Diyala Journal of Engineering Sciences

ISSN 1999-8716

Printed in Iraq

Vol. 04, No. 02 , pp. 130-140 , December 2011

AN APPRAISAL OF THE TRANSIENT RESPONSE OF A D.C. SHUMT MOTOR USING MATLAB/SIMULINK UNDER NO LOADING AND FULL LOADING CONDITIONS

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(Received:29/12/2009 ; Accepted:16/10/2011)

ABSTRACT:- Electric machines are used to generate electrical power in power plants and provide mechanical work in industries.

This paper describes the MATLAB/SIMULINK realization of the performance of a D.C. shunt motor and introduces model power components to use computer simulation as a tool for conducting transient by using Simulink and SimPower System. These simulation models were employed to calculate the speed *(N)*, torque *(T)*, armature current *(Ia)*, input and output power *(Pin and Pout)*, losses *(Plosses)* and efficiency *(η)* for the motor at no load and load conditions. The results obtained using MATLAB were compared with the practical results, the ratio of error is about (1-2) % was found. The SIMULINK was written in MATLAB languages version (6.5).

Keywords: D.C. Shunt Motor, MATLAB/SIMULINK, Controller Model, SimPower System.

1-INTRODUCTION

The theory of electrical circuits represents one of the most important parts of any electrical engineering education. The aim of this paper is analysis circuit and to experience the actual behavior of a *D.C.* shunt motor, this requires a powerful software mathematical tool [1].

MATLAB is a good software package for high performance numerical combination of analysis and visualization. It makes the combination of analysis capabilities more flexibility, more reliability, and powerful graphics [2, 3]. The modeling and simulation of this paper helped to generate expected outcomes of the project design, simulation software MATLAB is used to provide simulation design and results for evaluation the speed, torque and the armature current for a *D.C.* shunt motor. Simulink which is a sub program of matlab was used to complete the modeling and simulation [4]. Simulations are interactive, so user can change parameter on the spot and immediately see what happens [5].

These can be achieved by changing the setting in Matlab/ Simulink to investigate a *D.C.* motor responds to these changes.

The Simulink program will help the students without returning to the laboratory to use the actual *D.C.* motor.

Many researches dealt with this subject. *Saffet Ayasun and Gultekin Karbeyaz (2007)*," in their paper describes the matlab simulink realization of the D.C. motor speed control methods",. *Karung Berkunci´s (2006)* work," presents shunt connected direct current motor analysis using matlab laboratory",. *Tan Kiong Howe´s (2003),* evaluate the transient response of a D.C. motor by variation of terminal voltage, armature resistance, and field resistance using matlab/ simulink.

2- PRINCIPLES OF OPERATION OF D.C MOTOR

An electric motor operation is based on simple electromagnetism. Motor is a machine which converts electrical energy into mechanical energy that when a current-carrying conductors is placed in an external magnetic field, it experience a mechanical force proportional to the current in the conductor and to the strength of the external magnetic field and between them generate rotational motion [6].

The effect of flux distribution is very important, because the limits of successful commutation are directly influenced by the flux, also both the generated voltage and torque of armature current are influenced thereby [7].

The brushes, commutator contacts and rotor windings are such that when power is applied, the polarities of the energized winding and the stator magnets are misaligned, and the rotor will rotate until it is almost aligned with the stator's field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts and energize the next windings [8].

In the field resistance control, a series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the no-load speed of the motor and in the slope of the torque- speed curve [9].

The field current may be varied by placing a variable resistance in series with the field windings. Since the current in the field circuit is low, a low-wattage rheostat may be used to vary the speed of the motor due to the variation in field resistance. As f.eld resistance increase, field current will decrease. A decrease in field current reduces the strength of the electromagnetic field. When the field flux is decreased, the armature will be rotate faster, due to reduced magnetic field interaction. Thus the speed of a D.C. shunt motor may be easily varied by using a field rheostat [10].

