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A Novel Control Strategy of Electric Vehicle with Hybrid Energy Storage System using Interval Type 2.0 Fuzzy Logic Controller

Yogesh Shekhar | Adeeb Uddin Ahmad

Department of Electrical Engineering, Institute of Engineering and Technology, Lucknow, India.
Corresponding Author : yogesh.shekhar007@gmail.com

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ABSTRACT

This research work proposes an electric power train (EPT) with hybrid energy storage system (HESS) using an interval type 2.0 fuzzy logic controller (T2.0-FLC). EPT's will play a vital role in present and future transportation because they do not emit harmful gases and do not rely on fuel. In this proposed work, storage devices like battery, supercapacitor, and fuel cell will be considered for electric vehicle and a novel control strategy based on interval T2.0-FLC is used. There are various types of electric motors are generally used in Electric vehicles but In our proposed research work Permanent Magnet Synchronous Motor is used. This work implemented in different cases, starting from only solar powered electric vehicle to hybrid storage-Electric Vehicle having battery, solar, supercapacitor, and fuel cell. This research study gives a detail comparative analysis of the performance of hybrid electric vehicle between Type-1 FLC& IntervalType-2.0 FLC. Also shows the edge of Interval T2.0-FLC based electric vehicle over Type-1 FLC based electric vehicle as interval T2.0 approach having better response. The entire proposed scheme implemented with the help of MATLAB software.

KEYWORDS:Electric Vehicle(EV), Hybrid Energy Storage System, Permanent Magnet Synchronous Motor (PMSM), PI controller, Fuzzy logic controller (FLC), Interval T2.0-FLC, Energy Storage System(ESS).

1. INTRODUCTION

Electric vehicles have become much more popular due to their negligible environmental impact. Toxic gaseous emissions from fuel-powered vehicles are causing serious environmental problems. Electric vehicles have gradually replacing internal combustion engine vehicles in order to reduce emission of greenhouse gases. The motor drive used in an HESS based EV is different from standard industrial drives, must meet more stringent driving requirements. The most common machines used in electric vehicle propulsion are induction motors and PMSM. The fast addition in the sustainable sources has achieved Because of the exhaustion of the petroleum products. Among these renewable energy source (RES) Solar and Wind plays a major role[1]. But among these two the Solar PV has a drastic importance. The maximum power from solar PV can be attained by using different algorithms and the obtained output is given to the step up converter for increasing the magnitudes of voltage from the solar PV [2]. An ESS along with bidirectional converter (BDC) converter is connected to store the energy attaining from the solar PV for future purposes [3]. As mentioned [4]-[7], in the grid connected PV system, the excess energy obtained from solar PV is either fed to the grid or else stored in the energy storage devices. Some of the storage devices can be named as battery, super-capacitor and fuel cells. A battery energy storage system (BESS) will be used to boost the effectiveness of the discontinuous grid connected PV system. As researchers proposed in [8]-[9], the distribution energy systems requires different types of strategies related to power management which manage the power as well as keep the power quality in a regulated mode. The major considering devices for storing the energy is known to be batteries. The efficiency of the battery and performance of EV can be enhanced by employing good conditioning inverters and chopper circuits [10]-[13]. Due to connecting non-linear loads and their demand for more energy in a case in which availability of power supply is less from the sun, leads to inefficiency in the performance of the battery. To overcome this issue a new energy storage device was introduced known as Supercapacitor (SC) [15].As mentioned in [16], the balancing of power generation obtaining from solar PV is necessary. When compared to the batteries, supercapacitors are having more energy density. In [17] proposes that the absorption of fluctuations that are occurred due to high frequencies in the solar PV will be done by implementing the super capacitors and also it can be employed for smoothening out the power obtaining from solar based ESS. The SC will charge only when the HESS based system generate surplus energy i.e. sufficient to charge all energy storage devices [18]. The other utility which can be utilized as the energy storing device is Fuel cell. The Fuel cell is responsible to compensate further deficiency in energy produced by all utilities. We have used different types of controlling techniques based on the utilization of power electronic (PE) devices. This PE converter can be controlled by using different controlling techniques namely PI controllers, type-1FLC, ANFIS controllers, Neural Networks and interval T2.0-FLC. This research work mainly focused on PI controller, type-1 FLC and Interval T2.0-FLC. This paper proposes an interval T2.0-FLC based Electric vehicle connected to Solar PV-HESS.

STRUCTURE OF PAPER

The paper is organized as follows: In Section 1, encompasses an introduction and a review of existing methods in the literature.In Section 2possesses a system description in various cases. In Section 3 depicts the proposed topology. Section 4includes the results and Discussion. Section 5tells us about the future scope and concludes the paper with acknowledgement and references.

OBJECTIVES

To design various operating strategies (Solar PV Energy storage system, Solar PV-Battery, Solar PV-Super-capacitor and Solar PV-fuel cells energy storage system) for hybrid electric vehicles.Integration of different hybrid system's like Solar PV Energy storage system, Solar PV-Battery, Solar PV-Supercapacitor and Solar PV-fuel cells energy storage system as Type-1 Fuzzy Logic Controller based Electrical Power Train connected Solar PV-HESS. To replace Type-1 FLC withInterval Type-2.0 FLC as Interval Type-2.0 Fuzzy Logic Controller based Electrical Power Train connected Solar PV-HESS.To achieve comparative analysis of the performance of Type-1 FLC & Interval Type-2.0 FLC.

This research work aims to address the feasibility study of Hybrid electric vehicle with Interval-2.0 fuzzy logic controller.

2. DESCRIPTION OF THE SYSTEM

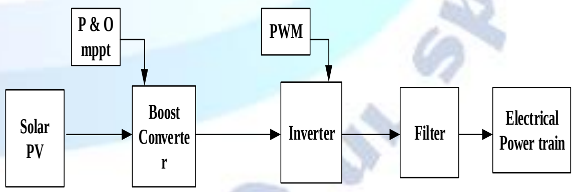


Figure 1: EPT connected Solar PV system

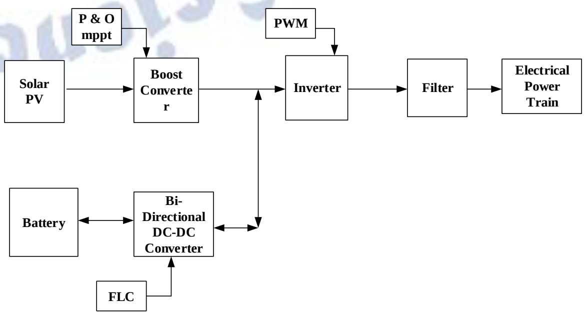


Figure 2: Electric Power Train connected Solar PV-BESS

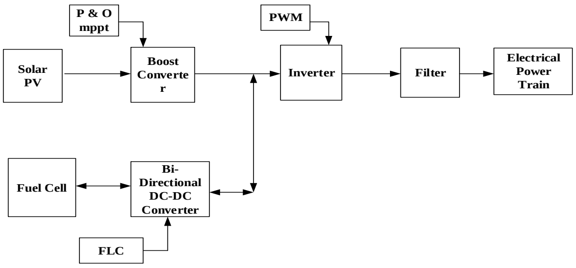


Figure 3: Electrical Power Train connected Solar PV-Fuel Cell

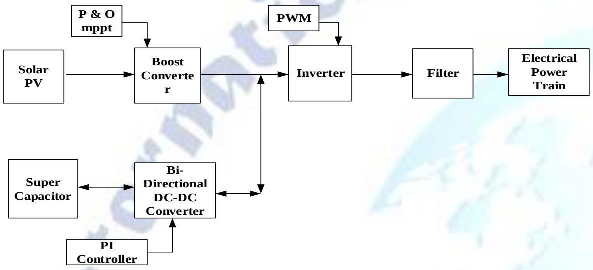


Figure 4: Electrical Power Train connected Solar PV-Supercapacitor

The above case-A depicted in figure-1 shows the proposed electric power train, which includes solar PV system, boost converter, inverter, filter and PMSM motor. The PMSM motor mainly utilized in Electric Vehicle applications because PMSM have high power factor, high efficiency and long life span. The PMSM motor operates with AC supply and the proposed system takes power from solar power generation that means the primary source is solar. As a result, the solar-generated electricity is converted into an alternating current supply by using an inverter. But the solar PV system produce low magnitude. As a result, the solar PV system is linked to the boost converter, which is then linked to the inverter. Finally inverter connected to PMSM motor through LC filter. Here the LC filter is employed for reducing harmonics in the inverter output. In this the boost converter is controlled by P&O MPPT topology and inverter is controlled by PWM generator. In the above diagram, no other energy storing devices are implemented. This research work also incorporates three additional cases. They were also clarified further. The equation for the solar PV model can be mentioned as:

The current output of PV module is:

$$I = N_p * I_{ph} - N_p * I_0 * \left[\exp\left(\frac{v * N_s + I * \frac{R_s}{N_p}}{n * V_t}\right) - 1\right] - I_{sh} \quad (1)$$

$$V_t = \frac{k * T}{q} \quad (2)$$

Photo-current I_{ph}

$$I_{ph} = [I_{sc} + K_i(T - 298)] * \frac{I_r}{1000} \quad (3)$$

Here

I_{ph}: PV current (A); I_{sc}: Short circuit current (A), V_T = terminal voltage T: Ambient temperature (K); Ir: intensity of light (solar irradiation)-(W/m²).

The above depicted remaining cases are continuation for the proposed work.In case-B depicted in figure-2, a battery along with BDC is connected in parallel to the Solar PV. The type of the battery implemented is lithium-ion battery. The BDC is controlled by using FLC. The equations related to battery are depicted below.

The battery terminal voltage for a charging situation with constant current is provided in Eq.4 with regard to time.

$$V_{bc}(t_c) = \left(\left(\frac{Q}{C} + I_C * R_2\right) * exp\left(-\frac{t_C}{R_2 * C_1}\right)\right) + V_0 - (I_C(R_1 + R_2)) \quad (4)$$

Similarly, Eq.5 gives the battery terminal voltage for a discharging case.

$$V_{bd}(t_d) = \left(\left(\frac{Q}{C} + I_d * R_2\right) * exp\left(-\frac{t_d}{R_2 * C_1}\right)\right) + V_0 - (I_d * (R_1 + R_2))(5)$$

R_1 and R_2 denotes the parameters of internal resistance, V_o denotes the output voltage, C_1 and C_2 denotes capacitance.

