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Analysis of Voltage and Armature Resistance Regulation of Direct Current Motors

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ABSTRACT

Direct current motors or often known as DC motors (direct current motors) were widely used as or car starters, children's toys, tape recorders, and so on. A common problem in DC motors is that the regulatory variable is very limited, because it generally only depends on the input voltage, which is direct current or DC voltage. Moreover, if it is used is a DC motor with a large capacity, adding problems to the amount of initial starting current of the motor. This research aims to calculatiin the regulation characteristics of a DC motor by changing the amount of armature voltage and armature resistance of the DC motor. As a case study, DC motor parameter data from US Electrical Motors are used. The analysis method used is to create modelling of DC motor control simulation using simulink model in the Matlab (Matrix Laboratory) application. The results obtained are the starting current of the DC motor before controlling 441.5 Ampere while the nominal current is 42.4 Amperes. After controlling with the addition of external resistance, the starting current becomes 73.59 Amperes and controlling by regulating the armature voltage with the starting current was only 44.98 Amperes. For DC motor rotation speed before controlling will change along with load changes, namely: 50% increase in load causes the rotation to 1712 rpm, 75% increase in load causes the rotation to 1696 rpm while a 35% load decrease causes DC motor rotation becomes 1777 rpm. Then after controlling: 50%, 75% increase in load and 30% decrease did not change the rotation speed because the rotation steady at 1750.71 rpm.
KEYWORDS: DC motors; simulation; simulink; matlab; armature voltage; armature resistance

1. INTRODUCTION

Controlling characteristics in DC motors have a relatively wide adjustment area under changing loading conditions but still produce relatively constant rotation [1]. Therefore, DC motors are widely used as movers in industry and household appliances such as tape recorders, starter motors, toy robots and so on. DC Motor type based on its characteristics consist of: series winding, separate exciting, shunt winding and compound winding DC motor [2].

Controlling of the DC motor was control the rotational speed until in a constant condition even though the loading is changed. Before the control system is applied to a DC motor, initial testing is done first to get the right variable in accordance with the characteristics of the DC motor, and not all DC motors can be directly tested especially on large capacity motors. Therefore, we need an exact modelling, starting from mathematical modelling until then simulating the model that has been created with the help of certain applications [3].

Simulation is one of the methods used to conduct experiments in finding the best results from system components. This is because it is very expensive and requires a long time if the experiment is tried in real confition. Simulink can be used to simulate the system in terms of observing and analyzing the behavior of artificial system. Artificial systems are expected to have very similar behavior to physical systems. If used correctly, the simulation will help the system analysis and design process. By conducting a simulation, in the short time the right decision can be determined and the cost is not too large because everything is enough to do with computers. The simulation approach begins with building a real system model. The model must be able to show how the various components in the system interact with each other so that it truly describes the behavior of the system. After the model is created, the model is transformed into a computer program. The application of simulation in a computer program is called Simulink. Simulink is one part of the Matlab application [4].

2. MATERIALS AND METHODS

2.1. Armature controlling modelling of DC motors circuit

Armature controlling of DC motor can be modeled into electric circuit models and a mechanical circuit models, shown in figure 1 [5]. From electrical dan mechanical circuit models of DC motors was obtained linear differential equation for each models. Thus, it can be transformed into an algebraic equation in complex variable, then the solution in variable *s* is solved for the dpendent variable, then the solution of the differential

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equation (the inverse Laplace transform of the dependent variable) may be found by use of Laplace transform table. Thus, simulink models can be made using the Matlab application [8,9], based on figure 2.

