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Performance Prediction of DC Motor Fed From Half-Controlled Bridge Rectifier

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Abstract— Controlled rectification is the process of obtaining a controlled output DC voltage from a constant AC voltage. This can be used in the speed control of the DC motor to provide rapid torque control and a quick starting response. In this work, a three-phase half-controlled bridge rectifier has been used. The average output DC voltage varies smoothly by varying the firing angle (α). Different methods of analysis such as state-space and Fourier-series, are used to obtain the performance of the DC motor fed from the bridge-rectifier supply. However, these methods do not deal with the prediction of the discontinuous conduction phenomenon which occurs during the operation of the DC motor with a variation of delay angle. This paper deals with the prediction of performance characteristics during the operation of the DC motor fed by a 3-phase half-controlled bridge rectifier, including the transient as well as steady-state operation with a variation of delay angle as well as application of load torque at starting.

Keywords: DC motor, speed control, 3-phase half-controlled bridge rectifier, discontinuous conduction

1. INTRODUCTION

The 3-phase half-controlled rectifier is the most frequently used in DC motor control systems. Two of the six semiconductor devices, one thyristor and one diode conduct at any time instant, as shown in Figure 1. The gating of each thyristor initiates a pulse of load current. Therefore, this is a six-pulse half-controlled rectifier [1-10]. The Simulink model is shown in Figure 2.

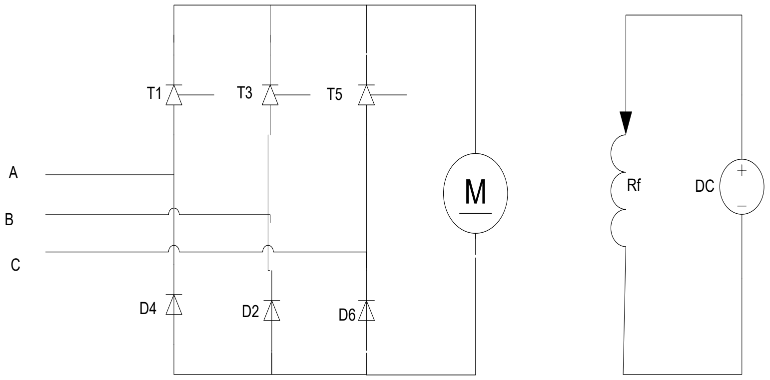

Fig. 1. Schematic diagram of the Circuit

Controlled rectification is the process of obtaining a controlled output DC voltage from a constant AC voltage. This can be used in the speed control of the DC motor to provide rapid torque control and a quick starting response [11-16]. In this work, a three-phase half-controlled bridge rectifier has been used. The average output DC voltage varies smoothly by varying the firing angle (α). Different methods of analysis such as state-space and Fourier-series are used to obtain the performance of the DC motor fed from the bridge-rectifier supply

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[17-21]. But these methods do not deal with the prediction of the discontinuous conduction phenomenon which occurs during the operation of the DC motor with a variation of delay angle. This paper deals with the prediction of performance characteristics during the conduction operation of the DC motor fed by a 3-phase half-controlled bridge rectifier, including the transient and steady-state operation with a variation of delay angle as well as the application of load torque at starting. Up to our knowledge and from the literature survey, the reasons for the discontinuous operation of the DC motor fed from a controlled rectifier, as well as their effects on the motor performance, have not been studied in any published work. An analytical solution is used to study the parameters governing the discontinuous conduction phenomenon.