3 -MOTOR MODELING SIMULATION AND MATHEMATICAL REPRESENTATIONS

The system contains a *D.C.* shunt motor, a model based on the motor specifications needs to be obtained, as shown in *Fig(1)*.

The basic motor equations are:-

$Eb = Vt - Ia\ Ra$ ………… (1)

$Eb = K\varphi W = K_f I_f W_m,$ …….. (2)

$Eb = K_m W_m$

$T = K \varphi I_a = K_f I_f I_a$ …….. (3)

$T = K_m I_a$, $Km = K_f I_f$,

:. $Km = Eb / W_m$ at separately excited

$K_a = K_f = Eb / W_m I_f$, at shunt excited

Applying Kirchhoff's Voltage Law:

$Vt = Eb + Ia\ Ra + La\ dia/dt$ ….. (4)

$Vt = I_f R_f + L_f\, di_f / dt$ ………. (5)

From equation (2)

$Vt = K_a I_f W_m + Ia\ Ra + La\ dia/dt$ …. (6)

The Laplace transform of equations (5, 6)

$Vt(s) = K_a I_f W_m(s) + Ia\ Ra + LaIa(s)$

$Vt(s) - Eb = Ia(s)\,[La(s) + Ra]$

:. $Ia(s) = Vt(s) - Eb / [La(s) + R$ ……. *(7)*

$Vt = I_f R_f + L_f I_f (s)$

:. $I_f (s) = Vt(s) / [L_f(s) + R_f]$ ………. *(8)*

Or equation (7): -

$Vt (s) = K_a I_f W_m(s) + Ia\ Ra\ (1 + s\ \tau a)$

Where: τa = La / Ra is the electrical time constant of the armature.

The dynamic equation for the mechanical system:-

$T = K_a I_f I_a = J\ dW_m / dt + BW_m + T_L$ ….... (9)

BW_m = is the rotational loss torque of the System.

The Laplace transform of equations:-

$T(s) = K_a I_f I_a (s)$

$= J.s.W_m(s) + BW_m(s) + T_L(s)$

$T(s) - T_L(s) = W_m(s) \times [J.s. + B]$

:. $W_m(s) = T(s) - T_L(s) / [J.s. + B]$ ……. *(`10)*

From (3) and (10)

$T(s) = J.s.W_m(s) + BW_m(s) + T_L(s)$

$= W_m(s) / [J.s. + B] + T_L(s)$

: .Wm(s) = T(s)-TL(s) / B [1+ τ_m.s] …… *(11)*

Where τ_m = J / B is the mechanical time constant of the system.

From (2) and (8)

Vt (s) = Eb(s) + Ia(s) R (1+s τa)

:. Ia(s) = Vt(s) – Eb(s) / Ra (1+s τa) …… *(12)*

The values of Pin, Pout, Plosses, and (η) can be calculated by:

Output power =Pout = Wm × T [KW]

Pout = 2 πNT/60 …….. *(13)*

Input power = Vt × Iin [KW]

Pin =Vt × (Ia +If) ……. *(14)*

Losses power = Pin - Pout ……… *(15)*

Efficiency (η) = Pout / Pin × 100 % …. *(16)*

A block diagram which represents the equations (7), (8) and (10) is shown in *fig. (2)*.

4- MODELING RESULT AND DISCUSSIONS

In this paper, the specifications of D.C. shunt motor were obtained from the engraving on the metal tag attached onto the motor, shown in *table (1)*.

To produce a good model design, there needs to be some amount of simulations, to avoid aimless trial and error techniques with the actual equipment of a *D.C.* shunt motor.

