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Original Research Article

THE ANALYSIS OF THE CONTINUOUS AND DISCONTINUOUS OPERATION MODE BY USING MATHEMATICA PROGRAM

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Abstract*:* The aim of this research is to write Mathematica Program valid for any DC motor specifications (A, R and L). In this paper Mathematica Program is presented. DC motor specifications in this research are A=6 A, R= 0.25 Ω and L= 1m H. Two mode of operations continuous and discontinuous are analyzed by the Mathematica Program. Varying batteries from 12 V to 108 V are applied in this Mathematica Program. The relationship between the maximum currents and the times for continuous and discontinuous mode of operations are illustrated by graphs. The effect of varying batteries upon the maximum currents is illustrated by graphs. Two main current equations for continuous and discontinuous mode of operation are analyzed by the Mathematica Program.

Keywords: DC motor, Batteries, Current, Mathematica, Program, Time.

Introduction*:* 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 enable 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. 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 [1].

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The purpose of a DC – DC converters is to supply a regulated DC output voltage to a variable –load resistance from a fluctuating DC voltage. In many cases the DC input voltage is obtained by rectifying a line voltage that is changing in magnitude. DC – DC converters are commonly used in application requiring regulated DC power, such as computer, medical instrumentation, communication devices, television receivers, and battery chargers [2-3].DC-DC converters are also used to provide a regulated variable DC voltage for DC motor speed control application. The output voltage in DC-DC converters is generally controlled using a switching concept, as illustrated by the basic DC-DC converter. Early DC-DC converters were known as choppers with silicon-controlled rectifiers (SCRs) used as the switching mechanisms. Modern DC-DC converters classified as switch mode power supplies (SMPS) employ insulated gate bipolar transistors (IGBTs) and metal oxide silicon field effect transistors (MOSFETs).

The switch mode power supply has several functions [4]:

1- Step down an unregulated DC input voltage to produce a regulated DC output voltage using a buck or step –down converter.
2- Step up an unregulated DC input voltage to produce a regulated DC output voltage using a boost or step-up converter.
3- Step down and then step up an unregulated DC input voltage to produce a regulated DC output voltage using a buck-boost converter.
4- Invert the DC input voltage using a Cuk converter.
5- Produce multiple DC output using a combination of SMPS topologies.

Method of solution

In order to solve the problem, the Program is written by using Mathematica program language as shown in figures [1-5].

```
V = 110;
R = 0.25;
L = 1.0 * 10^-3 // N;
τ = (L / R) // N
dt = 10^-3 // N;
n = 9;
K = 10;
IM = 1;
p = 1;
h = 1;
bn = 1;
tg = 1;
e = 1;
w = 1;
fg = 1;
vb = 1;
yo = 1;
sj = 1;
Do[vc[i] = i * 12, {i, 1, 9}];
Do[f[i] = i * 10, {i, 1, 100}];
i = 10;
(
Label[onefirst];
Print["T= ", T = 1 / f[i] // N];
 Print["f", i, " = ", f[i] // N];
tonmax[i] = 1 / (2 * f[i]);
Do[ton[ii] = (ii / 10) * tonmax[i] // N, {ii, 1, K}];
j = 1;
 Label[secondbegin];
 If[j ≤ n,
  m = 1;
  Print["tonx", j, "=",
   tonx[j] = τ * 2.303 * Log[10, (vc[j] / V) * Exp[T / τ] - vc[j] / V + 1]];
  Print[vc[j]];
  Label[firstbegin];
  no = 1;
  If[m > K,
```

Figure [1]: Mathematica Programpage 1

```
Do[Print[yahoo[yo]], {yo, tg, yo - 1}];
values = Table[yahoo[yo], {yo, tg, yo - 1}];
ListPlot[values, PlotJoined → True, AxesLabel → {"ton ", "tx "}];
tg += yo;
Do[Print[ttxx[yi]], {yi, 1, 85}];
j += 1;
Goto[secondbegin];,
If[ton[m] > tonx[j],
 Print[contiuos];
 t = 0;
 Print["Imin=",
  Imin[p] = ((V / R) ((Exp[ton[m] / τ] - 1) / (Exp[T / τ] - 1))) - (vc[j] / R)];
 Print["Imin=",
  rrmax = ((V / R) ((Exp[ton[m] / τ] - 1) / (Exp[T / τ] - 1))) - (vc[j] / R)];
 Label[thirdbegin];
 Print["frIo-", p, "=", "    ",
  frIo[p] = ((V - vc[j]) / R) (1 - Exp[-t / τ]) + rrmax (Exp[-t / τ])];
 Print["dist&frIo points", " ", fg, "=", abc[fg] = {sd[bn], frIo[p]}];
 ali[no] = {sd[bn], frIo[p]};
 no += 1;
 fg += 1;
 Print["t=    ", sd[bn] = t // N];
 If[t ≤ ton[m];
  frIo[p] > rrmax,
  bn += 1;
  p += 1;
  t += dt;
  Goto[thirdbegin];,
  Print["toff=", toff = 0, "cott=     ", cott = toff + ton[m]];
  Print["Imax=   ",
   Imax[h] = ((V / R) ((1 - Exp[-ton [m] / τ]) / (1 - Exp[-T / τ]))) - (vc[j] / R)];
  Print["Imax=   ",
   maxmax = ((V / R) ((1 - Exp[-ton [m] / τ]) / (1 - Exp[-T / τ]))) - (vc[j] / R)];
  Label[forthbegin];
  Print["secIo-", e, "=", "    ",
   secIo[e] = ((-vc[j]) / R) (1 - Exp[(-toff) / τ]) + Imax[h] (Exp[(-toff) / τ])];
  Print["ton[m]=", ton[m]];
```

