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Original Research Article

DESIGN OF A SYSTEM SAFETY ELECTRIC BREAK

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Abstract: In this paper the design of a safety electrical break for any DC motor especially the motor used with the DC-DC converter circuit is presented. The effect of ON time upon maximum current of the DC-DC converter is illustrated. The current increases as the t_{on} increases. The effect of injected voltage upon DC chopper performance is illustrated. The injection-protected voltage has a pronounced effect upon the chopper maximum current. It is reduce current through the chopper till it reaches the threshold current present through the power switch data sheet. The DC chopper under investigation has two modes of operation when the injection voltage equal to 12V. Inversely, at another level of the injected voltage the chopper has only one mode of operation .At this case the chopper operation works at the discontinuous mode only. As the current through the switch decreases to the previous value, the power switch will be turned OFF immediately. After that the next pulse must be generated for triggering the switch once again. The electrical break for the DC chopper motor is safe because the reverse current injected to the DC chopper circuit is decreased step by step and not rapidly. Hence, the breaking of the motor becomes very safe. The proposed work is verified on test cases and proven to be reliable.

Keywords: DC Chopper, DC-DC Converter, DC Motor, Safety Electrical Break

Introduction

DC motor is an electric power used in many applications such as on small size in toys and disk drives, or in large sizes to operate steel rolling mills, paper machines, or even tractors. Operating DC motor continuously all the time or turn it off all the time is not accepted using in DC motor applications, consequently, operating DC motor at specific times and disconnect it at other times by using power electronic

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devices is the solution. The control of electric power with power electronic devices has become increasingly important over the last 20 years. Whole new classes of motors have been enabled by power electronics, and the future offers the possibility of more effective control of the electric power grid using power electronics. The modern of power electronics began with the introduction of thyristors in the late 1950s. Now there are several types of power devices available for high-power and high frequency application [1]. The most notable power devices are gate turn-off thyristors, power Darlington transistors, power MOSFETs, and insulated-gate bipolar transistors (IGBTs). Power semiconductor devices are the most important functional elements in all power conversion applications. The power devices are mainly used as switches to convert power from one form to another. They are used in motor control systems, uninterrupted power supplies, high-voltage DC transmission, power supplies, induction heating, and in many other power conversion applications[2-4]. There are two ways to control with DC motor; mechanical and electrical, one of the electrical ways is DC CHOPPER. A chopper circuit is used to refer to numerous types of electronic switching devices and circuits. Through this paper, Different levels of voltages are supplied to the load using the Chopper. The illustration of the effect of voltage levels to the load is illustrated. The effect of frequency levels upon the performance of the Chopper circuit is presented. The DC Chopper output current is analysed at different duty cycles is illustrated. The effect of changing frequency is presented through the paper. Chopper drives are used all over the world in traction applications such as battery electric vehicles and mass rapid transit systems. A DC chopper is connected between a fixed-voltage DC source and a DC motor to vary the magnitude of the armature voltage. In addition to armature voltage control, a DC chopper can provide regenerative braking of the motors and can return energy back to the supply[5]. The chopper system can offer several operational benefits over conventional means of rectification [6]. There are many papers wrote about the chopper device in controlling the DC motor, but The main subject of this research is to build a computer program shows the levels of voltage when it is injected in the electrical circuit and its impact on the electric motor in braking process.

I. PROBLEM FORMULATION

(Fig. 1a) illustrates the basic principles of a chopper, in which both *Vo* and *Io* can only be positive. In that circuit diagram, the thyristor symbol enclosed in a circuit represents a thyristor that my be turned on and commutated by means of circuit elements not included in the diagram; D_1 is a free-wheel diode. Two possible conditions of operation are illustrated in (Fig. 1b and c), where it is assumed that the control is by means of frequency modulation.

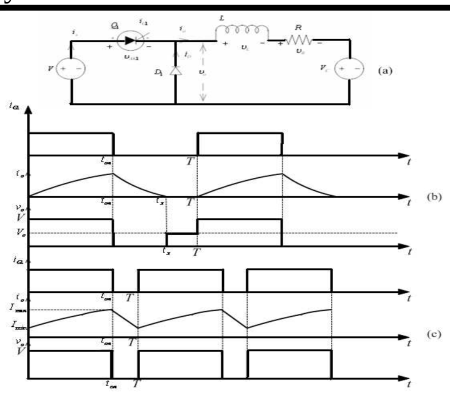


Fig. 1 : Basic of chopper circuit and voltage diagrams.

a. Circuit diagram of a DC chopper
b. Discontinuous mode
c. Continuous mode

In (Fig. 1b) the load current i_o is discontinuous, so that during the interval for which i_o is zero, $\upsilon_o = Vc$. In (Fig. 1c), the periodic time T has been reduced to such an extend that i_o has not ceased to flow before Q_1 is again turned on. As a consequence, the output voltage υ_o consists of a train of rectangular pulses of magnitude V. An increase of load circuit inductance L or a reduction of Vc would also tend to result in a continuous output current.

It is convenient to start by considering the case of continuous current operation illustrated in (Fig.1c). In the circuit of(Fig.1a), the equation of Kirchhoff's Voltage Law (KVL) is

$$-\upsilon_o + \upsilon_L + \upsilon_R + Vc = 0$$

Where

υ_o = output voltage

υ_L = inductance voltage

υ_R = resistance voltage

Vc=DC source

from which

$$\frac{di_o}{dt} + \frac{R}{L} i_o = \frac{\upsilon_o - Vc}{L} \quad (2)$$

i_o =output current

R, L = the resistance and inductance of the motor

When thyristor Q_1 is turned on at $t = 0$, then at $t = 0^+$, υ_o =**V**, and i_o =$I_{\min}$.

