Design of Intelligent Control of DC-DC Buck Converter Fed DC Motor

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***Abstract*-- In this paper we introduce intelligent regulation to control buck converter using PWM switching with reduced overshoot. Power IGBT is used as a switch and fuzzy logic controller based PWM gate signal is used for the purpose of control over the switch. The output voltage of the converter is fed back for improving dynamic response. This paper also illustrates the design to achieve smooth speed control of dc motor on the load side of the buck converter by means of fuzzy logic.When compared with other techniques like neural network and slide control, fuzzy control numerically evaluates structured knowledge. A brief description of fuzzy logic and its application has been explained first and it has been used for the evaluation of accuracy, precision and robustness despite of disturbances and uncertainity.**

Keywords—Intelligent control, Fuzzy Logic, Buck converter,DC Motor.

I. INTRODUCTION

The revolution of power semiconductor devices led to the tremendous growth of power electronic converters. Out of which the DC-DC converter has taken part a significant role in a wide range of applications. These converters are employed for increasing or decreasing the magnitude of the dc voltage. The various DC-DC converters are buck, boost and buck-boost converters [1]. The buck converter is employed for decreasing the dc voltage level to the desired value. Because of their light weight, high efficiency, compact size and reliability, they are used in a variety of applications such as computer power supplies, battery chargers, variable speed dc motor drives and a numerous other applications.

In the past few decades the DC-DC converters are controlled by analog integrated circuits and linear system design. Conventional control techniques employs PD, PI and PID controllers which provides linear characteristics but DC-DC converters exhibits nonlinear characteristics. Thus, the buck converters are desired to maintain constant output voltage which is unvarying in both steady and transient operations owing to the load disturbances [2]-[4]. This condition is said to be zero voltage regulation, where the output is said to be independent of the supply voltage and load current.The most preferred method to adopt this condition is direct duty ratio control and current mode control. Owing to the complexity of these methods, the recent approach was made towards fuzzy logic based control of DC-DC converters.

Fuzzy logic control can be adopted for nonlinear, uncertain systems without the aid of mathematical model.It has emerged as one of intelligent control technique as it invokes human way of thinking.Classical logic only permits propositions having a value of truth or falsity whereas fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false statement leading to the advent of human way of thinking [5].

Fuzzy logic can be employed for the speed control of dc motors. The speed control of dc motor is essential to provide high performance characteristics. Since the dc motor can develop high torque at low speed, it has been mainly used in electric traction applications such as electric locomotives and trams. Thus, there is a wide scope for high performance dc motor drives in areas such as rolling mills, robotic manipulators and household appliances [6]-[8]. They require speed controllers to achieve high performance and the desired task. Hence, in this paper, fuzzy logic controller along with DC-DC buck converter has been implemented to provide smooth speed control with reduced over overshoot and no oscillations.

II. DC-DC CONVERTER CIRCUIT MODEL

The buck converter circuit model is depicted in Fig.1. follows,

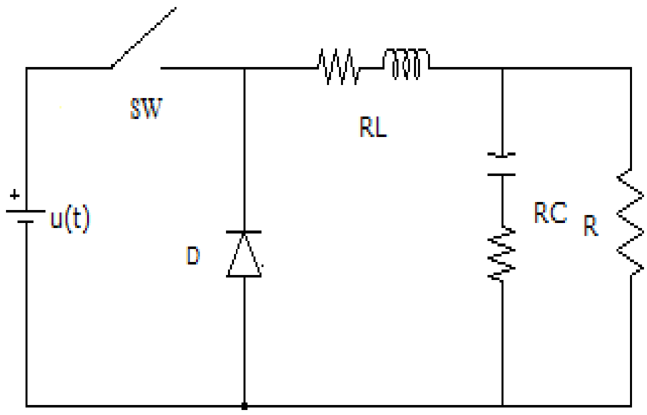

Fig. 1. Basic Buck Converter

The basic operation of the buck converter has the current in an inductor controlled by two switches (usually a transistor and a diode). In the idealised converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off and the inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle.

