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Closed loop Modelling of Flyback Converter for Speed Control of Separately Excited DC Motor

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Abstract—The speed of separately excited DC motor can be controlled from below and up to rated speed using flyback Converter as a DC-DC converter. The firing circuit receives signal from controller and then flyback gives variable voltage to the armature of the motor for achieving desired speed. The open control loops for controlling the speed of DC motor with flyback converter is to be developed. The model is simulated using PSIM .The simulation of DC motor drive is done and analysed under varying speed.

Keywords— Flyback converter, AC to DC converter, DC Motor, high voltage output, single control switch.

I. INTRODUCTION

Every electronic circuit is assumed to operate with some supply voltage which is usually assumed to be constant. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used with the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters [1].

The dc motors are used in various applications such as defence industries, Robotics, because of their simplicity, easy of application, reliability and lowest cost etc. the development of high performance motor drives is very important in industrial and other purpose applications. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response. In these applications, the motor should be precisely controlled to give the desired performance [2].

Single-switch AC-DC high frequency switching converter topologies with transformer isolations used for speed controlled of DC motor A detailed analysis and design is presented for single-switch topologies flyback, converters, with high frequency isolation for discontinuous conduction modes (DCM) of operation [3].

This approach is based on the cascade combination of a diode bridge rectifier and flyback converter. Step- down and step-up characteristics of the output voltage can be obtained.

Fly-back converter is the wildly used SMPS circuit for low output power applications where the output voltage is changed by changing the duty ration. The output power of fly-back type SMPS circuits may vary from few watts to less than 100 watts. The overall circuit topology of this converter is considerably simpler than other SMPS circuits. Input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by a simple capacitor filter. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation. In respect of energy-efficiency, fly-back power supplies are inferior to many other SMPS circuits but its simple topology and low cost makes it popular in low output power range.

The commonly used flyback converter requires a single controllable switch like, MOSFET and the usual switching frequency is in the range of 100 kHz. A two-switch topology exists that offers better energy efficiency and less voltage stress across the switches but costs more and the circuit complexity also increases slightly. The present lesson is limited to the study of fly-back circuit of single switch topology.

II. MODELING AND SYSTEM DESCRIPTION

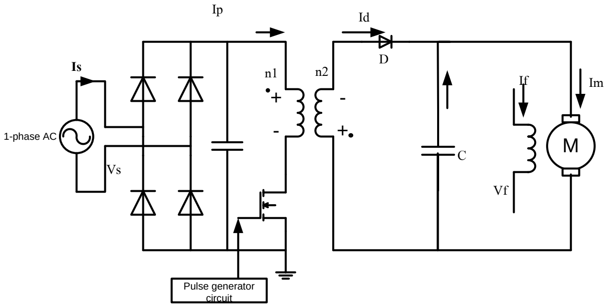

Fig. 1 Schematic diagram of flyback converter with DC Motor

Flyback transformer stored the energy from output of rectified circuit (DC) during switch is ON, and after the turn off it release the energy. The output voltage can be regulated by adjusting the amount of energy stored.

This system consists of a flyback converter using one MOSFET (M) and motor is used which is separately excited DC motor [1].

$$D=\left(\frac{Ton}{T}\right) \qquad (1)$$

Where, Ton is the ON period of the MOSFET, and T is the total period. ON time period Ton can be varied by changing the control voltage signal that is compared with the carrier signal to obtain the gate pulses.

A. Mode 1

When switch M is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode D connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary. Thus with the turning on of switch M, primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current.

Supply voltage is given by:

$$V_1 = V_d = L_m \frac{di_{Lm}}{dt} \Rightarrow \frac{diL_m}{dt} = \frac{\Delta iL_m}{dt} = \frac{\Delta iL_m}{DT} = \frac{V_d}{L_m} \qquad (2)$$

When M is closed:

$$\left(\Delta i_{L_m}\right) = \frac{V_d DT}{L_m} \qquad (3)$$

On the load side of transformer:

$$V_2 = V_1\left(\frac{N_2}{N_1}\right) = V_d\left(\frac{N_2}{N_1}\right) \Rightarrow V_D = -V_o - V_d\left(\frac{N_2}{N_1}\right) \qquad (4)$$