In case-C depicted in figure-3, the usage of battery will leads to the less efficiency and is of high cost which will leads to more maintenance requirement. So, to overcome this issue the battery is replaced with fuel cell (FC) along with BDC. This FC operates by using the Electrolysis principle. A primary battery that transforms chemical energy from a fuel cell into electrical energy. This chemical energy can be formed by the chemical reaction of oxygen. There are many other components that are incorporated as chemicals. In this work proton exchange membrane FC (PEMFC) hydrogen based fuel cell is employed along with BDC. This BDC is controlled by using FLC. The mathematical model of PEMFC is shown in the following equation. The voltage of the FC stack VFC is

$$V_{FC} = E_{oc} - N.A.\ln\frac{i_{FC}}{i_o}\left(\frac{1}{\frac{sT_d}{3}+1}\right)(6)$$

$$V_{FC} = E - R_{ohm}.i_{FC}(7)$$

Eoc stands for open circuit voltage i_{FC} for FC stack current, a for Tafel slope, i_o for interchange current, N for number of cells, Td for response time, and R for input impedance. The open circuit voltage E_{oc} is

$$E_{oc} = K_c.E_n(8)$$

Where Kc denotes the voltage constant at normal operating conditions and E_n denotes the Nernst voltage. As depicted in the comprehensive model, a fuel cell stack is represented by a regulated voltage source in series with a known resistance.

In case-D depicted in figure-4 the over usage of fuel cells will leads to the extraction of hydrogen and it is highly inflammable. To overcome this issue fuel cell is replaced with super capacitor (SC). In this case the energy will be provided by the help of SC. They can store more energy than capacitors and supply it at higher power outputs than batteries. The SCs store electrical energy at an electrode–electrolyte interface. The BDC converter is controlled by using PI controller. The solar and battery systems generate DC power, which is fed into the inverter, for converting DC to AC power. To reduce harmonic distortions, a filter is connected. The PMSM receives the inverted power supply. The obtained results are shown in the further sections.

In the Case-E, about the FLC based EPT Connected Solar PV-HESS consisting of all the energy sources together as shown in figure-5. All energy storage systems, including battery, super capacitors and fuel cells, will be able to store and provided energy in real time.For maximum utilization of renewable energy source like solar PV and for enhancing the performance of solar PV-HESS, here we will utilize the solar irradiation first and if solar is not properly available then we will move towards SC. If SOC of the SC goes down then we will utilize our battery for extracting the power with the help of FLC. PV-HESS is enough smart with the Type-1 FLC that it can extract power from the fuel cell, if all the remaining energy sources not able to provide appropriate power for traction. Further fuel cell will restore the battery and SC status. The accumulated DC power from the DC bus will be converted through inverter and converted AC power will supplied to PMSM drive after the filtering process. The obtained results are shown in further section.

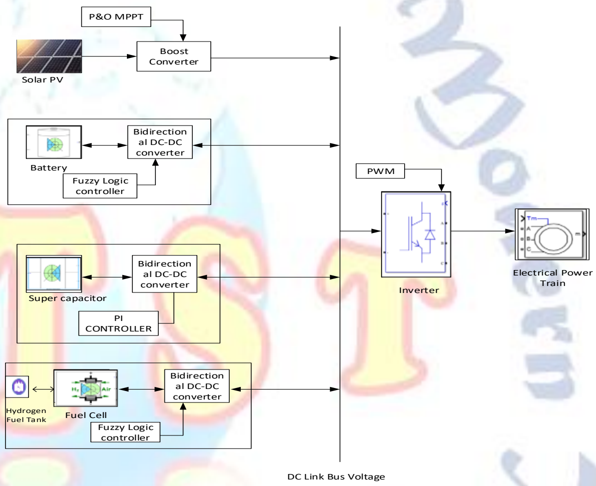


Figure 5: FLC based EPT connected Solar PV-BESS

The equations utilized in this research work in employing Type-1 FLC is as follows:

$$\mathbf{I_{error} = Fuzzy\ Logic\ Controller}\quad (9)$$

$$\mathbf{I_{error} = (V_{dcref} - V_{dc}) * K_p + 1/s(V_{dcref} - V_{dc}) * K_i}\quad (10)$$

$$\mathbf{Battery\ life = Voltage * \frac{Capacity}{Load}}\quad (11)$$

$$\mathbf{V_{error} = (I_{batref} - I_{bat}) * K_p + 1/s(V_{batref} - V_{bat})(12)}$$

In the case-F which represent by Figure-6. A interval Type-2.0 (IT-2.0) FLC is advanced counter part of the Type-1 FLC. But the only difference is at the defuzzification step a type reducer is employed. The IT-2.0 FLC is more beneficial than the Type-1 FLC. In IT-2.0 we have three membership function (MF). First and second MF is called upper MF and lower MF. In

IT-2.0 FLC the tertiary MF will be fixed (either 0 or 1). The IT-2.0 FLC is able to handle more uncertainty as compare to its Type-1 counterpart. In IT-2.0 FLC, the defuzzification process is different from Type-1 FLC. Here we are using centroid defuzzification after the type reduction. In this the IF-THEN rules can be formulated by using the input and outputs. A Triangular MF are used for input and output of IT-2.0 FLC.

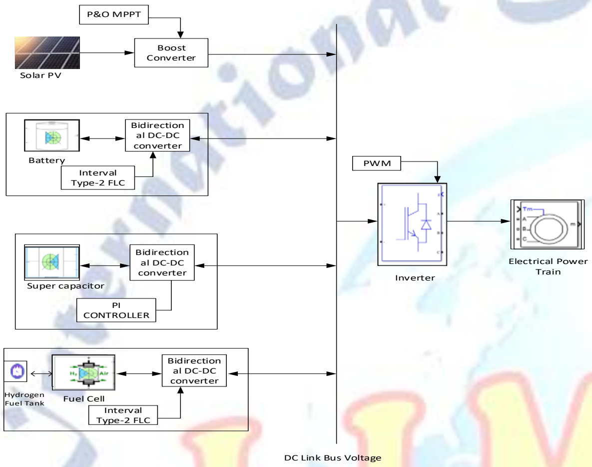


Figure.6. Interval Type-2 FLC based Solar PV-HESS

In this case we will replace the Type-1 FLC with IT-2.0 FLC and all the controlling strategy using different type of energy sources will be perform similar as case-E, with the help of IT-2.0 FLC. This IT-2.0 FLC will generate reference currents to the BDC converter by considering error of voltage and change in error of voltage as depicted in the below figures (18), (19) and (20).

3. CONTROLLING TOPOLOGY

A. Controlling topology at Solar PV side:

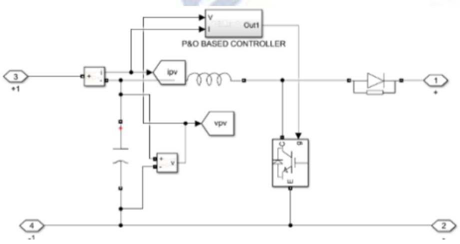


Figure 7:Boost converter simulink model

The above figures shows about the controlling topology implemented at the solar PV side. As discussed earlier, to increase the magnitudes of voltage obtaining from solar PV, a boost converter is employed.

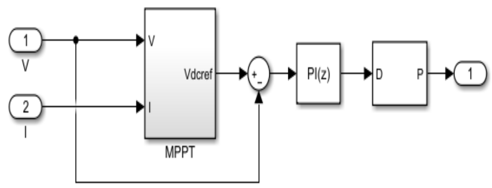


Figure 8: Simulink Model of P&O ALGORITHM BASED CONTROLLER

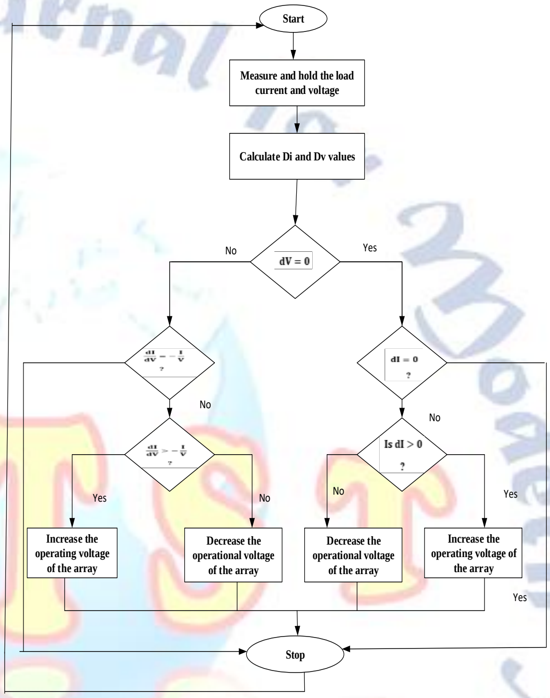


Figure 9: Flowchart of P&O MPPT

This step up converter is controlled by using perturbation and observation (P&O) and MPPT. Implementation of P&O is explained by a flow chart shown above with mathematical model of P&O technique.

B. Controlling topology of Bidirectional DC-DC Converter:

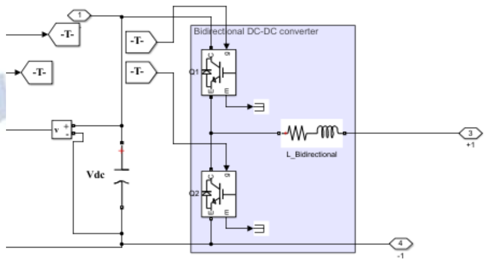


Figure 10: Simulink Model of BDC

In this implementation work the BDC converter plays a major role. This type of converter now a days is mainly used in electric vehicles. It's very useful for switching between energy storage. This BDC is controlled by using different controlling topologies in different energy storage systems. This can be clearly observed in the below shown figures. In the process of producing pulses to the BDC, the voltage controller and current also have their major contributions in this work.