From equation 2 and these initial conditions, the current will be

$$i_o = \frac{V - Vc}{R}\left(1 - \varepsilon^{-t_{on}/\tau}\right) + I_{\min}\varepsilon^{-t_{on}/\tau} \quad (3)$$

$0 \le t \le t_{on}$

Where

V = supply voltage

$I_{\min}$ =minimum current

t_{on} = on time

$$\tau = \frac{L}{R} \quad (4)$$

ε = exponential

At t=t_{on}, when Q_1 is commutated, the maximum current will be

$$\boldsymbol{I}_{\max} = i_o = \frac{V - Vc}{R}\left(1 - \varepsilon^{-t_{on}/\tau}\right) + I_{\min}\varepsilon^{-t_{on}/\tau} \quad (5)$$

and since υ_o then become zero. Due to condition of the free-wheeling diode D_1.

$$\frac{di_o}{dt} + \frac{R}{L} i_o = -\frac{Vc}{L} \quad (6)$$

Where

$$t^` = t - t_{on} \quad (7)$$

At $t^` = 0^+$, $i_o = \boldsymbol{I}_{\max}$

$$i_o = \frac{-Vc}{R}\left(1 - \varepsilon^{-t^`/\tau}\right) + I_{\max}\varepsilon^{-t^`/\tau} :$$

$$t_{on} \le t \le T \quad (8)$$

T=time period

At $t^` = T - t_{on}$, or t=T, $i_o = I_{\min}$

$$i_{\min} = -\frac{Vc}{R}\left(1 - \varepsilon^{-(T-t_{on})^`/\tau}\right) + I_{\max}\varepsilon^{-(T-t_{on})^`/\tau} \quad (9)$$

Solving the previous equations we get

$$I_{\max} = \frac{V}{R}\frac{\left(1 - \varepsilon^{-t_{on}/\tau}\right)}{\left(1 - \varepsilon^{-T/\tau}\right)} - \frac{Vc}{R} \quad (10)$$

$$I_{\min} = \frac{V}{R}\frac{\left(\varepsilon^{t_{on}/\tau} - 1\right)}{\left(\varepsilon^{T/\tau} - 1\right)} - \frac{Vc}{R} \quad (11)$$

From previous two equations ,it will be noted that when Q_1 is continuously turned on ,so that t_{on} =T, then

$$I_{\max} = I_{\min} = \frac{V - Vc}{R} \quad (12)$$

If t_{on} is decreased to the value t_{on}^x at which $I_{\min}=0$, then the converter is operating at the point of changeover from continuous-current operation, illustrated in Fig. 1b. For this boundary condition, from equation 11

$$\frac{Vc}{V} = \frac{\varepsilon^{(t_{on}^x/T)(T/\tau)} - 1}{\varepsilon^{(T/\tau)} - 1} \quad (13)$$

or

$$m=\frac{\varepsilon^{\rho\sigma}-1}{\varepsilon^{\sigma}-1} \quad (14)$$

where

$$m=\frac{Vc}{V} \quad (15)$$

m= the ratio between main supply and DC source.

$$\rho=\frac{t^{x}_{on}}{T} \quad (16)$$

Where

t^{x}_{on} = the time at which $I_{\min}=0$

ρ= the ratio between changeover point and time period.

σ=the ratio between time period and τ.

$$\sigma=\frac{T}{\tau} \quad (17)$$

$I_{\min}$=0, then from equation 5,

$$I_{max}=\frac{V-Vc}{R}\left(1-\varepsilon^{-t_{on}/\tau}\right) : 0 \le t^{`} \le t^{x}_{on} \quad (18)$$

and from equation 8 and 18

$$i_o=\frac{-Vc}{R}\left(1-\varepsilon^{-t^{`}/\tau}\right)+\frac{V-Vc}{R}\left(1-\varepsilon^{-t_{on}/\tau}\right)\varepsilon^{-t^{`}/\tau}$$

$$t_{on} \le t^{`} \le T \quad (19)$$

This current will become zero at time $t=t_x$, or $t^{`}=t_x-t_{on}$, and substitution of these conditions in equation 19 yields

$$t_x=\tau\ln\left\{\varepsilon^{t_{on}/\tau}\left[1+\frac{V-Vc}{Vc}\left(1-\varepsilon^{-t_{on}/\tau}\right)\right]\right\} \quad (20)$$

Where

t_x = the time at which i become zero.

Method of Solution

In order to solve the problem; some term are needed to be clarified which are: Pulse Width Modulation method an DC chopper.

PWM or Pulse Width Modulation (Fig. 2) refers to the concept of rapidly pulsing the digital signal of a wire to simulate a varying voltage on the wire. This method is commonly used for driving motors, heaters, or lights in varying intensities or speeds.

A few terms are associated with PWM:

- Period - how long each complete pulse cycle takes.
- Frequency - how often the pulses are generated. This value is typically specified in Hz (cycles per second).

Duty Cycle - refers to the amount of time in the period that the pulse is active or high. Duty Cycle is typically specified as a percentage of the full period.