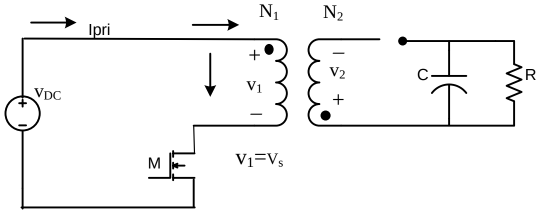

Fig.2 when main switch is ON

This mode of circuit has been described here In Mode-1 of circuit operation. Fig. (2) Shows current carrying part of the circuit and circuit that is functionally equivalent to the fly-back circuit during mode-1.

In Mode-1, the input supply voltage appears across the primary winding inductance and the primary current rises linearly. The following mathematical relation gives an expression for current rise through the primary winding.

B. Mode 2

When switch 'M' is turned off after conducting for some time. The primary winding current path is broken and according to laws of magnetic induction, the voltage polarities across the windings reverse. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. Fig. (3) Shows the current path during mode-2 of circuit operation while Fig. (3) Shows the functional equivalent of the circuit during this mode.

Primary voltage when M is open:

$$V_1 = -V_o\left(\frac{N_1}{N_2}\right) \quad \text{But} \quad V_2 = -V_o \tag{5}$$

So,

$$V_1 = V_2\left(\frac{N_1}{N_2}\right) = -V_o\left(\frac{N_1}{N_2}\right) \tag{6}$$

$$V_1 = L_m\frac{di_{Lm}}{dt} = -V_o\left(\frac{N_1}{N_2}\right) \Rightarrow \frac{di_{Lm}}{dt} = \frac{\Delta i_{Lm}}{dt} = \frac{\Delta i_{Lm}}{(1-D)T} = \frac{-V_o}{L_m}\left(\frac{N_1}{N_2}\right) \tag{7}$$

When M is open

$$\left(\Delta i_{Lm}\right)_{open} = -\frac{V_o(1-D)T}{L_m}\left(\frac{N_1}{N_2}\right) \tag{8}$$

Voltage across the switch

$$V_{SW} = V_d + V_o\left(\frac{N_1}{N_2}\right) \tag{9}$$

In mode-2, though primary winding current is interrupted due to turning off of the switch 'M', the secondary winding immediately starts conducting such that the net mmf produced by the windings do not change abruptly. (mmf is magneto motive force that is responsible for flux production in the core. mmf, in this case, is the algebraic sum of the ampere-turns of the two windings. Current entering the dotted ends of the windings may be assumed to produce positive mmf and accordingly current entering the opposite end will produce negative mmf.)

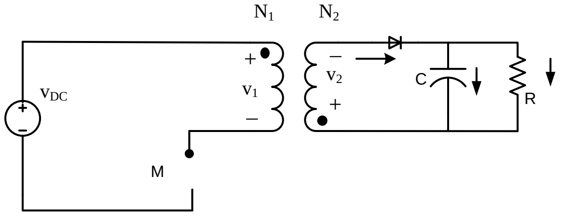

Fig.3 when diode is conduct

Continuity of mmf, in magnitude and direction, is automatically ensured as sudden change in mmf is not supported by a practical circuit for reasons briefly given below. mmf is proportional to the flux produced and flux, in turn, decides the energy stored in the magnetic field.

For steady- state operation,

From equation (2) & (3) is given by:

$$\left(\Delta i_{L_m}\right)_{closed} + \left(\Delta i_{L_m}\right)_{opened} = 0 \tag{10}$$

So,

$$\frac{V_d DT}{L_m} - \frac{V_o(1-D)T}{L_m}\left(\frac{N_1}{N_2}\right) = 0 \tag{11}$$

Output voltage of fly back converter is given by:

$$V_o = V_d\left(\frac{D}{1-D}\right)\left(\frac{N_2}{N_1}\right) \qquad (12)$$

From the above equation (4) if duty ration will changed then output voltage is also changed.

$$\left(L_m\right)_{min} = \frac{V_d(1-D)^2 R}{2f}\left(\frac{N_1}{N_2}\right) \qquad (13)$$

III. OPEN LOOP SIMULATION AND EXPERIMENTAL RESULTS

The performance of the flyback converter is assessed by inspection of the simulation results in the steady state conditions. The experimental system is built in the laboratory for comparison with computed results. Shows the steady-state characteristics for motor voltage, motor current, and supply current and motor speed versus duty ratio at no load [7].

