, triangular, and trapezoidal ones. The linguistic values produced by the fuzzy interface system (FIS) are used by fuzzy logic controller (FLC) to perform its purpose. On the basis of the information stored of the controlled procedure, the FIS maps the linguistic inputs to the output of the linguistic outputs through estimated reasoning.

The output of the FIS is powered to the defuzzification, which transforms the input values from the FIS values to the crisp output values. The conversation between fuzzy linguistic output values and input crisp values is often focused on the output membership functions, such as inputs.

4. FUZZY CHARGING MANAGEMENT SYSTEM

In the previous section, it was clearly shown that the position and distance of the charging EVs from the Medium Voltage to Low Voltage (MV/LV) transformer has a major impact of the stability on the utility grid. This fact imposes the necessity to take location of the connection of each charging vehicle to the utilty grid and its distance from the substation. In this portion, a priority charging mechanism for the coordination of EVs is proposed where the distribution system cannot accommodate all vehicles. The intent of the configured fuzzy CEMS is to define each EV's charging priority in order to select the number of EVs that can be charged and the EVs that will be charged based on their charging priority and network constraints. Fig. 4.1 illustrates the flowchart of the current fuzzy charging management system. The pseudocode for selection of the chargeable EVs based on their charging priorities is provided in Algorithm.

Algorithm Selection of the Chargeable EVs

1: **for each** time step **do**
2: Get the charging priorities of the EVs from the Fuzzy Logic Controller
3: Create a list for each phase that include the EVs to be charged and sorted in an ascending order of charging priority.
4: Perform grid's power flow analysis
5: **If** *voltage or ampacity violation* occur in a phase **then**
6: Remove EV with the lowest priority from each corresponding list
7: Return to action 3
8: **else**
9: Charge the selected EVs
10: **end if**
11: **end for**

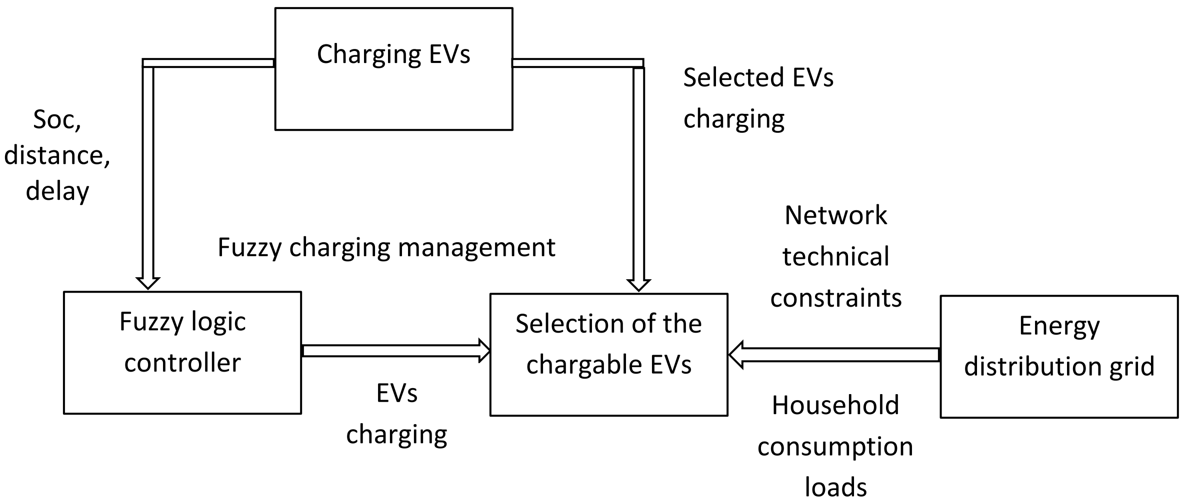
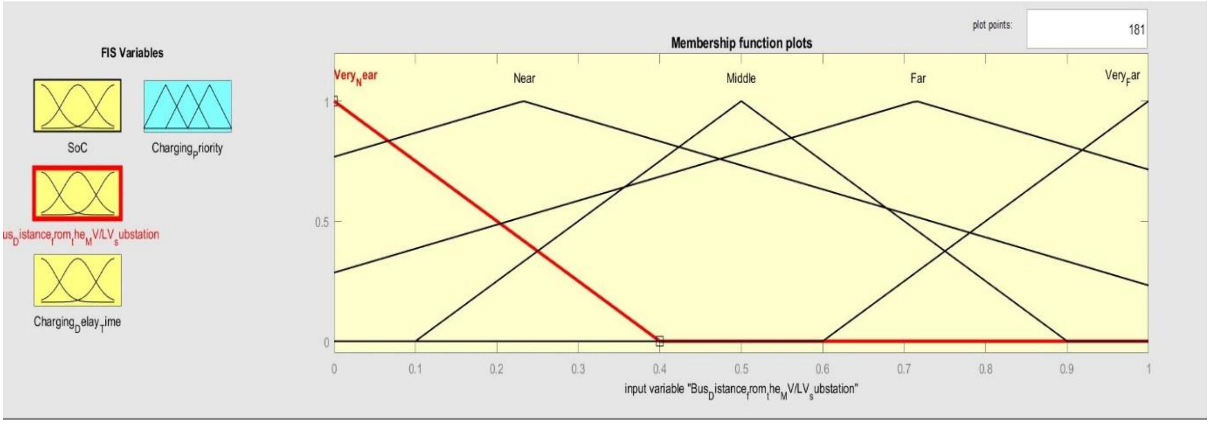


