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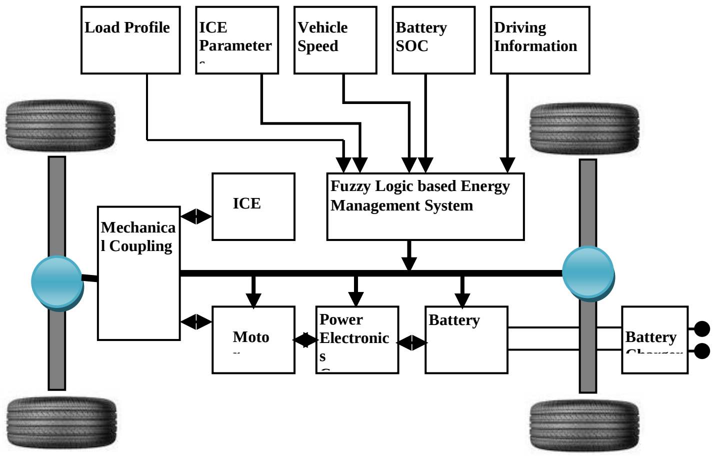

Fig. 1 Flow diagram of the proposed system

The Fuel Cell Stack block provides a generic model that represents hydrogen and air-fueled fuel cell stacks. The graphic below depicts an electrical model of a fuel cell that runs on a fuel flow rate. A basic model and a comprehensive model are the two blocks that make up the stack model. To transition between the two models, choose the level in the mask under Model detail level in the block dialogue box. The simulink model and corresponding circuit for the fuel cell are illustrated in Fig 2 and3.

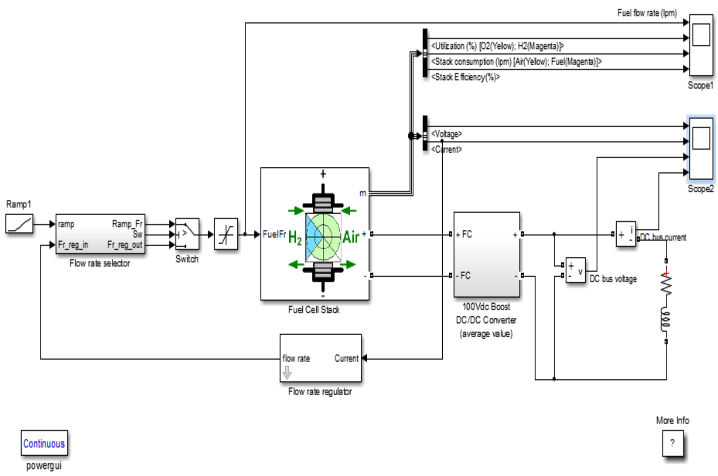

Fig. 2 Modellig of Fuel cell

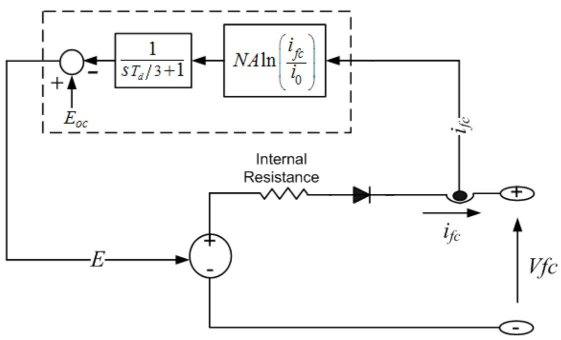

Fig. 3. Fuel cell equivalent circuit

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The performance of the single FC cell based on single FC current, voltage and power relationships is given in Fig. 4.

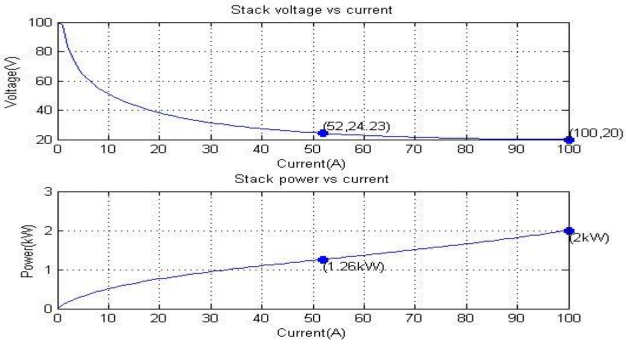

Fig. 4 Performance curve for single FC

The parameter selected for the simulation of the FC are described in the Table 1. The proposed system consider stack of 8 FCs to fulfill the power requirement.