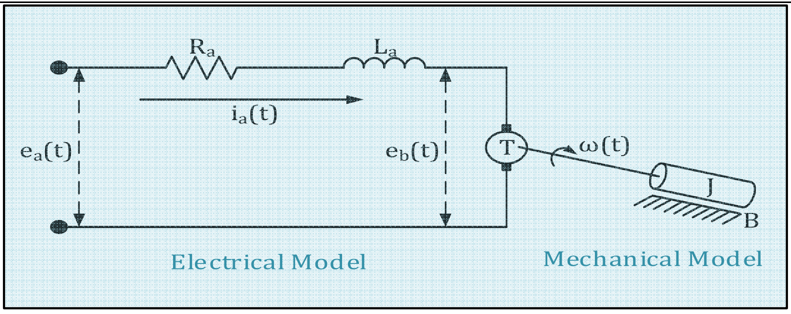


Figure 1. Electrical dan mechanical circuit models of DC motors

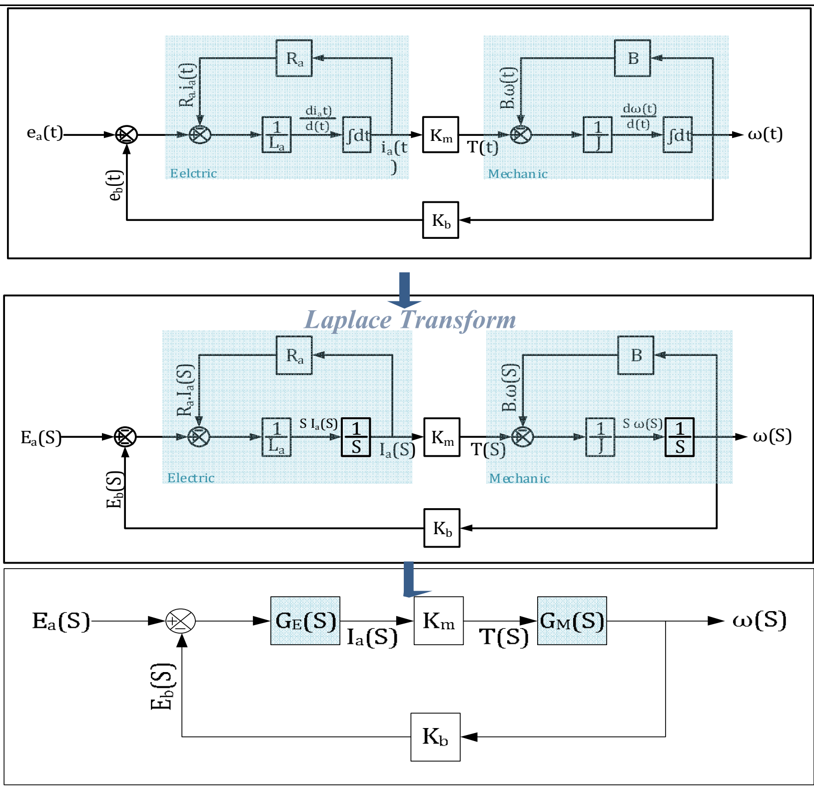


Figure 2. Transformation of differential function to laplace transorm of DC motors in block diagram representation

2.2. Determine paramates of DC motors

Electrical equipment generally has information about the device. As with a DC motor, it also has information called a name plate and has some information about the parameters of a DC motor such as mechanical power, nominal speed, inertia, armature voltage, armature current, resistance and inductance of the armature. The DC motor data used in this research refers to the ideal DC motor data from the U.S. Electrical Motors [6]. The DC motor parameters is made as shown on table 1.

Table 1. Result of DC motors parameter

No.	Data Motor	Symbol	Value	Unit
1	Mechanic capacity	P_{mek}	25	HP
			18642,4	Watt
2	Nominal speed	$\omega_{nom.}$	1750	RPM
			183,2596	rad/sec
3	Inertia	J	4,2	lb.ft^2
			0,177	kg.m^2
4	Armature Voltage	E_a	500	Volt
5	Armature current	I_a	42,4	Ampere
6	Armature Resistance	R_a	0,504	Ohm
7	Armature Inductance	L_a	0,015	Henry
8	Constant of motor	K_m	2,3983	N.m/Ampere
9	Constant of generator	K_b	2,6107	Volt . sec/rad
10	Load	B	0,5547	N. m. sec/rad
11	Torque	T	101,6864	N.m
12	Eficience	H	87,93	Percent (%)

2.3. Transfer function equation [G(s) and H(s)]

G(s) can be determined base on DC motor voltage [Ea(s)] and DC motor rotation [ω(s)], as follow [7]:

$$G(s) = \frac{\omega(s)}{E_a(s)} = \frac{K_o}{(S^2 + 2\xi\omega_n\ S + \omega_n{}^2)} \tag{1}$$

where :

$$K_o = \frac{K_m}{JL_a} \tag{2}$$

$$2\xi\omega_n = \frac{(J\,R_a + B\,R_a)}{JL_a} \tag{3}$$

$$\omega_n{}^2 = \frac{B\,R_a + K_m \cdot K_b}{JL_a} \tag{4}$$

Whereas H(s) can be determined base on DC motor voltage [Ea(s)] and DC motor current [Ia(s)], as follow:

$$H(s) = \frac{I_a(s)}{E_a(s)} = \frac{a\ S\ +\ b}{(S^2 + 2\xi\,\omega_n\ S + \omega_n{}^2)} \tag{5}$$

where :

$$a = \frac{1}{L_a} \tag{6}$$

$$b = \frac{B}{JL_a} \tag{7}$$

3. RESULTS AND DISCUSSION

3.1. Verification of Simulink Model with Analytic Solution

To verify the results to be obtained by using Matlab simulink, first the equation of rotation speed and armature current of the DC motor is calculated using data in table 1, as follow :

$$K_o = \frac{2{,}39833}{0.177 \times 0.015} = 903{,}300942$$

$$2\xi\omega_n = \frac{(0{,}177 \times 0{,}504 + 0{,}5547 \times 0{,}504)}{(0{,}177 \times 0{,}015)} = 36{,}7336$$

$$\omega_n{}^2 = \frac{(0{,}555 \times 0{,}504 + 2{,}3983 \times 2{,}6107)}{(0{,}177 \times 0{,}015)} = 2463,\ 537260$$

$$a = \frac{1}{0.015} = 66{,}6667$$

$$b = \frac{0.5547}{(0{,}177 \times 0{,}015)} = 208{,}9077$$

calculation of rotation speed :

$$G(s) = \frac{903{,}300942}{(S^2 + 36{,}7336\ S + 2463{,}537260)}$$

$$H(s) = \frac{66{,}6667\ S\ +\ 208{,}9077}{(S^2 + 36{,}7336\ S + 2463{,}537260)}$$

then :

$$\omega(s) = G(s) \,.\, E_a(s)$$

$$= \frac{903{,}200942}{(S^2 + 36{,}7336\ S + 2463{,}537260)}\ x\ \frac{500}{s}$$

$$= \frac{903{,}300942\ x\ 500}{s\,(S^2 + 36{,}7336\ S + 2463{,}537260)}$$

$$\omega(t) = L^{-1}\left[\frac{903{,}300942\ x\ 500}{s\,(S^2 + 36{,}7336\ S + 2463{,}537260)}\right]$$

or :

$\omega(t)$ = ***183,334134349565-183,334134349565**$e^{-18{,}3668t}$ **Cos (46,11t) – 73,025558054**$e^{-18{,}3668t}$ **Sin (46,11t))***

calculation of armature current :

$$I_a(s) = H(s)\ .\ E_a(s)$$

$$= \frac{66{,}6667\ S + 208{,}9077}{(S^2 + 36{,}7336\ S + 2463{,}537260)}\ x\ \frac{500}{s}$$

$$= \frac{33333{,}33353\ s + 104453{,}8605}{s\,(S^2 + 36{,}7336\ S + 2463{,}537260)}$$

$$I_a(t) = L^{-1}\left[\frac{33333{,}33353\ s + 104453{,}8605}{s\,(S^2 + 36{,}7336\ S + 2463{,}537260)}\right]$$

or :

$I_a(t)$ = ***42,3999-42,3999**$e^{-18{,}3668t}$ **Cos (46,11t) – 706,0091**$e^{-18{,}3668t}$ **Sin (46,11t))***

for initial condition (t = 0) :

$\omega(t)$ = *0*

$I_a(t)$ = *0*

for end condition (t = ∞), if in this case it is considered to be long enough when t = 100 :

$\omega(t) \sim \omega(t)_{nominal}$

$I_a(t) \sim I_a(t)_{nominal}$

Thus, the analytical solution of rotational speed and armature current of the DC motor armature controlling above can be used to verify the simulink model on Matlab application.