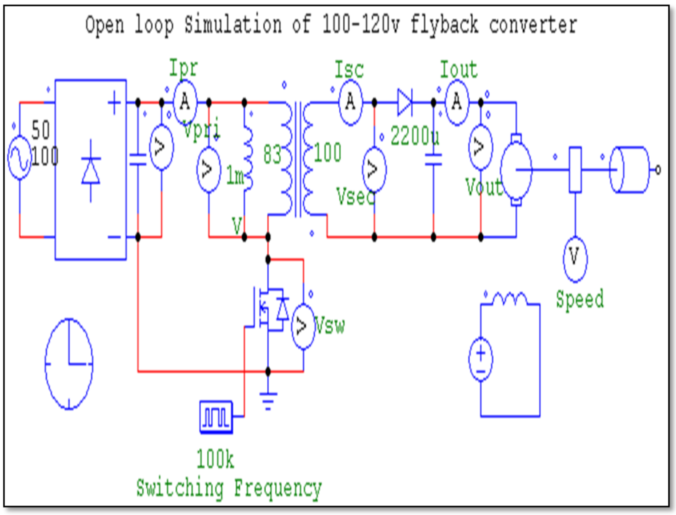

Fig.4 Open loop simulation model of Flyback converter for speed controlled DC motor.

Shows the steady-state waveforms of the supply voltage, current, motor voltage, and motor current and motor speed in the open loop operation with duty ratio maximum to minimum (50% to 40%).

Simulation studies are divided in to five categories:

a) Operation with 50% duty cycle.
b) Operation with 47% duty cycle.
c) Operation with 45% duty cycle.
d) Operation with 43% duty cycle.
e) Operation with 40% duty cycle.

TABLE 1
FLYBACK CONVERTER & MOTOR PARAMETER

Sr. no	Parameters	Value
1	Armature Resistance (R_a)	0.5Ω
2	Armature Inductor (L_a)	0.01 H
3	Armature Current (I_a)	10 amp
4	Field Resistance (R_f)	78Ω
5	Field Inductor (L_f)	0.02 H
6	Field Current (I_f)	0.5 amp
7	Speed In (N)	1200 rpm
8	Terminal Voltage (V_t)	120 V

9	Tunes Ration $\frac{N_2}{N_1}$	0.83
10	Switching Frequency (F_s)	100kH$_h$
11	Capacitor (C)	470 µf

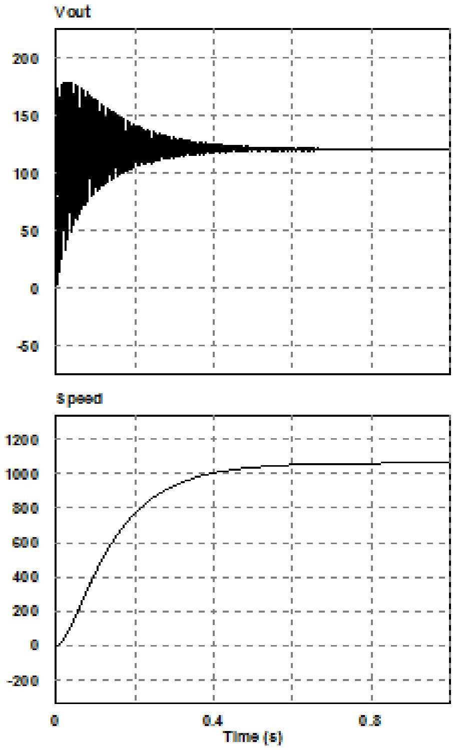

Fig.5 For (50% duty cycle) switching period [0,180]