Table 1: fuel cell simulation parameters

Parameter	**Specification**
Type of cell	Proton Exchange Membrane Fuel Cell (PEMFC)
Number of Cells	8
Nominal Stack efficiency (%)	55%
Voltage range	98- 100v
Working temperature (Celsius)	65 degree
Nominal Air flow rate (lpm)	300
Nominal air supply pressure (bar)	1 bar
Nominal fuel supply pressure (bar)	1.5 bar
H2	99.92%
O2	21 %
H2O	1 %

The battery block provides a generic dynamic model that characterizes rechargeable batteries. The battery specifications are given in table 2.

Table 2. Battery specifications

Parameter	**Value**
Nominal Discharge Current (d)	1.3 A
Internal Resistance	2 mΩ
Rated Capacity	6.5 Ah
Nominal Voltage (a)	1.18 V
Maximum Capacity (b)	7 Ah (5.38 h * 1.3 A)
Exponential Capacity (e)	1.3 Ah
Nominal Voltage (a)	1.18 V
Capacity @ Nominal Voltage (a)	6.25 Ah
Exponential Voltage (e)	1.28 V
Fully Charged Voltage (c)	1.39 V

Equation 1 and 2 are used for modeling of the lithium-ion battery type considering charging (i*<0) and discharging (i*>0) mode.

$$f_1(it, i*, i) = E_0 - K\frac{Q}{Q-it}i* - K\frac{Q}{Q-it}it - A.e^{-B.it} \quad (1)$$

$$f_1(it, i*, i) = E_0 - K\frac{Q}{Q-0.1Q}i* - K\frac{Q}{Q-it}it - A.e^{-B.it} \quad (2)$$

The range of various input and output variables considered for energy management of HEV such as SOC, upload, and PFC are given in Table 3-4. Total twenty rules are constructed for the control action generation of fuzzy logic-based energy management of HEV as given in Table 5.

TABLE 3. INPUT VARIABLES FOR FUZZY BASED EMS FOR HEV

Input Variable	**Level**	**Range (%)**
SOC	VL	0-40
	L	30-60
	M	50-80
	H	70-100
Pload	N	-1000-0
	VL	0-500
	L	400-1000
	M	900-1500
	H	1400-2000

The membership equations for the battery SOC are described in Equations 3-6. The SOC is split into different variables such as very low (VL), Low (L), medium (M), and high (H) with trapezoidal membership function (TMF).

$$SOC_{VL}(x) = \begin{cases} 1 & 0 \le x \le 30 \\ \frac{40-x}{10} & 30 < x \le 40 \end{cases} \quad (3)$$

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$$SOC_L(x) = \begin{cases} \frac{x-30}{15} & 30 \le x45 \\ \frac{60-x}{10} & 50 \le x \le 60 \\ 1 & 45 \le x \le 50 \end{cases} \tag{4}$$

$$SOC_M(x) = \begin{cases} \frac{x-50}{10} & 50 \le x \le 60 \\ 1 & 60 \le x \le 70 \\ \frac{80-x}{10} & 70 \le x \le 80 \end{cases} \tag{5}$$

$$SOC_H(x) = \begin{cases} \frac{x-70}{10} & 70 \le x \le 80 \\ 1 & 80 \le x \le 100 \end{cases} \tag{6}$$

The membership equations for the Load demand (PLoad) are described in Equations 7-11. The upload is divided into different variables such as no-load (N), very low (VL), Low (L), medium (M), and high (H) with trapezoidal TMF.

$$PLoad_N(x) = \begin{cases} 1 & -1000 \le x \le 0 \\ \frac{50-x}{50} & 0 \le x \le 50 \end{cases} \tag{7}$$

$$\mathrm{PLoad}_{VL}(x) = \begin{cases} \frac{x-50}{50} & 0 < x \le 50 \\ 1 & 50 \le x \le 400 \\ \frac{500-x}{100} & 400 \le x \le 500 \end{cases} \tag{8}$$

$$\mathrm{PLoad}_L(x) = \begin{cases} \frac{x-450}{50} & 450 < x \le 500 \\ 1 & 500 \le x \le 800 \\ \frac{1000-x}{200} & 800 \le x \le 1000 \end{cases} \tag{9}$$

$$\mathrm{PLoad}_M(x) = \begin{cases} \frac{x-900}{1000} & 900 < x \le 1000 \\ 1 & 1000 \le x \le 1400 \\ \frac{1500-x}{100} & 1400 \le x \le 1500 \end{cases} \tag{10}$$

$$\mathrm{PLoad}_H(x) = \begin{cases} \frac{x-1400}{100} & 1400 < x \le 1500 \\ 1 & 1500 \le x \le 2000 \end{cases} \tag{11}$$