Fig. 4.1 Block diagram of fuzzy charging algorithm

5. PROPOSED FUZZY INTERFACE SYSTEM

A real-time Mamdani sort fuzzy device controller determines the charging priority of each EV at each step, where its inputs are the vehicle's battery SoC, which ranges from 20% to 90%, the delay time, in which the EV is connected to the utility grid and waiting for the charging, which ranges from 0 to 60 minutes, and the distance of the EV's charger from the LV grid's substation, which ranges from 0 to 300 meter. The input membership functions, as seen in fig. 5.1 are used to transform the sets of the crisp input values into fuzzy linguistic values. Fig. 5.2 illustrates the output's membership function. The degree of membership variables in each of the fuzzy sets is defined by the membership functions. The shapes and numbers of the membership functions for the three input variables were selected based on the research team's prior knowledge. The linguistic variables in the proposed FIS have five fuzzy sets, with the left and right shoulders being triangular membership functions and the other three being trapezoidal membership functions. Both the input and output variables use the same number and size of membership functions. Table 5.1 shows the meanings of the multiple linguistic variables considered in the inputs and output membership functions.



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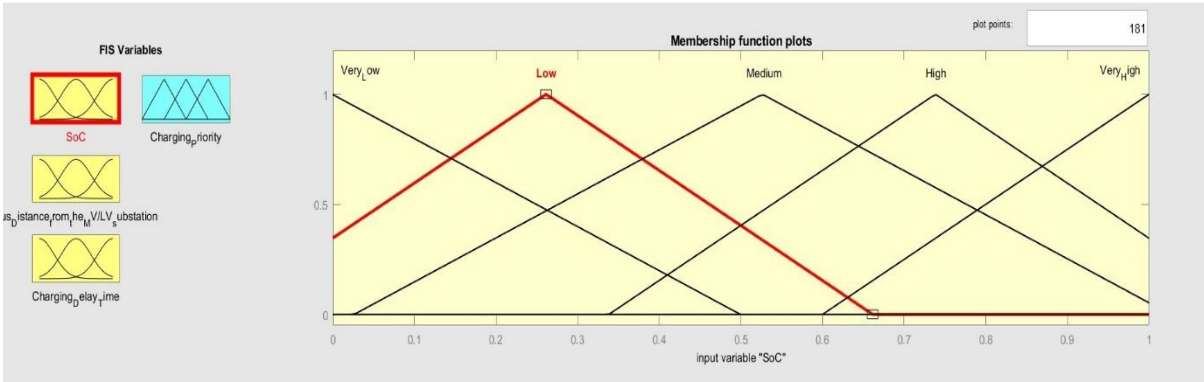

