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Simulation and Analysis of Full Wave Bridge Rectifier Connected to DC/DC Buck Converter Feeding DC Motor

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Abstract:In present day situation, the analysis of drive circuits for DC motors are advancing and recent innovative technologies make the system more cheaper and market friendly. The adjustable speed drive system is utilized for speed control purpose of DC motor. In this paper, open loop analysis and output response is studied for a Single phase full bridge rectifier connected to a DC motor feeding from a DC/DC Buck converter. The voltage regulator between two networks make the load voltage adjustable. The Matlab simulation software is used to analyze the system performance and its characteristics under various factors. The performance parameters such as ripple factor, motor and rectifier efficiency, voltage and current THD, and form factors of the system for various firing angles are compared and analyzed. Moreover it is observed that the system output voltage remains constant eventhough there is load and field disturbance in motor. Besides, if the firing angle increases form factor, ripple factor increases whereas the motor efficiency and rectifier efficiency decreases. The main aim of the paper is to prove that the developed model must transmit power with high efficiency and low ripple compared to existing models. The results presented in this paper match with the experimental results.

Keywords : Buck converter, DC motor, Form factor, Full bridge controlled rectifier, THD

I. INTRODUCTION

The analysis of DC motor fed single phase fully controlled rectifier is current topic which is discussed widely for many application purposes. High efficient with low ripple energy transmission is still a challenging task to be accomplished. . Thespeed of a dc motor can be controlled by controlling the dcvoltage across its armature terminals[1]. The aim of the paperis to simulate the dc drive scheme with armaturevoltagecontrol. The variable armature voltage control is generatedfrom single phase fully controlled bridge rectifier. Moreover, MATLABSimulation was developed to predict motor performance. Aswe know that rectifier control of dc motor is basicallyarmature voltage controller. In our present work we have simulated rectifier controlled DC drive circuit feeding from buck converter andcomparing their performance with [9] .

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The Root MeanSquares (r.m.s)values of current and voltage are responsible for copper losseswhile averagevalues are responsible for torque produced. Theaccurate prediction of the performance of dc motors can be determined by accurate evaluation of its parameters[2].

The specifications of the dc motor that we have used are5 HP,240V, 1750 rpm, field 150V separately excited dc motor.

II. DESIGN OF SINGLE PHASE RECTIFIER

A single phase rectifier is a power electronic circuit used to convert AC voltage and current to pulsating DC voltage and current with constant factors. It includes four bridge connected thyristors, AC voltage source fed from grid and a DC load. The design of a 3.73 kW, 400 V single phase full bridge rectifier feeding a DC load is carried out and tabulated as shown in Table 1. The operation of the rectifier is discussed below.

Table 1. Design Parameters of rectifier

Components	Designed values
AC voltage source	400 V, 50 Hz
Thyristor(SCR)	0.4 V , 0.001 Ω
Source inductance	10 μH
Coupling capacitor	60 mF
PIV(switches)	-600 V

Switches T1 and T2 are turned ON simultaneously for a period 20 ms i.e. half cycle period of AC supply voltage leaving T3 and T4 switches turned OFF. Alternatively, Switches T3 and T4 are triggered simultaneously for a period of next half cycle i.e., 20 ms leaving the remaining two switches reverse biased. The commutation time for the switches is calculated using Equation(1).

$$t_c = \frac{\pi-\alpha}{\omega} \qquad (1)$$

The maximum average output voltage is obtained at firing angle α = 0º. The average DC output voltage and power are given by Equations (2) and (3).

$$V_o = \frac{2V_m}{\pi} cos\alpha \qquad (2)$$

$$P_0 = V_0 I_0 \qquad (3)$$

Where

V_0 is average output voltage.
V_m is maximum value of input voltage.
w is switching frequency(rad/sec).

III. DC/DC BUCK CONVERTER

A DC/DC buck or step down converter is practically used to step down and regulate the input voltage delivering an output power equal to or less than the input DC power. A 3.73 kW DC/DC buck converter is designed and its parameters are listed in Table 2. The operation of the regulator is discussed below.

Table 2. Design Specifications of Buck converter

Components	*Parameters*
DC voltage source	*400 V*
Switch, S	*-600 V(PIV)*
Diode	*-450 V(PIV)*
Inductance, L	*3mH*
Capacitance, C	*2.2 μH*
Switching Frequency	*50 kHz*
Load	*3.73 kW, 240 V*

When the MOSFET switch is turned on for Ton seconds, the input voltage is applied across the LC load. The current flows through the switch S, inductance L, capacitance C, load and back to the source. When S is turned OFF, the diode D gets turned ON leaving the LC load disconnected from supply. During this period, capacitor current flows through the load operating the converter in continuous conduction mode.

The average output voltage across the load obtained is expressed using the Equation(4).

$$V_a = V_0 . k \tag{4}$$

The design values of L and C are calculated using the Equations(5) and (6).

$$L = \frac{V_0 k(1-k)}{\Delta I_L \times f} \tag{5}$$

$$C = \frac{\Delta I_L}{8 f \Delta V_c} \tag{6}$$

Where

k is duty cycle.
f is switching frequency
ΔI_L is ripple inductor current(4%)
ΔV_C output ripple voltage.
V_a is average output voltage.
V_0 is input voltage to the converter.

