Solar Powered Unmanned Aerial Vehicle with Fuzzy Logic Controller Based MPPT

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***Abstract*—The rapid growth in solar cell techniques makes the feasibility in unmanned aerial vehicle (UAV) scheme which reduces the exhaust emission. To conditioning the output voltage of the solar panel we need MPPT. The conventional MPPT is less efficient to use in UAV because sun irradiance is changing rapidly with the speed of UAV. So in this project it has been designed and implemented a fuzzy logic based voltage controller which can speed up system response towards the load change. The fuzzy logic controller is considered to differ the duty cycle of the DC-DC converter automatically such that to maintain the load voltage constant. The whole system is modelled and simulated in MATLAB/Simulink atmosphere. Simulation results shows that the MPPT using fuzzy logic can reduce the power loss and improve the system stability.**

Keywords: **Renewable energy, Hybrid renewable energy system, UAV, BLDC Motor.**

I. INTRODUCTION

The renewable energy system can be used to supply power with low emission and hence it reduces conventional vehicle emission by 92% [1]. The hybrid PV-battery power system therefore has higher availability to deliver continuous power and results in a better utilisation of power conversion and control equipment than with of the individual sources [2].

To obtain the maximum power, the voltage of a solar panel must be conditioned since the solar cell has a characteristic graph among voltage, power and current. Power conditioning generally uses a controlled converter using a certain algorithm called Maximum power point Tracking (MPPT). MPPT will condition the panel voltage to keep the panel working at the optimum conditions [3]. Most widely used algorithm for power optimisation is Hill Climbing algorithm and P&O. These algorithms which is easy to control but inefficient in terms of time. To overcome these deficiency Fuzzy logic controller is applied. In this paper fuzzy logic controller is considered to vary the duty-cycle of the DC-DC converter Such that to maintain the load voltage constant under varying rotor speeds of Brushless DC Motor.

II. SCHEME DESCRIPTION

A. Solar Powered UAV

Fig. 1 describes the solar powered UAV using Brushless DC Motor (BLDC). Energy received from the sun is collected by the solar panel is not enough to supply load then the battery will take over the load. Here the MPPT which helps in tracking the maximum power from the solar cell. During gliding the motor does not require more power, battery starts charging but solar power always fluctuate depend on solar irradiance and the position of the plane[4],[5]. The set of solar panels are divided into groups located in relatively equal planes of the wings, due to uneven illumination of the wing in flight and to obtain maximum efficiency factor. Power required for the cruise is depend on the speed and thrust of BLDC motor. Therefore we designed MPPT in such a way that it has to track fast and maximise it power to maintain the speed of the motor. The power circuit of the UAV has two to four MPPT converters, so we concentrate more on FLC based MPPT. This paper focus on scheming in MPPT controller is used to vary the duty cycle of the DC-DC converter.

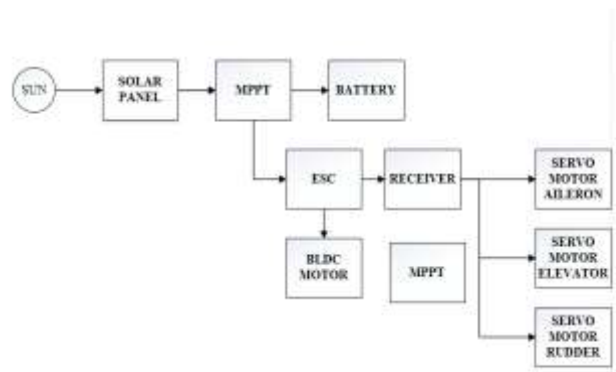


Fig. 1.schematic of UAV solar powered

B. Photovoltaic Model

A PV cell can be characterized by an equivalent circuit, as shown in Fig. 2. The features of this PV cell can be obtained using standard equation.

$$I = I_{PV} – I_O [\exp (V+R_S I/V_t a) - 1] – V+R_s I/R_p \qquad (1)$$

I_{PV} = photovoltaic current

I_O = saturation current

V_t =Ns k T/q, thermal voltage of array

Ns = cell connected in series

T = is the temperature of the p-n junction
K = Boltzmann constant
q = electron charge
R_s = equivalent series resistance of the array
R_p = equivalent parallel resistance of the array
a = diode ideality constant