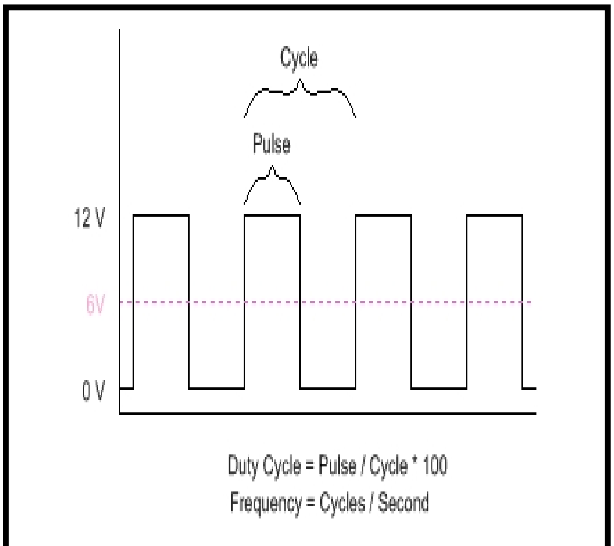
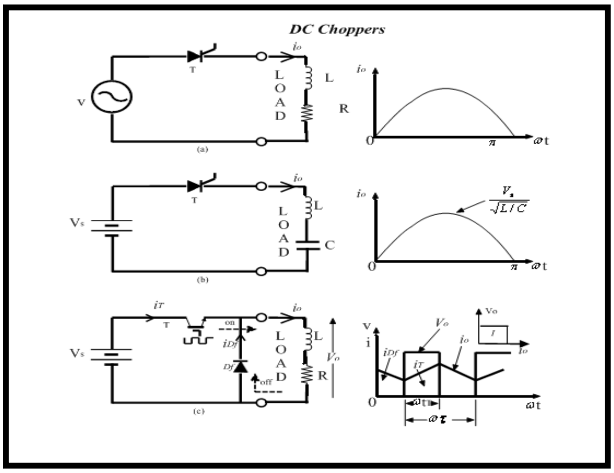


Fig. 2: PWM

DC CHOPPER



A DC choppers is a DC –to-DC voltage converter. It is a static switch electrical appliance that in one electrical conversion, changes a fixed dc voltage input to an adjustable dc output voltage without inductive or capacitive intermediate energy storage. The name chopper is linked to the fact that the output voltage is a `chopped up` quasi-rectangular version of the input dc voltage. Thyristor devices were used in conjunction with an AC supply that forces thyristor turn-off at ac supply current reversal. This from of thyristor natural commutation, which is illustrated in (Fig. 3a), is termed line or source commutation.

When a dc source is used with a thyristor circuit, energy source facilitated commutation is clearly not possible. If the load is an *R-C* or *L-C* circuit as illustrated in (Fig. 3b) the load current falls to zero whence the thyristor is in series with the dc supply turned off. Such a natural turn-off process is termed load commutation.
If the supply is dc and the load current has no natural zero current periods, such as with the R-L load, dc chopper circuit shown in (Fig. 3c), the load current can only be commutated using a self commutating switch, such as a GTO thyristor, GCT, IGBT or MOSFET. Any SCR is not suitable for such application because once the device is latched on the dc supply application, it remains on.

The dc in (Fig. 3c) is the simplest of the five dc choppers to be considered in this chapter. The single-ended, grounded-load, dc chopper will be extensively analysed [7].

(Fig.4) illustrates the proposed flow chart constructed to represent the steps of solving the problem using PWM and DC Chopper. Computer software is built according to the steps illustrated in the flow chart. The chart is constructed for obtaining the two mode of operation of the DC chopper, continuous and discontinuous. The effect of the injection voltage upon DC chopper performance is added to the flow chart. The computer program based upon the flow chart is constructed using Mathematica Software.

The case used here is based on chopping frequency of 100Hz. Consequently, t_{on} is selected such that;

$$t_{on} < T$$

where T=1/f=0.01 sec.

then at different selected values of t_{on}, which are selected in the range of

$$0.1\frac{T}{2} \le t_{on} \le 0.9\frac{T}{2}$$

The injected protected voltage (V_{inj}) level is selected also in the range of

$$12V \le V_{inj} \le 108V$$

Hence, at one selected level of V_{inj}, t_{on} is changed within its previous range. The results obtained from the program are as follow;

- I_{max} which represented the maximum value obtained of current at different values of t_{on} at specified level of V_{inj}.
- i the instantaneous values of current at specified value of t_{on} and V_{inj}.
- Minimum current of DC chopper determined where the chopper current becomes continuous.

t_x which illustrates the time at which the current output of the DC chopper reduces to zero value. At this instant the DC chopper current mode become discontinuous