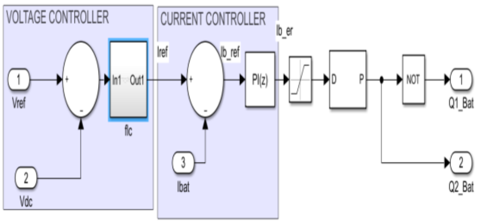


Figure 11: Schematic Representation of controlling topology implemented in BDC

C. Fuzzy Logic Controller:

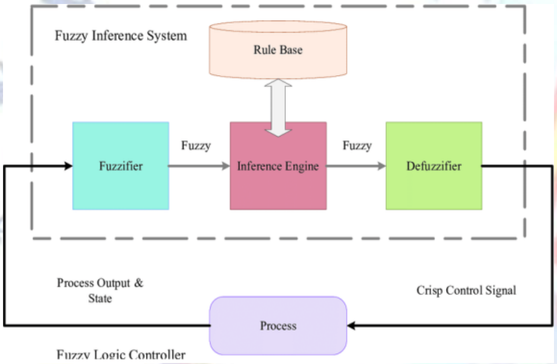


Figure 12: Schematic Representation of FLC

FLC, which operates based on logical rules formed by input and output arguments. And also it converts crisp values to fuzzy values (analog to logical). It is implemented by using the membership functions. The FLC system mainly compresses of 4 major parts known as fuzzification (converts fuzzy sets to crisp sets), rules base, inference engine and defuzzification (crisp sets to fuzzy sets) which can be shown in figure-12.

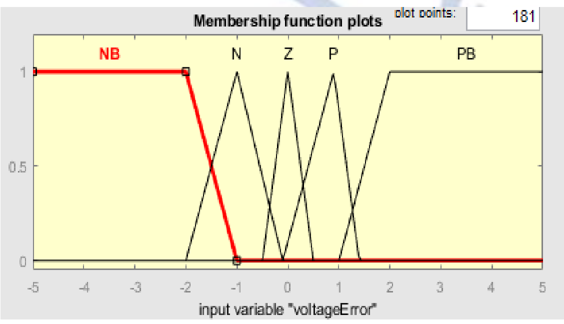


Figure 13: Voltage error

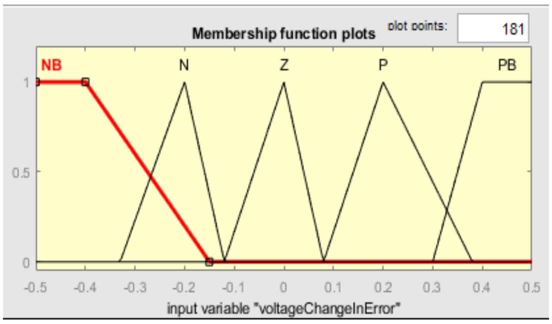


Figure 14: Voltage change in error

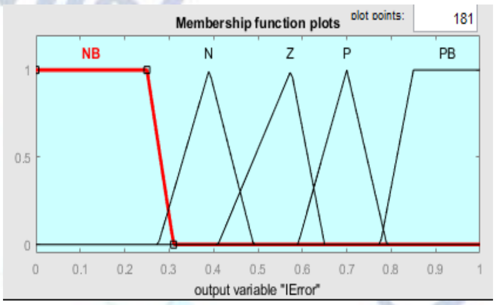


Figure 15: Reference current

Table-1: Rules for Type-1 FLC

Error/D error	NB	N	Z	P	PB
NB	PB	PB	P	Z	Z
N	P	P	Z	Z	Z
Z	Z	Z	Z	Z	Z
P	Z	Z	N	N	N
PB	N	N	N	NB	NB

The above table-1 convey the information about the rules implemented by executing Type-1 FLC. It consists of 5x5=25 rules. In this work, the Type-1 FLC takes two inputs named voltage error and voltage change in error as shown in figure-13 & 14 respectively to operate and generates output as reference currents as shown in figure-15. Here the two inputs are actual dc link voltage and change in dc link voltage.

D. Interval Type-2.0 Fuzzy Logic Controller:

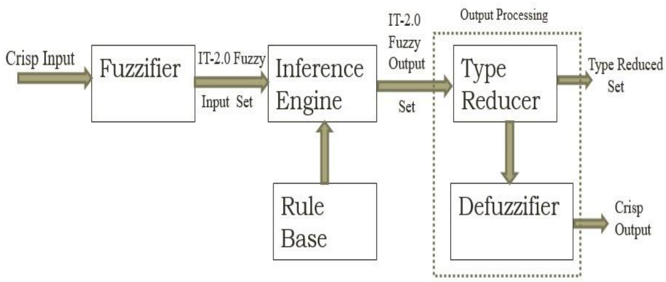


Figure 16: A general block diagram of IT-2.0 FLC

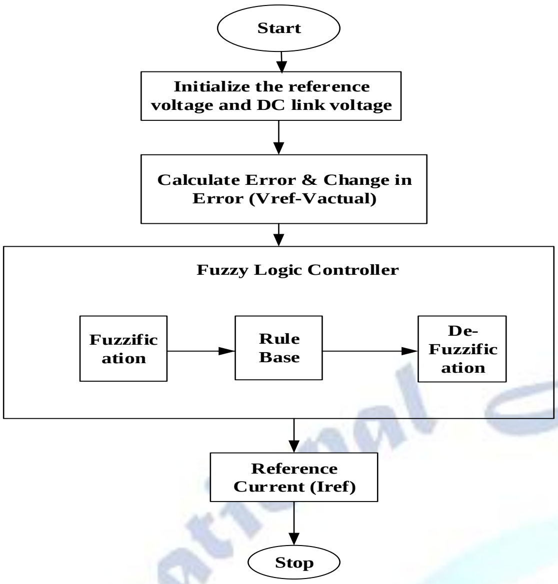


Figure 17: Flow Chart of Fuzzy Logic Controller

This work related flowchart of FLC in Case-E & Case-F is represent in Figure-17.The above figure-16 shows the general block diagram of Interval Type-2.0 FLC. Here, we see the only difference in output processing of IT-2.0 FLC is different from Type-1 FLC. The type-reduction module and the defuzzification module are two steps in the output processing. The type reduction module does the defuzzification by mapping the Interval Type-2.0 fuzzy outputs of the inference engine to a Type-1 fuzzy set. The type-reduction module's Type-1 fuzzy results are finally converted into crisp output values by the defuzzification module in order to derive the real control action by averaging the type-reduced set.

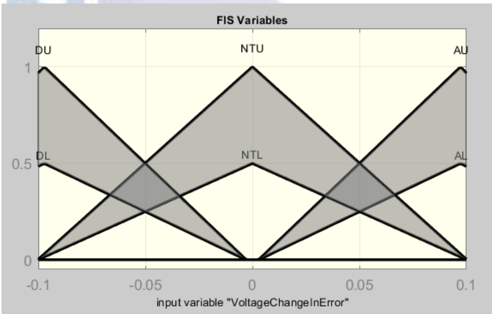


Figure 18. Voltage error

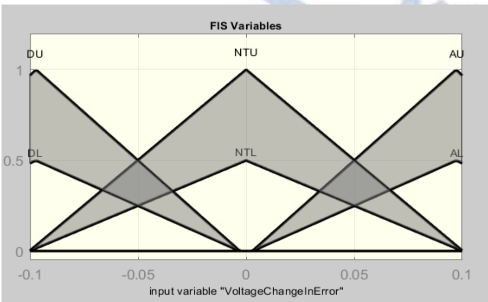


Figure 19. Voltage change in error

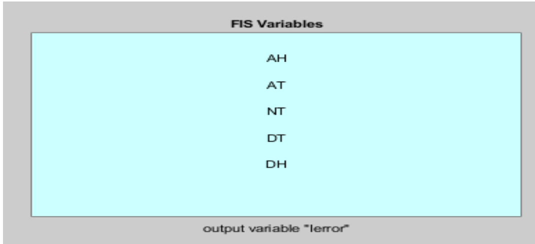


Figure 20. Reference Current

Table-2: Rules for IT-2.0 FLC

E/CE	*D*	*NT*	*A*
D	*DH*	*DT*	*NT*
NT	*DT*	*NT*	*AT*
A	*NT*	*AT*	*AH*

The error (E) and change in error (CE) are divided into three fuzzy sets each. The MFs of E and CE are shown in above figure-18 & 19 respectively. The E and CE MFs are taken as trapezoidal MF for providing precision result. The Rule base of IT-2.0 MFs are tabulated in the above table-2, Where A denotes appreciate, NT denotes Neutral, D defines depreciate. The output MFs are shows in above Figure-20 where, AT shows appreciate tiny, DT shows depreciate tiny, DH shows depreciate huge, NT shows Neutral and AH shows appreciate huge.

E. LCL Filter :

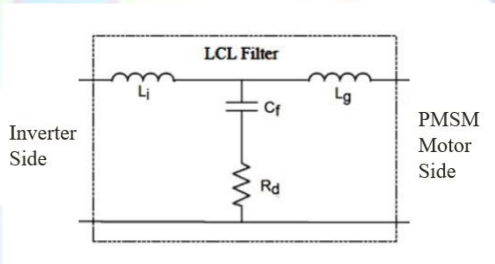
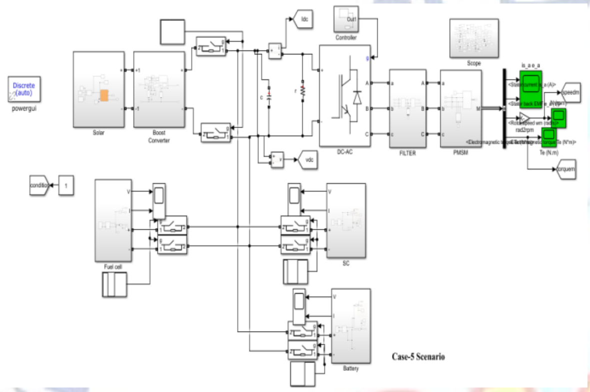


Figure 21: Circuit Diagram of LCL Filter

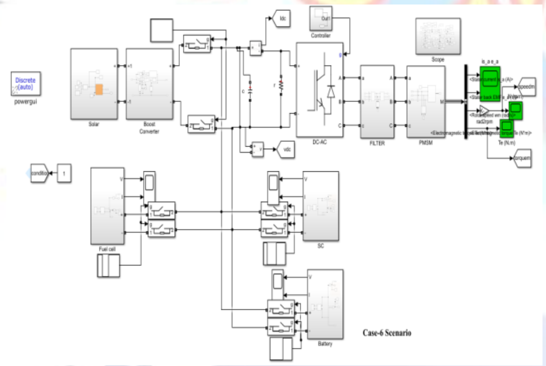
In this research work employed passive filter to reduce the high-order harmonics on the output side of inverter. There are many different types of passive filter available like L, LC and LCL filter. Compared to L and LC filter, LCL filter has better attenuation capacity of high-order harmonics. In this research LCL filter is utilized to reduce the harmonic ripples, with low value of inductor and capacitor values. The basic circuit diagram of LCL filter is shown in figure-21, where Li represent inverter side inductance, Lg shows PMSM motor side inductance, C_f is Filter capacitance and the damping resistanceR_d.