For simplicity single diode model with adjusting parameters is used here. So this model is perfect for power electronics designers who are looking for an easy and effective model for simulation of photovoltaic devices with power converters. The practical photovoltaic device presents hybrid behaviour, which may be of current or voltage source depending on the operating point. The applied photovoltaic device has a series resistance R_S whose influence is stronger when the device operates in the voltage source region and a parallel resistance R_P with stronger influence in current source region of operation. The R_S resistance is the sum of several structural resistance of the device. The R_P resistance exists mainly due to the leakage current of p-n junction and depends on the fabrication method of the photovoltaic cell. The I-V characteristic of the photovoltaic device is shown in Fig.2. Depends on the internal features of the device (Rs, Rp) and on external influences such as irradiation level and temperature. The light produced current of the photovoltaic cell depends linearly on the solar irradiation [3] and is also subjective by the temperature according to the following equation.

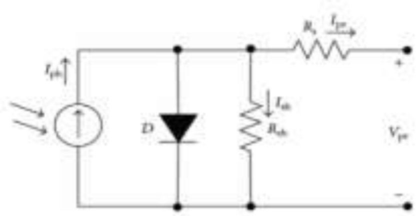


Fig: 2 Represents simplified diagram of solar cell

$$Ipv = (Ipv_{,n} + KI\Delta_T)G/Gn \quad (2)$$

$Ipv_{,n}$ = is the light generated current at nominal condition (25^0C and 1000 W/ m^2)

$\Delta_{T} = T - Tn$
T = actual temperature [K]
Tn = nominal temperature [K]
K_I = current coefficients
G = irradiation on the device surface [W/m^2]
Gn = nominal irradiation

The diode saturation current Io and its dependence on the temperature so that the net effect of the temperature is linear variation of open circuit voltage according to the applied voltage/temperature coefficient.

$$Io = \frac{Isc,n + K1\Delta T}{\exp\left(voc + \frac{Kv\,\Delta T}{avt}\right) - 1} \quad (3)$$

Kv = voltage coefficients

K_I = current coefficients

We can form an array of several identical modules connected in series. The output voltage is increased proportionately to N_{ser} and the current remain unchanged. The equivalent series and parallel resistance are directly proportional to the number of modules. We can form an array of several identical modules connected in parallel. The output current is increased and the voltage remains unchanged. The equivalent series and parallel resistance are inversely proportional to the number of parallel modules.

III. FLC MPPT CONTROLLER

The input voltage of the inverter is maintained constant via DC-DC converter which is connected in between the PV array and the voltage source inverter. The voltage through the DC-DC converter is fed to a three-phase, six-step, and quasi-square wave IGBT inverter a three phase's fixed amplitude and fixed frequency supply is obtained to feed the BLDC motor. It should be noted that the control logic of such dc-dc converter has to be different which it is fed from a stiff DC source. The duty ratio of the chopper is found to increase linearity with increase in cell temperature and hence the intensity. Here close loop fuzzy controller is automatically varied the duty cycle of DC-DC converter to obtained constant dc voltage at inverter input terminal. The output voltage of the inverter will provide the required reactive power according to the change in irradiance, temperature and speed. PI controller cannot compensate the parameter variation in the process and the adaption to move new environment is difficult. On the other hand response from the hill climbing method from MPPT tracking is having some energy loss as compare to fuzzy. Therefore the fuzzy control algorithm is accomplished of refining the tracking performance as related with the classical methods for linear and nonlinear loads. Also, fuzzy logic is appropriate for nonlinear control because does not use complex mathematical equation. The two FLC response variables are the error E and change of ErrorΔE. The behaviour of a FLC depends on the shape of membership functions of the rule base. In this paper a fuzzy logic control scheme is proposed for maximum solar power tracking of the PV array with an inverter for supplying the BLDC motor. They have advantages to be strong and comparatively simple to design since they do not require the knowledge of the exact model.

The membership function values are assigned to the linguistics variables using five fuzzy subset called negative big (NB), negative small (NS), Positive Big (PB), Positive Small (PS), Zero(ZO).The range of input variable "Error" is selected as

[-1, 1], since this input is given to the fuzzy logic controller after normalisation. The range of second variable "change in error" is chosen after analysing the behaviour of the system as [-0.002 0.002]. The range of the output variable is taken as [-15 15].Using IF-THEN rules, 25 rules are designed in the matrix table and these rules are shown in table I.

