Combined Armature and Field Speed Control of DC Motor For Efficiency Enhancement

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ABSTRACT—This paper presents the comparison of armature voltage control and combined armature voltage and field control of a separately excited dc motor using PI controller. This research paper is a comparison analysis so on comparing the two systems it is found that the efficiency of DC motor is enhanced by controlling both armature voltage and field voltage simultaneously which are decided by PI controller.In this paper power electronics converter (BUCK CHOPPER) are utilized to control armature voltage and field voltage simultaniously.GTO is used as a power electronics switch in this paper.The MATLAB simulation of armature voltage control and combined armature and field voltage control are compared and the simulation results of speed and enhancement of efficiency are also analyzed in this paper.

Keywords—separately excited dc motor, speed control of DC motors, PI controller, hysteresis current controller, Efficiency enhancement.

I.INTRODUCTION

DC motors are used in many applications like electric railway traction and many more industrial fields such as rolling mills, paper industries etc, because they can provide a high starting torque. The big and practical advantage of DC motor over AC motors that the range of speed control. In DC motor we can control the speed below and above the rated speed by using different methods and techniques.The speed control above the rated speed can be achieved by using field current control method and below the rated speed by varying the armature voltage known as armature voltage control method. The speed of DC motor is directly proportional to the armature voltage(V_a) and inversely proportional to the field current(I_f). In armature voltage control, the rage of speed control is from zero to rated speed.While in the field control, the speed control range from constant reference speed up to 120%-130% rated can be achieved but with loss of the motor developed torque.

DC motors are used in many applications like electric trains, vehicles, cranes and robotics manipulators. They require controlling of speed to perform their tasks. Initially speed control of DC motor has been done by voltage control[1].Semiconductors too like MOSFET, IGBT and GTO have been used as switching devices to control speed[2].

In this paper the combined armature and field speed control of separately excited DC motor using PI controller is discussed and the comparison between armature control of DC motor is performed and it is found that the efficiency of combined armature and field method is found better in comparison to the armature control of the dc motor.

DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. Many varieties of control schemes such as proportional (P), proportional integral (PI), proportional derivative integral (PID), adaptive and fuzzy logic controller (FLCs) have been developed for speed control of DC motors [3].

Speed control means intentional change of the drive speed to a value required forperforming the specific work process. Speed control is a different concept from speedregulation where there is natural change in speed due change in load on the shaft.Speed control is either done manually by the operator or by means of some automaticcontrol device. One of the important features of DC motor is that its speed can be controlled with relative ease.

II MATHEMATICAL MODEL OF THE SEPARATELY EXCITED DC MOTOR

In this section the main equations of a separately excited DC motor will be explained in detail, It is important to know the main relationship between armature voltage(E_b), field voltage(E_f), speed of motor, and developed torque. Figure (1) shows the equivalent circuit diagram of a separately excited DC motor.

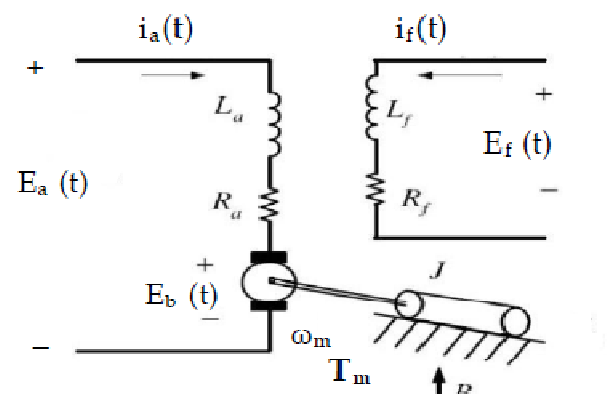

Fig. 1. Equivalent circuit diagram of a separately excited dc motor

$$Ea(t) = \left(\mathrm{Ra} * ia(t)\right) + \left(La * \frac{dia}{dt}\right) + Eb(t) \text{--------------(1)}$$