IV. DESIGN OF A DC MOTOR LOAD

A motor is an electromechanical device used to convert an electrical energy into a mechanical energy based on the principle of electromagnetic induction and Fleming's left hand rule. A 5 HP, 240 V, 1750 rpm separately excited DC motor is designed and the specifications are listed in Table 3.

Table 3. Design Specifications of DC Motor

Parameters	Values
Rating	5 HP, 240 V
Speed at rated power	1750 rpm
Armature resistance	0.78 ohms
Armature inductance	0.016 H
Field resistance	150 ohms
Field inductance	112.5 H
Mutual inductance	1.28 H
Rated torque	23.75 Nm

The field system is separately excited by a DC voltage of 150 V and the armature system is connected across the regulated voltage supply. The voltage across the armature is given by the equation(7).

$$E_a = V_a - I_a R_a - L_a \frac{di_a}{dt} - V_{brush} \tag{7}$$

Where

E_a is armature voltage.
$I_a R_a$ is armature voltage drop.
V_{brush} is brush drop voltage(1 – 2 V/brush).

The torque input to the machine is calculated using the Equation(8).

$$T_m = \frac{60 P_a}{2\pi N} \tag{8}$$

The electrical and equivalent mechanical model of the DC motor are synthesized and given in Equations(9) and (10).

$$V_a(s) = E_a(s) + I_a(s)[R_a + sL_a] \tag{9}$$

$$T_e(s) = T_m(s) + \omega(s)[B + Js] \tag{10}$$

Where

B is equivalent friction of motor.
J is equivalent inertia of motor.

V. OPEN LOOP ANALYSIS OF DC MOTOR FED FROM SINGLE PHASE BRIDGE RECTIFIER FEEDING BUCK CONVERTER

The single phase full bridge rectifier, DC/DC buck converter and DC motor load are integrated and open loop analysis is performed. The DC motor is considered as effective load to the rectifier. The open loop circuit model of the device is simulated using Matlab/Simulink model as shown in Figure 1 and their performances are evaluated.

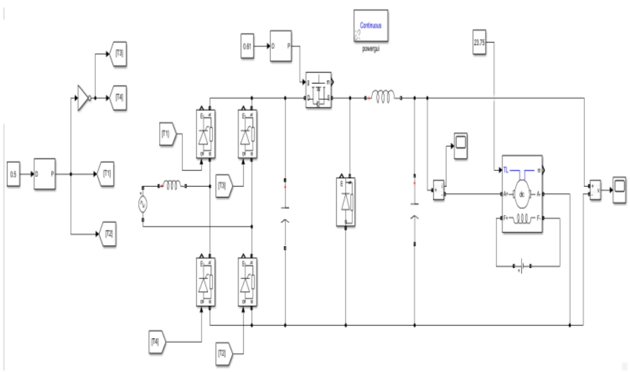

Figure 1 Simulation model of DC motor fed from regulated Single phase rectifier

The simulation model is analyzed for steady state and dynamic conditions of the system.

A. Steady State Analysis

The load torque, input voltage and duty ratios are kept constant throughout the simulation. The simulation is run for 0.5 seconds. The output voltage response and output power response data are captured and shown in Figures 2 and 3 respectively.

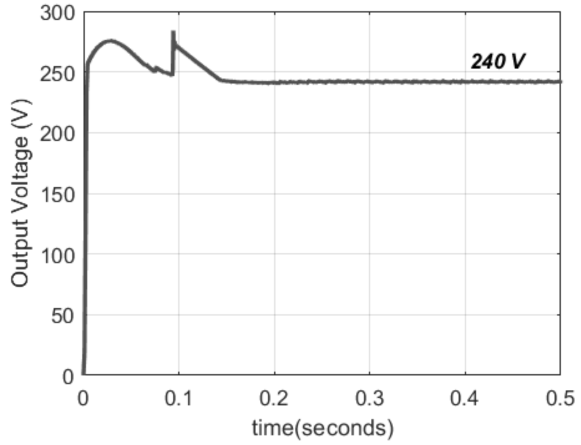

Figure 2. Output voltage response of DC motor under T_L = 23.75 Nm

From Figure 2, it is observed that the voltage initially rises to 280 V and reaches a steady state value of 240 V in 0.15 sec.

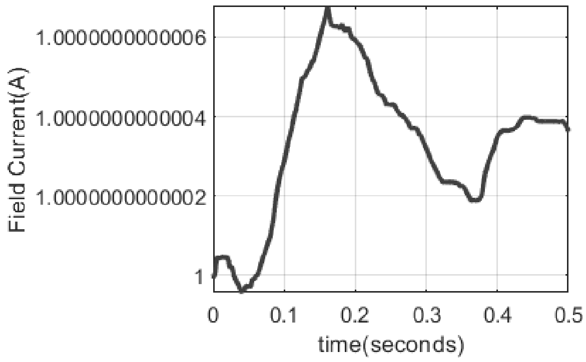

Figure 3 Field current variation under constant torque

It is clear that the field current is maintained at 1A and varied between 1 A and 1.0000000000008 A.