Figure [2]: Mathematica Program page 2

```
Print["contt&secIo points", " ", fg, "=", abc[fg] = {distt[e], secIo[e]}];
 ali[no] = {distt[e], secIo[e]};
 no += 1;
 fg += 1;
 e += 1;
 Print["toff=      ", zz[w] = toff // N];
 w += 1;
 Print["f=      ", f[i]];
 Print["T-ton[m]=      ", (T - ton[m]) // N];
 If[toff ≤ (T - ton [m]),
  toff += dt;
  Goto[forthbegin];,
  Do[Print[ali[no]], {no, 1, no - 1}];
  values = Table[ali[no], {no, 1, no - 1}];
  xccx[vb] = ListPlot[values, PlotJoined → True, PlotRange → {0, Imax[h]},
    AxesLabel → {" T ", Imax[h] " Imax= "}, PlotLabel → {"frequency =100Hz "},
    Frame → True, FrameLabel → {"T → Sec.", "I → Amp."},
    FrameStyle → Thickness[0.01], PlotStyle → {Thickness[0.01]},
    TextStyle → {FontFamily → "Times", FontWeight → "Bold", FontSize → 12}];
  ccx[vb] = ListPlot[values, PlotJoined → True, PlotRange → {0, Imax[h]},
    AxesLabel → {" T ", "Imax" }, PlotLabel → {"frequency = 100Hz"},
    Frame → True, FrameLabel → {"T → Sec.", "I → Amp."},
    FrameStyle → Thickness[0.01], PlotStyle → {Thickness[0.01]},
    TextStyle → {FontFamily → "Times", FontWeight → "Bold", FontSize → 12}];
  ight[vb] = Print["Imax= ", Imax[h], "    ", "VB= ", vc[j], "      ",
    "freq.= ", f[i], "      ", "T= ", T, "      ", "Imin= ", Imin[p], "      ",
    "ton[m]= ", ton[m]];
  vb += 1;
  Clear[no];
  h += 1;
  m += 1;
  Goto[firstbegin];];];
, Print[dicontinuos];
t = 0;
Print["Imax", h, "= ", Imax[h] = ((V - vc[j]) / R) (1 - Exp[-ton[m] / τ])];
```

Figure [3]: Mathematica Program page 3

```
Label[sixbegin];
Print["frIo-", p, "=", "    ", frIo[p] = ((V - vc[j]) / R) (1 - Exp[-t / τ])];
Print["t=    ", sd[bn] = t // N];
Print["dist&frIo points", " ", fg, "=", abc[fg] = {sd[bn], frIo[p]}];
ali[no] = {sd[bn], frIo[p]};
no += 1;
fg += 1;
If[t ≤ ton[m];
 frIo[p] > Imax[h] ,
 bn += 1;
 p += 1;
 t += dt;
 Goto[sixbegin]; ,
 Print["toff=   ", toff = 0];
 Label[sevenbegin];
 Print["secIo-", e, "=", "     ",
  secIo[e] = ((-vc[j]) / R) (1 - Exp[-toff / (τ)]) +
    ((V - vc[j]) / R) (1 - Exp[-ton[m] / (τ)]) (Exp[-toff / (τ)])];
 Print["ton[m]", sj, "=", cvton[sj] = ton[m]];
 sj += 1;
 Print["distt=        ", distt[e] = toff + ton[m]];
 Print["distt&secIo points", " ", fg, "=", abc[fg] = {distt[e], secIo[e]}];
 ali[no] = {distt[e], secIo[e]};
 no += 1;
 fg += 1;
 e += 1;
 Print["toff=      ", zz[w] = toff // N];
 w += 1;
 Print["f=      ", f[i]];
 Print["T-ton[m]=       ", (T - ton[m]) // N];
 If[toff ≤ (T - ton[m]),
  toff += dt;
  Goto[sevenbegin]; ,
  Do[Print[ali[no]], {no, 1, no - 1}];
  values = Table[ali[no], {no, 1, no - 1}];
  ttxx[yo] =
```