4. RESULTS AND DISCUSSION

By employing Matlab-2018a Software, The proposed system has been simulated. The performance results in case-A to case-F like voltage, current & power of solar PV, battery, super capacitor & fuel cell energy storage system. Also voltage, current & power of DC bus and Inverter, PMSMs speed, torque, and electro-magnetic force, and SOCs of battery & SC energy storage systems are further shown in this section.



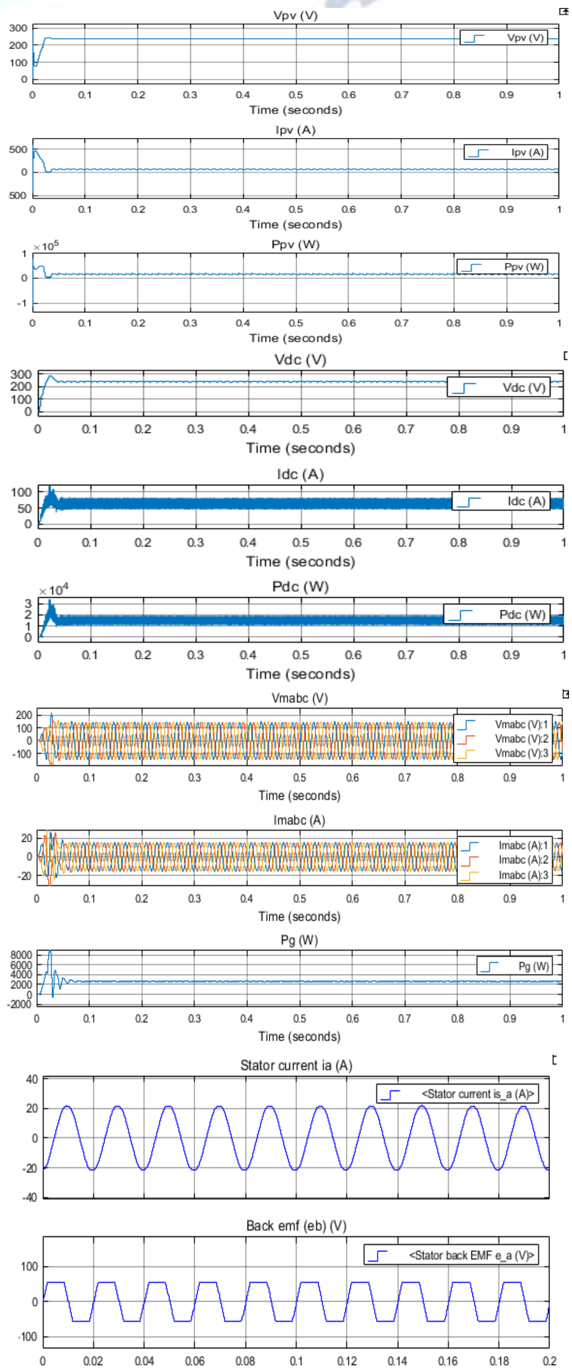
a) Simulink Model of Type-1 Fuzzy Logic Controller based Electrical Power Train connected Solar PV-HESS

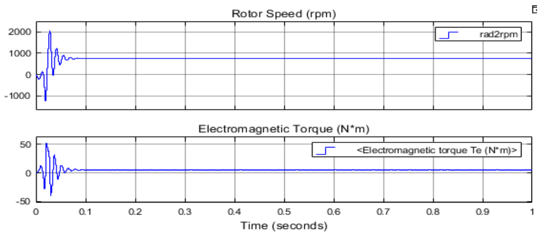


b) Simulink Model of Interval Type-2 FLC based Electrical Power Train connected Solar PV-HESS

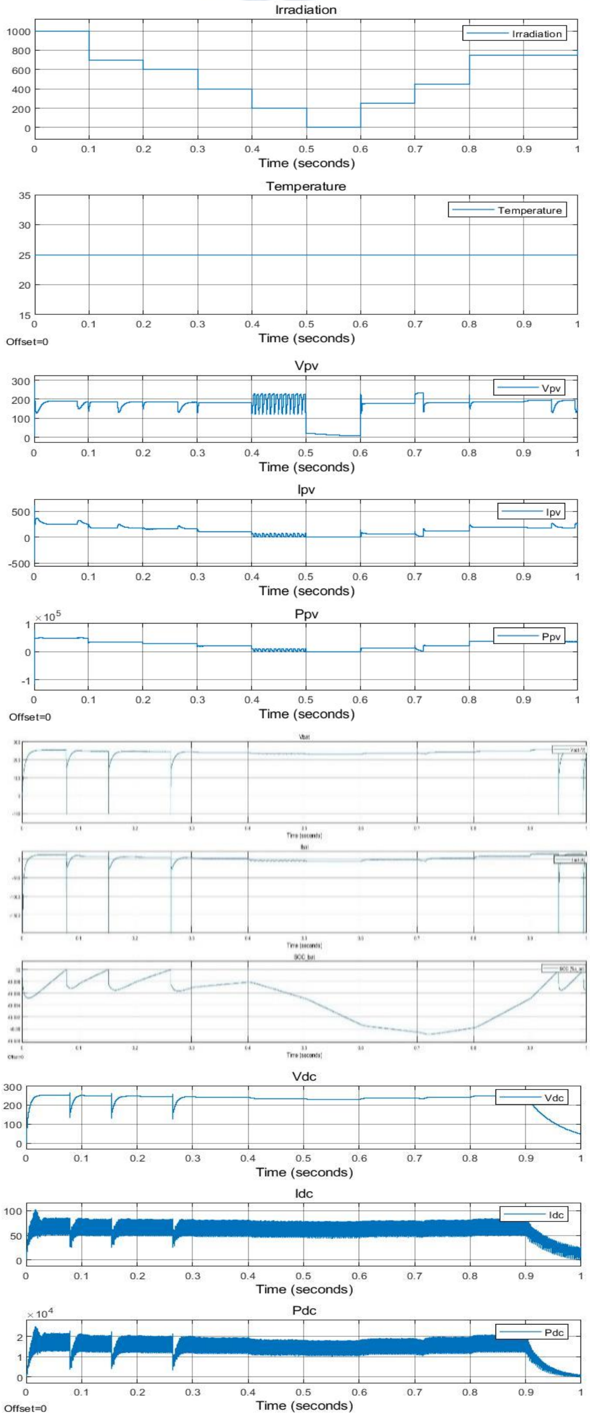
Figure 22: Simulink Models of Case-E and Case-F

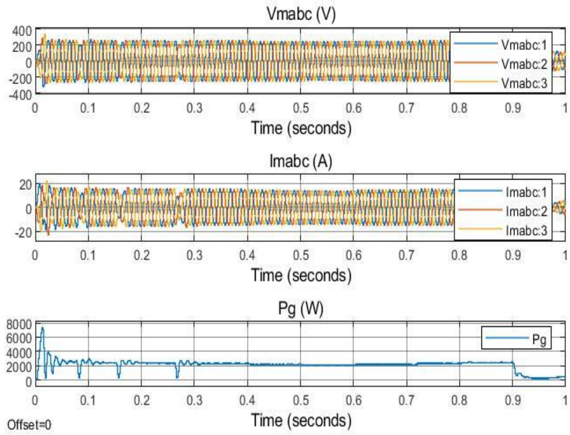
The figure-22 represent the Simulink models of case-E and case-F. In the segment (A) Simulink Model of Type-1 Fuzzy Logic Controller based EPT connected Solar PV-HESS controlling configuration, a Type-1 FLC is used to control the reference currents of battery and fuel cell energy storage system with the comparison of DC bus to DC reference voltage (240V). And In the segment (B) Simulink Model of interval Type-2.0 FLC based EPT connected Solar PV-HESS controlling configuration, a IT-2.0 FLC is used to control the reference currents of battery and fuel cell energy storage system with the comparison of DC bus to DC reference voltage (240V). In both cases reference current generate pulses for the BDC and this help to the discharge/charging position of the super capacitor and battery and it's also fulfill the demand of power as requirement of the load. The solar PV & SC energy storage system is fulfill the demand of power for the load as per the availability. Further in case-E & case-F results we can see How's the proposed system taken in this research work is working.

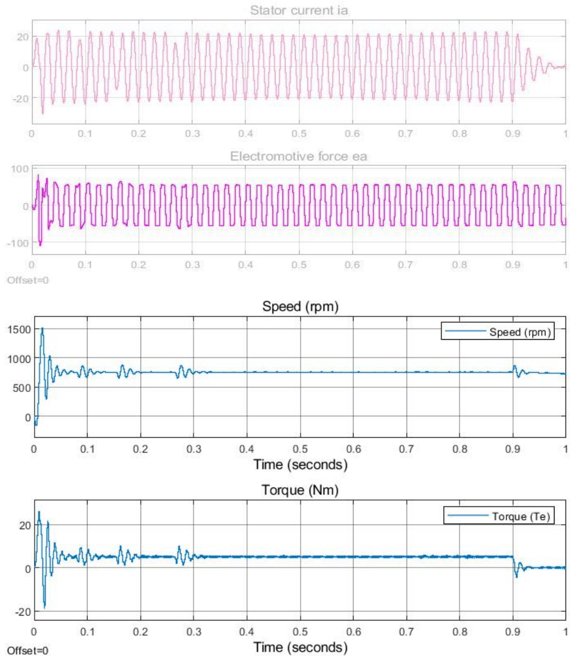




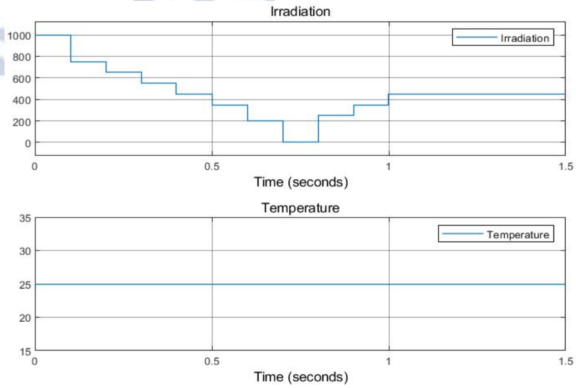
A. Simulation results obtained in EPT connected only Solar PV system – solar PV Power, Voltage, Current (Ppv, Vpv, Ipv), DC link voltage, Current, Power (Vdc, Idc, Pdc), Inverter related power, voltage and current (Pg, Vmabc, Imabc), PMSM related back emf (eb), stator current (ia), torque and rotor speed.