TABLE 4. OUTPUT VARIABLES FOR FUZZY BASED EMS FOR HEV

Output Variable	**Level**	**Range (W)**
PFC	Z	0-100
	L	50-300
	M	250-500
	H	450-650

The membership equations for the FC power control variable (PFC) are described in Equations 12-15. The upload is divided into different variables such as zero (Z), Low (L), medium (M), and high (H) with TMF.

$$PFC_Z(x) = \begin{cases} 1 & 0 \le x \le 50 \\ \frac{80-x}{30} & 50 \le x \le 80 \end{cases} \quad (12)$$

$$PFC_L(x) = \begin{cases} \frac{x-50}{50} & 50 < x \le 100 \\ 1 & 100 \le x \le 200 \\ \frac{300-x}{50} & 250 \le x \le 300 \end{cases} \quad (13)$$

$$PFC_M(x) = \begin{cases} \frac{x-250}{50} & 250 < x \le 300 \\ 1 & 300 \le x \le 450 \\ \frac{500-x}{50} & 450 \le x \le 500 \end{cases} \quad (14)$$

$$PFC_H(x) = \begin{cases} \frac{x-400}{100} & 400 < x \le 500 \\ 1 & 500 \le x \le 650 \end{cases} \quad (15)$$

TABLE 5. RULES FOR FUZZY BASED EMS FOR HEV

Fuzzy Rule Base		
Input		***Output***
SOC	***Pload***	***PFC***
VL	N	Z
VL	VL	L
VL	L	M
VL	M	H
VL	H	H
L	N	Z
L	VL	L
L	L	M
L	M	M
L	H	H
M	N	Z
M	VL	Z
M	L	L
M	M	L
M	H	M
H	N	Z
H	VL	Z
H	L	Z
H	M	L
H	H	L

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SIMULATION RESULTS AND DISCUSSIONS

The anticipated system is simulated using MATLAB R2018b on the personal computer having a core i5 processor with 2.84 GHz speed and 8GB RAM. The schematic of the anticipated EMS system is illustrated in Fig. 5.

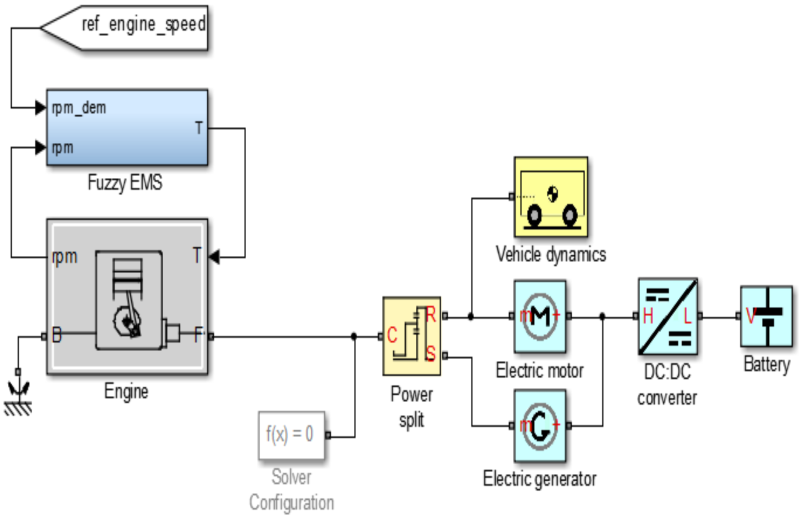
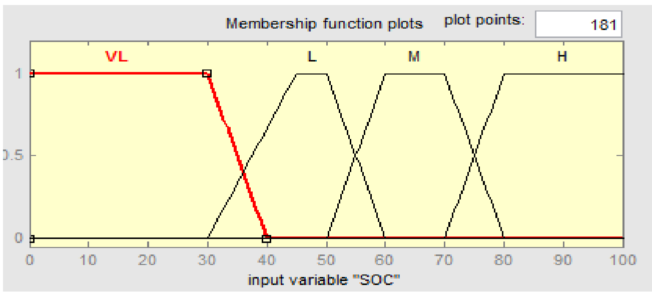


Fig. 5 Simulink schematic of the proposed system

Table 6 gives a detailed description of the various electrical parameters and vehicle dynamics used for the simulation.