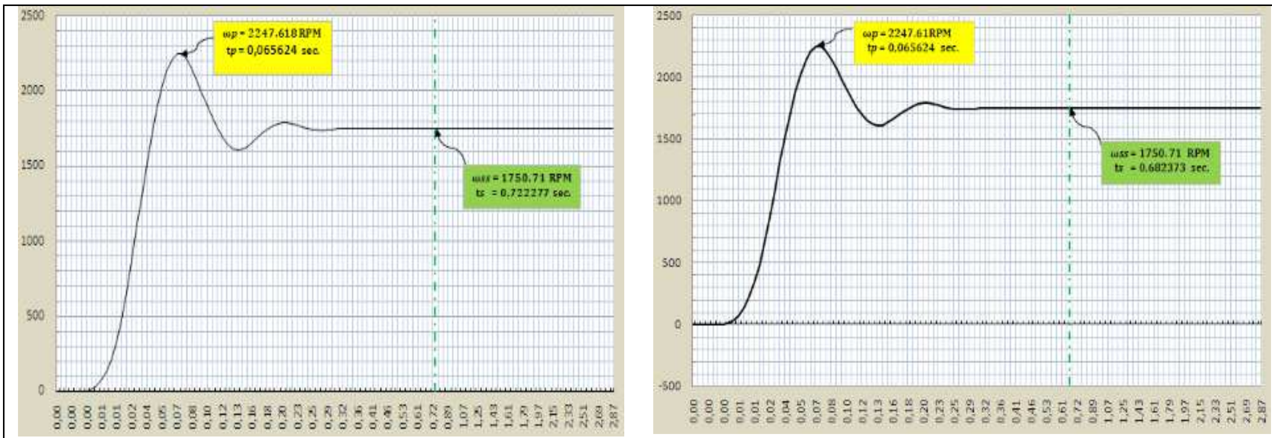
The results in the figure above, then can be made a comparison in graphical between simulink solution with analytic solution, as shown in tabel 2.

Table 2. The result of ω(t) and Ia(t) based on simulink solution and analytic solution

t (second)	Simulink Solution		Analytic Solution		Error (%)	
	rotation [ω(t)](rpm)	Armature Current [ia(t)](Ampere)	rotation [ω(t)](rpm)	Armature Current [ia(t)](Ampere)	ω(t)	ia(t)
0,000000	0,00	0,00	0,00	0,00	0,000000	0,000000
0,000000	0,00	0,00	0,00	0,00	100,000000	2,393721
0,000002	0,00	0,05	0,00	0,05	13,392843	0,001510
..	...	...	...	...	...	...
0,020496	659,09	418,09	659,07	418,09	0,002697	0,000833
0,024301	861,29	437,38	861,27	437,38	0,002714	0,000541
0,028481	1086,81	**440,64**	1086,78	**440,63**	0,002652	0,000148
0,032686	1307,84	427,47	1307,81	427,47	0,002528	0,000335
0,036928	1516,80	400,42	1516,77	400,42	0,002354	0,000930
0,041240	1708,10	361,93	1708,06	361,93	0,002135	0,001673
0,045658	1876,86	314,39	1876,82	314,39	0,001873	0,002626
0,050224	2018,84	260,13	2018,81	260,14	0,001568	0,003903
0,054999	2130,34	201,44	2130,32	201,45	0,001218	0,005740
0,060074	2207,89	140,54	2207,87	140,55	0,000817	0,008750
0,065624	**2247,62**	79,42	**2247,61**	79,43	0,000354	0,015270
0,071195	2246,04	26,87	2246,04	26,88	0,000121	0,040827
0,076758	2210,79	-14,84	2210,81	-14,83	0,000591	0,060396