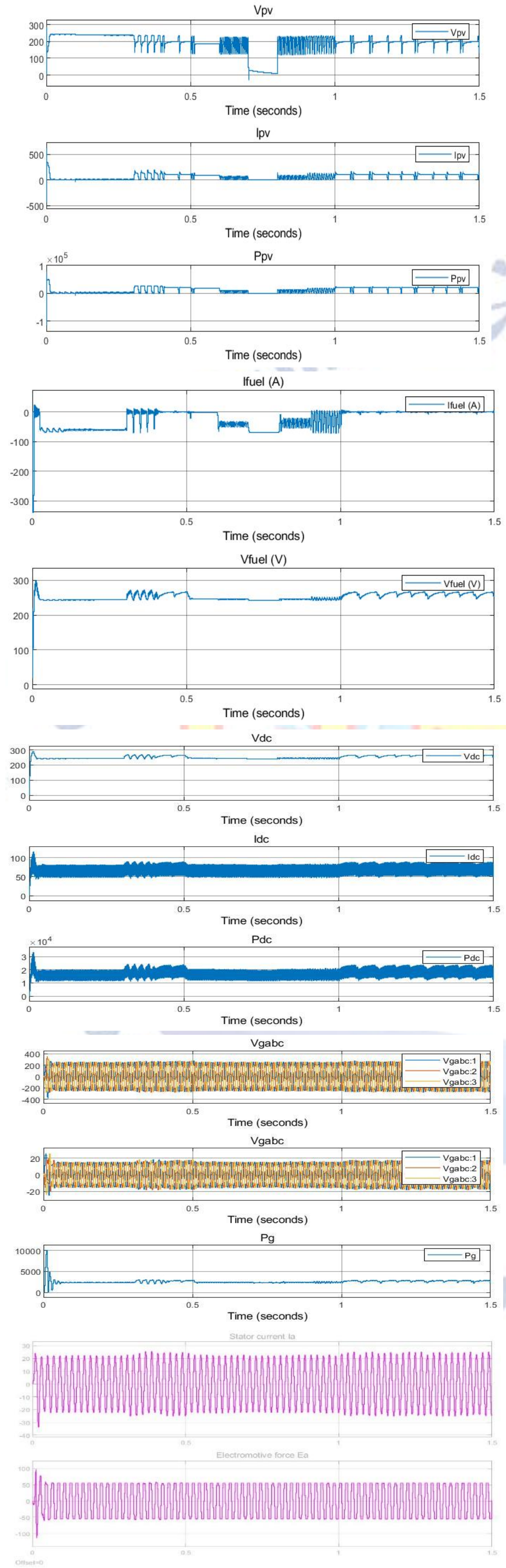


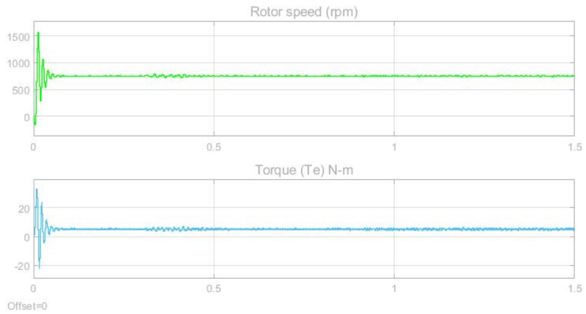




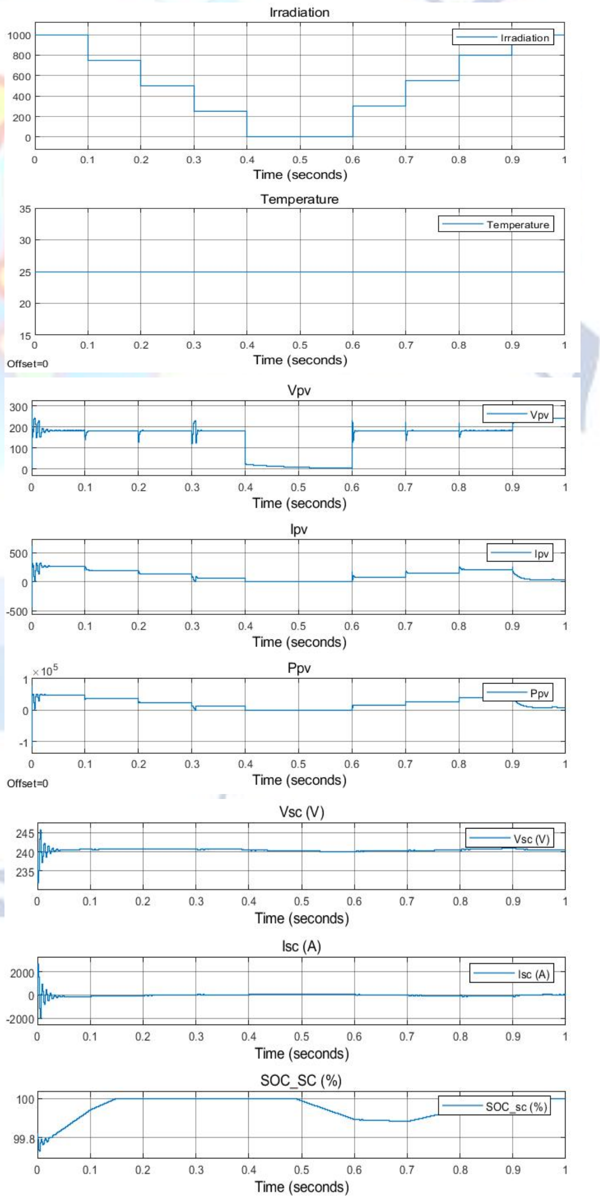
B. Simulation results obtained in EPT connected Solar PV-Battery system- solar irradiation(W/m2), temperature (^{0}C), solar PV Power, Voltage, Current (Ppv, Vpv, Ipv), Battery voltage, current, SOC (Vbat, Ibat, Bat_soc), DC link voltage, Current, Power (Vdc, Idc, Pdc), Inverter related power, voltage and current (Pg, Vmabc, Imabc), PMSM related back emf (eb), stator current (ia), torque and rotor speed.

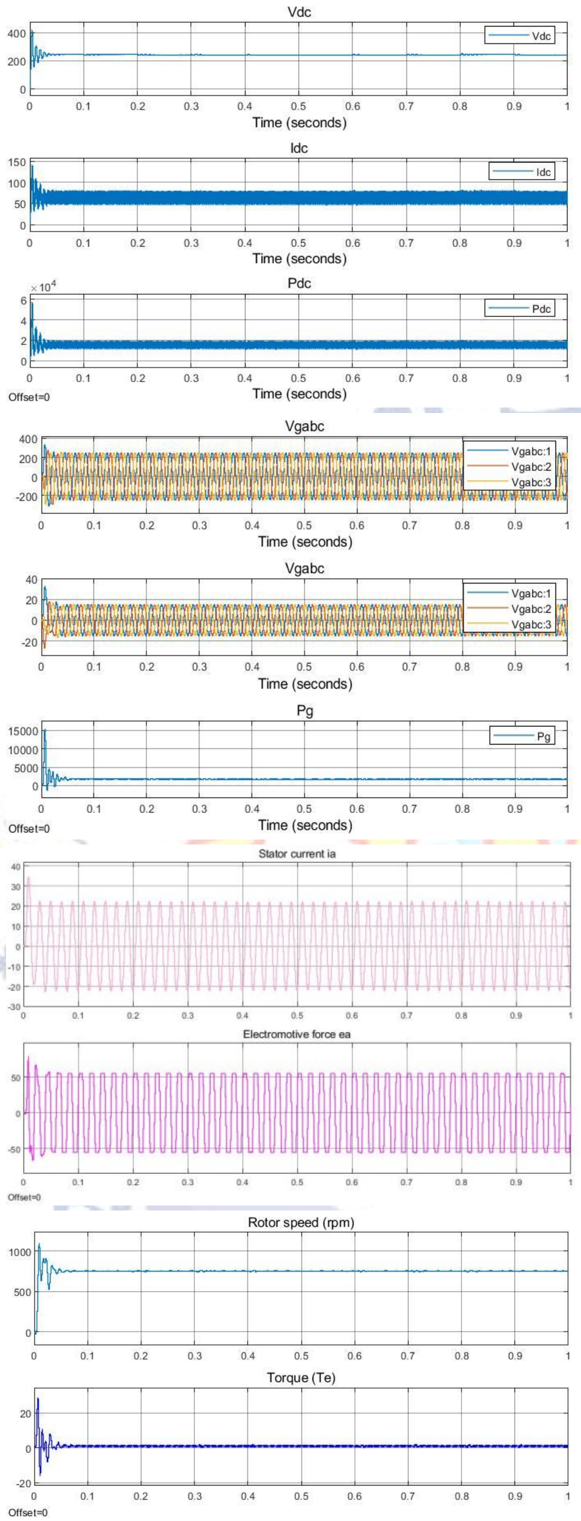






C.Simulation results obtained in EPT connected Solar PV-Fuel Cell system- solar irradiation(W/m2), temperature (^{0}C), solar PV Power, Voltage, Current (Ppv, Vpv, Ipv), Fuel cell voltage, current, (Vfuel, Ifuel), DC link voltage, Current, Power (Vdc, Idc, Pdc), Inverter related power, voltage and current (Pg, Vgabc, Igabc), PMSM related back emf (eb), stator current (ia), torque (Te) and rotor speed.