The conceptual model of the buck converter is best understood in terms of the relation between current and voltage of the inductor. Beginning with the switch open (in the "off" position), the current in the circuit is 0. When the switch is first closed, the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current[4]. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load.

Over time, the rate of change of current decreases, and the voltage across the inductor also then decreases, increasing the voltage at the load. During this time, the inductor is storing energy in the form of a magnetic field. If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor, so the net voltage at the load will always be less than the input voltage source[9]. Thus, it is very useful in circuits devoid of electrical isolation and also they are equipped with low conduction loss.

In continuous mode, The rate of change of I_L can be calculated from:

$$V_L = L\frac{dI_L}{dt} \tag{1}$$

With V_L equal to $V_i - V_o$ during the On-state and to $-V_o$ during the Off-state. Therefore, the increase in current during the On-state is given by:

$$\Delta I_{L_{on}} = \int_0^{t_{on}} \frac{V_L}{L}\,dt = \frac{(V_i - V_o)}{L} t_{on},\; t_{on} = DT \tag{2}$$

Conversely, the decrease in current during the Off-state is given by:

$$\Delta I_{L_{off}} = \int_{t_{on}}^{T=t_{on}+t_{off}} \frac{V_L}{L}\,dt = -\frac{V_o}{L} t_{off},\; t_{off} = (1-D)T \tag{3}$$

In discontinuous mode,the average value of I_L can be sorted out geometrically as follow:

$$\begin{aligned} \bar{I}_L &= \left(\frac{1}{2} I_{L_{max}} DT + \frac{1}{2} I_{L_{max}} \delta T\right)\frac{1}{T} \\ &= \frac{I_{L_{max}}(D+\delta)}{2} \\ &= I_o \end{aligned} \tag{4}$$

The inductor current is zero at the beginning and rises during t_{on} up to I_{Lmax}. That means that I_{Lmax} is equal to:

$$I_{L_{Max}} = \frac{V_i - V_o}{L} DT \tag{5}$$

Substituting the value of I_{Lmax} in the previous equation leads to:

$$I_o = \frac{(V_i - V_o)DT(D+\delta)}{2L} \tag{6}$$

And substituting δ by the expression given above yields:

$$I_o = \frac{(V_i - V_o)DT\left(D + \frac{V_i - V_o}{V_o} D\right)}{2L} \tag{7}$$

III. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy logic control deviates from other methods by means of accommodating expert knowledge in controller design. It is one of the most successful application of fuzzy set theory. The main advantage of this method is the use of linguistic variables rather than numerical values. Linguistic variables are those whose values are sentences in a natural language which may be represented by fuzzy sets.

A fuzzy logic control is built up by a group of rules based on the human knowledge of system behaviour. MATLAB/Simulink model is built to study the dynamic behaviour of DC-DC converter[10]. Further, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at the same time, which is not possible with linear control technique. Thus, fuzzy logic controller has potential ability to improve robustness of DC-DC converter.

There are two inputs for the fuzzy controller designed for buck converter. The first input is said to be the error in input voltage with respect to the reference value of the desired output voltage and the second input is said to be the difference between successive errors. The two inputs are then fed into fuzzy controller. The output of the FLC is the change in duty cycle.

The basic configuration of a fuzzy logic controller is represented as follows:

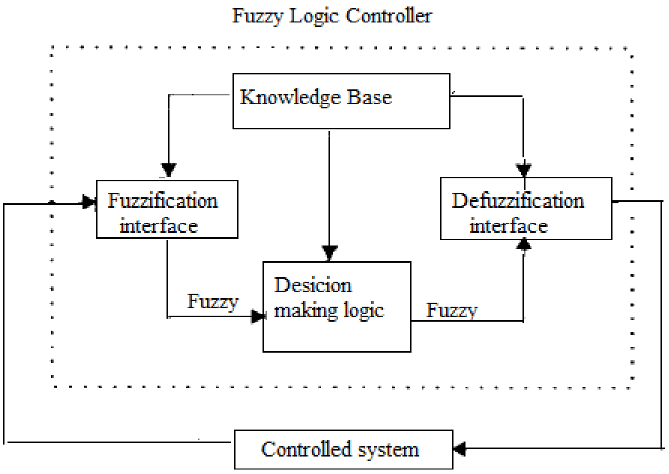

Fig. 2. Basic configuration of FLC

The FLC is basically comprised of four basic components as follows:

A. *Fuzzification*

The first step in the design of a fuzzy logic controller is to design membership functions for the inputs. These functions are assigned to the linguistic variables using five fuzzy subset as follows:

NB negative big;

NS negative small;

ZE zero equal;

PS positive small;

PB positive big.

Variable e and ce are selected as the input variables, where e is the error between reference voltage (Vr) and actual voltage (Vo) of the system, ce is the change in error in the sampling interval.Fuzzy sets must be designed for each input and output variables.The output variable is the reference signal for PWM generator G. Triangular membership functions are selected for all these process owing to its simplicity [3]-[4].

The number of fuzzy levels is not fixed and depends on the input resolution. In this case, five fuzzy levels are chosen. The value of each input and output variable is normalised in [-100,100] by using suitable scale factors. They are defined by the following library of fuzzy set values for the error (e) and change in error (ce) and output:

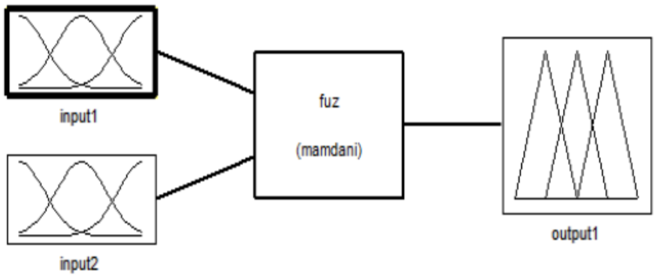

Fig. 3. Membership function for e and ce

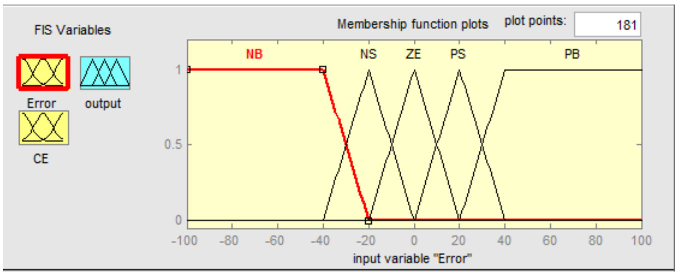

Fig. 4. Membership function plots - error

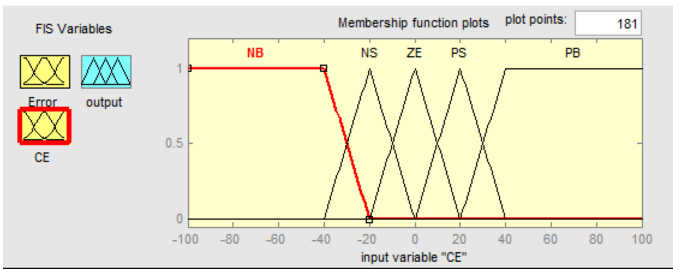

Fig. 5. Membership function plots – change in error

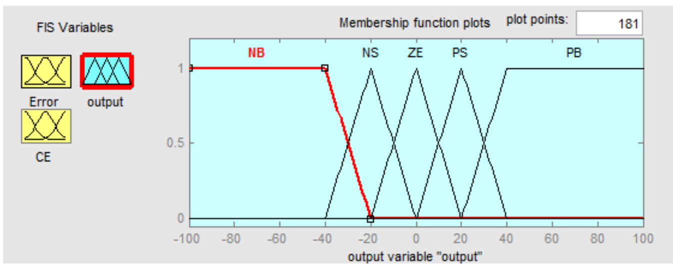

Fig. 6. Membership function plots - output

B. *Rule base or knowledge base*

The collection of rules is called a rule base. It consist of two components namely called fuzzy sets (data base) and fuzzy control rule base. IF a set of conditions are satisfied, THEN a set of consequences are inferred. The control rules which associate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behaviour [9].A rule based controller is easy to understand and can be implemented efficiently [2]. The following table illustrates the rules for error and change of error.