Table 6: Electrical parameter and vehicle dynamics specifications

Parameter	**Value**	**Unit**
Battery Capacity	20	Ah
Battery Nominal Voltage (Max)	300	V
Converter Output Voltage	500	V
Motor Efficiency	94	%
Maximum Motor Torque	450	Nm
Motor Maximum Power	100	kW
Vehicle mass	1000	Kg
Tire radius	0.25	m
ICE Maximum Power	100	kW



a)

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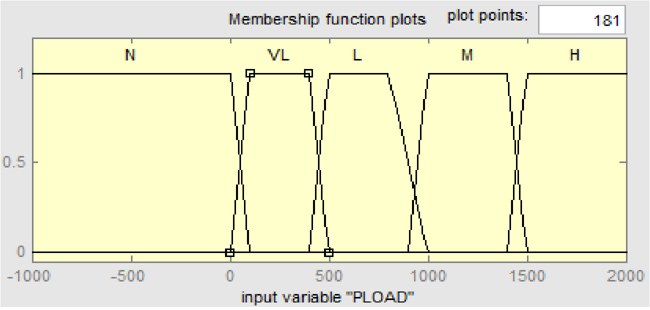
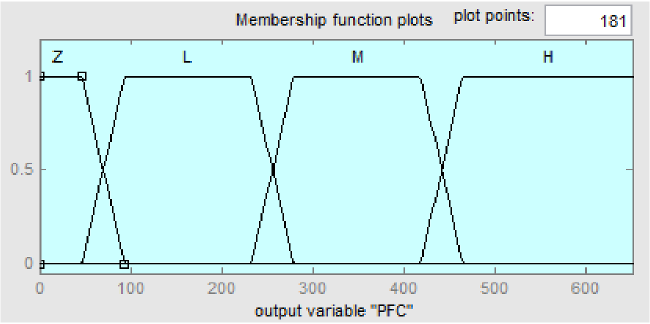


b)



c)

Fig. 3 Visualization of Fuzzy membership functions for input and output variables a) SoC b) PLoad c) PFC

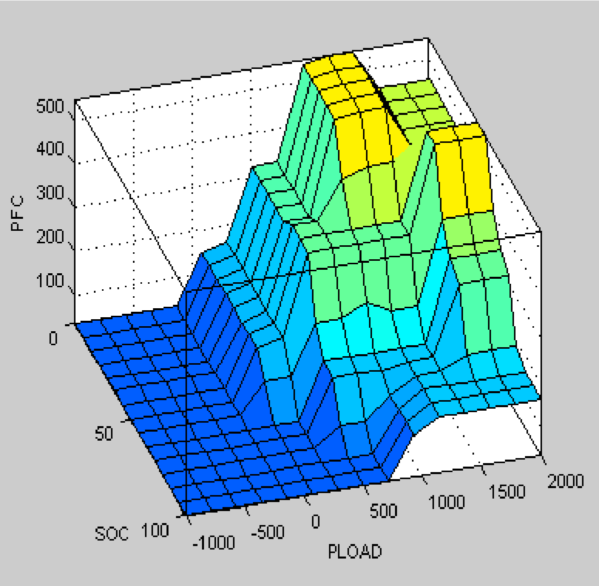


Fig. 6. Surface plot for SOC vs PFC vs PLoad

The visualization of Fuzzy membership functions for input and output variables and surface plot for SCO vs PFC vs PLoad is shown in Fig. 5 and 6. The surface plot depicts that when the load is higher and the battery SOC is lower then it shows the need of turning ON of fuel cell. When the plod is lower and SOC is higher then it indicates that the fuel cell can be turned OFF.

The consequences of the system is estimated for the different random SOC and PLoad condition that results in 96.00% accuracy. Some of the sample control conditions for distinct input conditions are illustrated in Fig. 7-8.

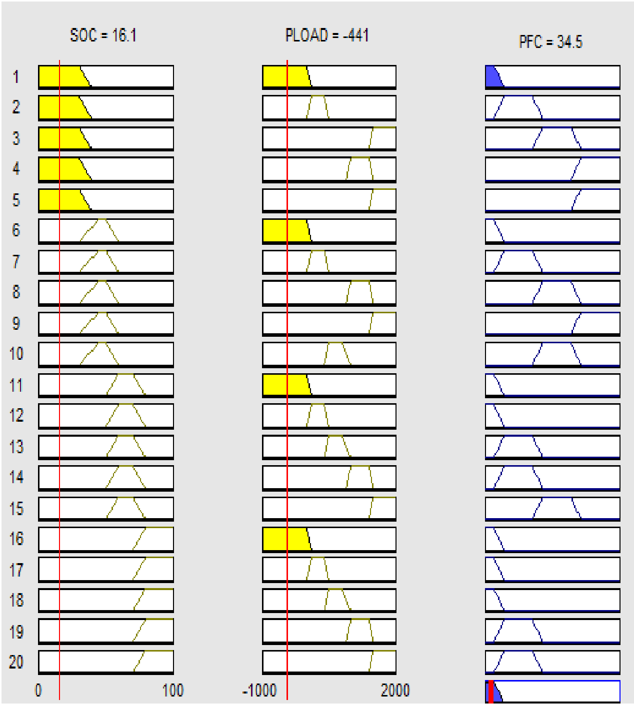


Fig. 7. Fuzzy rule viewer for very low PFC (34.5) for input variables SOC=16.1% and Pload=-441