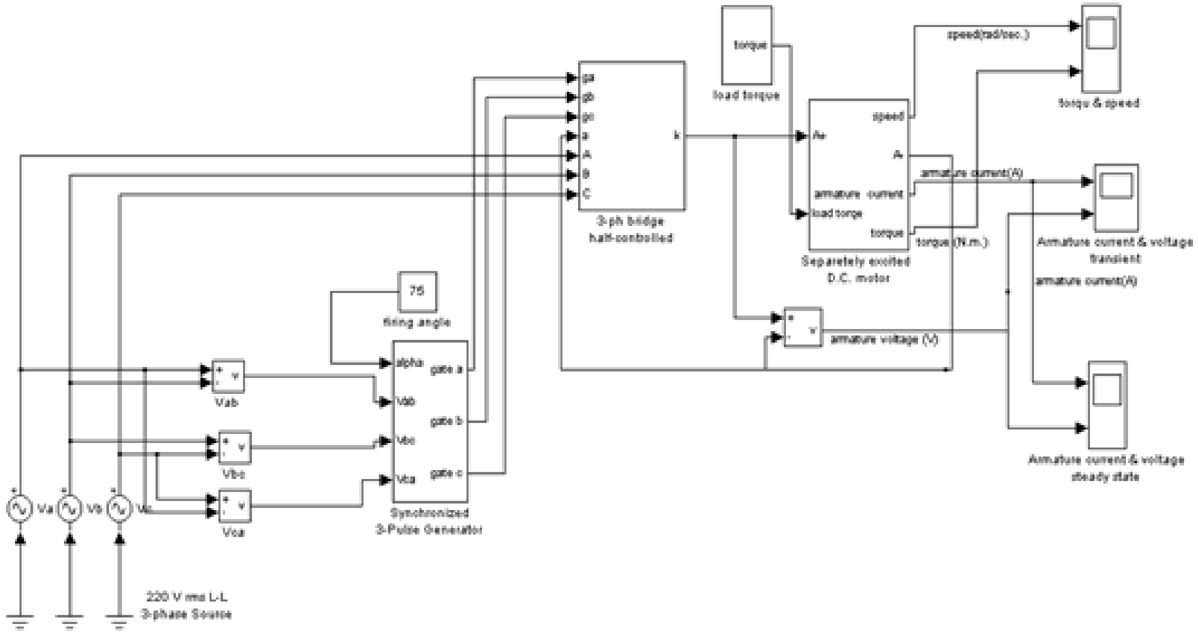

Fig. 2. Simulink Model for the 3-phase half-controlled rectifier.

2. SYSTEM ANALYSIS

2.1 Numerical Solution [2]

The DC motor fed from a half-controlled 3-phase bridge rectifier supply is shown in figure (1). The system is represented by the following voltage and torque balance linear differential equations:

$$\frac{di_a(t)}{dt} = \frac{1}{L_a}\left(V_a(t) - R_a \bullet i_a(t) - K_m \bullet w(t)\right) \qquad \textbf{(1)}$$

$$\frac{dw(t)}{dt} = \frac{1}{J}\left(K_m \bullet i_a(t) - B \bullet w(t) - T_L\right) \qquad \textbf{(2)}$$

Where:

V_a= average motor armature voltage (V).
i_a= instantaneous motor armature current (A).
w(t)= instantaneous motor speed (rad./sec.).
B= motor torque friction or damping coefficient (N.m/rad./sec.).
K_m= motor constant (N.m/A).
J= motor moment of inertia (Kg.m^2)
L_a= motor armature inductance. (H)
R_a= motor armature resistance. (Ω)

T_L= motor load torque (N.m)

There are two distinct cases in which the conduction periods of the

thyristors and diodes are different. These cases are α≤60° and α>60°, where (α) is the firing delay angle of the thyristors. Tables (1) and (2) give the conduction periods of thyristors and diodes and the armature voltage for α≤60° and α>60°, respectively.

Table 1: 3-phase bridge half-controlled rectifier (α≤60°).