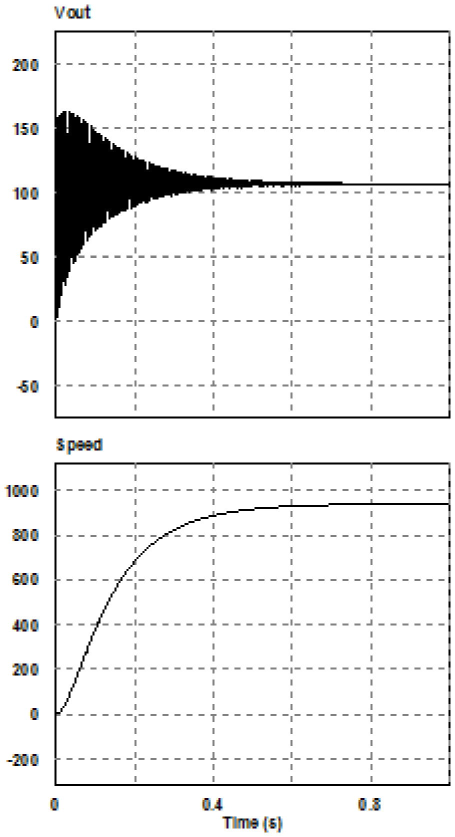

Fig.6 For (47% duty cycle) switching period [0,169]

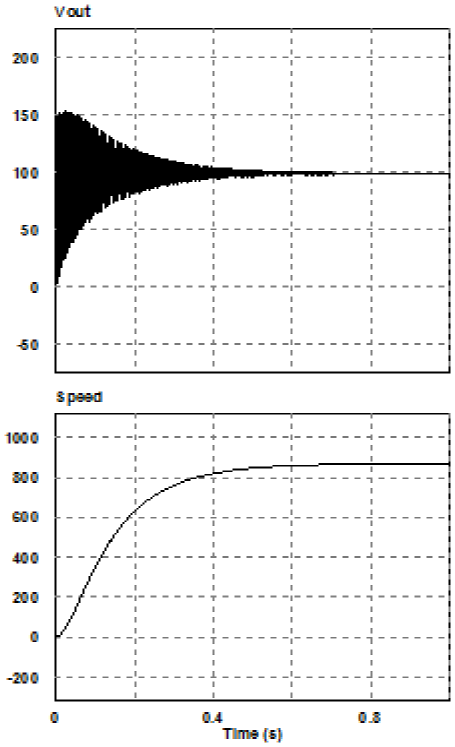

Fig.7 For (45% duty cycle) switching period [0,162]

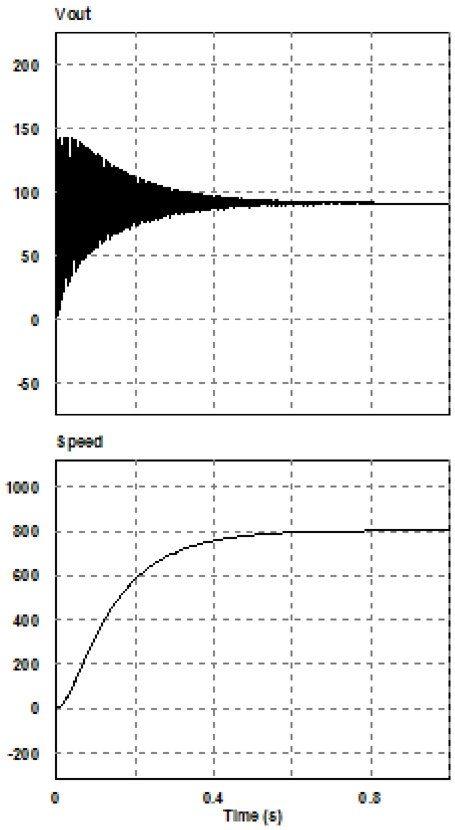

Fig.8 For (43% duty cycle) switching period [0,155]