$$Ef(t) = \left(Rf * if(t)\right) + \left(Lf * \frac{dif}{dt}\right) \text{--------------(2)}$$

$$Eb(t) = Ke * Wm \quad \text{-------------(3)}$$

$$Ke = Laf * if(t) \quad \text{-------------(4)}$$

$$Te(t) = Ke * ia(t) \quad \text{-------------(5)}$$

$$\text{Efficiency} = \frac{Pout}{Pinput} * 100\ \% \quad \text{--------(6)}$$

$$Pinput = Pa + Pf \quad \text{---------(7)}$$

$$Pa = Ea * Ia \quad \text{---------(8)}$$

$$Pf = Ef * If \quad \text{---------(9)}$$

$$Pout = Tsh * Wm \quad \text{-------(10)}$$

$$\text{Efficiency} = \frac{Pout}{Pa + Pf}$$

$$\text{Efficiency} = \frac{Tsh * Wm}{(Ea * Ia) + (Ef * If)} * 100\% \quad \text{-------(11)}$$

Where; Ea= The input terminal voltage (source), (V);
E_b=The back emf, (V);
R_a : The armature circuit resistance, (ohm);
ia : The armature current, (Amp);
L_a : The armature inductance, (H);
L_{af} : The field- armature mutual inductance (H);
J : Moment of inertia of motor shaft. (Kg-m2);
T_e : Torque produced by the motor, (N-m);
T_{sh} : Shift torque , (N-m);
W_m: Rotor speed, (rad/s) ;
B : Viscous friction coefficient, (N-m/rad/sec);
T_l : The load torque, (N.m);
Ke : The motor constant, (V/A- rad/s).

The developed torque(Te) is directly proportional to armature current(Ia) ,motor flux(□) ,as indicated in equation no. (5).

We know that in separately excited DC motor the field current is directly develops the field flux. So we write eq 12 are as:

I_f α □ ----------(12)

On combining equation 5 and equation 12 we get a new equation shown in fig 13.

$T_e = K_t I_a$□ ----------(13)

Where □ is field flux (Wb) .There is a linear region in the magnetizing curve between flux (□) and field current (If) ,in other words ,proportional relationship .

$$T_e = K_t I_a\, I_f \quad \text{----------(14)}$$

In the armature voltage control of separately excited DC motor which utilizes constant field current, the control system contains armature current as a feedback to indicate the load torque. Whereas, in this paper for combined armature and field control the feedback of the controller is the product of armature current and the field current to represent the load torque as indicated by equation (14).

III .SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR

The expression of speed control of DC motor is given by equation 15.

$$\omega = \frac{(Vt - Ia * Ra)}{K\phi} \quad \text{-----------(15)}$$

Therefore speed (ω) of any type of DC motor – series, shunt, compound andseparately excited can be controlled by changing the quantities on right hand side ofthe expression. So the speed can be varied by changing:

(i) Terminal voltage of the armature Va
(ii) External resistance in armature circuit Ra
(iii) Flux per pole □.

The first two cases involve changes that affect the armature circuit and the thirdinvolves change in magnetic field. Therefore speed control of DC motor is classified asarmature control methods and field control methods.

a).Armature Voltage control

With armature voltage control, the field current(I_f) is kept approximately constant and the armature current is varied by the control signal provided by PI speed and hysterias current controller. In armature voltage control the field current is constant it means flux density(B) is also constant and due to this the field flux in field circuit is maintained constant by making field current constant. So the equation of Torque is directly depends on armature current and armature current can be easily varied by varying armature voltage.

b).Combined armature and field control

The speed of a separately excited DC motor can be varied from zero to rated speed mainly by armature voltage control inthe constant torque and linearly varying power region. The speed of DC motor above rated speed can be achieved in constant power and hyperbolic torque region by reducing field flux.Combined armature and field speed control with torque and power are shown in fig 2.