Conduction period (degree)	**Conduction Thyristor and Diode**	**Load voltage(Va)**
$\alpha \to 60+\alpha$	T_1 & D_6	V_{ab}
$60+\alpha \to 120+\alpha$	T_1 & D_2	V_{ac}
$120+\alpha \to 180+\alpha$	T_3 & D_2	V_{bc}
$180+\alpha \to 240+\alpha$	T_3 & D_4	V_{ba}
$240+\alpha \to 300+\alpha$	T_5 & D_4	V_{ca}
$300+\alpha \to 360+\alpha$	T_5 & D_6	V_{cb}

Table 2: 3-phase bridge half-controlled rectifier (α≥60°).

Conduction period (degree)	**Conduction Thyristor and Diode**	**Load voltage(Va)**
$\alpha \to 60+\alpha$	T_1 &D_6	V_{ab}
$60+\alpha \to 120+\alpha$	T_1 & D_2	*zero*
$120+\alpha \to 180+\alpha$	T_3 & D_2	V_{bc}
$180+\alpha \to 240+\alpha$	T_3 & D_4	*zero*
$240+\alpha \to 300+\alpha$	T_5 & D_4	V_{ca}
$300+\alpha \to 360+\alpha$	T_5 & D_6	*zero*

Where

$V_{ab}=V_{Lm}sin(wt+60)$
$V_{ac}=V_{Lm}sin(wt)$
$V_{bc}=V_{Lm}sin(wt-60)$

The computation starts with initial conditions i_a=0 , w=0 and wt= α. Then, the computer calculates the new values of armature current and speed at each iteration step, and the rectifier is tested whether in the ON or OFF state of conduction. If the rectifier is in the OFF state, then the equation (1) above vanishes, and equation (2) becomes:

$$\frac{dw(t)}{dt}=\frac{1}{J}\left(-B\bullet w(t)-T_L\right) \quad \textbf{(3)}$$

If at any instant (i_a= 0) (discontinuous conduction state), equation (3) has to be solved for succeeding iterations until the rectifier becomes in ON state. A flow chart of the computer program is shown in Figure 3. Both transients, as well as steady-state solutions are obtained.