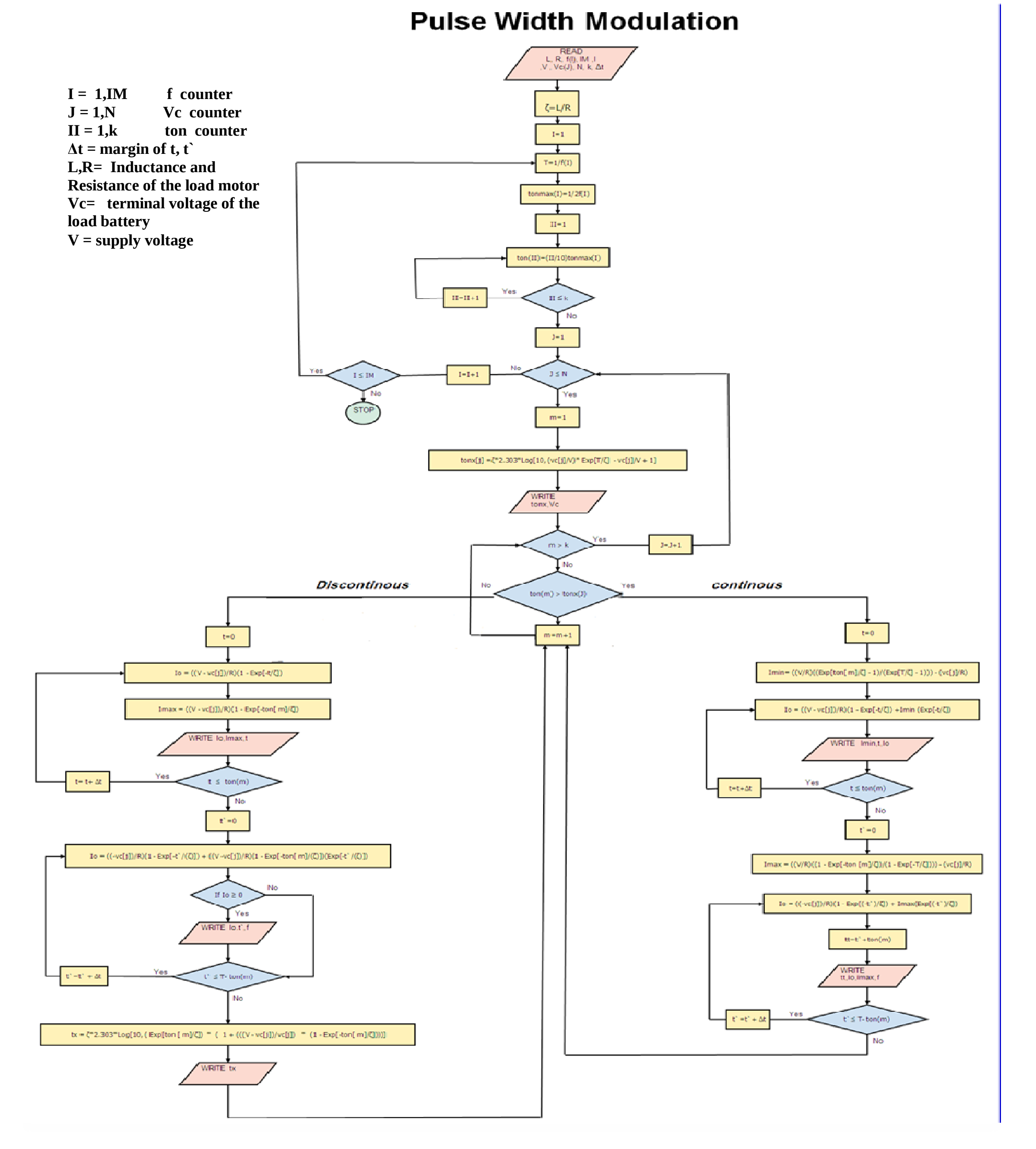


Fig. 4: Proposed flow chart

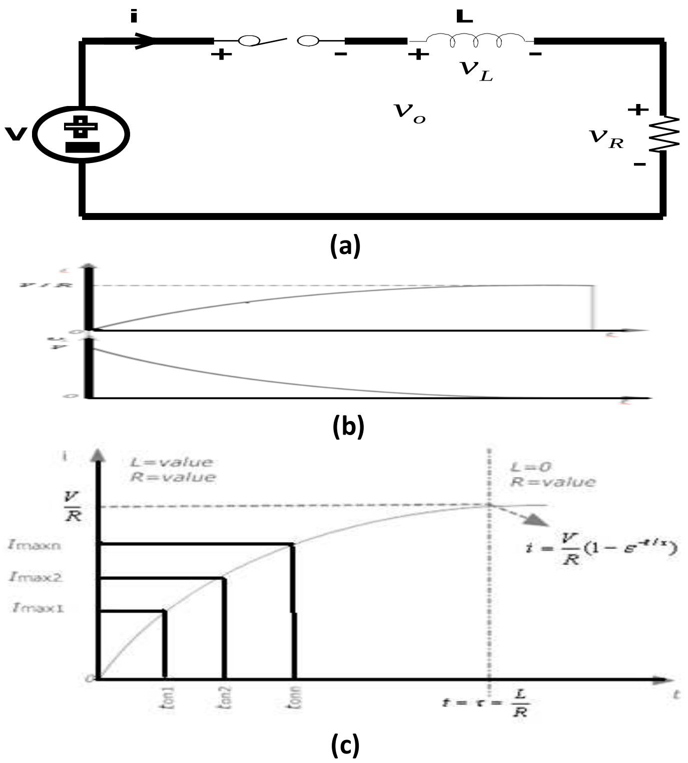


Fig.5 : DC source and RL circuit.

(Fig.5b)illustrates the relationship between the instantaneous current(i) against time (t).

Equation (3) illustrates that, the increasing of t_{on} increases I_{max}. The physical analysis of the increasing I_{max} against t_{on} is as follows;

The chopper current load is represented by RL circuit contains DC supply of voltage as shown in(Fig.5a).

The instantaneous current is

$$i = \frac{V}{R}(1 - \varepsilon^{-(R/L)t}) \qquad (21)$$

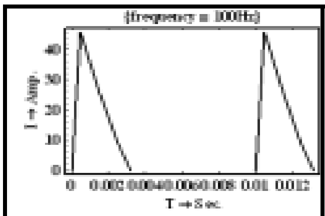
This current reaches to its maximum at $t = \tau = L/R$

Hence, I_{max}=V/R

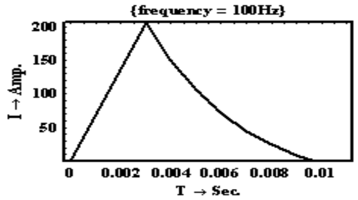
The current reaches to maximum value at $t = \tau = L/R$. After $t = \tau$, the current becomes stable at value $i = I_{\max} = V/R$. This means that the effect of the coil is in the range of $0 \le t \le \tau$ only. After that the coil has no any effect upon the current.