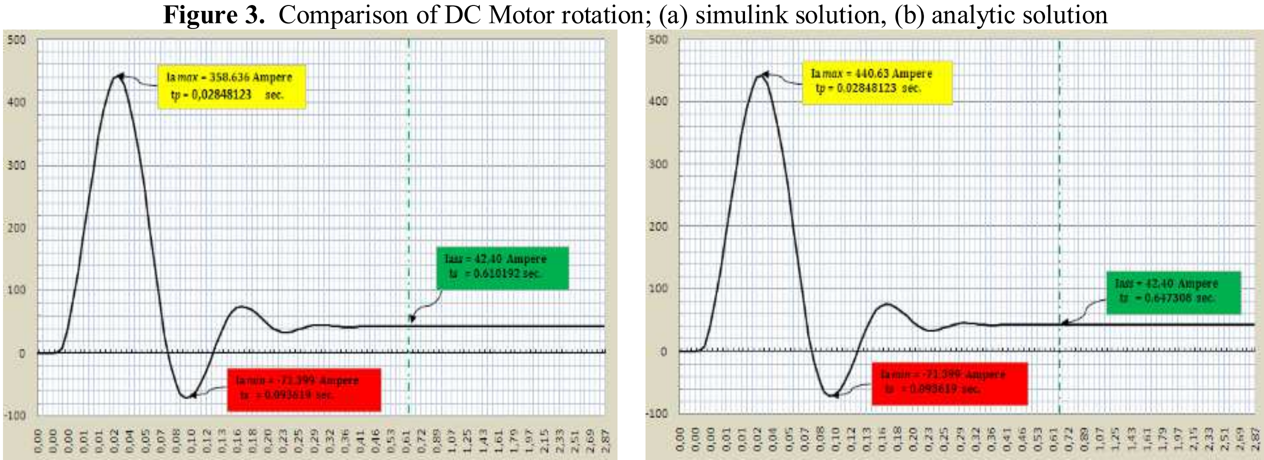
0,082394	2149,62	-45,23	2149,64	-45,22	0,001042	0,013763
0,088128	2070,43	-64,01	2070,46	-64,00	0,001451	0,004667
0,093619	1986,83	-71,39	1986,87	-71,39	0,001770	0,000399
0,099018	1904,12	-69,91	1904,16	-69,91	0,001993	0,004907
0,104422	1826,27	-61,41	1826,30	-61,42	0,002105	0,010263
..	...	...	...	...	...	...
0,578316	1750,69	42,42	1750,69	42,42	0,000328	0,006938
0,610192	1750,73	**42,40**	1750,73	42,40	0,000356	0,007447
0,640937	1750,72	42,40	1750,72	42,39	0,000329	0,007761
0,682373	1750,70	42,40	**1750,71**	**42,40**	0,000278	0,007351
0,722277	**1750,71**	42,40	1750,71	42,40	0,000317	0,006800
0,775835	1750,71	42,40	1750,71	42,40	0,000366	0,007703
0,827309	1750,71	42,40	1750,71	42,40	0,000298	0,007324
..	...	...	...	...	...	...
2,987309	1750,71	42,40	1750,71	42,40	0,000321	0,007314
3,000000	1750,71	42,40	1750,71	42,40	0,000321	0,007314

The results on the table above, then can be made a comparison in graphical between simulink solution with analytic solution, as shown in Figure 3 and 4.



(a) (b)

Figure 3. Comparison of DC Motor rotation; (a) simulink solution, (b) analytic solution



(a) (b)

Figure 4. Comparison of DC Motor armature current; (a) simulink solution, (b) analytic solution

3.2. Controlling of DC Motor

Control DC motor is needed because changes in the rotation speed of a DC motor depend on the rise or decrease motor load. The loading changes usually called with disturbance. Applicatively, it is certainly expected that with interference of distrubance that occurs rotation speed possibility may still rotate at nominal speed.

When the motor is started, there is a current surge of 441,5 Ampere and so on when the motor is stopped there is a surge of -395,8 Ampere. The nominal current of the DC motor itself is only 42,4 Ampere, the current is about 10 times greater at the start-stop. Surely thing It must be avoided because it can damage the motor. Meanwhile the maximum motor rotational speed occurs at start amounted to 2251 rpm. Technically, increasing in rotation can still be held by motor because it is still below top speed a motor of 2300 rpm, but practically this should be avoided because it can cause damage of the shaft when the DC motor start start as shown o figure 5. Therefore a control system is needed to reduce the amount of starting current when the dc motor is started as shown in figure 6 and still maintain the motor rotation despite the changing load on the motor.

Rising the loads turns the motor rotation slower, opposite if the load decrease the rotation will faster. That indication can be seen in figure 7(a); increasing load by 50%, the rotation decreases 37 rpm from its nominal to 1712 rpm, for 35% load reduction then the motor rotation increases by 27 rpm becomes 1777 rpm and for 75% increase in load then the rotation of the motor decreases 55 rpm become 1696 rpm. Then after controlling: 50%, 75% increase in load and 30% decrease did not change the rotation speed because the rotation steady at 1750,71 rpm as shown in figure 7(b).