From the specification of the *D.C.* motor and the equations; Calculate the constant torque (K_f) or (K_a), at no-load;

Vt = 220 volt, I_f = 0.75 ampere, from the equation (2); then the torque constant:

$(K_f) = Eb / I_f W_m$,

As the speed in terms of *(N) (r.p.m.)*, *N* = 1800 r.p.m., to convert to *(rad / s)*, then the speed $W_m = 2\pi N/60$, W_m = 2× 3.14 ×1800/60 = 188.4 rad/s,

And

K_f = 220/ 0.71 ×188.4 = $\underline{1.644}$ =K_a

The value of B obtains from calculates the mechanical equation as follows:-

From equation (9) and when $T_L = 0$ (no-load), at steady state, Ia and Wm, stabilized then;

$dW_m/dt = 0.$

$K_f I_f I_a = J * dW_m / dt + BW_m + T_L.$

$\therefore dW_m/dt = K_f I_f I_a - BW_m = 0, \quad T_L = 0.$

$\therefore K_f I_f I_a = BW_m,$

$\therefore B = K_f I_f I_a / W_m,$

$B = 1.644 \times 0.71 \times 1.8 / 188.4,$

$B = 0.01115.$

Ia = 1.8 ampere from the measurements of experiment at no-load.

J = 0.117 $Kg*m^2$ the value of the armature (rotor) inertia.

After the measuring of the values resistance and inductance (Ra, La) of the armature windings and the shunt field windings (Rf, Lf)for the D.C. shunt motor in electrical machines laboratory*(D.C. Machines laboratory),* their values were:-

Ra = 2 Ω. La =16.2mh. Rf = 210 Ω. Lf = 5.47 H.

And varies resistance connected in series with shunt field windings to obtain speed about (1800 r.p.m.) at no load, the varies resistance shown in table *(2)*.

The average of the constant torque, $K_f = K_a = 1.607$. And

IL= 0, 2, 3, 5, 6, 8, 9, 10, 12, 13, 14, 15. Ampere.

Where the field current (If) is constant If= 0.71 ampere. Take K_a at no load when the speed is (1800 r.p.m.) and Eb =Vt, IaRa is neglected because the voltage drop (IaRa) is very small.

$K_a = K_m = Eb / I_f W_m$, Ka=220/0.71×188.4 =1.644.

Comparing the results of table (3) and table (4), the values of (If) is kept constant of a (0.71 amp.) while this value was (0.698 amp.) at simulation technique. This slight difference may be of recording the direct data obtained from the devices.

The same observations were recorded for the Ia (amp.) T (N.M.) and Wm (rad/s). This difference was calculated and it was found to be about (1-2) %

The *D.C.* shunt motor was modeled using characteristics transfer function of electrical and mechanical of the motor as shown in *fig.(3)*.

5- SIMULATION RESULTS AND DISCUSSIONS

D.C. motors are used to drive mechanical loads, some applications require that the speed remain constant as the mechanical load is applied to the motor changes.

A: Simulation Results At no-load:

At speed *(Wo)* on no-load, the produced no-load current is small and not enough to carry the load so the motor starts to slow down. And the e.m.f. becomes smaller, resulting in a higher current and higher torque.

At no-load to obtain the speed (1800r.p.m.) connect variable resistance in series with the shunt field circuit, its shown in *table (2)*, increase the resistance, the speed increase until to obtain (N= 1800r.p.m.), the relation between them linearity, the results of simulations for the *D.C.* shunt motor model at no load is shown in *Fig. (4)*.

A series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the no-load speed of the motor; this method is one of the most common speed control methods for dc shunt motor.

Fig.(5), shows the output waveform of the starting torque which has a high value in the beginning, after that it drops to an approximate torque equal to the torque imposed *(2.1 N.M.)*, the output waveform armature current shows a large increasing, at starting, after that it drops to reach the approximate armature current (Ia) (*1.8 amp.),* and the output waveform of the speed in (rad/s), it is very clear that there is a large increase in the speed at the beginning but at steady state the speed remains constant at *(188.4 rad/s)(1800r.p.m.)*at no load.

B: Simulation Results At load:

At load (change in the mechanical load), when the mechanical load applied to the shaft vary, the armature current rises and the speed drops. The mechanical load torque reaches (21 *N.M.*).