The previous Figure illustrates that as *ton* increases in the range of $0 \le t_{on} \le \tau$,the DC chopper current is increasing according to rising exponential function. The DC chopper control range $0 \le t \le \tau = L/R$, after this range $t < \tau$, the system loses control. Consequently, the DC motor speed becomes approximately constant. At this point we conclude that, the control range of t_{on} must be in the range within the value of τ.

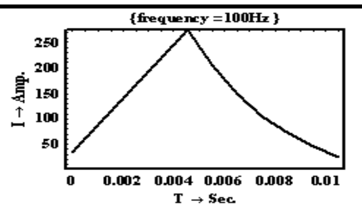
Results & Discussion:



T= 0.01, t_{on}[m]= 0.0005.

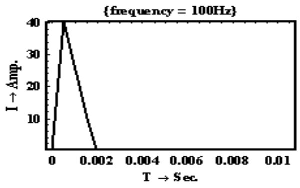


T= 0.01, t_{on}[m]= 0.003.

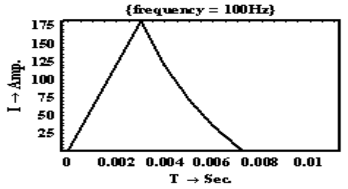


T= 0.01, I_{min}= 33.8507, t_{on}[m]= 0.0045.

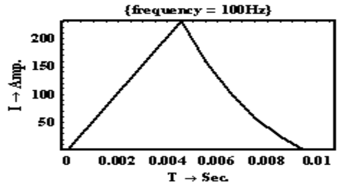
Fig. 6: Relationship between I and T at voltage batteries (V_B)= 12



T= 0.01, t_{on}[m]= 0.0005.

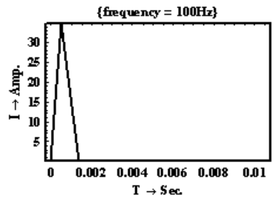


T= 0.01, t_{on}[m]= 0.003.

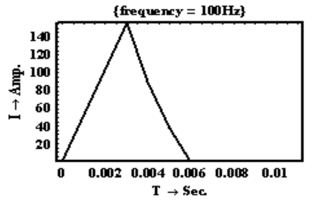


T= 0.01, t_{on}[m]= 0.0045.

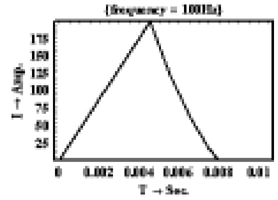
Fig. 7: Relationship between I and T at voltage batteries (V_B)= 24



T= 0.01, t_{on}[m]= 0.0005

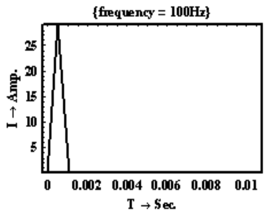


T= 0.01, t_{on}[m]= 0.003.

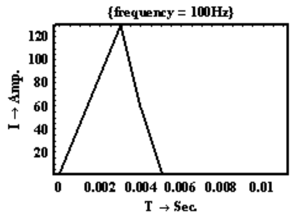


T= 0.01, t_{on}[m]= 0.0045.

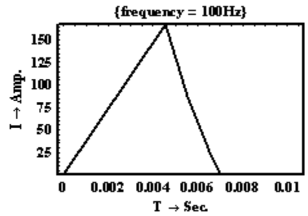
Fig. 8: Relationship between I and T at voltage batteries (V_B)= 36



T= 0.01, t_{on}[m]= 0.0005.

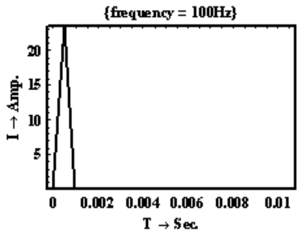


T= 0.01, t_{on}[m]= 0.003.

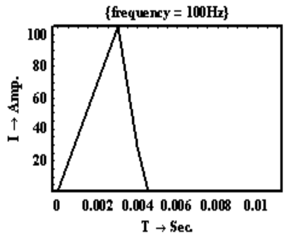


T= 0.01, t_{on}[m]= 0.0045.

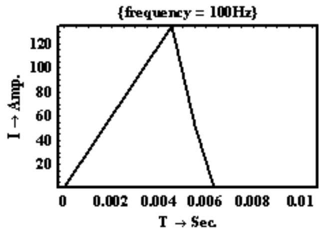
Fig. 9: Relationship between I and T at voltage batteries (V_B)= 48



T= 0.01, t_{on}[m]= 0.0005.

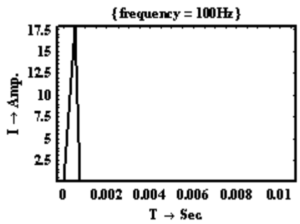


T= 0.01, t_{on}[m]= 0.003

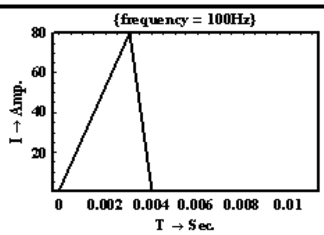


T= 0.01 t_{on}[m]= 0.0045.