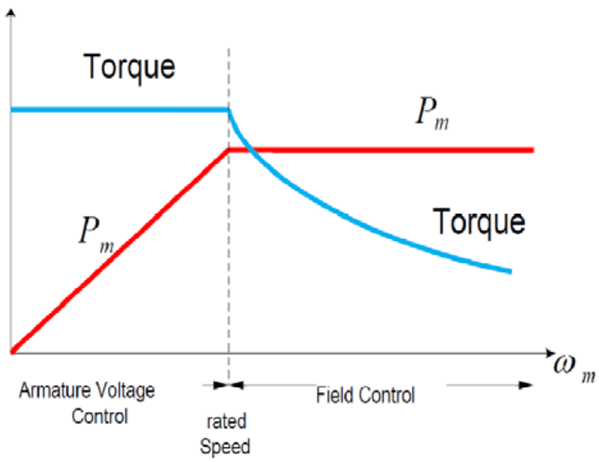

Fig 2. Combined armature and field control of DC motor

IV .CONTROLLER DESIGN

The motor speed depends on the amplitude of the applied voltage. The amplitude of the applied voltage isadjusted using the PWM technique. The required speed is controlled by a speed controller, which isimplemented as a conventional proportional-integral (PI) controller. The difference between the actual andrequired speeds is input to the PI controller which then, based on this difference, controllers the requiredDC-bus current. The required DC-bus current is controlled by a current controller, which is also implemented as a conventional proportional-integral (PI) controller. The difference between the actual andrequired DC-bus current is input to the PI controller which then, based on this difference, controls the dutycycle of the PWM pulses, which correspond to the voltage amplitude required to maintain the desiredspeed.

The current controller, which is the inner-loop controller, is updated more frequently, for example everyPWM period, compared to the speed controller, which is the outer-loop controller.

In this research two controllers are used are as:

(a). PI speed Controller

(b). Current Controller

The speed controller, as well as the current controller, calculates the PI algorithm given in the equationbelow:

$$u(t) = Kc[e(t) + \frac{1}{T}\int_0^t e(t)dt]$$

After transforming the equation into a discrete time domain using an integral approximation with the Backward Euler method, we get the following equations for the numerical PI controller calculation:

$$u(k) = up(k) + uI(k)$$
$$up(k) = Kc * e(k)$$
$$uI(k) = uI(k-1) + Kc * \left(\frac{T}{TI}\right) * e(k)$$

Where:

e(k) = Input error in step k
w(k) = Desired value in step k
m(k) = Measured value in step k
u(k) = Controller output in step k
up(k) = Proportional output portion in step k
uI(k) = Integral output portion in step k
uI(k-1) = Integral output portion in step k-1
TI = Integral time constant
T = Sampling time
Kc = Controller gain

The PI controller is standard and proved solution for the most industrial application. The main reason is its relatively simple structure, which can be easily understood and implemented in practice, and that many sophisticated control strategies, such as model predictive control, are based on it. An application with large speed capabilities requires different PI gains than an application which operates at a fixed speed. In addition, industrial equipment that are operating over wide range of speeds, requires different gains at the lower and higher end of the speed range in order to avoid overshoots and oscillations. Generally, tuning the proportional and integral constants for a large speed control process is costly and time consuming. The task is further complicated when incorrect PI constants are sometimes entered due the lack of understanding of the process.

The speed and current controllers are combining control system are shown in fig 3.

The hysteresis loop value for the current controller is selected to be 3.

The value of proportionalconstant(Kp) and Integral constant(Ki) are taken by trial and error method and that are comes to be 1.6 and 16 respectively.

The maximum current control limit for this research is taken to be 80 Amp.

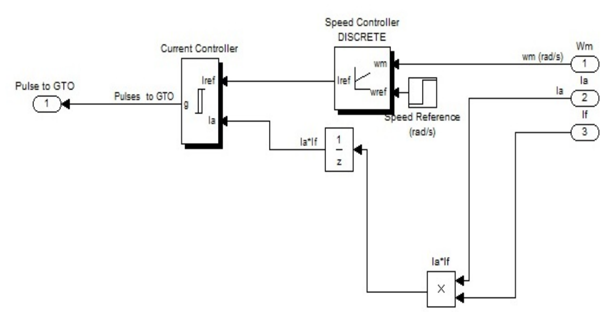

Fig 3.Speed and current control system of combined armature and field control.