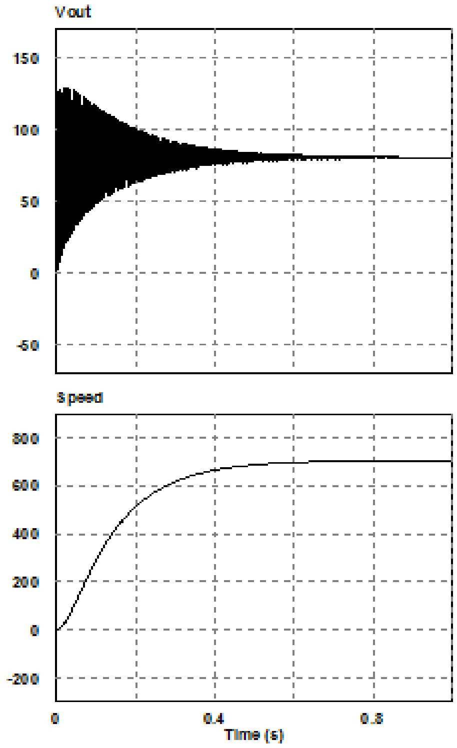

Fig.9 For (40% duty cycle) switching period [0,144]

IV. OPEN LOOP RESULT ANALYSIS

TABLE 2

Constant Input Voltage (V)	Duty Cycle	Measured Speed (rpm)	Calculated Output Voltage (V)
100	50%	1100	120
100	47%	950	106
100	45%	820	98.57
100	43%	790	90.88
100	40%	700	80.32
100	37%	605	70.75
100	35%	500	64.87