Figure [4]: Mathematica Program page 4

```
τ * 2.303 * Log[10, (Exp[ton [m] / τ]) *
          ( 1 + (((V - vc[j]) / vc[j])  *  (1 - Exp[-ton[m] / τ])))];
        xccx[vb] = ListPlot[values, PlotJoined → True, PlotRange → {0, Imax[h]},
          AxesLabel → {" T ", Imax[h] " Imax "},
          PlotLabel → {"frequency = 100Hz"}, Frame → True,
          FrameLabel → {"T → Sec.", "I → Amp."},
          FrameStyle → Thickness[0.01], PlotStyle → {Thickness[0.01]},
          TextStyle → {FontFamily → "Times", FontWeight → "Bold",
            FontSize → 12}];
        ccx[vb] = ListPlot[values, PlotJoined → True, PlotRange → {0, Imax[h]},
          AxesLabel → {" T ", " Imax "}, PlotLabel → {"frequency = 100Hz"},
          Frame → True, FrameLabel → {"T → Sec.", "I → Amp."},
          FrameStyle → Thickness[0.01], PlotStyle → {Thickness[0.01]},
          TextStyle → {FontFamily → "Times", FontWeight → "Bold",
            FontSize → 12}];
        ight[vb] = Print["Imax= ", Imax[h], "   ", "VB= ", vc[j], "        ",
          "freq.= ", f[i], "      ", "T= ", T, "      ", "tx= ", ttxx[yo],
          "     ", "ton[m]= ", ton[m]];
        vb += 1;
        Clear[no];
        h += 1;
        Print["tx", yo, "=",
          ttxx[yo] = τ * 2.303 * Log[10, (Exp[ton [m] / τ]) *
            ( 1 + (((V - vc[j]) / vc[j])  *  (1 - Exp[-ton[m] / τ])))]];
        Print[yahoo[yo] = {ton[m], ttxx[yo]}];
        yo += 1;
        m += 1;
        Goto[firstbegin];
        ];];];];
  , i += 1;
  If[i ≤ IM,
   Goto[onefirst]; ,
   Break];]
 ]
Do[Print[abc[fg]], {fg, 1, fg - 1}];
Show[xccx[1]];
Print[ight[1]];
```

Figure [5]: Mathematica Program page 5

Results & Discussion: As results of the Mathematica Program, there are a lot of graphs and relations between the currents and times. Few graphs are selected as an example from the program results. As shown in figures [6 & 7], these represent discontinuous mode of operation which means that the motor will turn off for a period of time and turn on again. As shown in figures [8, 9 & 10], these represent continuous mode of operation which means the motor is turned on the whole time. These figures [8,9 & 10] are the only continuous mode of operation that are obtained from the program results for all the batteries injected. The relationship between the maximum current and the time at which a different size of batteries are used is illustrated in figures [11-19].The relationship between the normal time (ton) and the turn off time (tx) when different sizes of batteries are used is illustrated in figures [20-27, 32]. Family of curves for the relationships between maximum currents and times are illustrated in figure [28]. Family of curves for the relationships between the normal time (ton) and turn off time are illustrated in figure [29]. As shown in figure [28], the maximum currents of the batteries are decreasing when the extra battery is injected into the system. Also, of note in figure [29], the Imax and tx curves are decreasing when extra battery is added to the system. Figure [30] illustrate the relationship between Imax of the batteries and all the sizes of batteries, of note the curve is decreasing steadily. Figure [31] shows the curves of batteries 12V and 24V are dropped dramatically because the turn off time (tx) at this level of batteries equals zero, and the Imax work at continuous mode of operation.