From the simulation results shown in *Fig*. (6) the armature current rises, from no-load at *(1.8 amp.)* to the full load current *(19.8amp.)* at steady state, shows the variation of torque from *(2.1N.M.*) at no-load to the value *(21 N.M.)* at full load at steady state and *Te =22.7 N.M.,* and the reduction of speed in (rad/s) of the shunt motor from no-load at (188.4 rad/s)(1800r.p.m.) to (157 rad/s)(1500r.p.m.) at full load, this cause to diminish e.m.f., resulting in higher current and a corresponding higher torque, leads to slow down the speed.

The simulation results for calculating Pout, Pin, Plosses, and η, from the equations (13, 14, 15, and 16) are shown as; *fig. (7) and fig. (8).*

Fig (7) Shows the output power versus time at full load, P out = 3.564KW, the input power versus time at full load, Pin =4.5 KW. And shows the curve of the losses in power versus time at full load, P losses = 0.9365 KW.

Since the power losses =0.9365KW, then power is dissipated in:-

1- Power losses converted directly to heat in the resistances of the current paths.
2- Mechanical energy developed within the device is absorbed in friction and windage converted to heat.
3- The energy absorbed by coupling field is converted to heat in magnetic core loss for magnetic coupling or loss for electric coupling.

Fig. (8) Shows the efficiency versus time at full load, the efficiency of the motor, η = 80%.

8- CONCLUSION

** In this paper, the block diagram of a *D.C.* shunt motor was developed by using matlab / Simulink, the exact simulated with expected waveform output were obtained, for example the armature current, torque, speed and output power characteristic of the d.c. shunt motor.

** High protection, increases complexity in operation of the protection equipments by increasing the supply voltage drop and transient torque which can damage the mechanical drive, one of the advantages of having simulink is, increasing the simplicity of the operation of protection equipments and low cost.

** From the obtained results, it was very clear that simulation can be very helpful tool to study the dynamic behavior of *D.C.* shunt motor and its interaction, with reading experiment.

** Simulation model of *D.C.* shunt motor and feedback control system for *D.C.* motor drives have been developed using MATLAB/SIMULINK and it has been shown that proposed simulation model correctly predict the effect of the field resistance on the torque-speed characteristic of the *D.C.* shunt motor.

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Table(1): Specifications of a D.C. Shunt Motor

D.C. motor specification	
Tipo	160L
Model Number	61.5.75F
Power	2.94KW
Horse Power	4
Voltage	220 V
Current	15.4 A
Field Voltage	220 V
Field Current	1.06 A
Speed	1500 r.p.m.
Wd	Compound

Table (2): Simulation results at no load condition.

Eb = Vt-IaRa	W_m rad/s)	N .p.m.)	T .M.)	Ia mp.)	Km=Ka =Eb/I_fW_m
216.4	188.4	1800	.22	1.8	1.618
213.2	85.78	1775	3.58	3.4	1.616
211.2	83.17	1750	4.8	4.4	1.624
206.6	78.98	1710	7.63	6.7	1.625
204.4	77.93	1700	9.3	7.8	1.618
198.8	74.27	1665	12.4	10.6	1.607
196.4	172.7	1650	14.1	11.8	1.602
194	70.61	1630	15.5	13	1.602
188	67.47	1600	19.6	16	1.581
185.6	64.85	1575	21.5	17.2	1.586
183	62.23	1550	22.9	18.5	1.588
180	157	1500	23.8	20	1.615

Table (3): The experimental results at load.