Adjustable e and Δe are selected as the input variables, where e is the error between the reference voltage (Vr) and actual voltage (VO) of the system, Δe is the change in error in the sampling interval. The output variable is the reference signal for PWM creator U. Triangular membership functions are certain for all these process. The range of every membership function is decided by the previous knowledge of the proposed scheme parameters.

Inference appliance mainly consists of fuzzy rule base and fuzzy implication sub blocks. The inputs are now fuzzified are fed to the inference appliance and the rule base is then applied. The output fuzzy set are then identified using fuzzy implication method. Here we are using MIN-MAX fuzzy implication method.

Once fuzzification is completed, output fuzzy range is located. Since at this stage a non-fuzzy value of control, a defuzzication stage is needed. Centroid defuzzification method is used for defuzzification in the proposed scheme.

The membership utility of the variables error, change in error and change in reference signal for PWM generator are shown in fig.3, 4, and 5.

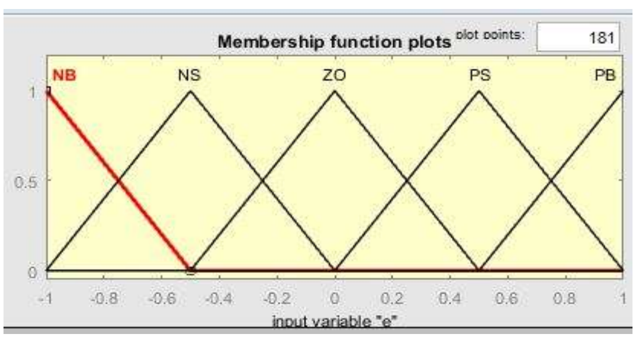


FIG: 3 Membership function plot of Error

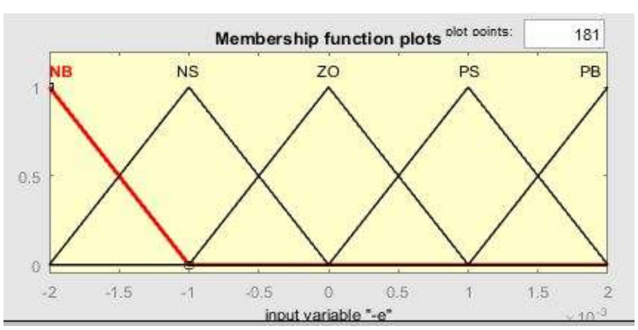


FIG: 4 Membership function plot of Change in Error

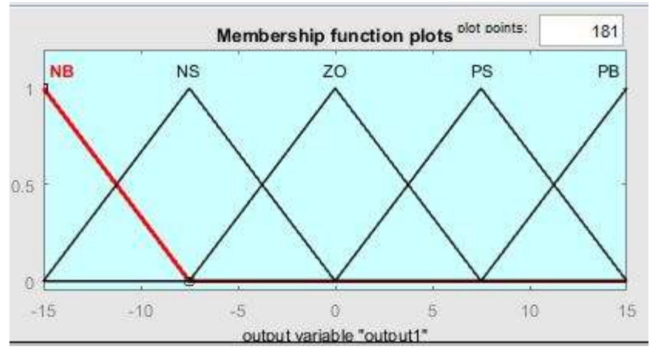


FIG: 5 Membership function plots of 'U'

TABLE I FUZZY LOGIC TABLE

e / Δe	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

Where e = Error and ¨e = change in error

IV. RESULT AND DISCUSSION

Modelling and simulation scheme with FLC is proposed in this paper and their per phase steady state characteristics under varying irradiance, temperature are discussed in this section and they are simulated in mat lab (2016a) environment. Hill climbing fuzzy based MPPT system is explained in fig: 9 and 10.