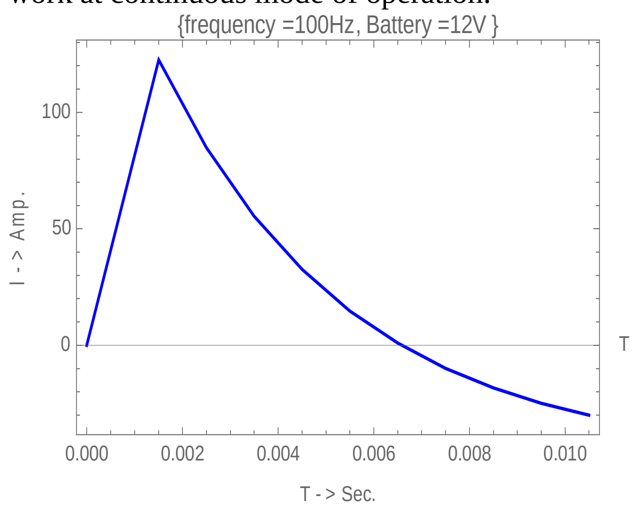

Figure [6]: Discontinuous Mode at Battery 12V

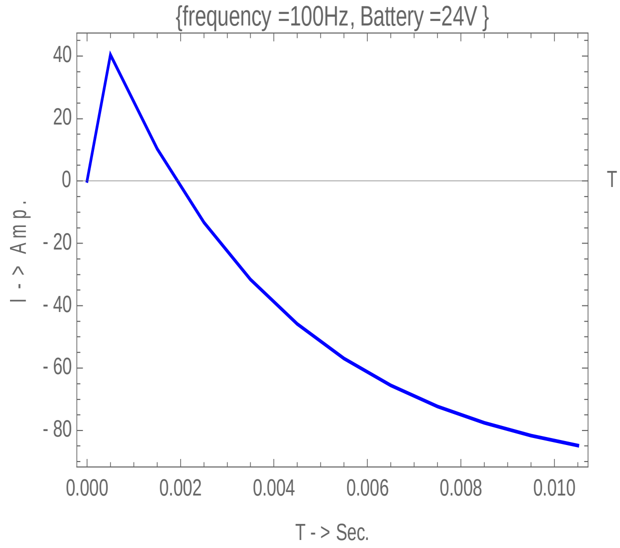

Figure [7]: Discontinuous Mode at Battery 24V

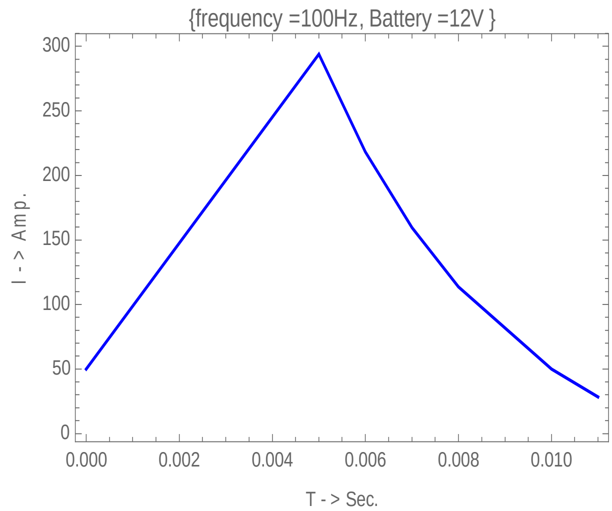

Figure [8]: Continuous Mode at Battery 12V

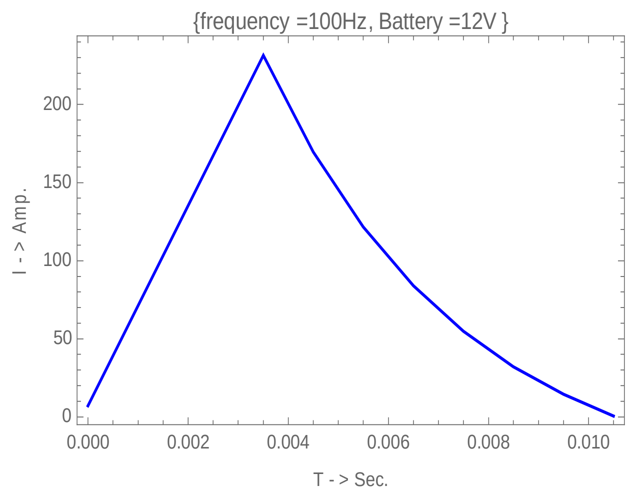

Figure [9]: Continuous Mode at Battery 12V

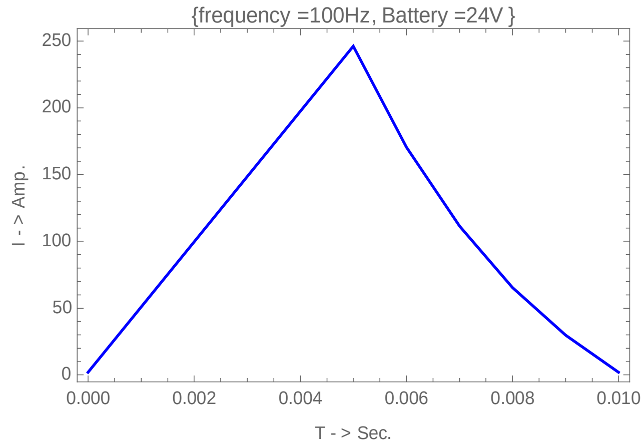

Figure [10]: Continuous Mode at Battery 24V

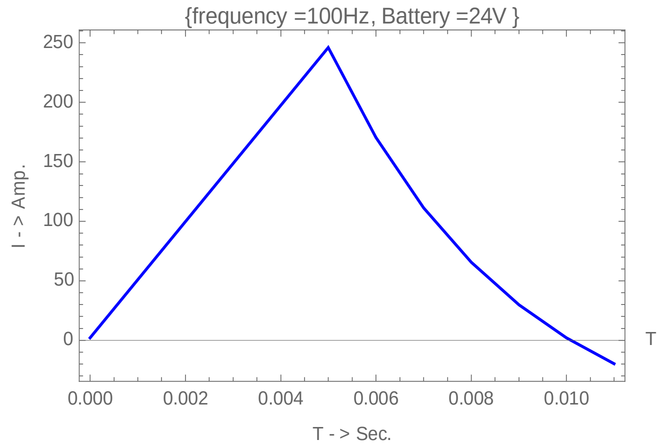