V. OVERALL SYSTEM DESIGN USING MATLAB

The system deignedin MATLABsimulinkenvironment is used to investigate the performance of the separately excited DC motor using PI controller and enhance the efficiency of DC motor. The efficiency calculation blocks areshown in Figure (4) based on equation (11).

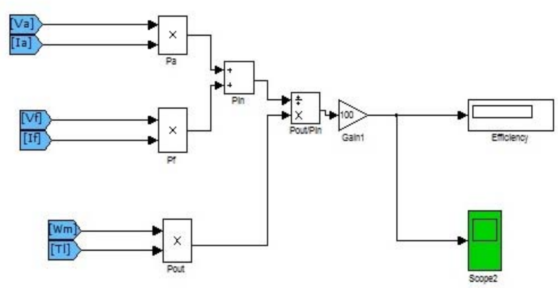

Fig 4. DC motor efficiency calculation block

The MATLAB Simulink model of armaturevoltage control of separately excited DC motor is shown in fig 5.

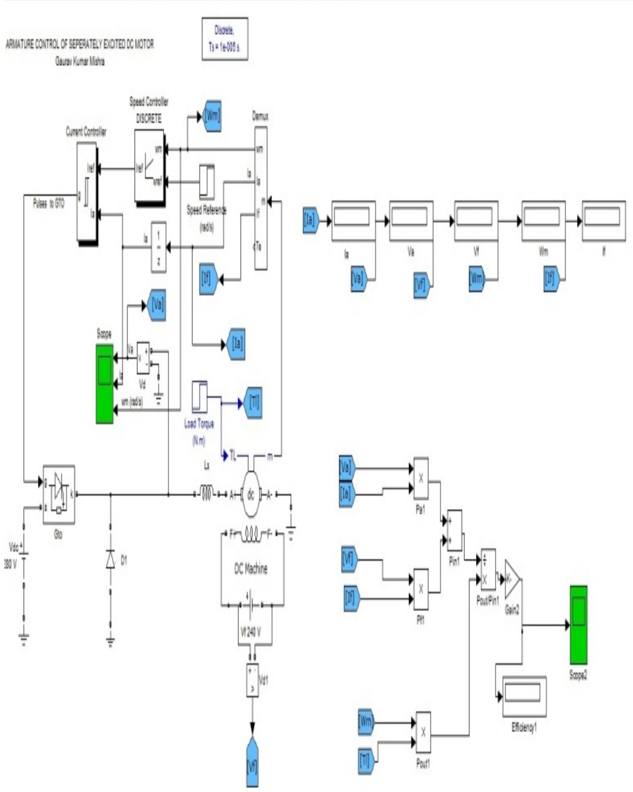

Fig 5. SIMULINK diagram of armature control of DC Motor

The Simulink diagram of combined armature and field control of separately excited DC motor containing speed and current controller efficiency calculation block is shown in fig 6.

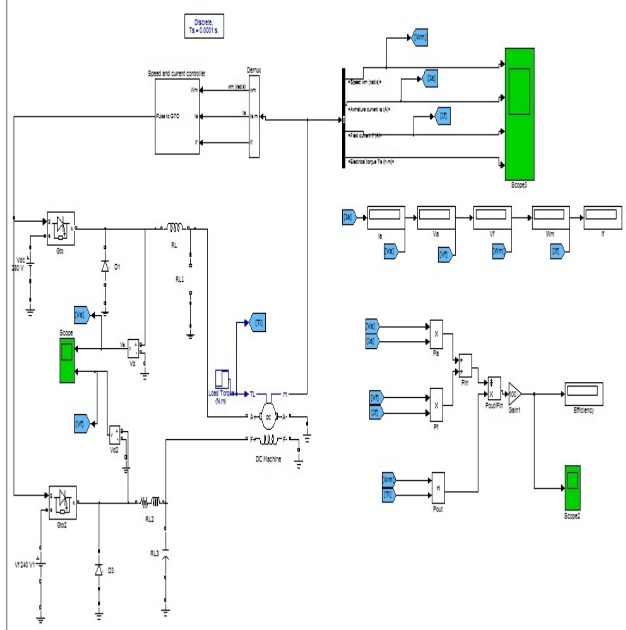

Fig 6. SIMULINK diagram of combined armature and field control of separately excited DC motor