Rf +Rser. (Ω)	W_m (rad/s)	N (r.p.m.)	If (Amp.)	Ia (Amp.)	T (N.M.)
210	126.8	1211.47	1.048	0.795	1.369
220	132.7	1267.83	1.0	0.887	1.459
230	138.7	1325.16	0.957	0.980	1.542
240	144.6	1381.53	0.917	1.023	1.549
250	150.5	1437.90	0.88	1.125	1.627
260	156.4	1494.27	0.846	1.243	1.729
270	162.2	1549.68	0.815	1.315	1.762
280	168.1	1606.05	0.786	1.443	1.864
290	173.9	1661.47	0.759	1.55	1.935
300	179.7	1716.88	0.733	1.629	1.965
315	188.4	1800	0.698	1.797	2.063

Table (4): The simulation results at load**.**

N (r.p.m.)	W_m (rad/s)	TL (N.M.)	Te (N.M.)	Ia (Amp.)	If (Amp.)
1800	188.4	0	2.06	1.787	0.698
1771.3	185.4	2	4.06	3.54	0.698
1743.6	182.5	4	5.97	5.2	0.698
1715.0	179.5	6	8.0	6.96	0.698
1686.3	176.5	8	9.95	8.66	0.698
1657.6	173.5	10	11.9	10.4	0.698
1629.0	170.5	12	13.9	12.1	0.698
1600.3	167.5	14	15.9	13.8	0.698
1571.7	164.5	16	17.8	15.5	0.698
1544.0	161.6	18	19.8	17.23	0.698
1515.3	158.6	20	21.7	18.9	0.698
1500	157	21	22.68	19.8	0.698

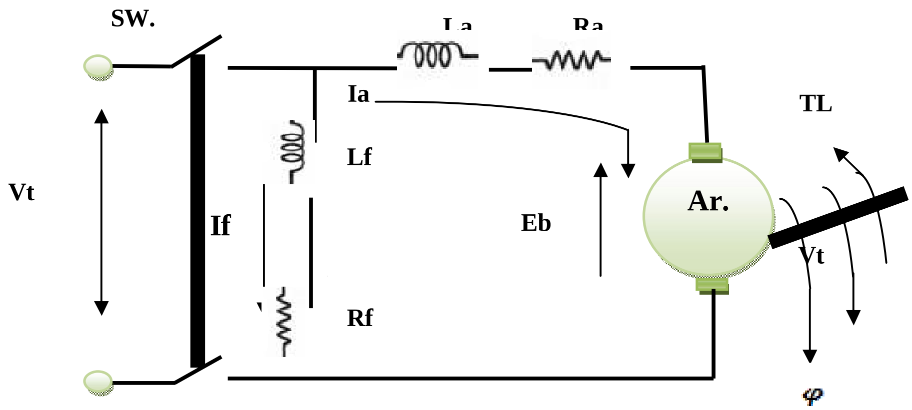

Fig.(1): Schematic Diagram of D.C. Shunt Motor.