Figure [12]: Relation between Imax & T at Battery 12V

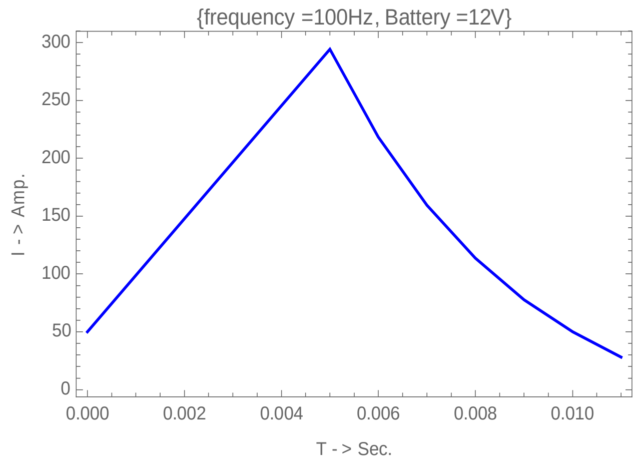

Figure [11]: Relation between Imax & T at Battery 12V

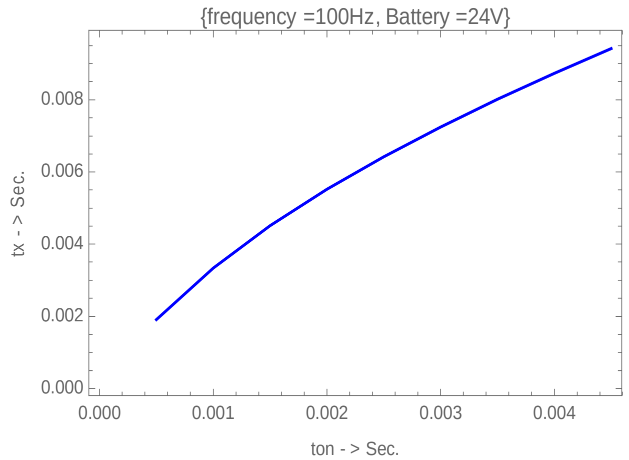

Figure [21]: Relation between tx& T at Battery 12V

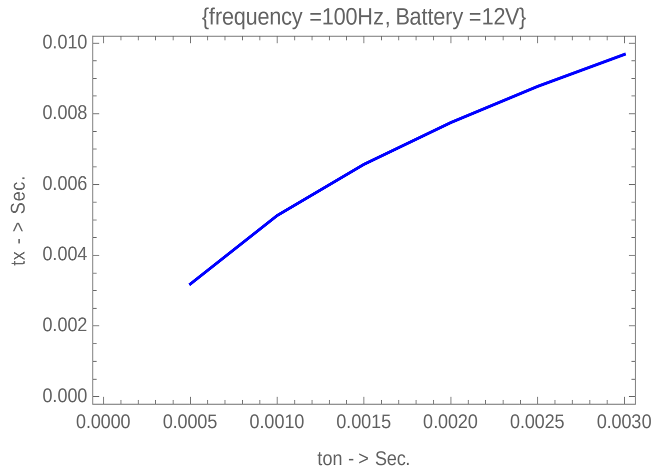

Figure [20]: Relation between tx& T at Battery 12V

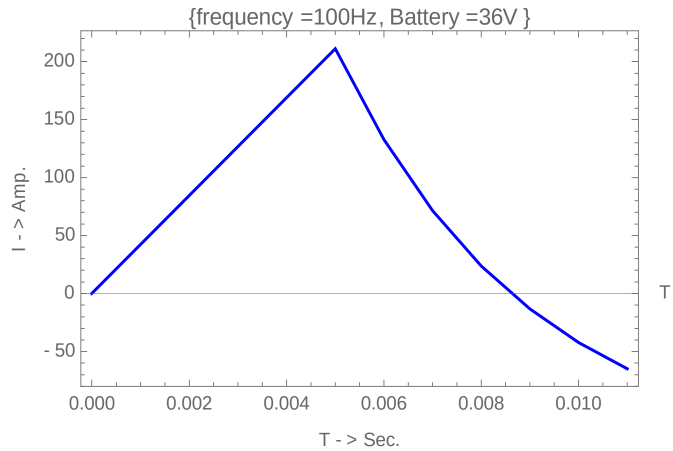

Figure [13]: Relation between Imax & T at Battery 12V

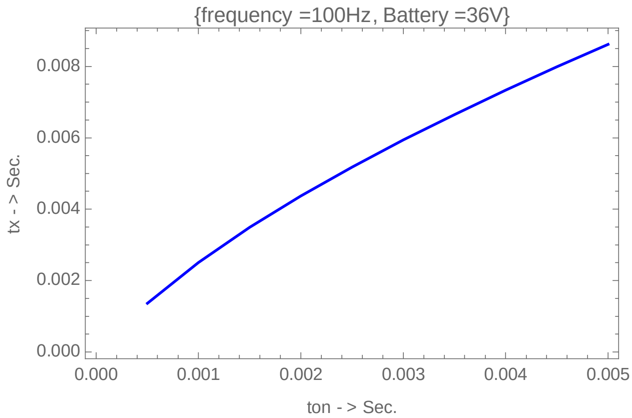

Figure [22]: Relation Between tx& T at Battery 12V