D. Simulation results obtained in EPT connected Solar PV-Super capacitor system- - solar irradiation(W/m2), temperature (^{0}C), solar PV Power, Voltage, Current (Ppv, Vpv, Ipv), Battery voltage, current, SOC (Vbat, Ibat, Bat_soc), DC link voltage, Current, Power (Vdc, Idc, Pdc), Inverter related power, voltage and current (Pg, Vmabc, Imabc), PMSM related back emf (eb), stator current (ia), torque and rotor speed.

The above waveform- A to D is describe the simulation results of the proposed cases- A to D. In all 4 cases, the torque (Te) are kept constant, i.e. 5 N-m. Waveform-A, simulation result obtained in EPT connected solar pv system is described the proposed case-A. In this case the Temperature and Irradiation are kept constant i.e. 25^{0}C & 1000 W/m2. Here, it means the solar pv energy system is enough to fulfill the demand of power as requirement of PMSM drive. The DC power obtained from solar PV energy system will be converted through inverter and converted AC power will supplied to PMSM drive after the filtering process.

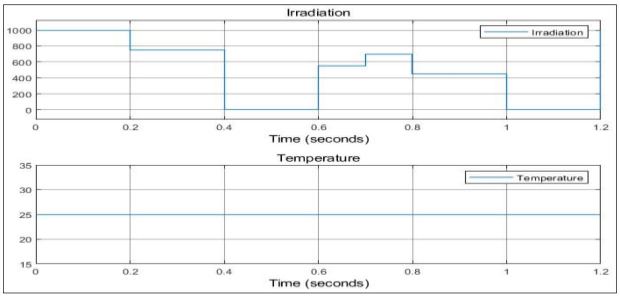
In case- B to D both availability & non-availability of solar PV power are found. Thereby, the battery, fuel and supercapacitor energy storage system have been brought together to meet the power demand of the drive system. In these three cases the Temperature are kept constant i.e. 25^{0}C but the Irradiation is vary in between 0 to 1000 W/m2.

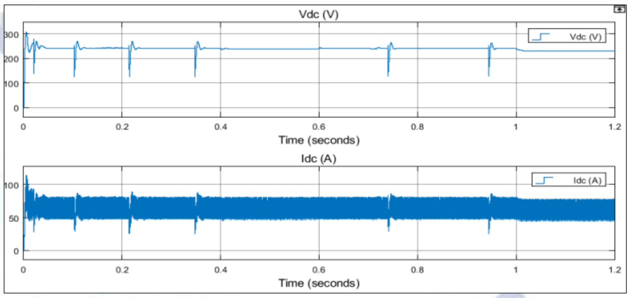
Waveform-B, simulation result obtained in EPT connected solar PV-battery system is described the proposed case-B. As we clearly see the waveform of battery current (Ibat) is vary according to the solar PV power that means Here, when solar PV energy system is unable to fill the power demand of PMSM drive system then battery energy storage system is active to fill the power demand. The charging and discharging of battery is clearly appear in the waveform of battery SOC (SOC_bat). The controller Type-1 FLC installed in the battery energy storage system maintains the DC bus voltage by comparing it to the DC reference voltage (240V) and regulate the battery reference current. The DC power obtained from solar PV-battery energy system DC bus will be converted through inverter and converted AC power will supplied to PMSM drive after the filtering process. And we see in waveform of battery SOC, when the electric vehicle stopped (Te=0) at 0.9s to 1s then the available solar PV power is charged the battery.

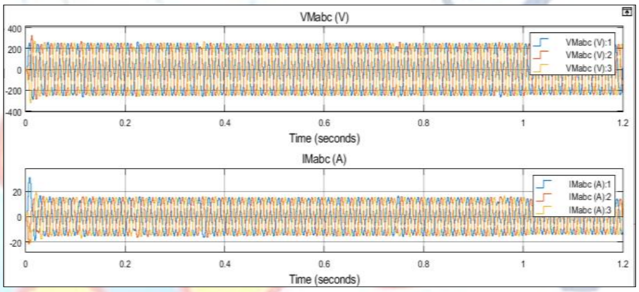
Waveform-C, simulation result obtained in EPT connected solar PV-fuel cell system is described the proposed case-C. As we clearly see in the waveform of fuel current (Ifuel) is vary according to the solar PV power variation. Also the controller Type-1 FLC installed in the fuel cell energy storage system maintains the DC bus voltage by comparing it to the DC reference voltage (240V) and regulate the fuel cell reference current. The DC power obtained from solar PV-fuel cell energy system DC bus will be converted through inverter and converted AC power will supplied to PMSM drive after the filtering process.

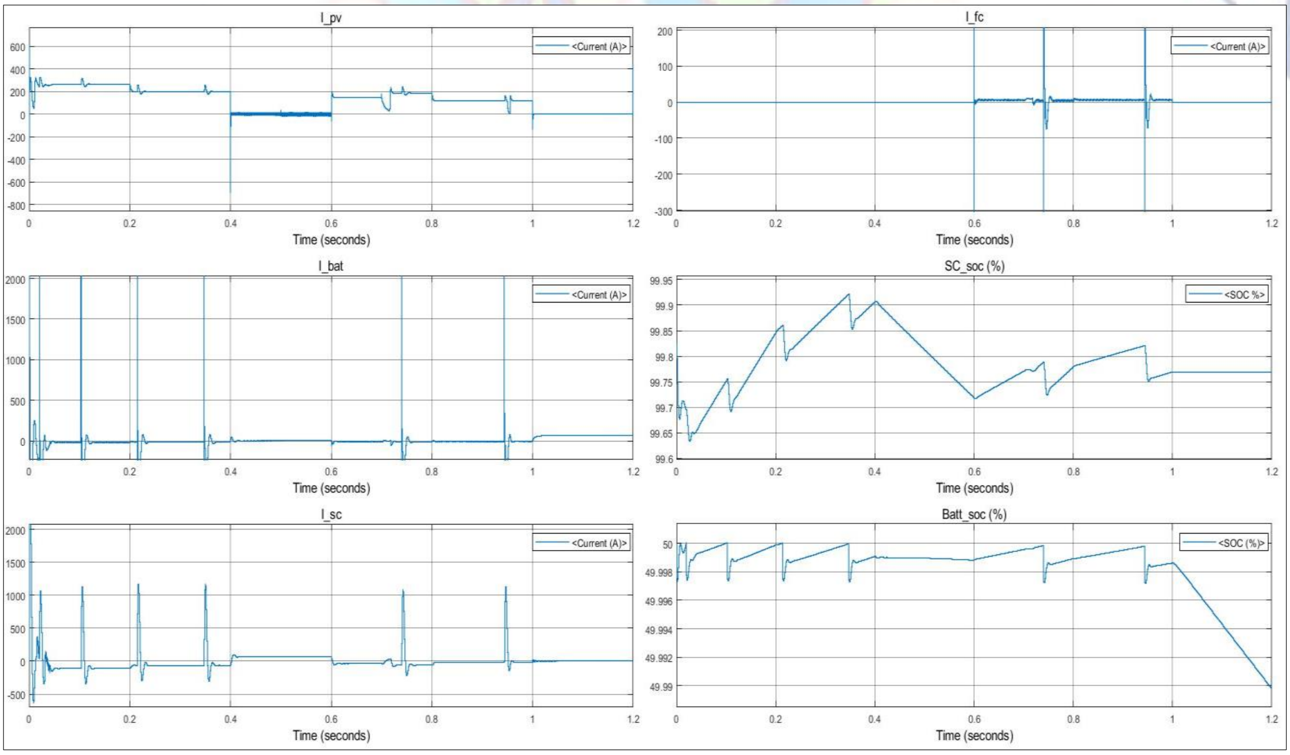
Waveform-D, simulation result obtained in EPT connected solar PV-supercapacitor system is described the proposed case-D. As we clearly see in the waveform of SC current (Isc) is vary according to the solar PV power variation. The DC power obtained from solar PV-supercapacitor energy system DC bus will be converted through inverter and converted AC power will supplied to PMSM drive after the filtering process. The charging and discharging of SC is clearly appear in the waveform of supercapacitor SOC (SOC_sc).