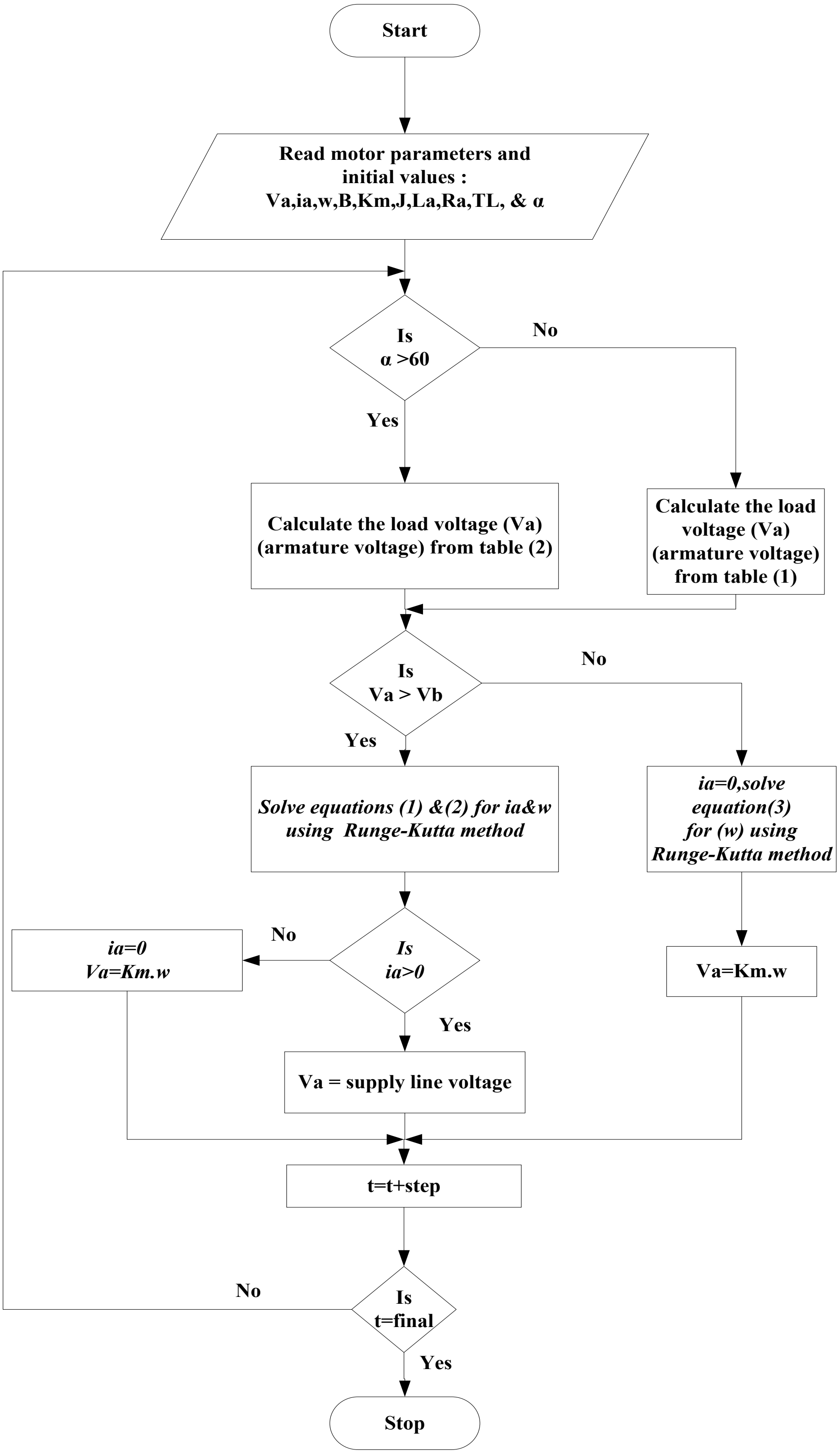

Fig. 3. Flowchart of the computer program.

2.2 Analytical solution [3]

During the ON state of the rectifier, the instantaneous armature current equation can be written as:

$$i_a(t) = \frac{V_{Lm}}{Z}\sin(wt + \alpha - \Phi) - \frac{V_b}{R_a} + \left\{\frac{V_b}{R_a} - \frac{V_{Lm}}{Z}\sin(\alpha - \Phi)\right\}e^{-\frac{R_a}{L_a}t} \quad \textbf{(4)}$$

Where V_{Lm}=maximum 3-phase supply line voltage.

$Z = \sqrt{R_a^2 + X_{La}^2}$ =armature impedance (Ω).

$\Phi = \tan^{-1}\left(\frac{X_{La}}{R_a}\right)$=impedance angle.

V_b = armature back e.m.f = $K_m.w$(t)

In case of discontinuous conduction, the following condition must be satisfied in equation (4):

$(i_a(t)) = 0$ **at** $wt = 0$ **(5)**

$(i_a(t)) = 0$ **at** $wt = \theta$ **(6)**

Where (θ) is the conduction angle of the rectifier. In a discontinuous conduction: θ= (2Π/3)-Δ.

Where Δ is the discontinuous conduction angle. From equations(4-5), the condition of discontinuous conduction is derived as:

$$\frac{V_b}{R_a} \geq \frac{V_{Lm}}{Z}\sin(\alpha - \Phi) \quad \textbf{(7)}$$

Also, to find the discontinuous conduction angle (Δ), equation (6) is substituted in equation (4), and the result is a transcendental equation that the computer can solve to find the angle (Δ).

3. RESULTS AND DISCUSSION

A Simulink/MATLAB results were taken on a small separately excited DC motor, which has the following parameters: R_a=4Ω, L_a=0.086 H, K_m=1.46 N.m/A, J=0.017 Kg.m^2, V_a=220 V, field resistance (R_f)=370 Ω, field voltage (V_f) =220 V, rated speed =1500 r.p.m and the rated power=1.2 KW. The motor is fed from a half-controlled rectifier connected to a 3-phase supply, 220 V line voltage, and (50) Hz supply frequency, as shown in Figure 1.