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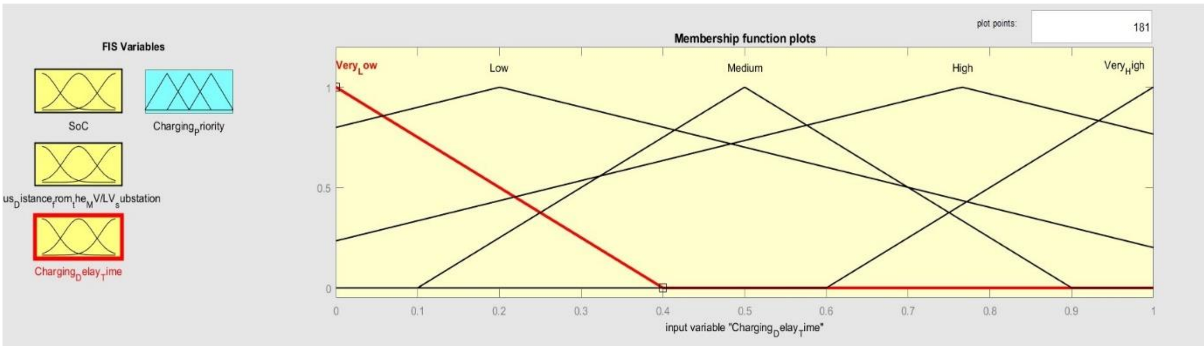

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Fig. 5.1 Membership functions for every input and output: (a) SoC; (b) Bus distance from the MV/LV substation; (c) Charging delay time.

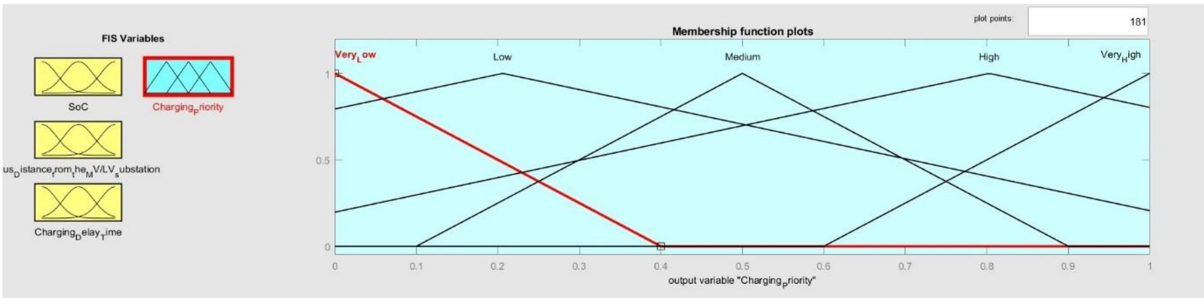
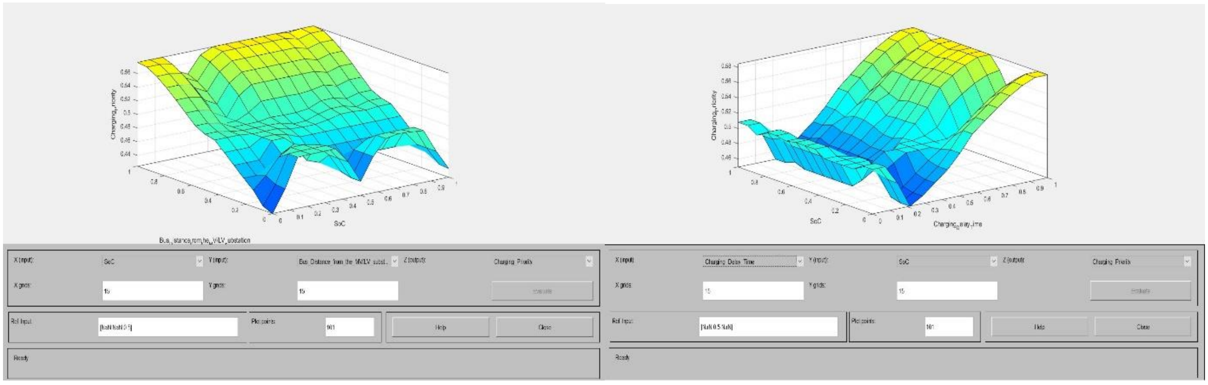