VI .SIMULATION RESULTS

A comparative simulation results are presented for the two cases:

a). Armature voltage control

b). Combined armature and field control

The waveform of armature current armature voltage and speed of a separately excited DC motor is shown in fig 7.

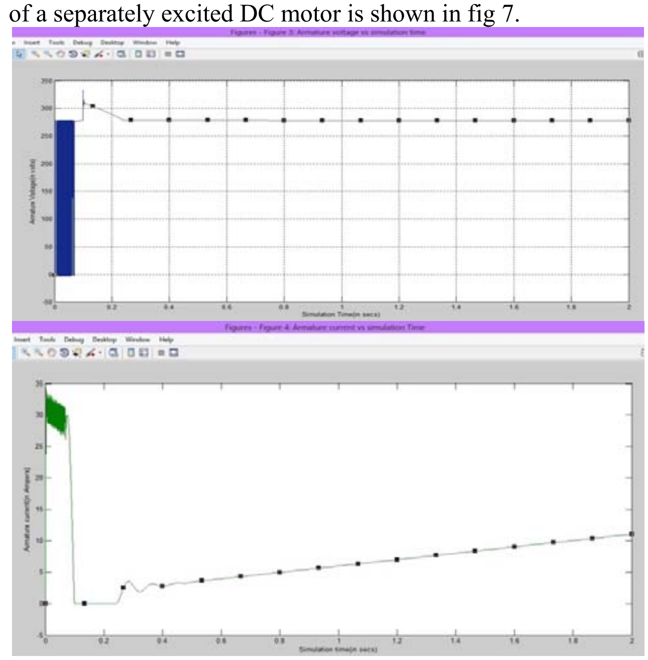

Fig 7. Armature voltage and armature current in armature voltage control of DC motor waveform

The waveforms of armature current and field current in combined armature and field control of separately excited DC motor is shown in fig 8.

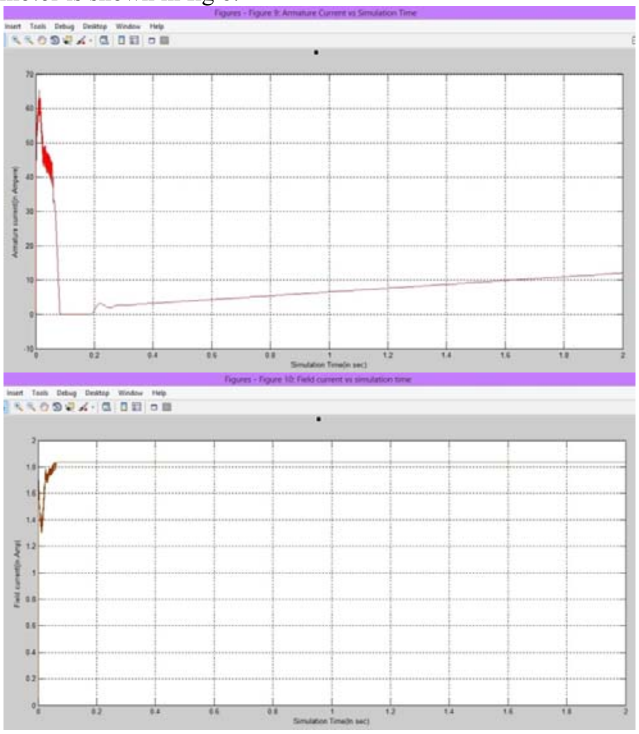

Fig 8. Armature and field current in combined control mode of DC motor

The waveform of armature voltage and field voltage of combined control mode of dc motor are shown in fig 9.