MATLAB SIMULATION

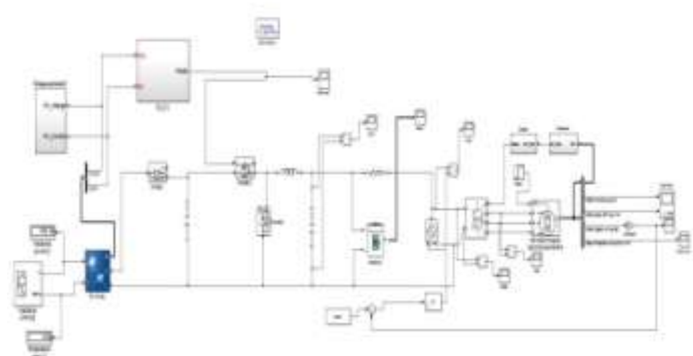


FIG: 6 solar power UAV with BLDC motor

From the simulation results, it can be deduced that the fuzzy controller is faster than Hill climbing controller and PI in the transitional state, and present also much smother signal with less fluctuation in steady state.

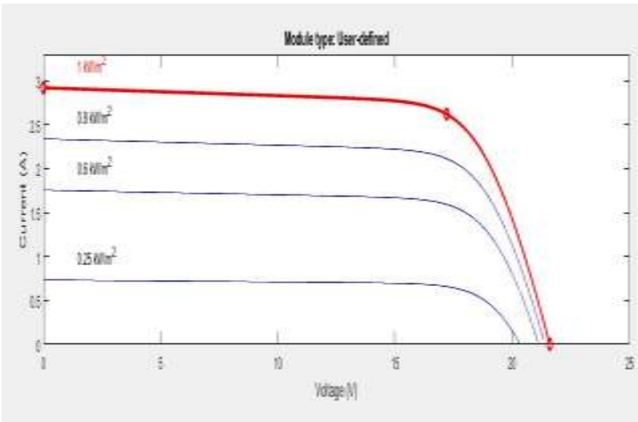


FIG: 7 I-V Characteristics for different irradiations

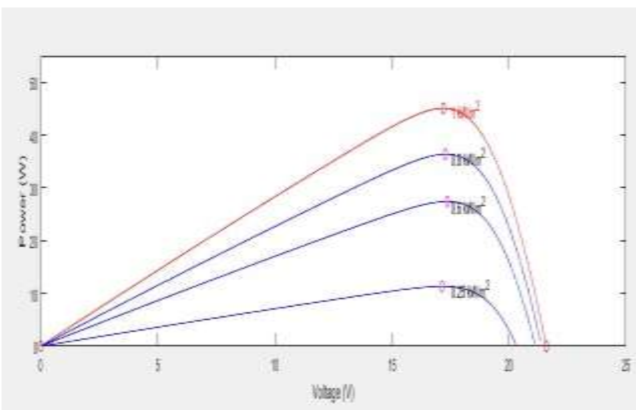


FIG: 8 P-V Characteristics for different temperature

Hill Climbing and Fuzzy based MPPT system has similar scheme. The difference is based on the algorithm to determine the duty cycle. Hill Climbing and Fuzzy based MPPT systems are explained through Figure 9 and 10 respectively. Figure: 10 show the simulation of MPPT system towards the change of irradiance.