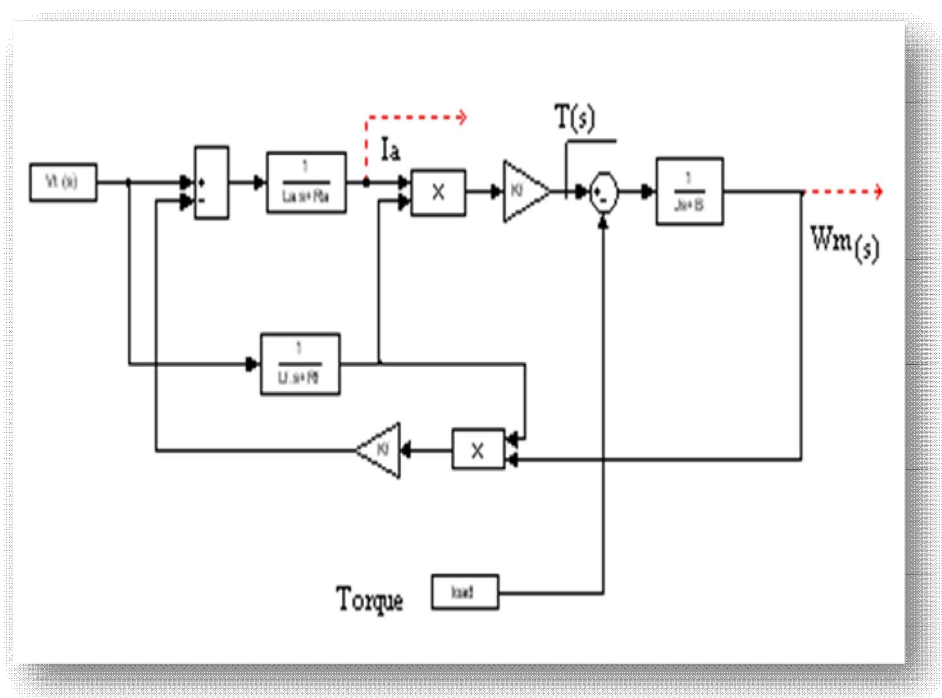

Fig.(2): Simulink Model of D.C. Shunt Motor.

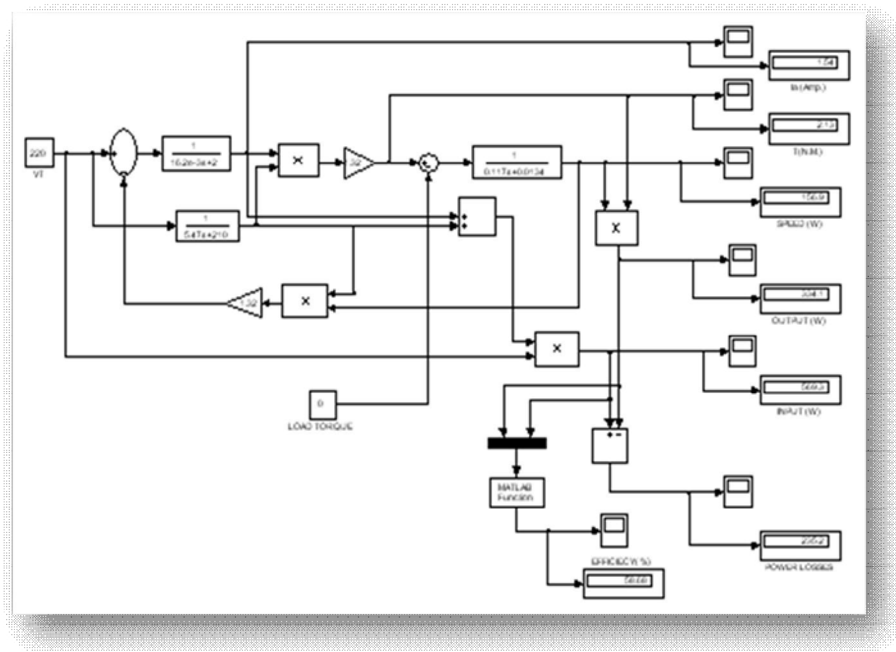

Fig.(3): Simulink Model for D.C. Shunt Motor with the Constant Values.

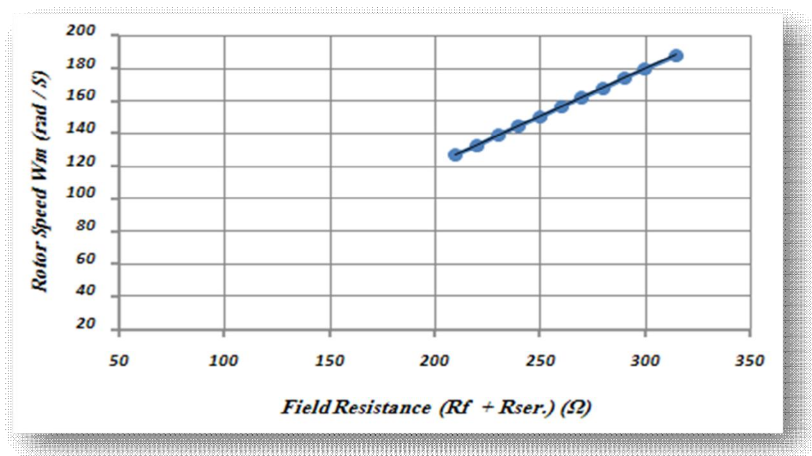

Fig.(4): Rotor Speed (Wm) Versus Field resistance (Rf +Rser.)(Ω) At no load.