Fig. 5.2 illustrates the output's membership function

Table 5.1 Definition of the FLC inputs and output membership functions.

FLC inputs	
Variables	Fuzzy States
SoC	VL, L, M, H, VH
Bus distance from the MV/LV substation	VN, N, M, F, VF
Charging delay time	VL, L, M, H, VH
FLC output	
Variable	Fuzzy States
Charging priority	VL, L, M, H, VH

The membership functions of the input variables, the membership function of the output variable and the compilation of fuzzy rules cover the fuzzy interface system. The fuzzy rules use a list of IF-THEN statements to map the linguistic input variables (SoC, space, delay time) to the output variable. There are three linguistic inputs in the present FIS, each with five stages. As a consequence, 125 fuzzy rules have been made. Tables 5.2, 5.3, 5.4, 5.5 show the fuzzy rules in matrix form for each of the EVs' distance fuzzy states, respectively. The rules for each of the routines were developed using the expertise and experience of the research team members. It's clear that a given set of linguistic input values will allow several fuzzy rules at the same time. The SoC's linguistic inputs, the distance and the charging delay time are all combined to decide the rule strength of each fuzzy rule. The min-max aggregation approach was used to measure the charging priority of linguistic value from the many implications of the fuzzy rules. Figure 21 illustrates the surfaces of the proposed FIS. The surfaces are three-dimensional curves that represent the mapping from inputs to outputs thus taking into account the system's membership functions and fuzzy rules.



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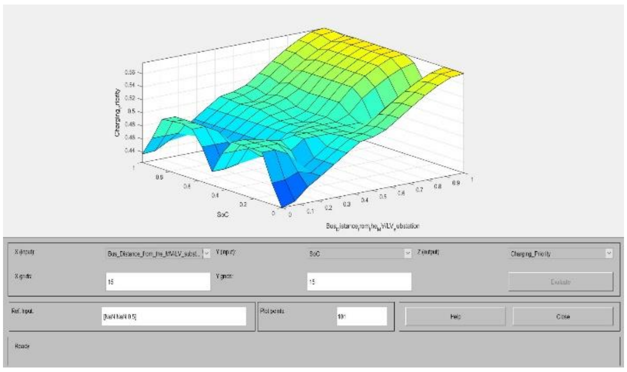

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Fig. 5.3. The surfaces of the Fuzzy logic priority management system: (a) depending on the state-of-charge and the charging delay time; (b) depending on the bus distance and the state-of-charge; (c) depending on the bus distance and the charging delay time. In each surface, the midpoint of the remaining input variable is considered.

Table 5.2. Fuzzy rules of the proposed system, when the level of the distance variable from the main MV/LV substation is Very Near.

SoC\Delay Time	Very Low	Low	Medium	High	Very High
VL	H	H	H	VH	VH
L	H	H	H	H	VH
M	M	H	H	H	VH
H	M	M	M	H	H
VH	L	L	L	M	M

Table 5.3. Fuzzy rules of the proposed system, when the level of the distance variable from the main MV/LV substation is Near.

SoC\Delay Time	Very Low	Low	Medium	High	Very High
VL	H	H	H	VH	VH
L	M	H	H	H	VH
M	M	M	H	H	VH
H	L	M	M	M	H
VH	VL	L	L	L	M

Table 5.3. Fuzzy rules of the proposed system, when the level of the distance variable from the main MV/LV substation is Middle.