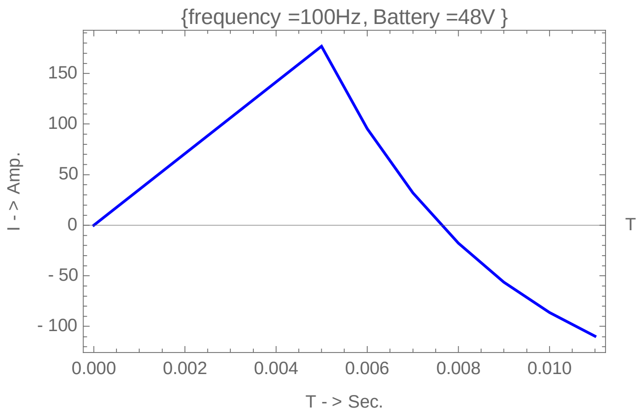

Figure [14]: Relation between Imax & T at Battery 12V

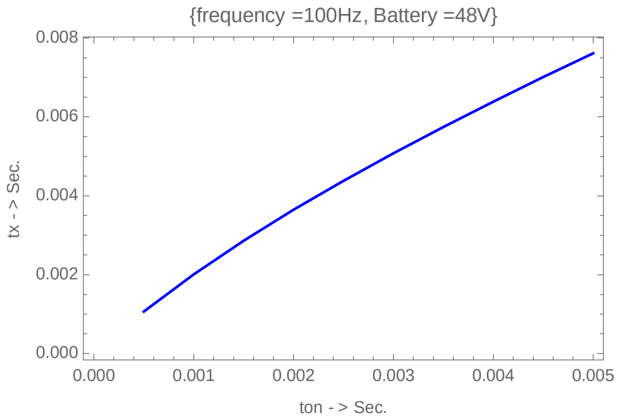

Figure [23]: Relation between tx& T at Battery 12V

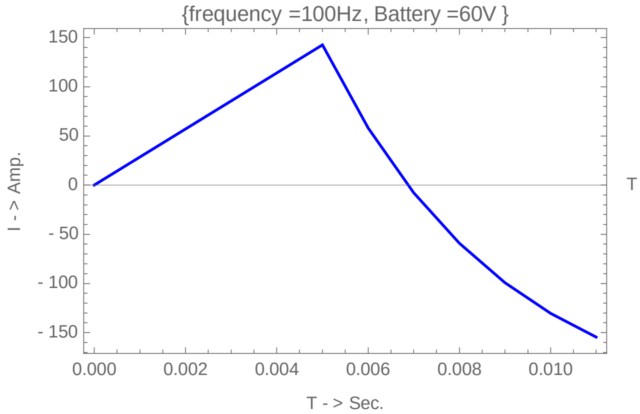

Figure [15]: Relation Between Imax & T at Battery 12V

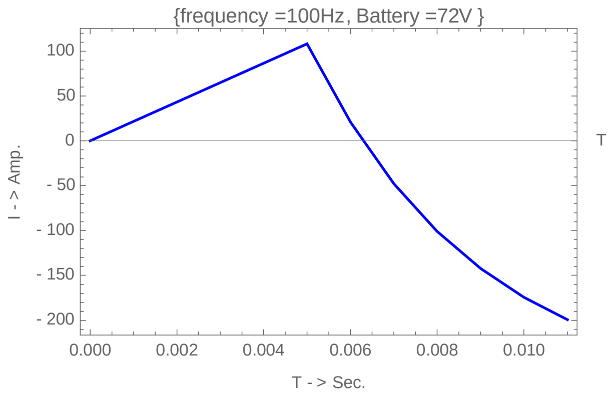

Figure [16]: Relation between Imax & T at Battery 12V

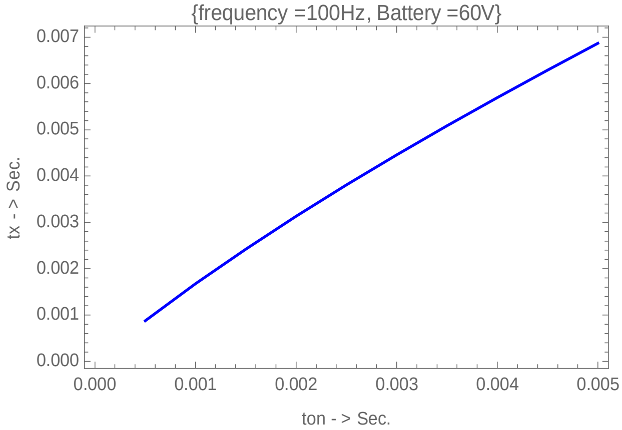

Figure [32]: Relation between tx& T at Battery 12V