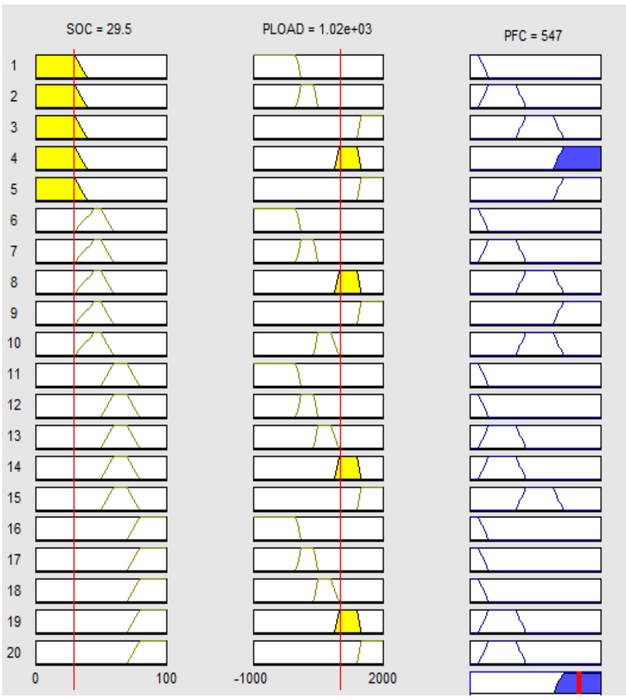


Fig. 8. Fuzzy rule viewer for very high PFC (547) for input variables SOC=29.5%, and Pload=1020

The outcomes of the proposed EMS model is authenticated for the different values of the SOC and Load demand and it is observed that it is able to provide the power to the HEV for longer duration as shown in Fig. 9. The system uses the FC power source in critical conditions only that helps to minimize the fuel cost.

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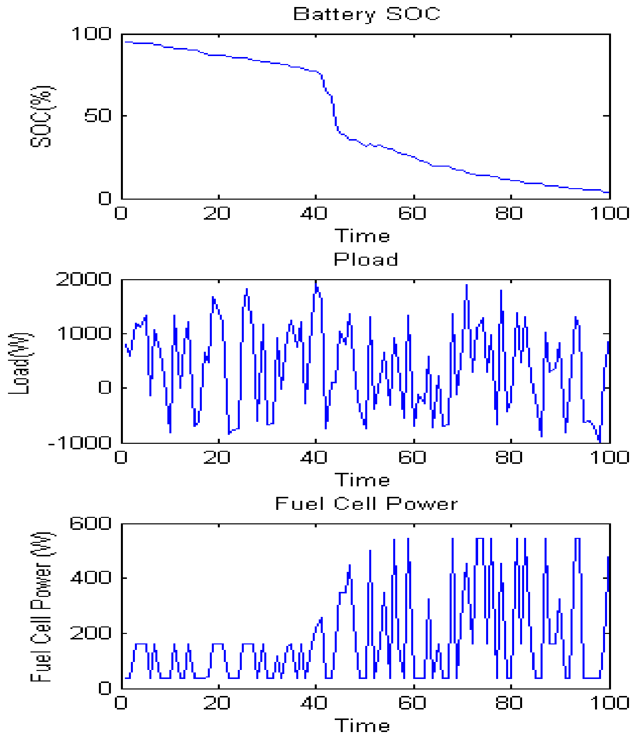

Fig. 9 Proposed EMS control scenario

CONCLUSIONS AND FUTURE SCOPE

Thus, this paper offers a fuzzy logic-based EMS for a hybrid electrical vehicle based on battery SOC, different vehicle dynamics and driving conditions. It provides the precise control of the FC power based on battery SOC and load profile by considering different vehicle conditions such as vehicle dynamics, atmospheric pressure, etc. The fuzzy logic-based EMS provides efficient and automatic control of the power flow in a HEV. The fuzzy logic based EMS provides simple rule base EMS that is simple to implement on the hardware platform and provides lesser computational efforts. It provides multi-objective control of the vehicle speed in various driving conditions. In the future, various renewable energy sources can be used to charge the battery.

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