SoC\Delay Time	Very Low	Low	Medium	High	Very High
VL	H	H	H	H	VH
L	M	M	H	H	H
M	M	M	M	H	VH
H	L	L	L	M	M
VH	VL	VL	L	L	M

Table 5.4. Fuzzy rules of the proposed system, when the level of the distance variable from the main MV/LV substation is Far.

SoC\Delay Time	Very Low	Low	Medium	High	Very High
VL	M	H	H	H	VH
L	M	M	M	H	H
M	L	M	M	M	H
H	L	L	L	M	M
VH	VL	VL	L	L	M

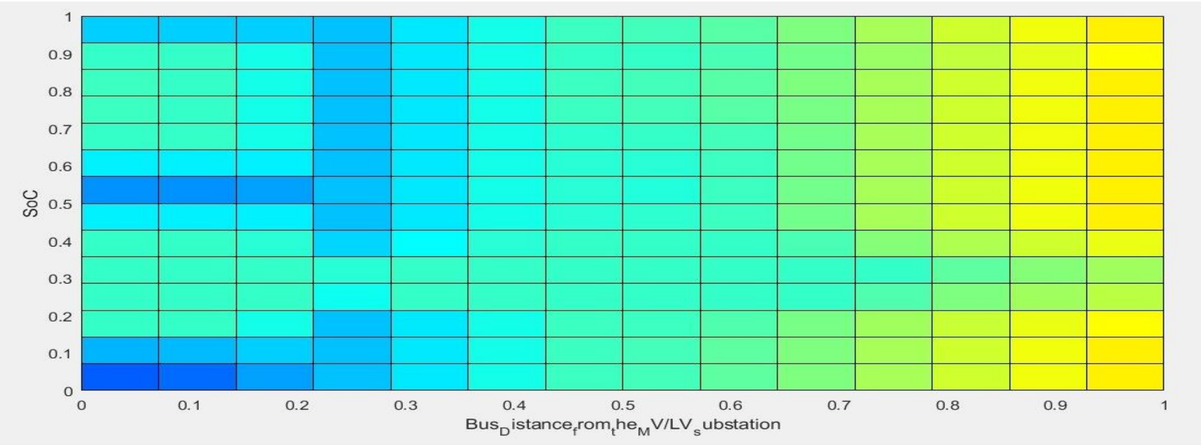
Table 5.5 Fuzzy rules of the proposed system, when the level of the distance variable from the main MV/LV substation is Very Far.

SoC\Delay Time	Very Low	Low	Medium	High	Very High
VL	M	M	H	H	VH
L	M	M	M	M	H
M	L	L	M	M	H
H	VL	L	L	L	M
VH	VL	VL	VL	L	L

Each EV's charging priority is calculated based on the defuzzification method of the FIS's, which transforms the linguistic charging priority variable extracted from the fuzzy interface system into a numerical value varying from 0 to 1. The FIS defuzzification is based on the centre of gravity (centroid) since it is the most effective technique for the application [34,51,52,53]. The EV with the highest output value gets the highest preference for charging at its maximum potential of power.

6. SIMULATION SITUATIONS

The whole system is being used to investigate the impact of CEMS in low-distribution grids and to evaluate charging algorithms by analysing a range of cases based on the behaviour and the state of EVs.