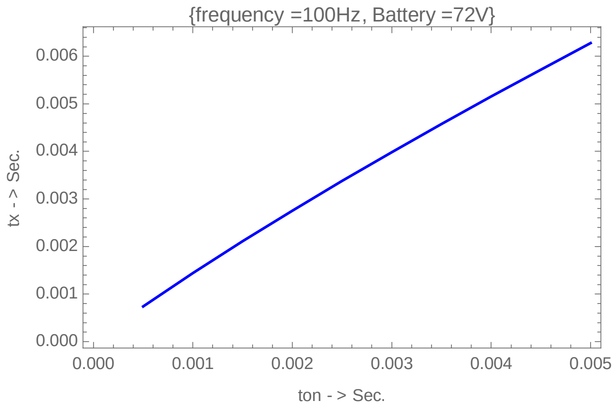

Figure [24]: Relation Between tx& T at Battery 12V.

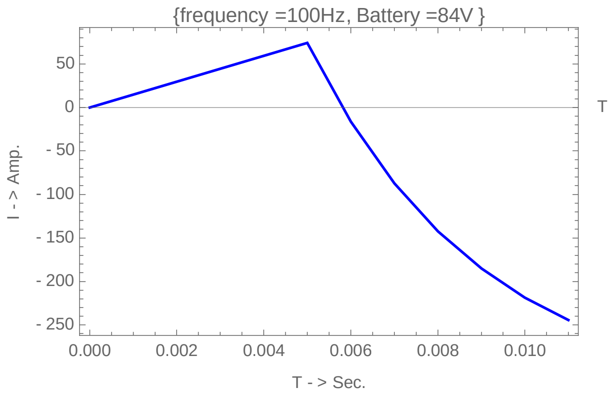

Figure [17]: Relation Between Imax & T at Battery 12V.

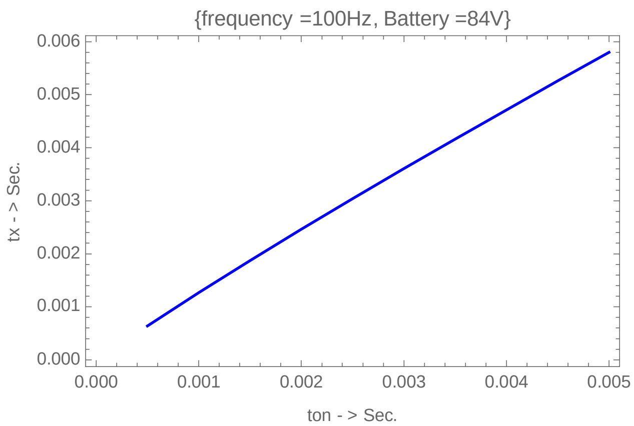

Figure [25]: Relation Between tx& T at Battery 12V.

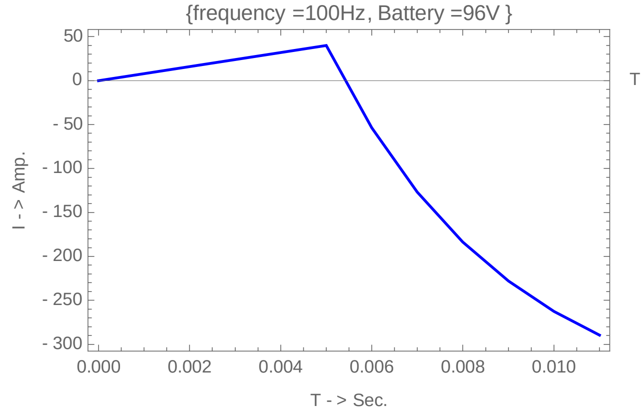

Figure [18]: Relation Between Imax & T at Battery 12V.

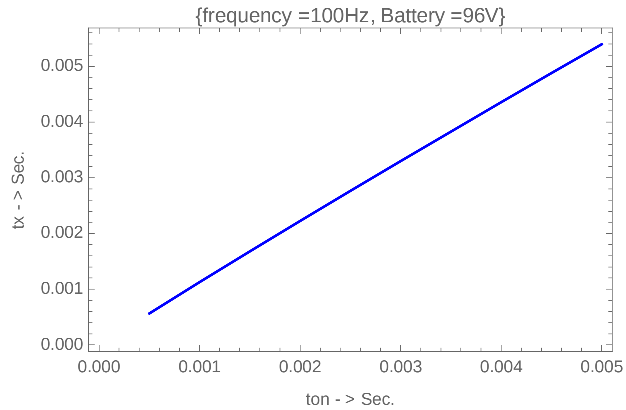

Figure [26]: Relation Between tx& T at Battery 12V.