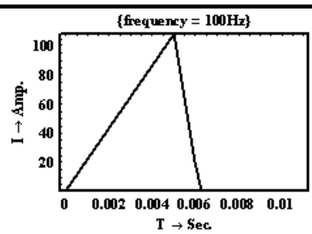
Fig. 10: Relationship between I and T at voltage batteries (V_B)= 60



T= 0.01, ton[m]= 0.0005.

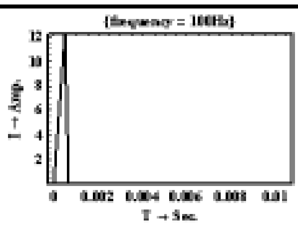


T= 0.01, ton[m]= 0.003

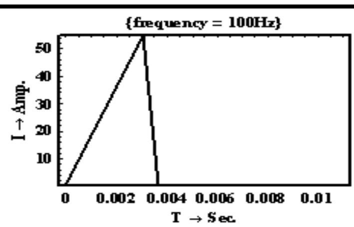


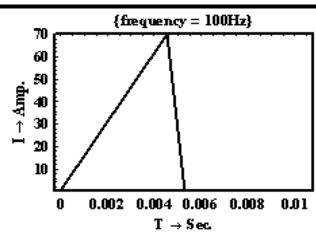
T= 0.01, ton[m]= 0.0045.

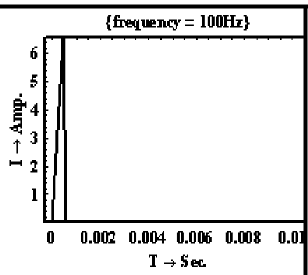
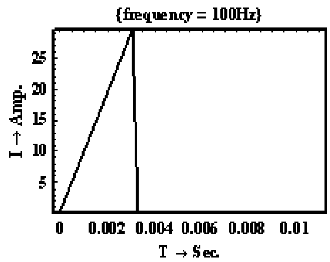
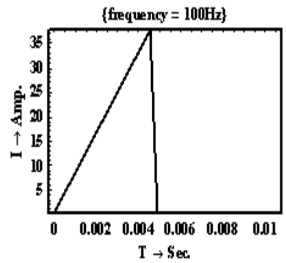
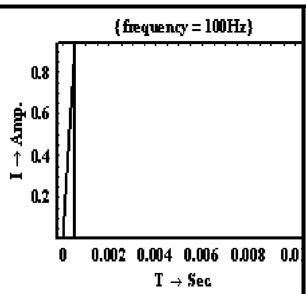
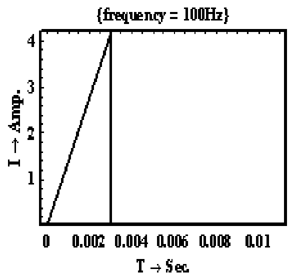
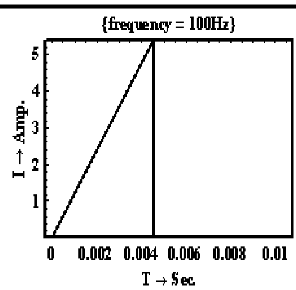
Fig. 11: Relationship between I and T at voltage batteries (V_B)= 72



T= 0.01, t_{on}[m]=





0.0005.	T= 0.01, t_{on}[m]= 0.003.	T= 0.01, t_{on}[m]= 0.0045.
Fig. 12: Relationship between I and T at voltage batteries (V_B)= 84		
 T= 0.01, t_{on}[m]= 0.0005.	 T= 0.01, t_{on}[m]= 0.003.	 T= 0.01, t_{on}[m]= 0.0045.
Fig. 13: Relationship between I and T at voltage batteries (V_B)= 96		
 T= 0.01, t_{on}[m]= 0.0005.	 T= 0.01, t_{on}[m]= 0.003.	 T= 0.01, t_{on}[m]= 0.0045.
Fig. 14: Relationship between I and T at voltage batteries (V_B)= 108		

Family of curves are obtained by using the computer program representing the two modes of operation as follow;