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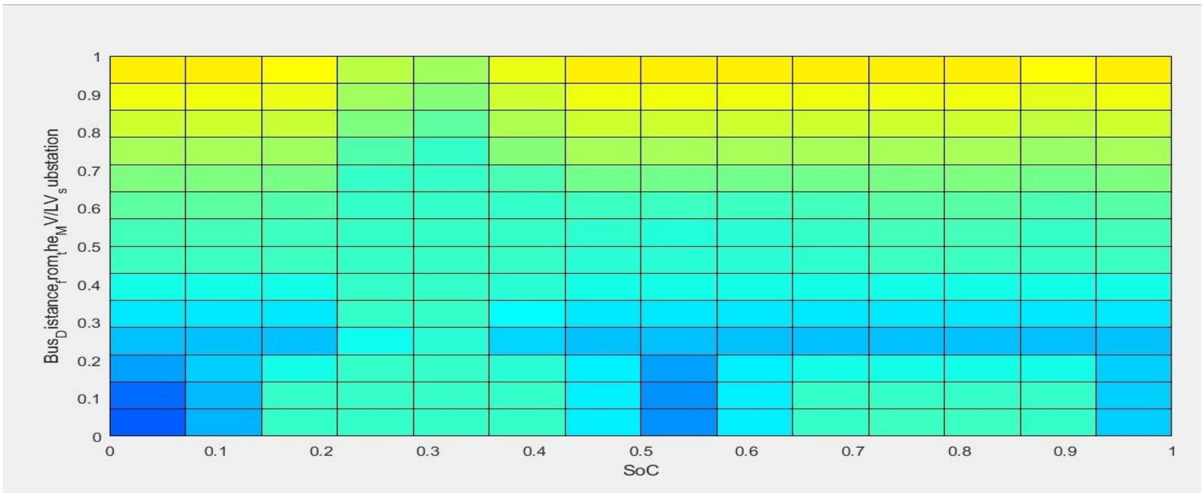

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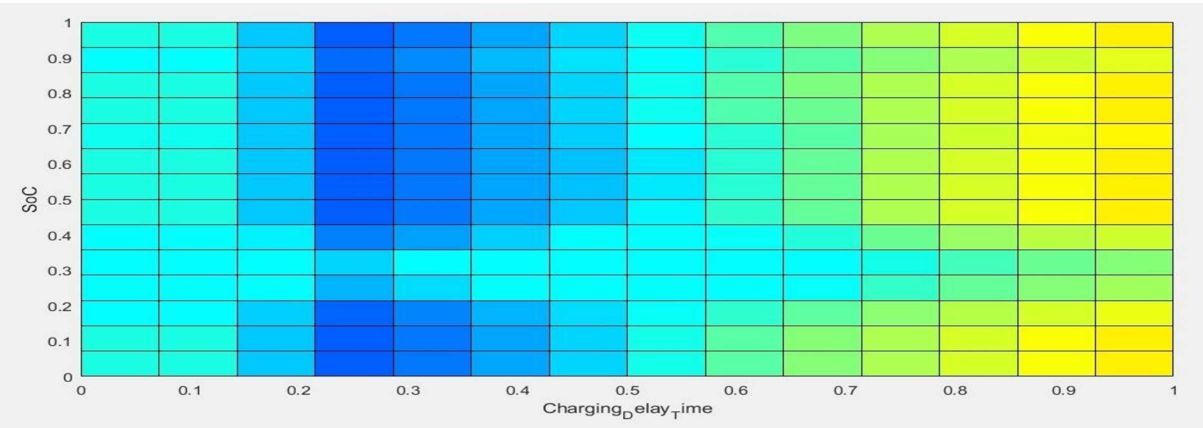