Figure (4) shows the MATLAB results for the armature voltage and armature current at the firing delay angle (α=30°) of the rectifier with the motor starting at no load torque. Figure (5) shows the steady-state armature voltage and current when (α=60°) with no-load torque. Figure (6) shows the steady-state armature voltage and current when (α=60°) with a load torque of (5) N.m. applied to the motor at start. From these results, it can be shown that the armature voltage and current are continuous for small values of firing delay angles and high load torque application. At the same time, they have become discontinuous, and spikes appear at light loads and high firing delay angles of the rectifier.

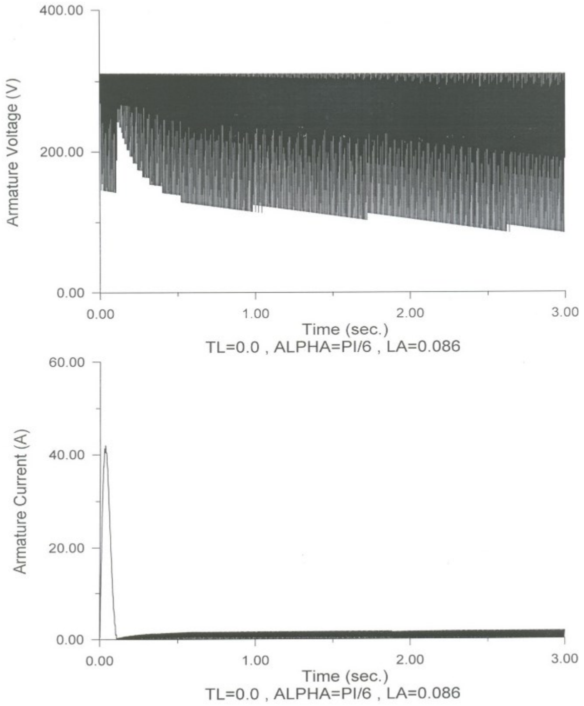

Fig. 4: Matlab results for starting of motor voltage and current.

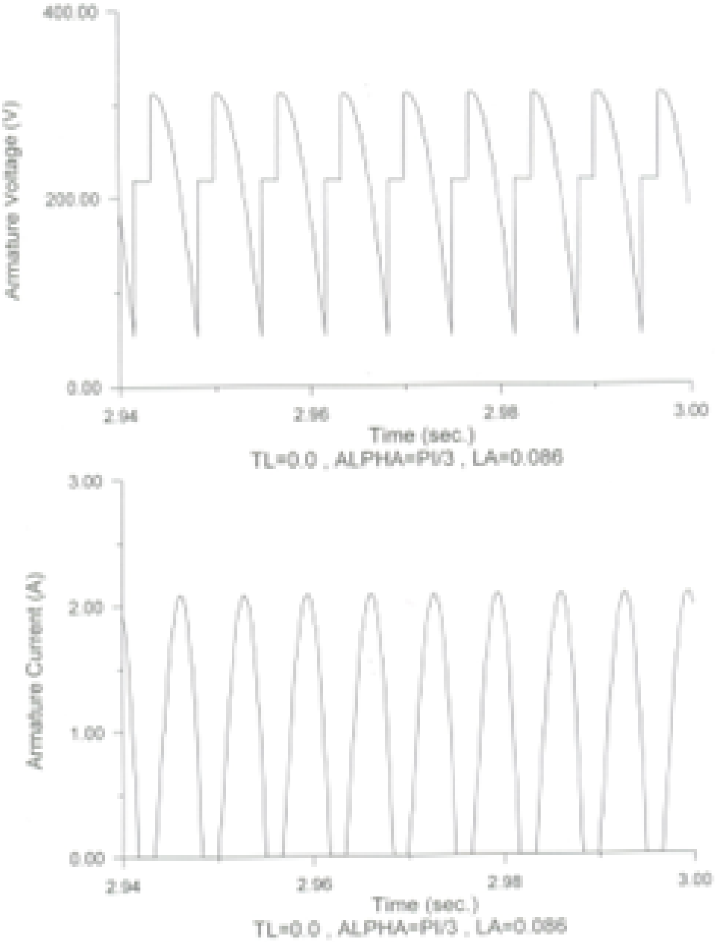

Fig. 5. Matlab results for steady-state motor voltage and current.