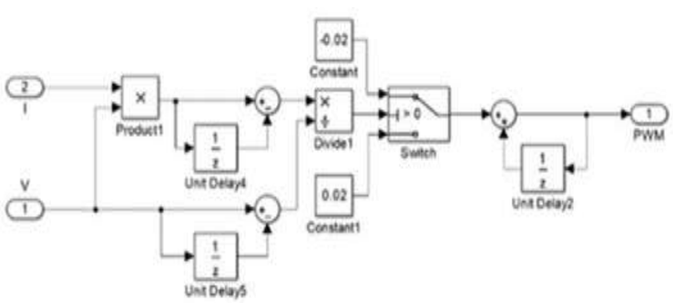


Fig: 9. Hill climbing based MPPT control algorithm

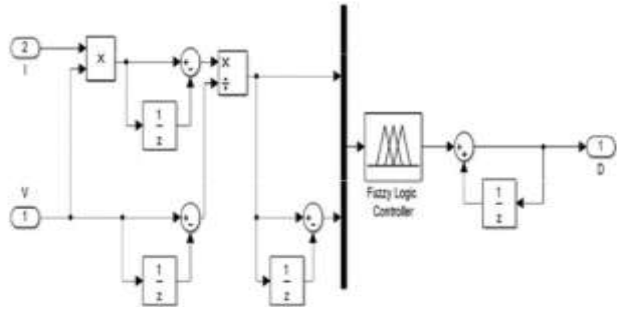


Fig: 10. Fuzzy based MPPT control algorithm

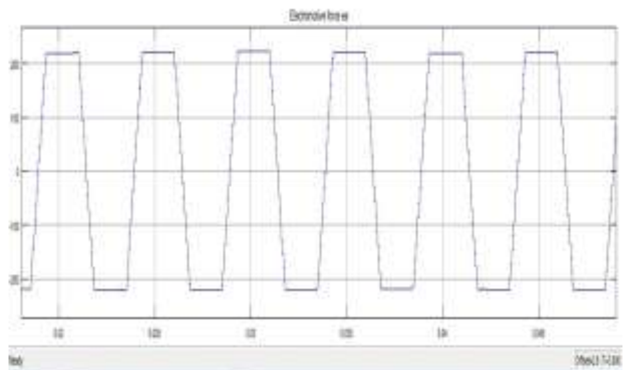


FIG: 11. BLDC Motor stator current

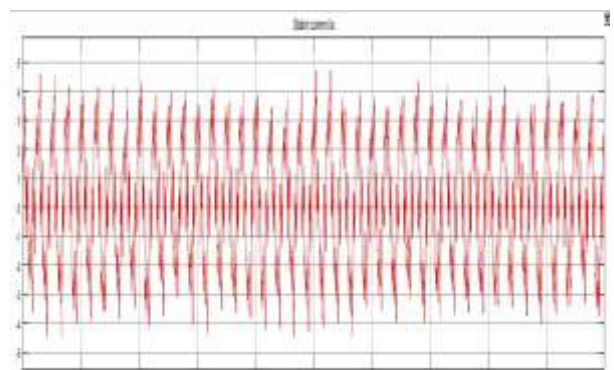
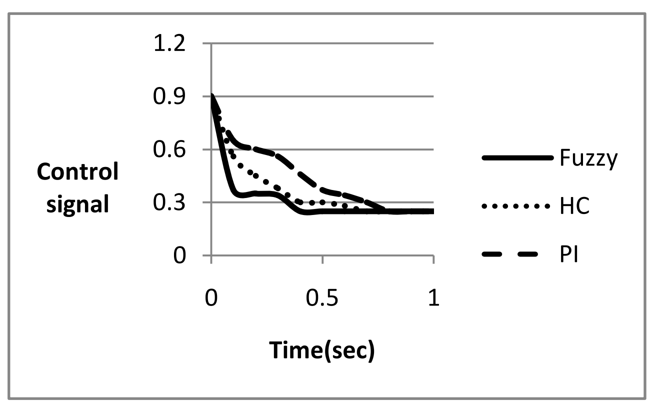


FIG: 12. BLDC Motor EMF



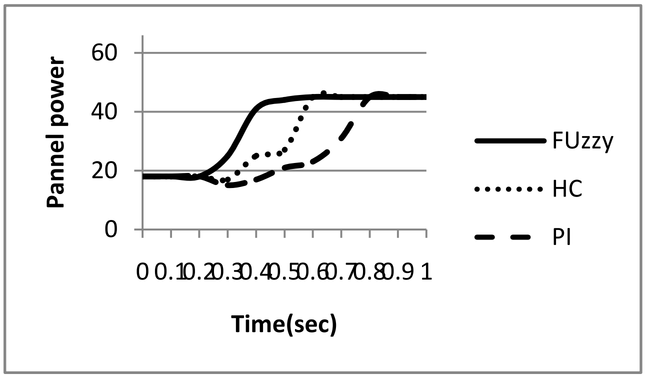
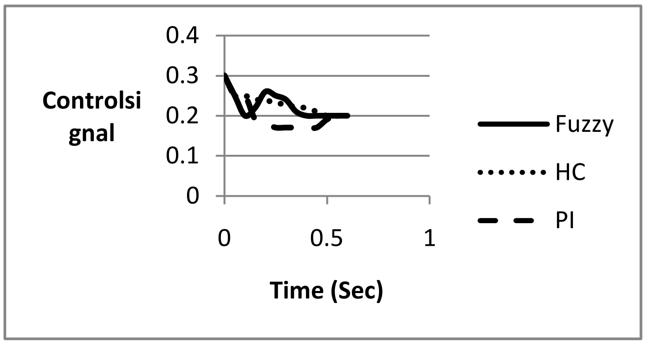