B. Dynamic Analysis

The dynamic analysis of the system involves the disturbance due to variation inmotor torque and speed variation. These factors are discussed below separately and their corresponding output responses are analyzed.

C. Performance of system due to torque variation

In a scenario where torque may vary during an operation and it varies from 23 Nm to 26 Nm at 0.5 sec. The simulation is run for 0.8 seconds.

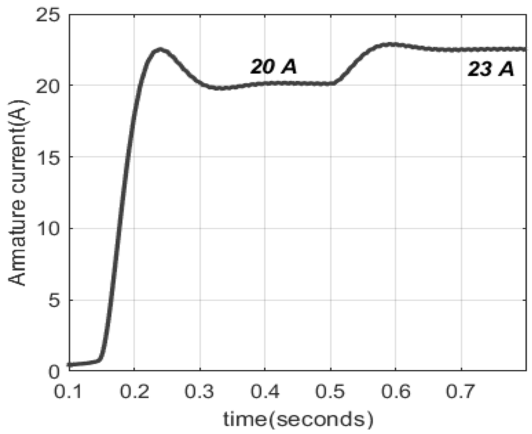

Figure 4. Output current response due to TL variation

The output responses are plotted as shown in figure 4. The current suddenly increases from 20A and reaches 23 A in 0.12 sec due to torque variation from 23 Nm to 26 Nm at 0.5 seconds.

D. Performance of system due to torque variation

In a scenario where field current may vary during an operation. The field current undergoes a step variation from 1 A to 1.33 A at 0.4 sec. The simulation is run for 1 second. The output response is shown in Figure 5.

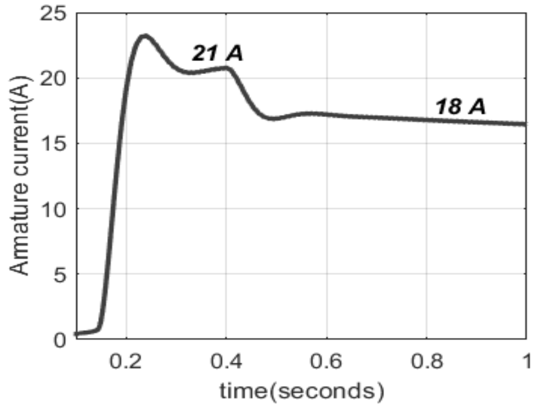

Figure 5 Armature current response for field current variation

From the Figure 5, the armature current decreases from 21 A and reaches 18 A in 0.15 seconds due to step change in field current from 1 A to 1.33 A.

E. EQUATIONS

The output voltage of the DC motor is calculated as follows:

Mode I (Switch S is ON)

When S, T1 and T2 are turned ON, on applying KVL we get,

$$V_m \sin \omega t = L\frac{di}{dt} + E_a + I_a R_a + L_a\frac{di_a}{dt} \qquad (11)$$

On solving we get,

$$i_a(t) = \frac{V_m}{Z_1}\{Ae^{-t/\tau} + B\cos\omega t + \frac{C}{\omega L_1}\sin\omega t\} \qquad (12)$$

Where

$$A = \frac{-R_a{}^2}{\omega},\ B = \frac{-R_a{}^2}{\omega L} \text{ and } C = \frac{\omega R_a}{L}$$

Mode II (Switch S is OFF)

When diode D is ON, the voltage across the capacitor is fed to DC motor load. Applying KVL,

$$\frac{Cdv_a}{dt} = \frac{1}{L}\int_{t1}^{t2} i\,dt + i_a(t) \qquad (13)$$

The average voltage across the DC motor is calculated using Equation (14).

$$V_a = V_m k_1 \cos\alpha \quad (14)$$

Where

$k_1 = \frac{2k}{\pi}$ is constant.

VI. PERFORMANCE PARAMETERS

The performance parameters of the integrated system is tabulated and shown in Table IV.

Firing angle(deg)	0	30	45	60	90
Rectifier efficiency (%)	81	77	71.5	68	57.6
Form factor	1.13	1.16	1.23	1.305	1.59
Ripple factor	0.6	0.675	0.694	0.785	0.995
Motor efficiency (%)	84.23	83.56	80.45	79.56	68.25
Voltage THD	0.28	0.295	0.30	0.35	0.46
Current THD	0.135	0.147	0.138	0.124	0.182

It is clearly seen that ripple factor increases with increase in firing angle to the thyristor.

VII. CONCLUSION

The analysis of full bridge rectifier based circuits is simulated using Matlab/Simulink and obtained experimental results were tabulated. The performance parameters shows that themotor efficiency for single phase fully controlled rectifier fedDC motor is better when compare with the performance described in [9]. Besides,if the firing angle increases, the form factor,ripple factor increases but with the increase in firing anglemotor efficiency and rectifier efficiency decreases.

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