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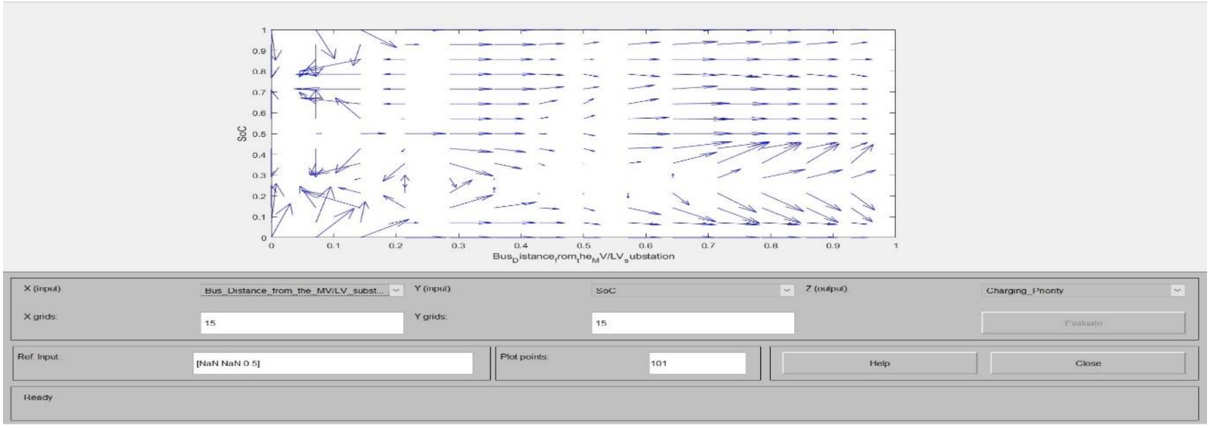
Fig. 6.1. EVs state for simulation cases: (a) case 1; (b) case 2; (c) case 3; Green color declares that EVs are parked; Blue color declares that EVs are charging; Yellow color declares that EVs are connected but not charged due to low priority.

7. RESULTS

Fig. 6.1 illustrates how each EV's charging status is influenced by the fuzzy energy management strategy. Because of the increased number of charging EVs, which arrive at charging points at the same time in Case 1 and within a comparatively narrow charging window for two hours in Case 2, most of the EVs are experiencing charging delay times, according to the results of Fig. 6.1 a, b. In Cases 3, though, the charging status of the EVs is still impaired, though to a lesser degree than in Cases 1 and 2.



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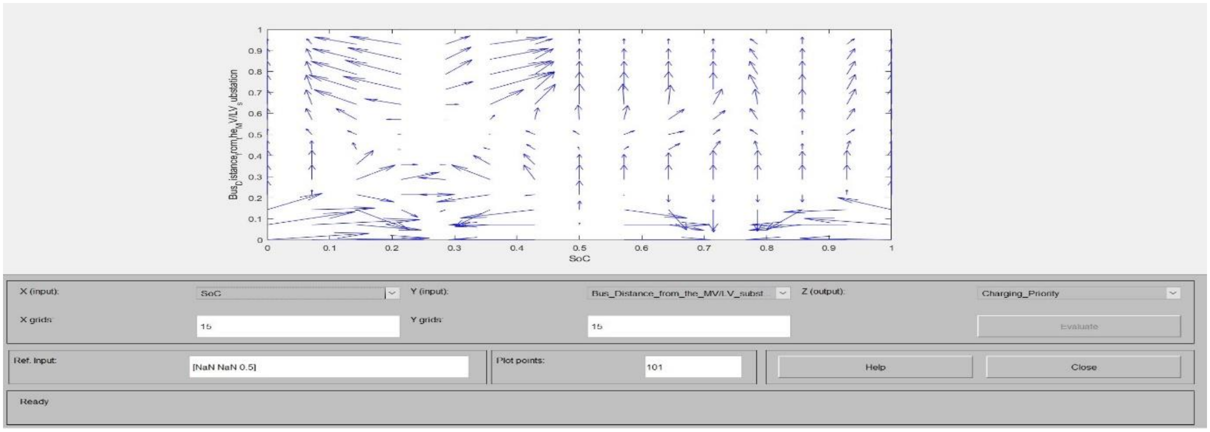