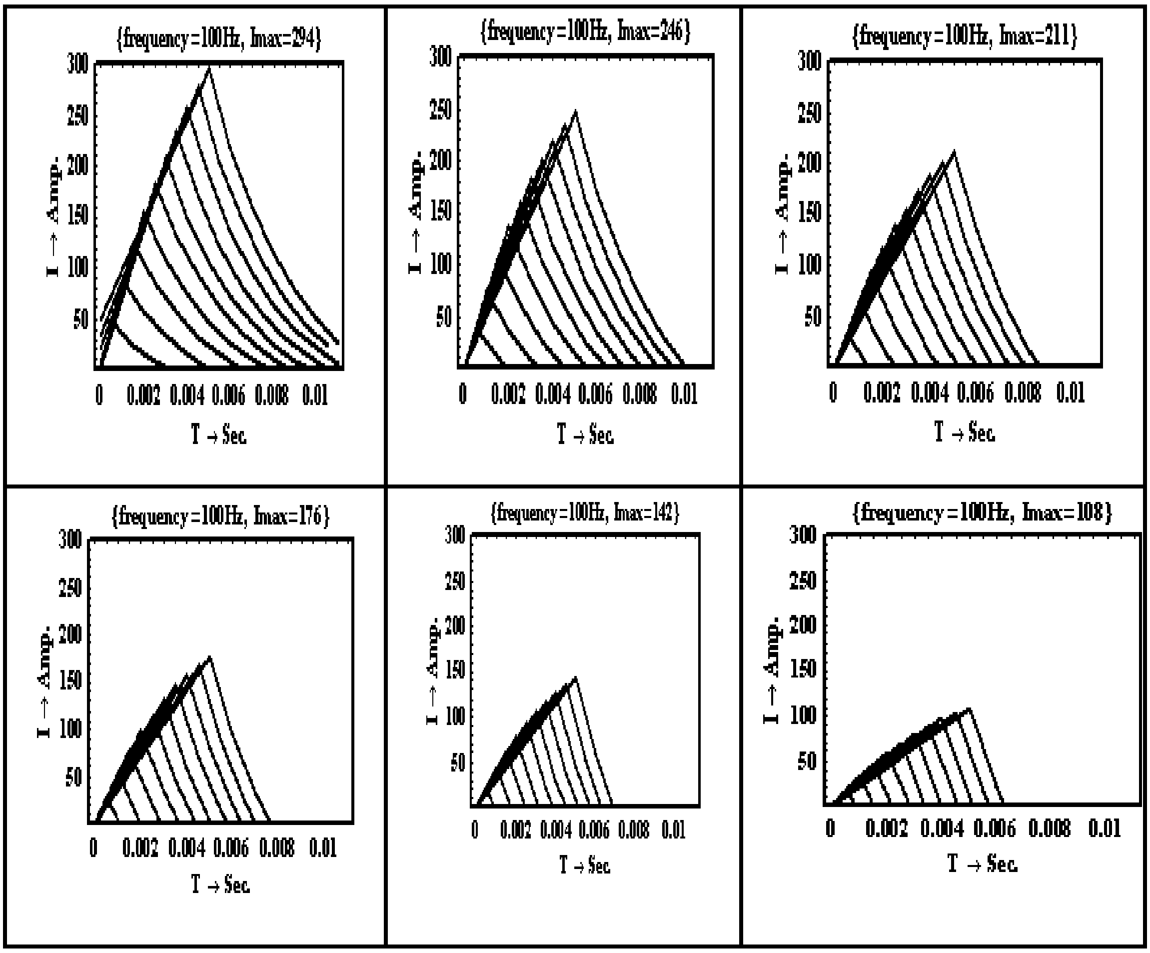
(Fig. 6) to (Fig. 14) represents the instantaneous DC chopper output currents at different values of t_{on} and also illustrate the effect of t_{on} upon I_{max} at different values of V_{inj}. Through all charts, the current reduces according to the decaying exponential function. The current decreases from I_{max} to I_{min}or zero. All charts represents the discontinuous current, only(Fig. 6) illustrates to continuous mode. DC chopper operation at level of injected protected voltage of 12V. The slope of rising of the instantaneous currents is increased according to the increase of t_{on} upon I_{max}.

(Fig. 15) illustrate the effect of t_{on} upon the maximum DC chopper current.

(Fig. 16) illustrate the effect of t_{on} upon maximum I_{max} as well as t_x and V_{inj}takes as a parameter. Fig.16 illustrate that as t_{on} increases, the chopper maximum current increases. As V_{inj} increases I_{max} decreases. The injection of voltage to the DC chopper circuit results of reverse current to the chopper circuit. This current opposes the main current. Hence, the total current passes through the chopper circuit will be decreases. As the power switch used is a thyristor, the reverse current from the injection supply will be reduced the main current. As the current through the chopper circuit reaches to or less than the threshold current, the thyristor will be turned off. To operate the DC chopper power switch, a pulse must trigger the thyristor once again. Consequently, the operation must be designed depending on the load type.

(Fig. 17) represents the effect of DC chopper *ON* time upon t_x at different values of the protected injected voltage. The injected voltage has a pronounced effect on the DC chopper operation. At 12V injection voltage the DC chopper has the two modes of operations, the discontinuous and the continuous mode. Inversely, at other injection voltage level larger than 12V, one mode only of operation will be obtained.

In order to verify our approach, a case study is used and is implemented on Mathematica with intel 2.2 GHz & 4 GB RAM. The case study is based on the DC motor used as a load on the DC chopper has specification of R= 0.25Ω, L=1mH where R is load resistance and L is load inductance .The chopper is supplied by power supply of 110v. The injection supply used for the protection of the DC motor can be used as batteries of another supply of different values in the range of 12≤Vinj.≤108.The injection supply must not exceeds the power supply value. The previous specifications are used as an example only. The research strategy can be applied with all DC motors and injected supplies of any different values.



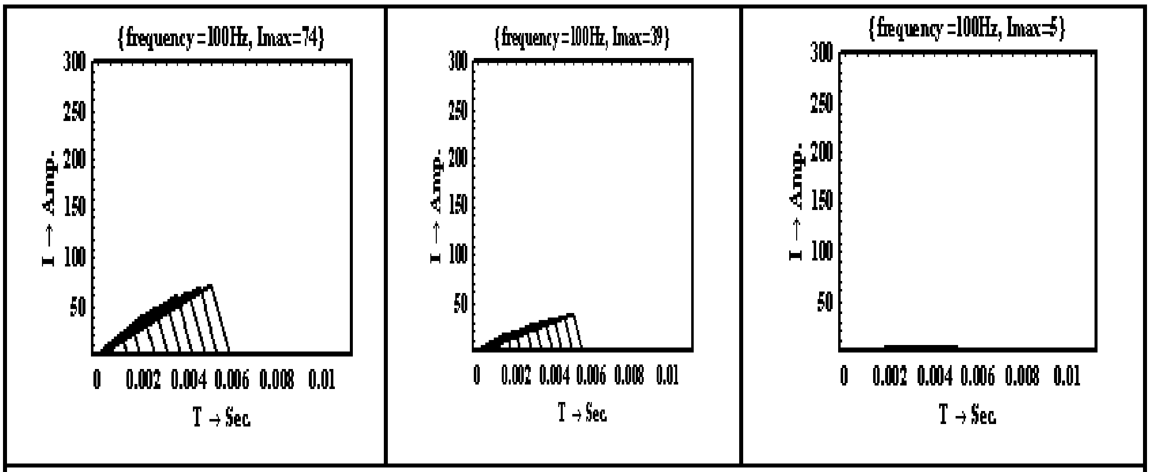


Fig.15 : Family of curves for relationship between I and T at voltage batteries (V_B) from 12V to 108V