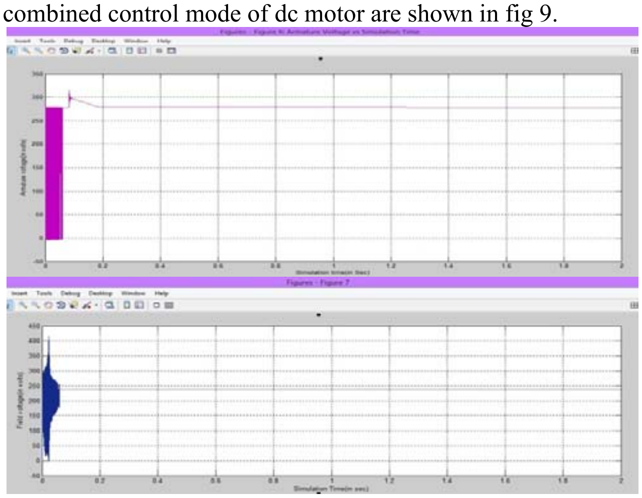

Fig 9. Armature voltage and field voltage of combined armature and field control of DC motor

The waveform of efficiency variation with torque and speed torque characteristics are shown in fig 10 and 11 respectively in the armature and field control method of separately excited DC motor. The waveform of efficiency vs load torque in armature voltage control of DC motor is shown in fig 12.