Table 1: Rules for error and change of error

(e) / (de)	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

The derivation of the fuzzy control rules is based on the following criteria:

1) When the output of the converter is far from the set point, the duty cycle must be varied in a large range, so as to bring the output to the set point quickly.

2) When the output of the converter is approaching towards the set point, a small change of duty cycle isinvoked.

3) When the output of the converter is nearer to the set point and if it approaches rapidly, the duty cycle must be kept constant in order to prevent overshoot.

4) When the set point is reached and if the output is still varying, the duty cycle must be varied slightly to keep the output constant.

5) When the set point is reached and the output is steady, the duty cycle remains unchanged.

6) When the output is said to be above the set point, the sign of the change of duty cycle must be negative,and vice versa.

C. *Inference engine*

The fuzzy engine is the kernel of a fuzzy logic controller, which has the capability of simulating human decision making based on fuzzy concepts and inferring fuzzy control actions using fuzzy implication (fuzzy relation) and the rules of inference in fuzzy logic.It mainly consist of fuzzy rule base and fuzzy implication sub blocks.

In this case, MIN-MAX implication method is used to perform control decision. It is based on the minimum function to describe the AND operator present in each control rule and the maximum function to describe the OR operator. It tends to simulate human way of thinking or decision making[6]-[7]. This means that the fuzzy inference engine handles rule inference where human experience can easily be injected through linguistic rules.

D. *Defuzzification*

The process of converting fuzzy variables to crispy or non-fuzzy output is defined as defuzzification. Thus, in this process all the actions performed where combined and converted into a single fuzzy output signal which is said to be the control signal of the system. The output depends on the rules and position associated with the non-linearity existing in the system[11]-[12]. A control curve is developed based on the input-output relationship prevailing in the system with the aim to minimize the effect of non-linearity.

IV. SIMULATION RESULTS

The waveform obtained from the MATLAB Simulink model has been studied below:

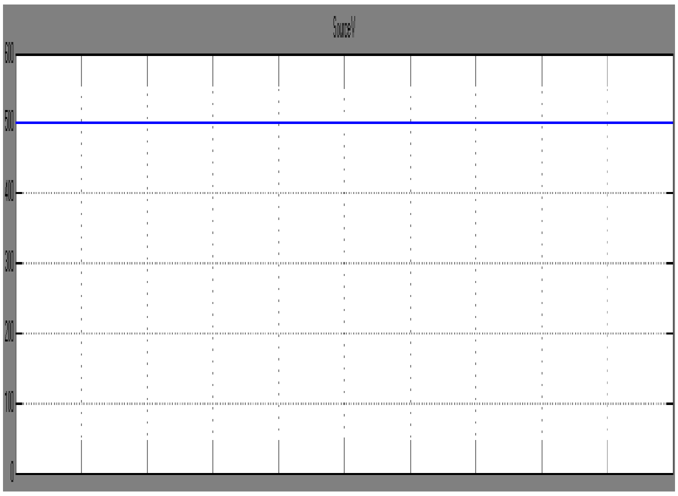

Fig. 7 . Source voltage waveform

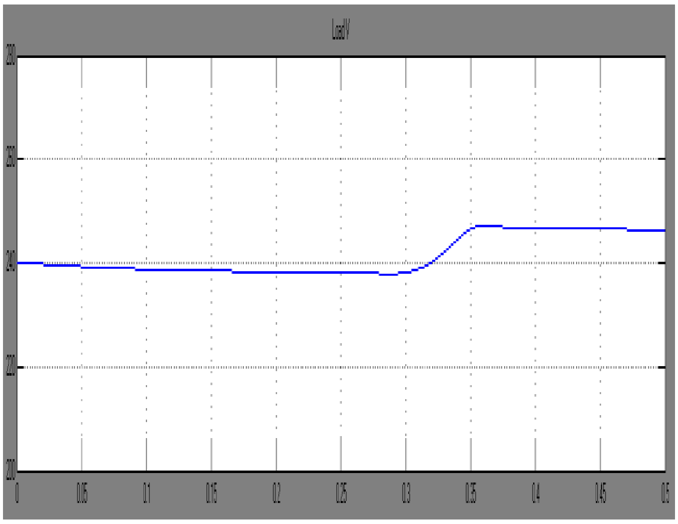

Fig. 8. Output voltage waveform with PI controller

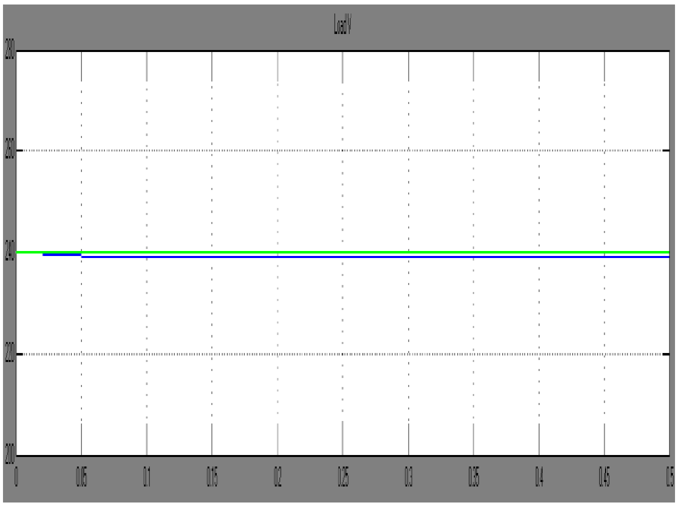

Fig. 9. Output voltage waveform with fuzzy controller

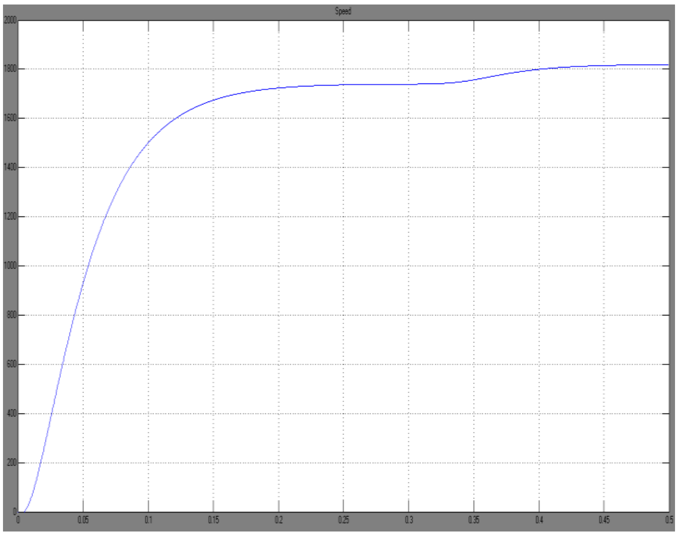

Fig. 10. Motor Speed response curve with PI controller

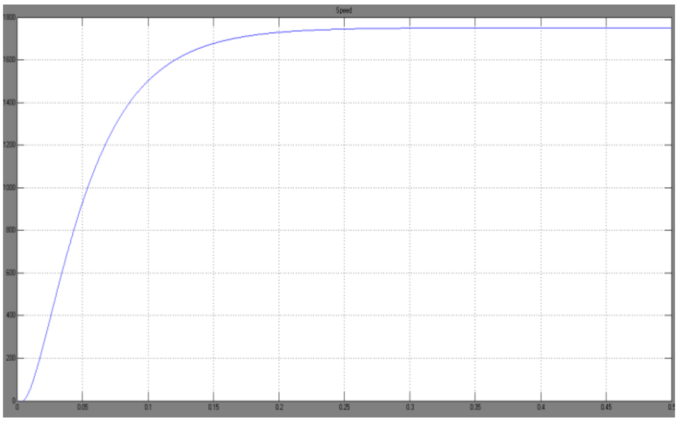

Fig. 11. MotorSpeed response curve with fuzzy controller

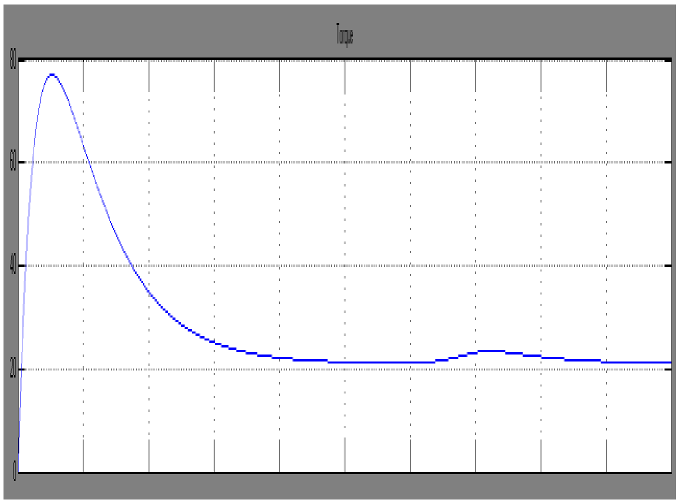

Fig. 12. Torque response waveform with PI controller

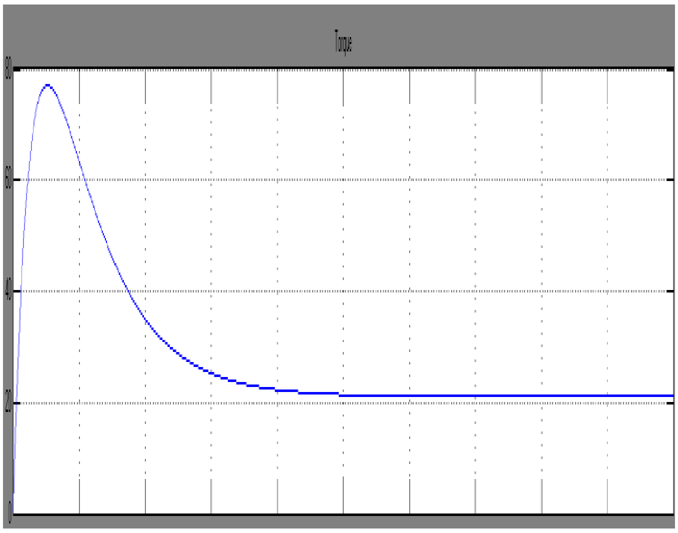

Fig. 13. Torque responsewaveform with fuzzy controller

V. CONCLUSION

Design of the intelligent controller on speed control of DC motor using DC-DCbuck converter was implemented with MATLAB/Simulinkand the results has been achieved successfully. The closed loop circuit with fuzzy logic controller with reduced overshoot shows the better performance compared to the conventional PI controller.An output voltage of 239.2 V was obtained with an input of 500V DC supply. The waveforms were obtained, studied and were found to be same as the desired waveforms. Also the speed of the separately excited DC motor at the load side of the buck converter operating at 240V is regulated at a constant rated speed of about 1751 rpmby the implementation of fuzzy logic controller.There is a wide range scope of applications of high performance DC motor drives in area such as rolling mills, electric trains, robotic manipulators andthe home electric appliances.They require speed controllersto perform tasks. Hence, a fuzzy based DC motor speed control system was designed.The simulation model is implemented in MATLAB/Simulink environment. From theoutput speed wave form, we can see that the proposedfuzzy logic controller is able to provide smooth speed control with less overshoot.Hence, the circuit confirmed the requirement of the proposed approach.