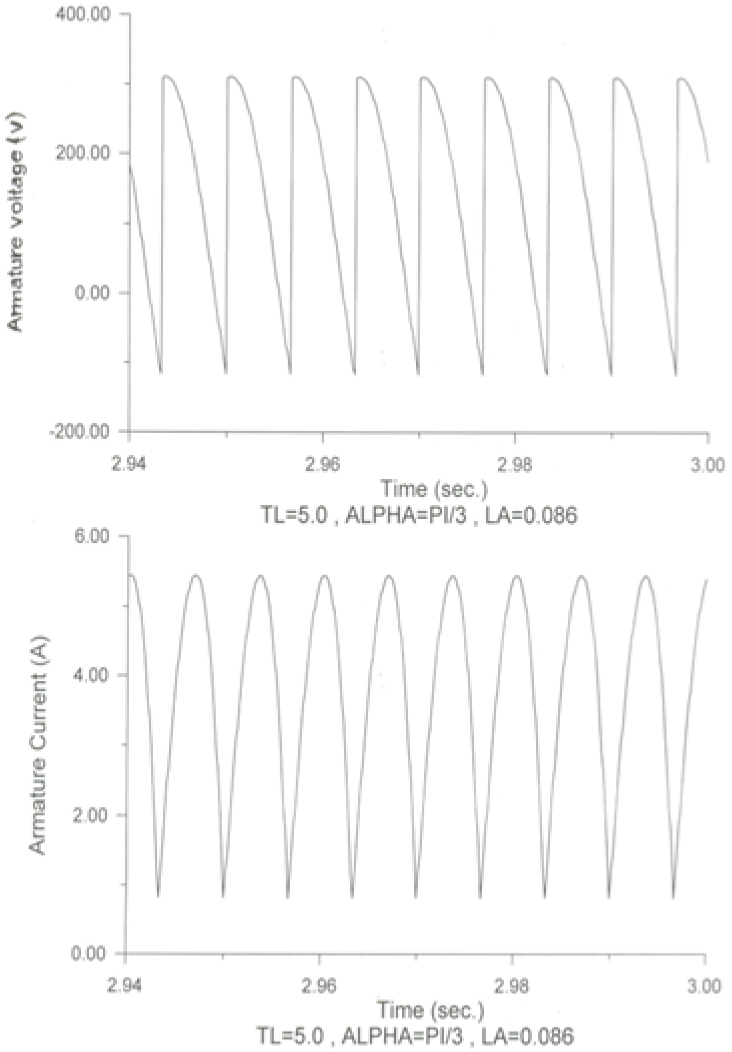

Fig. 6. Matlab results for steady-state motor voltage and current.

4. CONCLUSION

Numerical analysis using MATLAB/Simulink is applied for studying the performance of separately excited DC motor fed from a 3-phase bridge half–controlled rectifier. Motor voltage and current are obtained for both continuous and discontinuous conduction cases. It is noted that full load torque and advanced firing angles ($\alpha \leq 30^o$) lead to continuous conduction, while no-load torque and delayed firing angles ($\alpha \geq 30^o$) result in discontinuous conduction, and high spikes will appear in the motor voltage. From these results, the DC motor must be started at an advanced firing angle ($\alpha \leq 30^o$) with a load torque to avoid the discontinuous conduction case, which leads to a deterioration in the performance of the motor.

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