Fig: 13. Fuzzy ,PI, and P&O response : for a fast solar irradiance increase (from500 to 1000W/m^2 at 25°c)



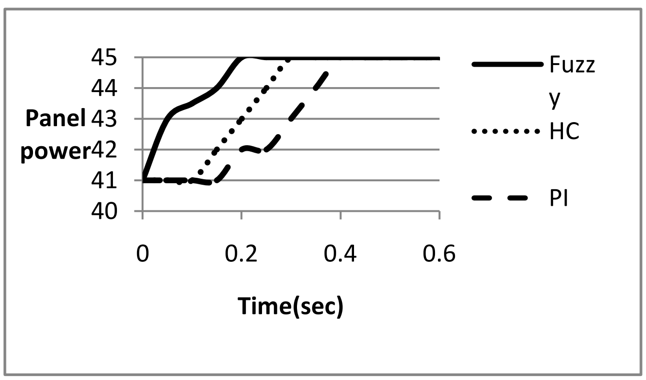
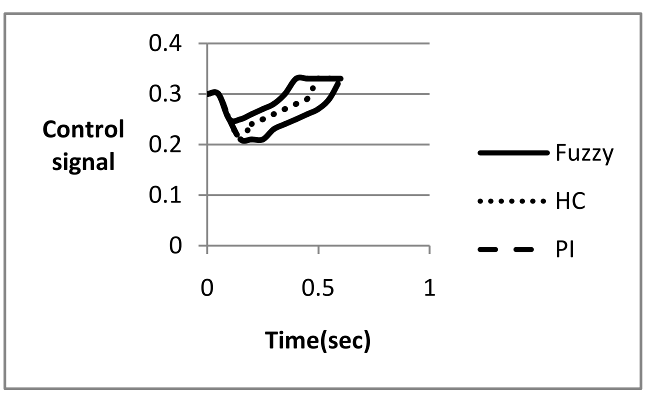


Fig: 14. Fuzzy ,PI, and P&O response : for a fast temperature decreases (from 40°c to 20°c) at 1000W/m^2 of solar irradiance.



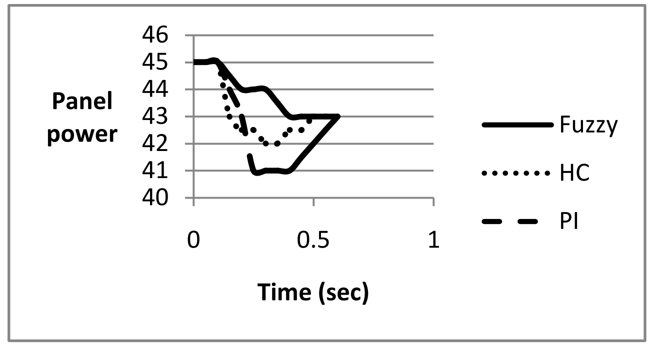


Fig: 15. Fuzzy, PI and P&O response: for a fast temperature increases (from 20°c to 40°c) at 1000W/m^2 of solar irradiance.

The simulated per phase voltage and current waveform is shown in fig11, 12.Figure shows even though extra load is applied the voltage across the BLDC motor remains constant. MPPT FLC has greater efficiency than that of Hill Climbing algorithm either on irradiance change or temperature change or load change. Results are presented with the comparison between system incorporating different configuration as Hill climbing, PI, and Fuzzy MPPT controller. To focus the suggested system good acts, the following simulations were presented for fast solar irradiance from 500 to 1000 W/m^2 at fixed temperature of 25°C and fast decrease and increase in temperature differences from 40° C to 20° C and 20° C to 40° C respectively at fixed solar irradiance of 1000W/m^2.

V. CONCLUSION

This paper proposes the FLC suitable for solar power UAV application. The variations in duty-cycle to maintain constant load voltage with variations in irradiance is achieved with the proposed fuzzy logic controller with optimized rule-base. Using the mathematical model described the photo-voltaic, dynamic and steady state characteristics are discussed. The simulated waveforms are focused on both the steady-state and dynamic behaviour with demonstrate the validity of the proposed model.

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