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APPENDIX

A MATLAB based modelling and simulation of the proposed method based on fuzzy logic controller was carried out successfully and the desired results were obtained. Thus, the figure (Fig. 14.) depicts the Simulink model of the proposed method as follows:

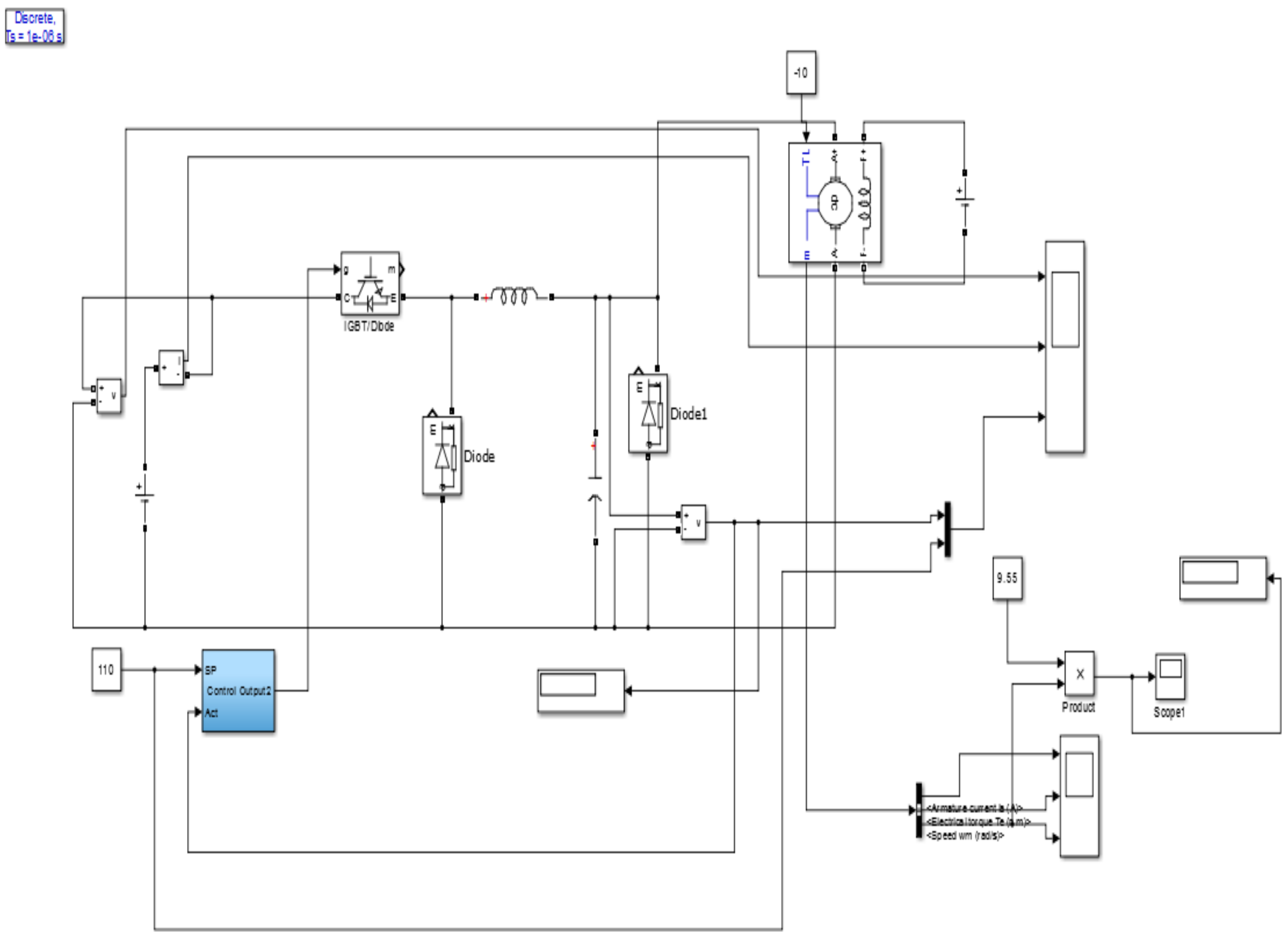

Fig. 14. MATLAB/Simulink model of the proposed method