I. CLOSED LOOP SIMULATION AND EXPERIMENTAL RESULTS

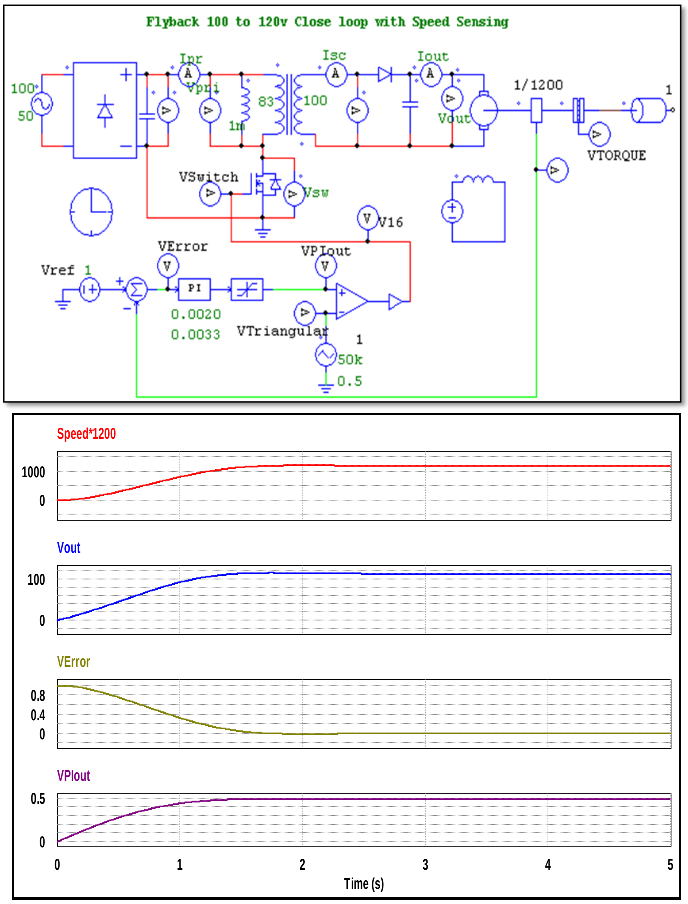

Figure 10 Wave form of Closed loop Speed Sensing Simulation

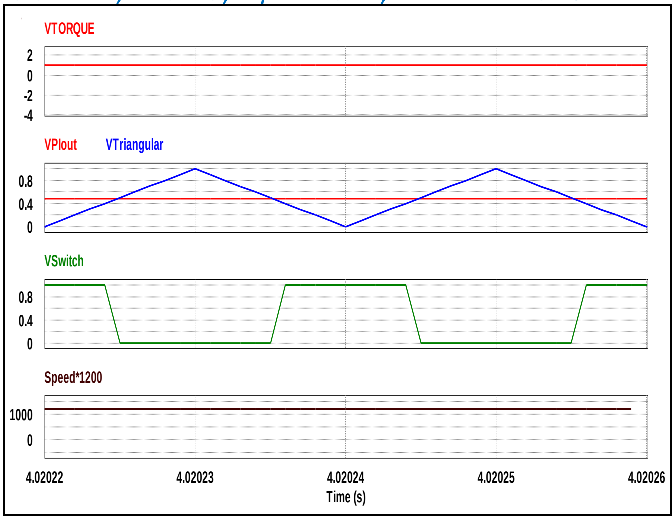

Figure 111 Wave form of Closed loop Speed at NO LOAD Sensing Simulation

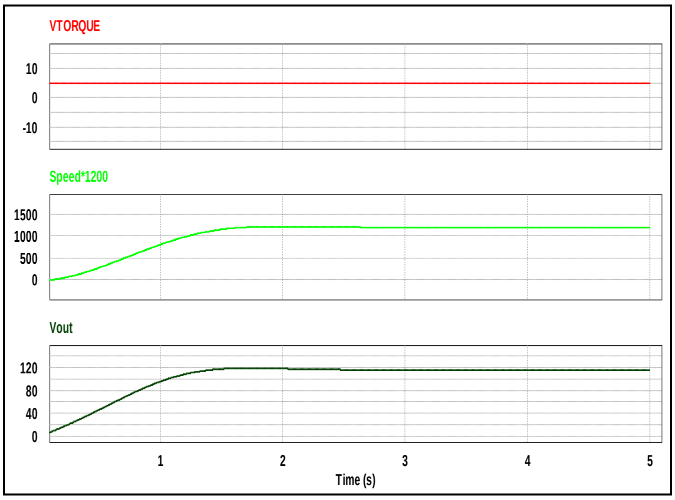

Figure 12 Wave form of Closed loop Speed at T=5 Sensing Simulation

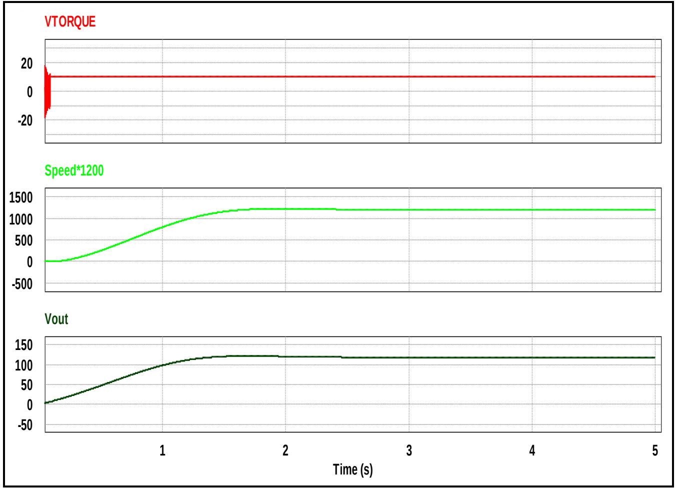

Figure 132 Wave form of Closed loop Speed at T=10 Sensing Simulation

Shows in Fig.(10-13) the steady-state waveforms of the motor voltage, and motor current and motor speed in the Closed loop operation with Different Torque.

II. CLOSED LOOP RESULT ANALYSIS

TABLE 3

SR NO.	Open loop		Closed loop		APPLIED TORQUE (T)
	Speed (rpm)	Output Current (amp)	Speed (rpm)	Output Current (amp)	
1	1200	2.90	1200	1.2	2
2	1190	5.55	1200	4.5	4
3	1160	8.23	1200	6.7	6
4	1142	10.93	1200	8.9	8
5	1115	13.62	1200	11.12	10
6	1090	16.33	1200	13.33	12
7	1050	22.4	1200	20.3	15

CONCLUSION

In this paper a complete modelling and simulation of an open loop as well as Closed loop speed control system for a separately-excited DC motor is developed. This is based on the combination of an uncontrolled diode bridge rectifier and fly back converter. In this fly back converter only one switch (MOSFET) is required for speed controlled therefor switching losses will very less and by changing the duty ratio from 50% to 40% output voltage is to be decreased and speed controlled is too achieved.

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