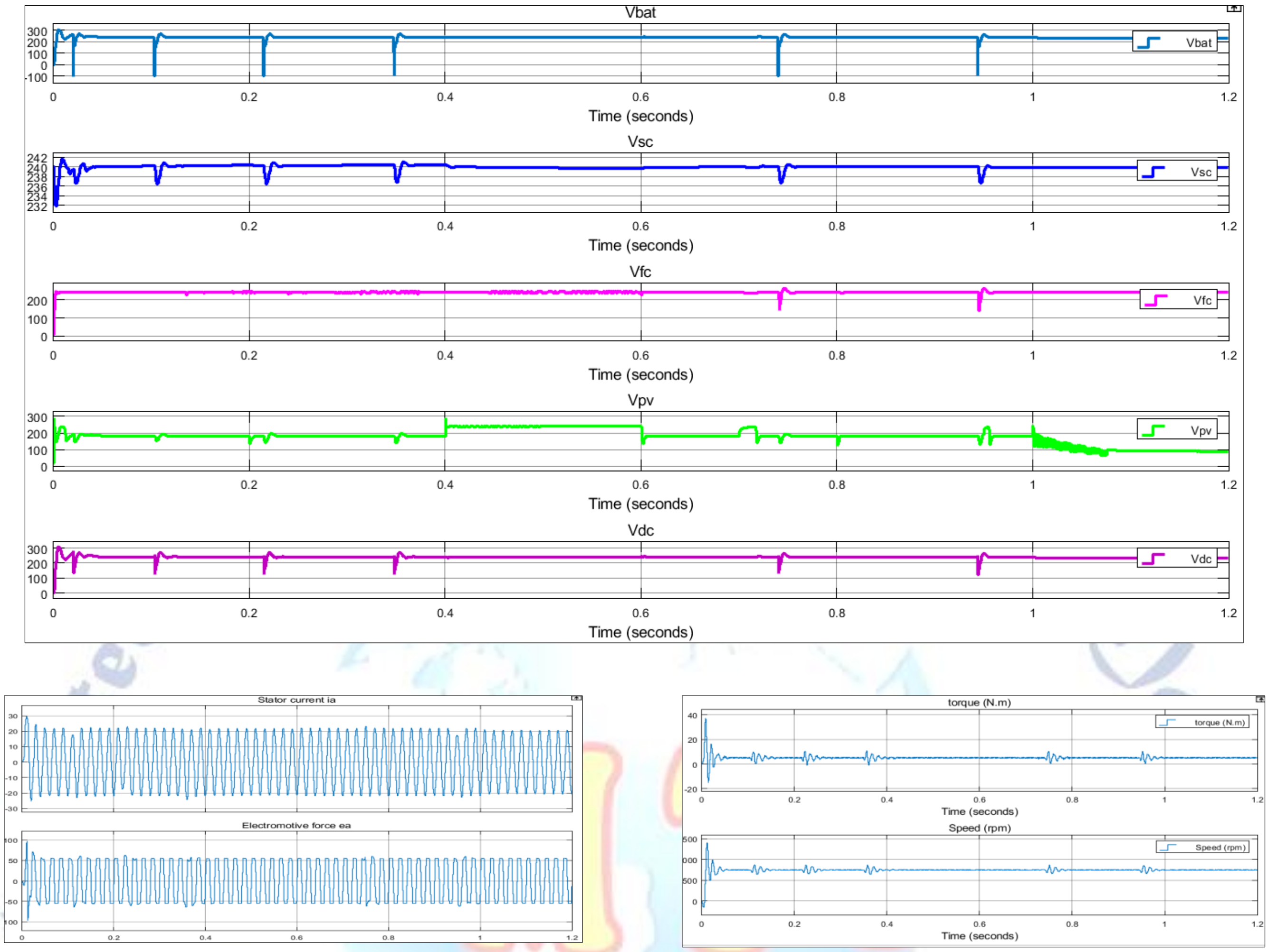
The response time of power obtained from solar PV system is faster in fuzzy-based cases. Similarly, PV current and voltage waveforms are obtained. However, there will be some distortions in the waveforms during the initial period before it settles into a stable position. This can also happen during the boosting up stage. In 4-cases, the inverting stage is made up of three phases. As a result, the obtained results will be sinusoidal in shape and have a constant amplitude.





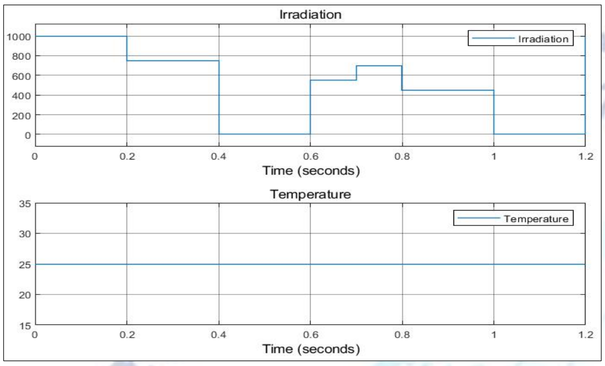


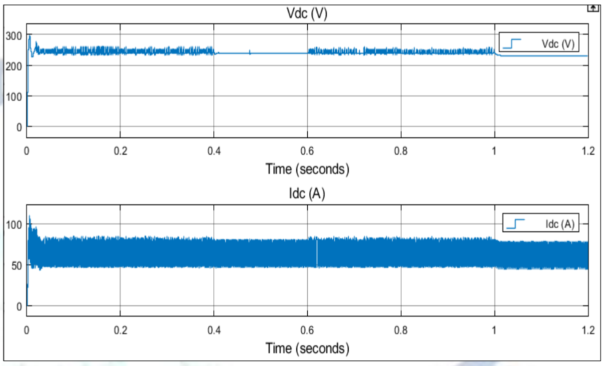


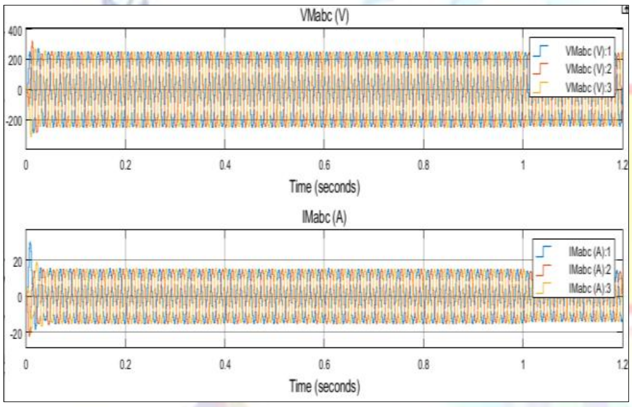


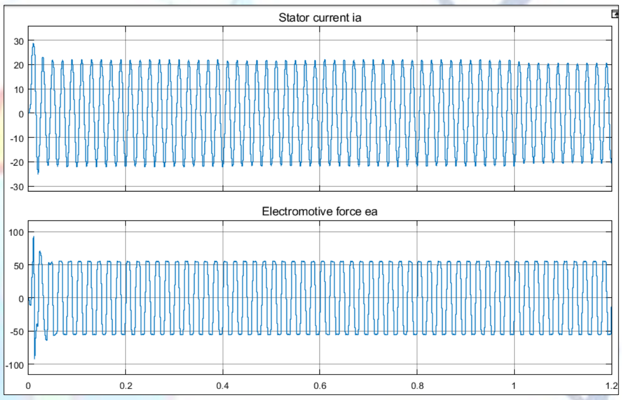
E. Simulation results obtained type-1 FLC based EPT connected to PV-Hybrid Energy Storage System- solar irradiation(W/m2), temperature (^{0}C), DC link voltage, Current, (Vdc, Idc), Inverter related voltage and current (VMabc, IMabc), Current of all energy sources with battery & SC SOC (I_pv, I_bat, I_sc, I_fc, SC_soc, Batt_soc), Voltage of all energy sources with DC bus voltage (Vbat, Vsc, Vfc, Vpv, Vdc), PMSM related back emf (eb), stator current (ia), torque (Te) and rotor speed(rpm)

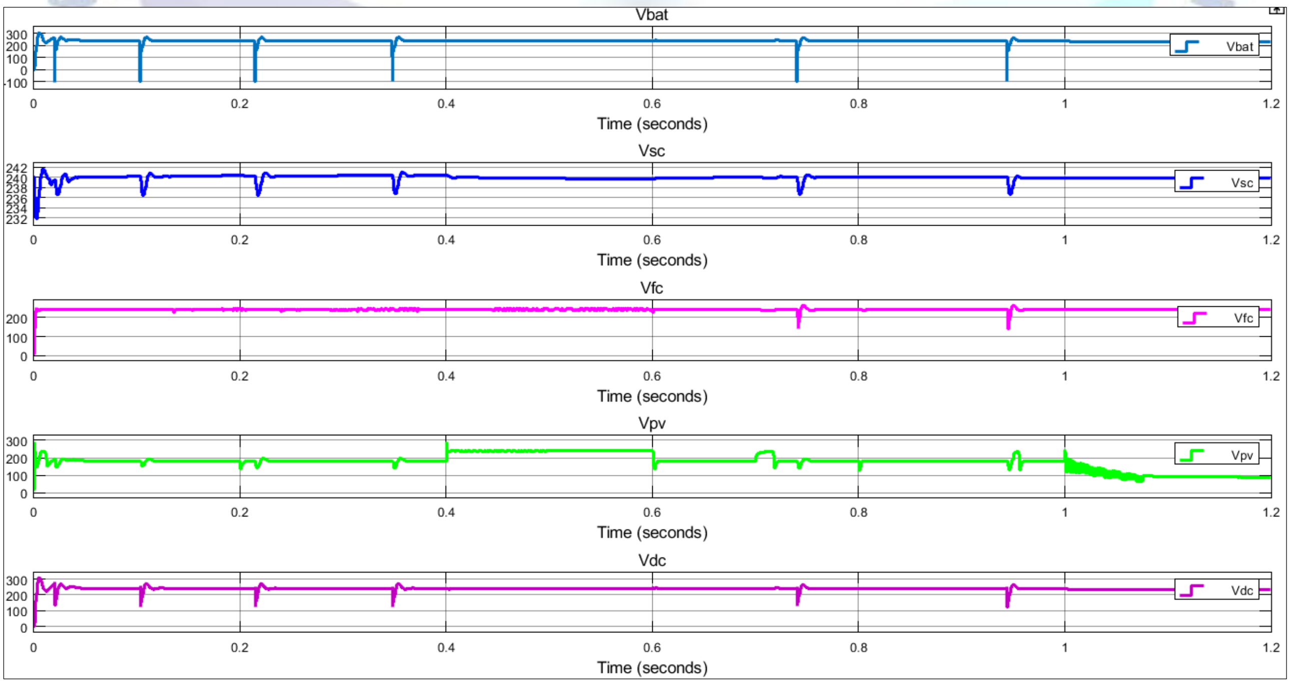
Waveform-E, simulation result obtained in EPT connected solar PV-Hybrid energy storage system is described the proposed case-E. In this condition the solar irradiance has varied with different values and the temperature is maintained constant at 25^{0}C with respect to different timing durations. At 0 to 0.2s, the irradiance is set to 1000 W/m^2 the battery and super capacitor is in charging mode and the fuel is deactivated. From 0.2 to 0.4s the irradiance value is set to 750 W/m^2 the battery is get activated, both battery and super capacitor are getting charged whereas the fuel cell is deactivated. From 0.4 to 0.6s the power from solar is not available then the battery will get activated and is in charging mode although the super capacitor is in discharging mode it will get activated whereas the fuel cell get deactivated. From 0.6 to 0.7s the irradiance value is set to 550W/m2 and from 0.7 to 0.8s the irradiance value is set to 700W/m2, in the meantime the battery and super capacitor is in charging mode and the battery is activated whereas the fuel cell is activated. In this activation period of fuel cell some amount of current is drawn and the remaining power is available from the solar. At 0.8 to 1s the irradiance is set to 450W/m2 the battery is in charging mode and all the sources are get activated and is in working condition. From 1 to 1.2s the availability of power from solar is absent, the fuel cell and supercapacitor is not available. At this point of time battery will get discharged and it gets activated to supply the power to the loads. Then the DC power obtained from solar PV-Hybrid energy storage system DC bus will be converted through inverter and converted AC power will supplied to PMSM drive system after the filtering process. The charging and discharging of battery and SC is clearly appear in the waveform of battery SOC (Batt_soc) &supercapacitor SOC (SC_soc). Based on this approach the simulation results are depicted above. In this case the BDC is employed with Type-1 FLC.