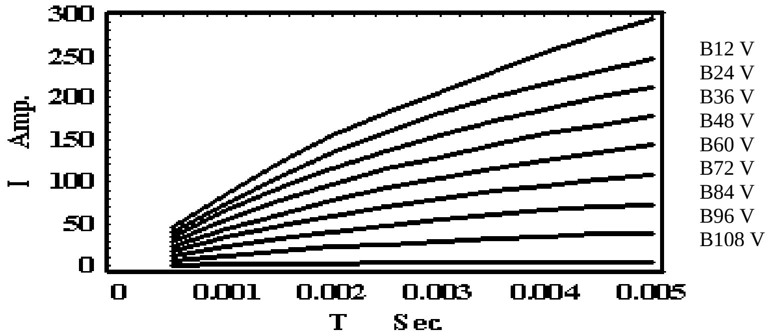


Fig. 16: The relationship between (Imax & ton), Vinj **(** battery) takes as a parameter.

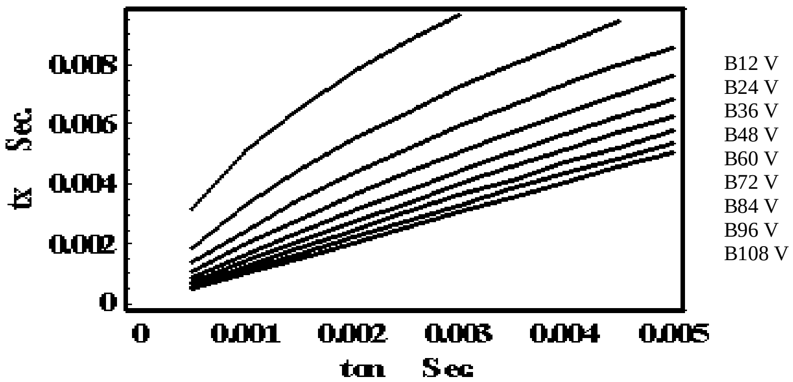


Fig. 17: The relationship between t_{on} & t_x Vinj (battery) takes as a parameter .

The block diagram of the proposed DC chopper system is illustrated in(Fig.18). The DC chopper system contains main supply, power switch, load, injected protected supply, blocking diode and the triggering circuits system. The preferable power switch that must be used with the large power motor is a thyristor instead of another. The thyristors have large values of reverse voltage but other switches can be destroyed by very small reverse voltage. The blocking diode is used for discharging the stored energy in the motor coils during the interruption of the power supply of the motor.The injected protected supply can be used as a batteries or DC supply connected in series with the motor. The purpose of using this supply is the protection of the large load motor used. The triggering circuit is used for controlling the load motor. The results have shown the superiority of the proposed approach in solving such problems.

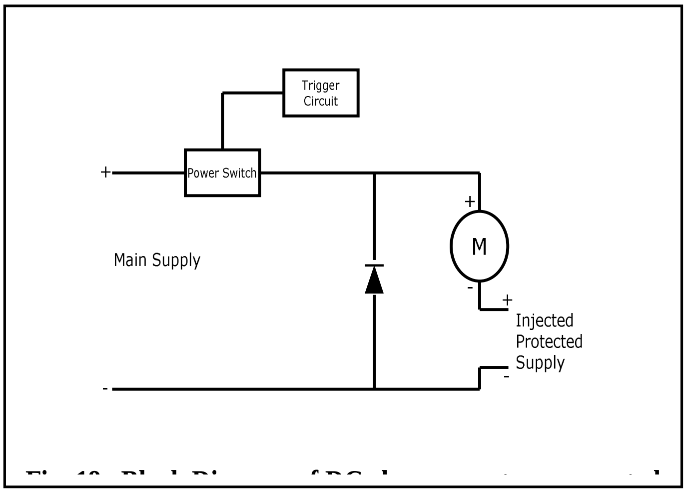


Fig. 18: Block diagram of the proposed DC chopper system

Conclusion

This paper represents the design of a safety electrical break for any DC motor especially the motor used with the DC-DC converter circuit. The effect of *ON* time upon maximum current of the DC-DC converter is illustrated. The previous current increases as the t_{on} increases. The effect of injected voltage upon DC chopper performance is illustrated. The injection-protected voltage has a pronounced effect upon the chopper maximum current. It is reduce current through the chopper till it reaches the threshold current present through the power switch data sheet.

The DC chopper has two modes of operation when the injection voltage equal to 12V. Inversely, at another levels of V_{inj} the chopper has only one mode of operation, at this case the chopper operation at the discontinuous mode only.

As the current through the switch decreases to the previous value, the power switch will be turned *OFF* immediately. After that the next pulse must be generated for triggering the switch once again. The electrical break for the DC chopper motor is safe because the reverse current injected to the DC chopper circuit is decreased step by step and not rapidly. Hence, the breaking of the motor becomes very safe.

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