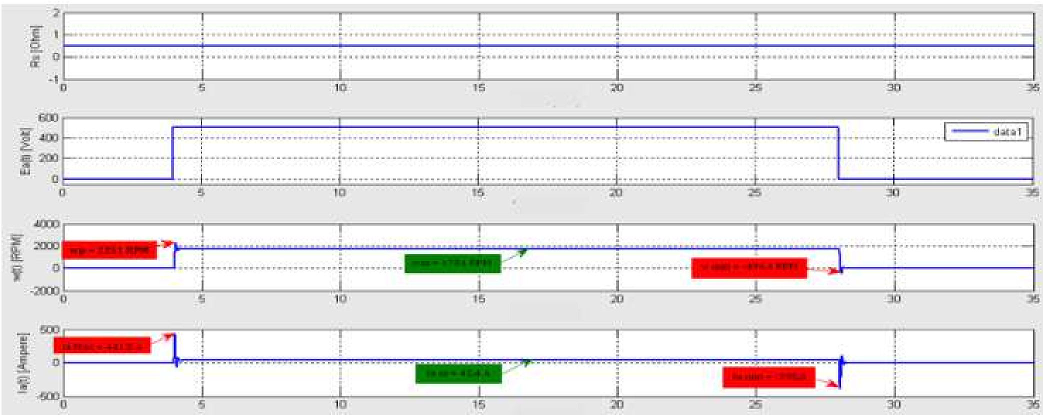
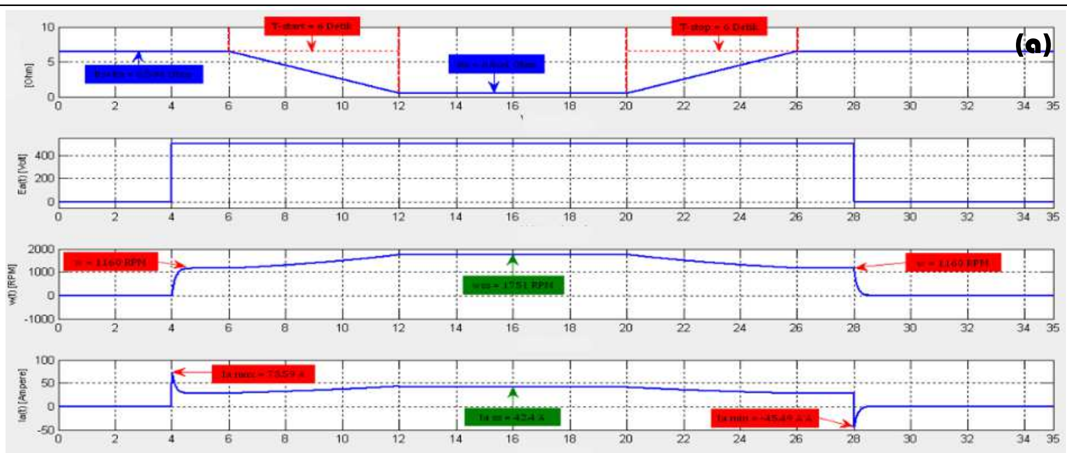


Figure 5. The simulation result of uncontrolling DC motor without loading



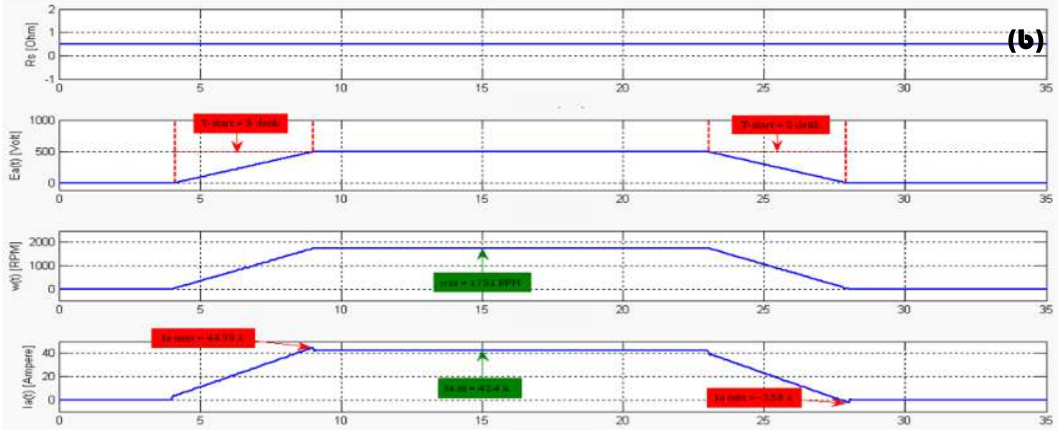


Figure 6. The simulation result of controlling DC motor without loading; (a) Armature Resistance Variation and (b) Armature Voltage Variation