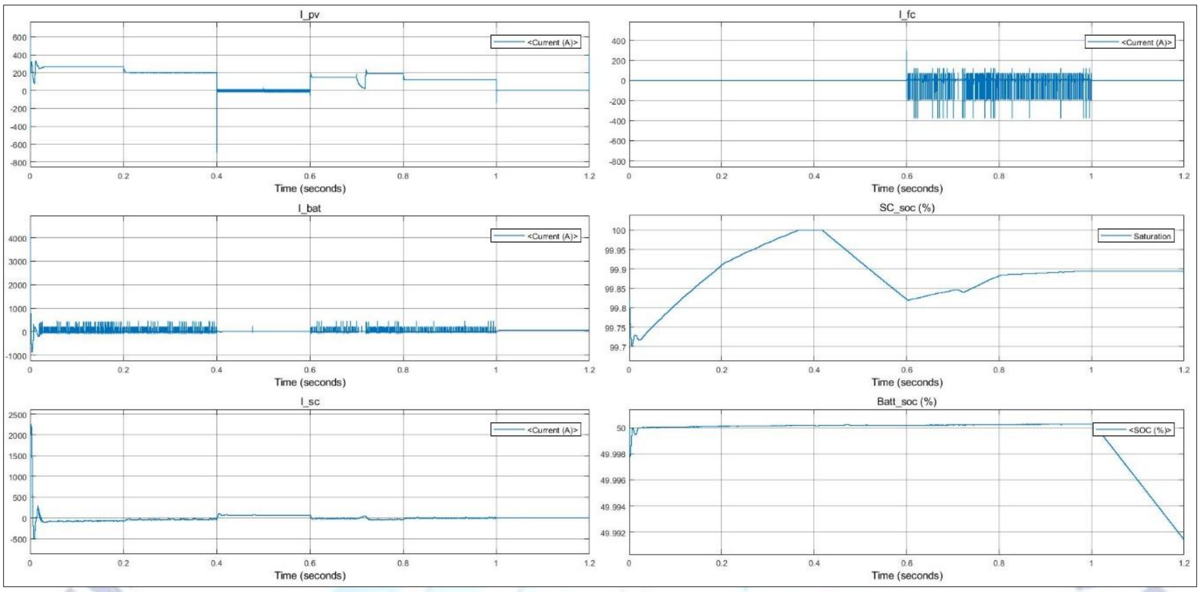


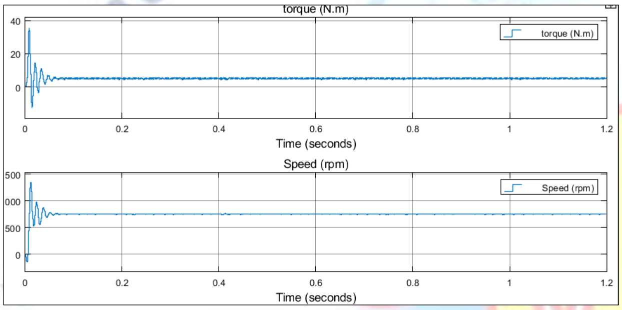












F. Simulation results obtained interval Type-2.0 FLC based EPT connected to PV-Hybrid Energy Storage System- solar irradiation(W/m2), temperature (^{0}C), DC link voltage, Current, (Vdc, Idc), Inverter related voltage and current (VMabc, IMabc), PMSM related back emf (eb), stator current (ia), Voltage of all energy sources with DC bus voltage (Vbat, Vsc, Vfc, Vpv, Vdc), Current of all energy sources with battery & SC SOC (I_pv, I_bat, I_sc, I_fc, SC_soc, Batt_soc), torque (Te) and rotor speed(rpm).

Figure 23: Simulation results of all cases

Waveform-F, simulation result obtained in EPT connected solar PV-Hybrid energy storage system is described the proposed case-F In this condition the solar irradiance has varied with different values and the temperature is maintained constant at 25^{0}C with respect to different timing durations. At 0 to 0.2s, the irradiance is set to 1000 W/m^2 the battery and super capacitor is in charging mode and the fuel is deactivated. From 0.2 to 0.4s the irradiance value is set to 750 W/m^2 the battery is get activated, both battery and super capacitor are getting charged whereas the fuel cell is deactivated. From 0.4 to 0.6s the power from solar is not available then the battery will get activated and is in charging mode although the super capacitor is in discharging mode it will get activated whereas the fuel cell get deactivated. From 0.6 to 0.7s the irradiance value is set to 550W/m2 and from 0.7 to 0.8s the irradiance value is set to 700W/m2, in the meantime the battery and super capacitor is in charging mode and the battery is activated whereas the fuel cell is activated. In this activation period of fuel cell some amount of current is drawn and the remaining power is available from the solar. At 0.8 to 1s the irradiance is set to 450W/m2 the battery is in charging mode and all the sources are get activated and is in working condition. From 1 to 1.2s the availability of power from solar is absent, the fuel cell and supercapacitor is not available. At this point of time battery will get discharged and it gets activated to supply the power to the loads. Then the DC power obtained from solar PV-Hybrid energy storage system DC bus will be converted through inverter and converted AC power will supplied to PMSM drive system after the filtering process. The charging and discharging of battery and SC is clearly appear in the waveform of battery SOC (Batt_soc) &supercapacitor SOC (SC_soc). Based on this approach the simulation results are depicted above. In this case the BDC is employed with interval Type-2.0 FLC.

Also we observe that the waveform, Current of all energy sources with battery & SC SOC (I_pv, I_bat, I_sc, I_fc, SC_soc, Batt_soc) in case-F is automatically improved over the Current of all energy sources with battery & SC SOC (I_pv, I_bat, I_sc, I_fc, SC_soc, Batt_soc) in case-E due to the controlling strategy, so here, it can be noticed that the IT2.0 FLC is superior performance as comparison of Type-1 FLC.

Table 3: Comparison Saving in Interval Type-2.0 as comparision of Type-1 FLC

Energy Storage System (SOC)	Initial SOC (%)	Max. Charging Point (%) (Achieved by charging)	End Dis-Charging Point (%) (Achieved by charging-Discharging)	Consumption (%)	Consumption Saving in IT-2.0 (Case-F) as comparision of Type-1 (Case-E) (%)
Super-Capacitor_Type-1	100	99.992	99.77	0.222	
Super-Capacitor_IT-2.0	100	100	99.894	0.106	**52.25**
Battery_Type-1	50	50	49.9898	0.0102	**13.72**
Battery_IT-2.0	50	50.003	49.9915	0.0088	

The above table-3 represent about the comparison of consumption saving of battery and supercapacitor in Case-E and Case-F by implementing Type-1 FLC and IT-2.0 FLC. Here we see from the table; the supercapacitor energy and battery energy is utilized 0.222% and 0.0102% in case of Type-1 FLC (Achieved by completion of whole process of Case-E). Also the supercapacitor energy and battery energy is utilized 0.106% and 0.0088% in case of interval Type-2.0 FLC (Achieved by completion of whole process of Case-F). According to the consumption of supercapacitor and battery energy the saving in supercapacitor energy is 52.25% and battery energy is 13.72%. In context of this, we can see here, the battery and supercapacitor save more energy in the case of IT-2.0 FLC as compare to Type-1 FLC so we can conclude that the IT-2.0 FLC-based hybrid electric vehicle have better performance achieved as compare to Type-1 FLC based hybrid electric vehicle.

Table 4: Comparison of THDs

Parameters	**Type-1 Fuzzy (%)**	**Type-2 fuzzy (%)**
Stator current	**6.05**	**5.21**
Back emf	**24.14**	**21.79**
Inverter voltage	**4.61**	**3.11**
Inverter current	**6.06**	**2.92**
Motor voltage	**6.08**	**4.60**
Motor current	**8.13**	**6.77**

The above table-4 represent about the comparison of Total harmonic distortions (THDs) in different parameters by implementing T1-FLC and IT-2.0 FLC. The parameters like stator current, back emf, inverter voltage, inverter current, motor voltage and motor current has less number of harmonic distortions by implementing IT-2.0 FLC in the controlling topology when compared to Type-1 FLC. So, it can be noticed that the IT-2.0 FLC evaluates superior performance over Type-1 FLC. So accordingly we can say that the performance of Hybrid electric vehicle based on IT-2.0 FLC is very good.

5. FUTURE SCOPE AND CONCLUSION

This research work implemented a novel integrated model using an Interval Type-2.0 FLC of an EPT (electrical power train) with a HESS. It's consist of solar PV, Battery, Fuel cell and Supercapacitor with controllers as input shows practical response. The PMSM drive system is give the desired output at different condition of

Solar PV irradiance and torque input which is give the satisfactory performance as required execution of the system.

The simulation results at the different scenarios consist of EPT connected Solar PV system, Type-1 FLC based EPT connected to solar PV-BESS, PI controller based EPT connected solar PV-Supercapacitor energy storage system, Type-1 FLC based EPT connected to solar PV-Fuel cell system, Type-1 FLC based EPT connected to PV-HESS, and Interval Type-2.0 FLC based EPT connected to PV-HESS is the validation of model and compared the good performance of each system. Among the majority of these cases, the Interval Type-2.0 FLC based EPT connected to PV-HESS performs best and has the lowest THD content. Also we see that the IT-2.0 FLC evaluates superior performance over Type-1 FLC. So accordingly we can say that the performance of Hybrid electric vehicle based on IT-2.0 FLC is very good. This improves the power quality of the system and ensuring that it responds quickly. The proposed work's performance was evaluated using Matlab/Simulink 2018a software.

The model presented here based on growing needs of renewables and zero carbon emission which is the key features of the sustainable development of the society. The researcher can take it as the key model of hybrid electric vehicle with complex integration of renewable sources. In future scope of this project is implemented with the advanced controllers like - ANFIS controller or Neural Network controller.By using these controllers the system performance and efficiency may be increased compared to our proposed fuzzy logic controller method.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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