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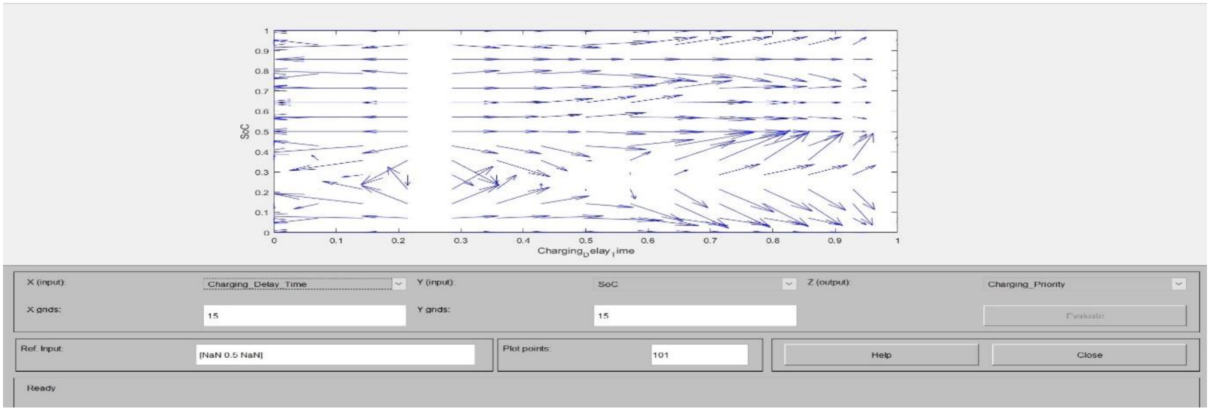

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Fig. 7.1 Total duration of charging time for each EV in uncontrolled charging process and fuzzy priority management system: (a) case 1; (b) case 2; (c) case 3.

let us consider, as an example of EV 30. Case 1 (Fig. 6.1 and Fig. 7.1) shows that the EV arrives at the charging point slower than the other EVs, due to the fact that the difference between the charging points and the main substation is one of the primary variables considered in the proposed energy management system. Due to the fuzzy energy storage system's low priority, the EV stands for billing. Because of the low SoC and the reality that this EV's charge is postponed, the controller is forced to lift the EV's priority. In comparison, the priority of EVs which are charged during the EV's delay time decreases. After that, the EV continues charging. Cases 2 and 3 have a two and four-hour time period in which EVs are connected to charging points, respectively. In Case 2, the EV 30 arrives at 14:40 h, and in Case 3, it arrives at 15:35 h. During this time, the charging of EVs has no effect on the distribution grid's normal operation, allowing all linked EVs to be charged, including EV 30. The charging period of the EVs is influenced by the distance of the charging points, as seen in Figure 24, and the factors of charging delay time as well as the SoC ensure the charging of the EVs farthest from the substation by increasing their priorities. Furthermore, by comparing the outcomes of Cases 2 and 3 in Fig. 6.1 b,c to the results of Case 1, which is represented in Fig. 7.1, it can be shown that a lower percentage of EVs suffer from charging delay times. However, the bulk of EVs face charging delays.

CONCLUSION

The number of EVs in use is expected to increase significantly in future years because of the many advantages they present compared to conventional ones. The results of an unregulated charging mechanism in a low voltage distribution grid case study were explored in this article, and a charging coordination management strategy was proposed. The simulation findings show that the voltages in the system's buses and the thermal limitations of the lines are significant limiting factors for EV penetration in energy distribution networks. the distance between the charging EVs and the substation is a critical factor for the definition of the overall chargeable vehicles. When charging EVs are close to the substation, the average consumption of chargeable EVs is up to 21.5 percent higher according to the results.

As a result of analysing the findings, an energy management system was developed for the synchronisation of EV charging processes in low voltage distributed grids with respect to network constraints, by incorporating EVs distance from the substation for the first time as a crucial factor for the preference of chargeable EVs. The proposed EV charging control system is based on fuzzy logic, and it takes into consideration the SoC of the charging EVs', distance from the grid's substation and charging delay period. The results of the cases analysed suggest that utilising distance in the proposed fuzzy management system will minimise the charging period of EVs by up to 14.7 %. Thus, in all modelling cases, taking into consideration the EVs' distance from the substation has a beneficial effect on the charging times of the EVs, i.e. it decreases the charging time of the vehicles and increases the grid's energy utilisation.

Future work would focus on improving the weights of the presented fuzzy management system by reducing EV charging times and implementing more advanced charging management algorithms focused on computational intelligence hypotheses, as well as introducing more sophisticated charging management algorithms.

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