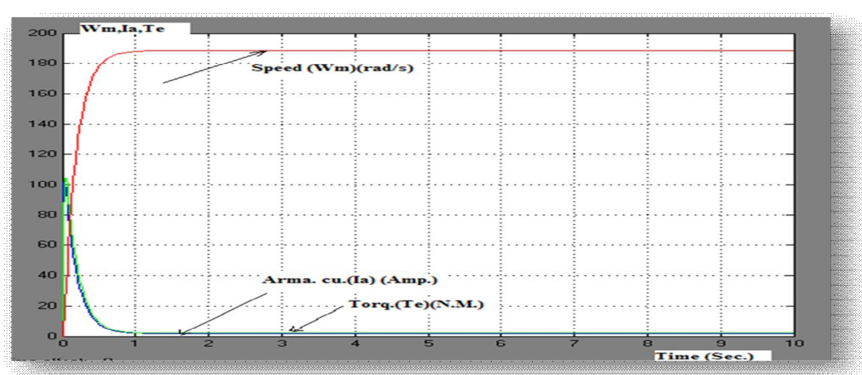

Fig.(5): Simulated Output Ia, Te, and Wm Versus Time (Sec.) at no load.

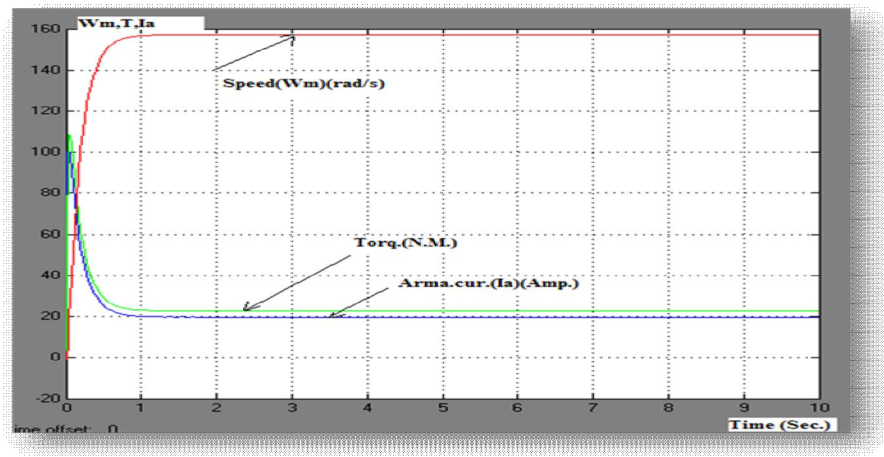

Fig.(6): Simulated Output Ia, Te, and Wm Versus Time (Sec.) at full load**.**

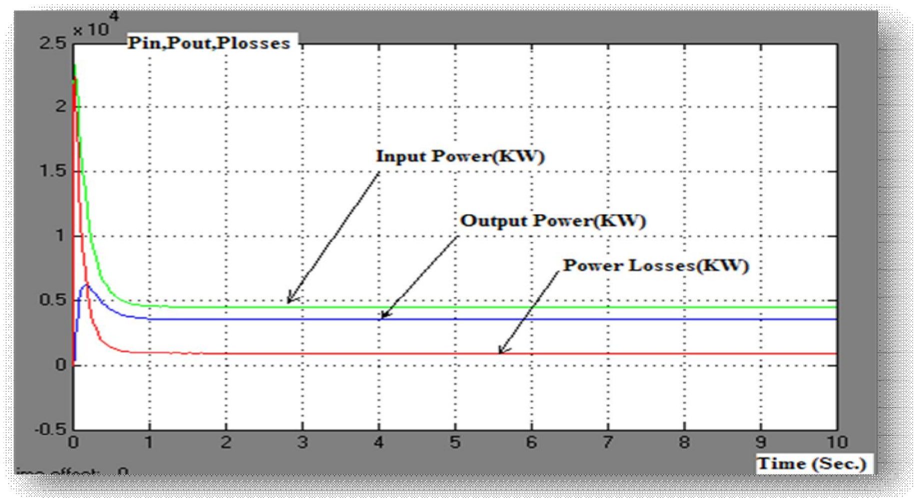

Fig.(7): Simulated Pout, Pin, and losses Versus Time (Sec.).

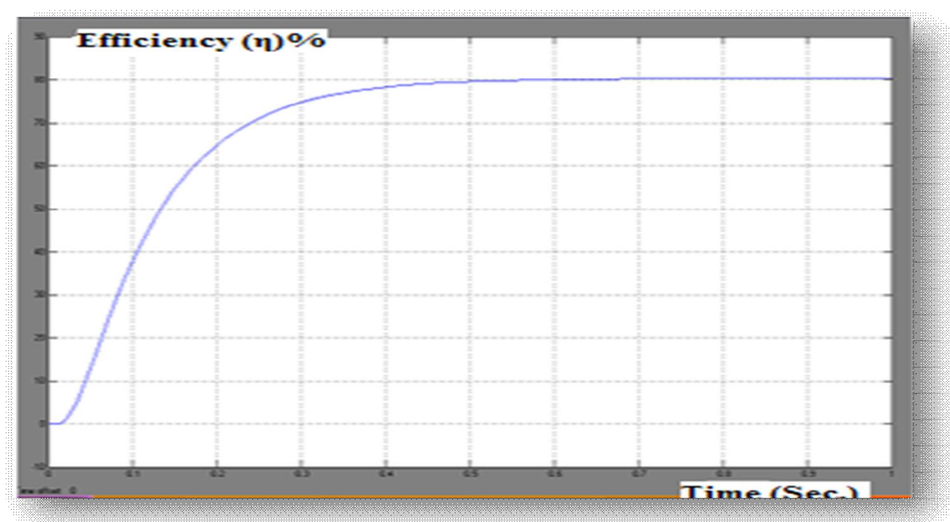

Fig.(8): Simulated Efficiency (η) % Versus Time (Sec.).

تقييم الحالة العابرة لمحرك تيار مستمر ذو أثارة متوازية بأستخدام ماتلاب / سيملنك تحت ظروف حالات اللاحمل والحمل الكامل

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الخلاصة

تسخدم المكائن الكهربائية لتوليد الطاقة الكهربائية في محطات الطاقة الكهربائية ولتزويد العمل الميكانيكي في الصناعات.

يصف البحث عملية ادراك الماتلاب / سيملنك لأداء محرك تيار مستمر ذو اثارة متوازية ويقدم نموذج للمكونات الكهربائية لأستعمال المحاكاة بالكومبيوتر كأداة لأجراء الحالة العابرة بأستعمال نظام Simulink و Simpower. هذه النماذج أستخدمت لحساب كل من السرعة (N) والعزم (T) وتيار المنتج (Ia) والقدرة الداخلة والخارجة (Pin and Pout) والفقد في القدرة (P losses) وكفاءة المحرك (η) تحت ظروف حالات اللاحمل والحمل الكامل. تمت مقارنة نتائج الماتلاب مع النتائج العملية وكانت نسبة الخطأ فيها بمعدل حوالي % (2-1) والتي حصلنا عليها من استخدام الماتلاب. المحاكاة كتبت في نظام الماتلاب / سيملنك ،لغة النسخة (6.5).