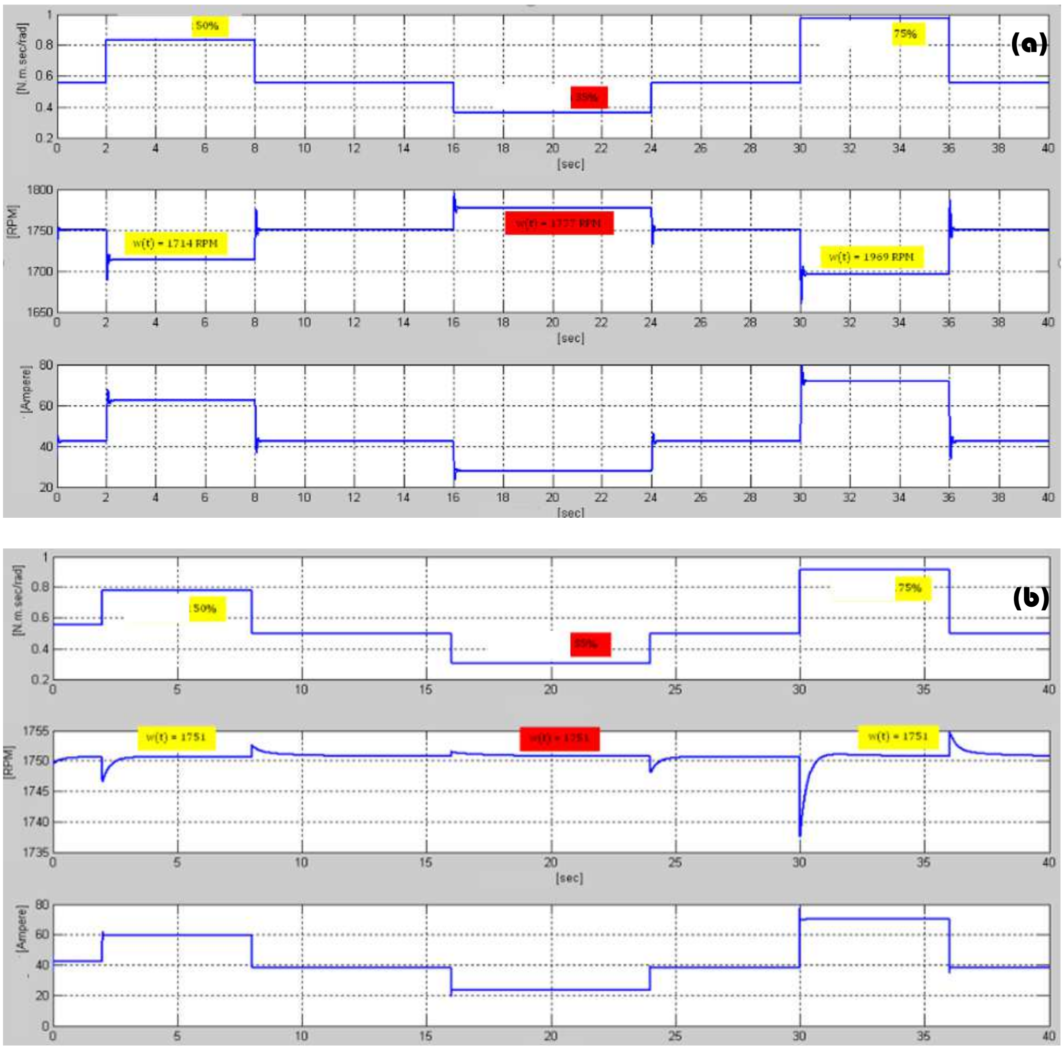


Figure 7. The simulation result of DC motor with loading; (a) Uncontrolling state and (b) Controlling State

4. CONCLUSION

Based on the research and the results of this research was obtained:

(a) Without controlling at starting condition made the starting current of DC motor reach 441,5 Ampere and when the motor is stopped there is a current surge of -395,8 Ampere while the nominal current only 42,4 Ampere. The current is about 10 times greater at the start-stop. Surely, it must be avoided because it can damage the motor. As well as, increasing load by 50%, the rotation slower to 1712 rpm, for 35% load reduction made the motor rotation increases becomes 1777 rpm and for 75% increase in load made the rotation become 1696 rpm.

(b) After controlling: 50%, 75% increase in load and 30% decrease did not change the rotation speed because the rotation steady at 1750,71 rpm as shown in figure.

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