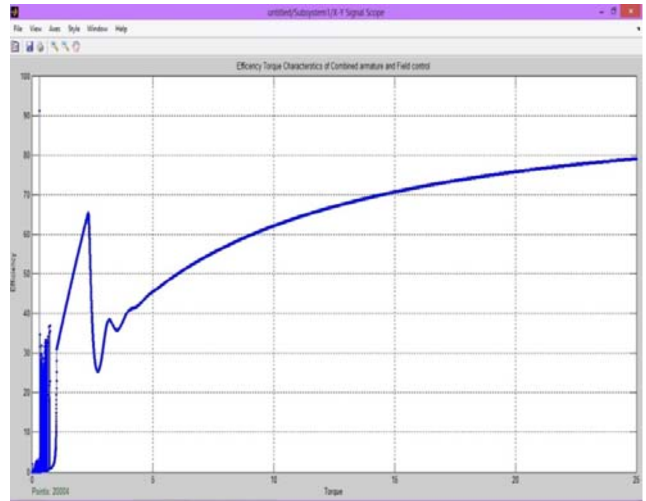

Fig 10.Efficiency vs Load Torque in armature field speed control of DC motor

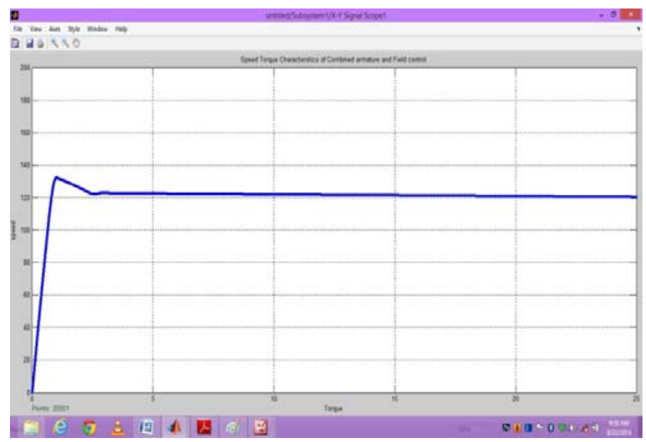

Fig 11. Speed Torque characteristics of combined armature and field control

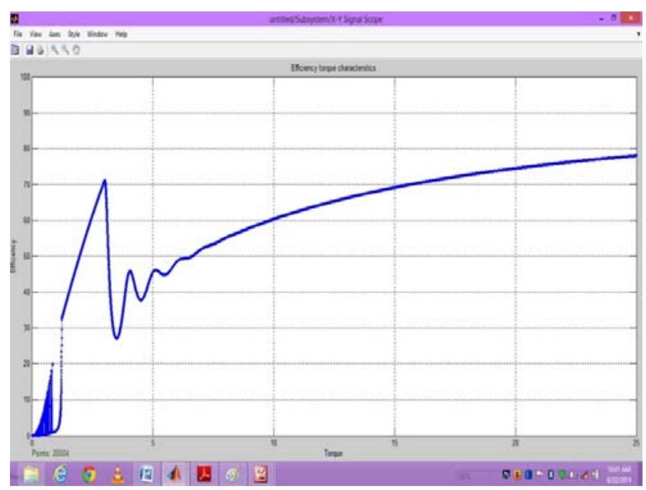

Fig 12. Efficiency vs Load Torque in armature voltage speed control of DC motor

VI .CONCLUSIONS

The efficiency of the combined armature voltage and field current control of Separately excited DC motor is 1.02 % greater than the efficiency of armature control of separately excited DC motor at full load torque condition. At half load condition the efficiency of combined armature and field control of DC motor is increased by 1.886 % than the armature voltage control of DC motor.

The speed of separately excited DC motor is controlled and is not affected with the change in load torque condition.

The comparison of efficiency with the linearly varying torque is shown in fig 13.The comparison of speed is shown in fig14. Black color line shows the speed and efficiency variation with simulation time in armature voltage control and Pink color line shows the speed and efficiency variation with simulation time incombined armature voltage and field current control of separately excited DC motor.

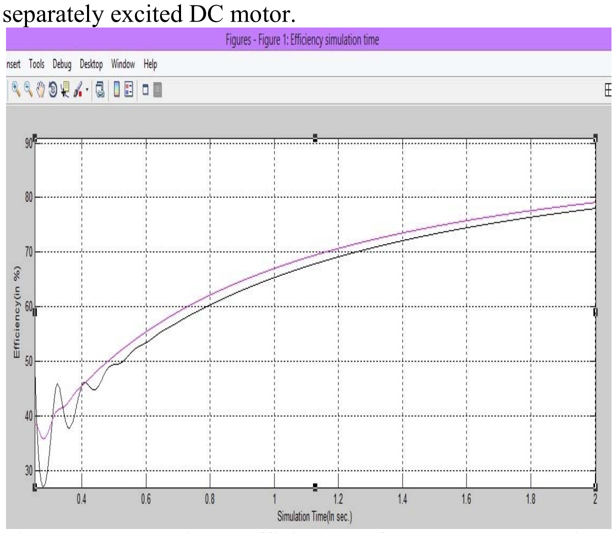

Fig 13. Comparison efficiency of armature control and armature field control of DC motor

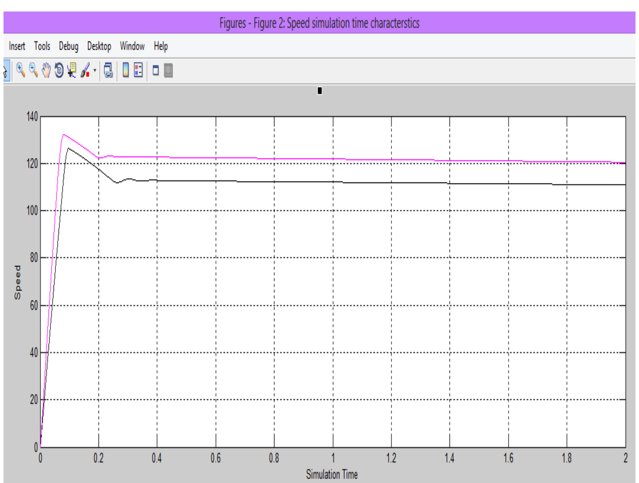

Fig 14. Speed comparison in the two discussed mode of speed control of DC motor

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