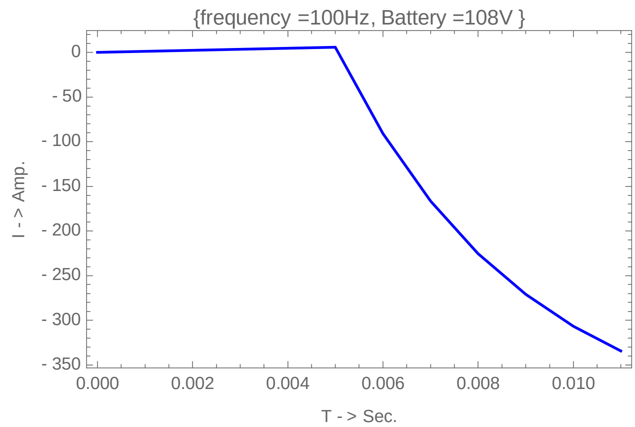

Figure [19]: Relation Between Imax & T at Battery 12V.

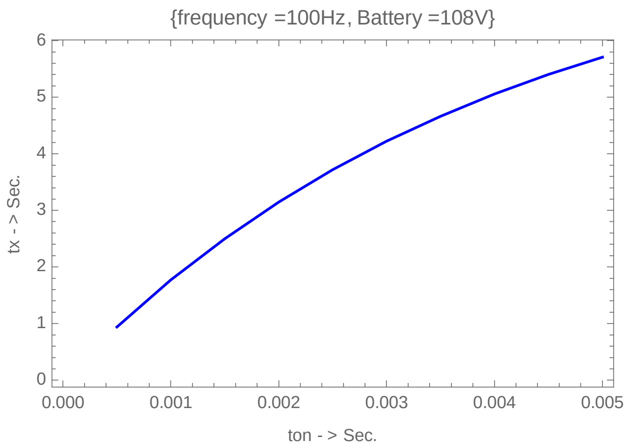

Figure [27]: Relation between tx& T at Battery 12V.

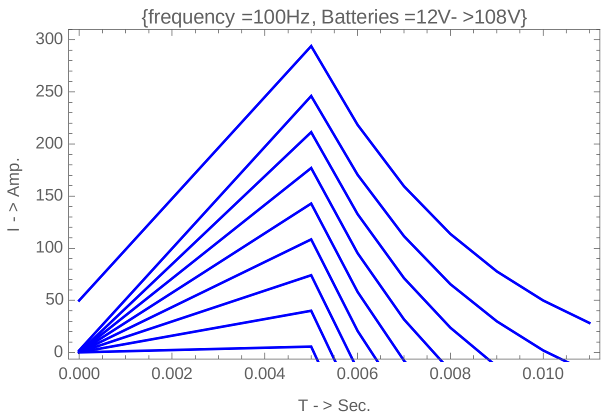

Figure [28]: Family of curves Between Imax & T at Batteries 12V-108V.

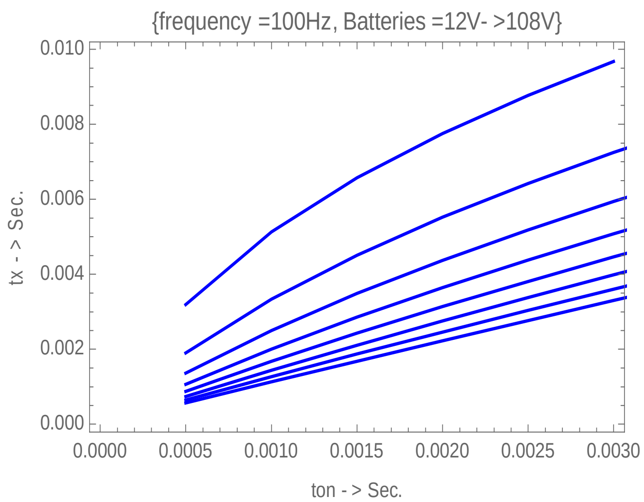

Figure [29]: Family of Curves Between ton & tx at Batteries 12V-108V.

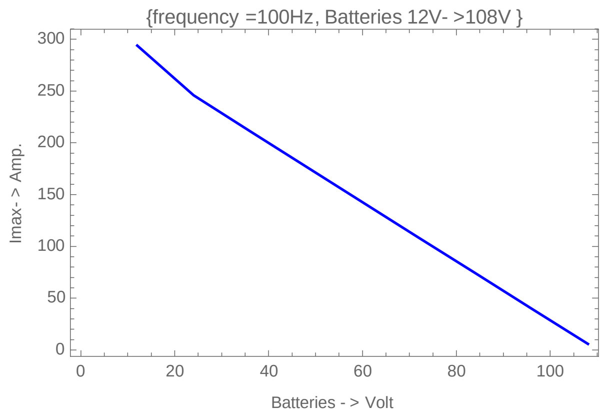

Figure [30]: Relation between Imax & Batteries.

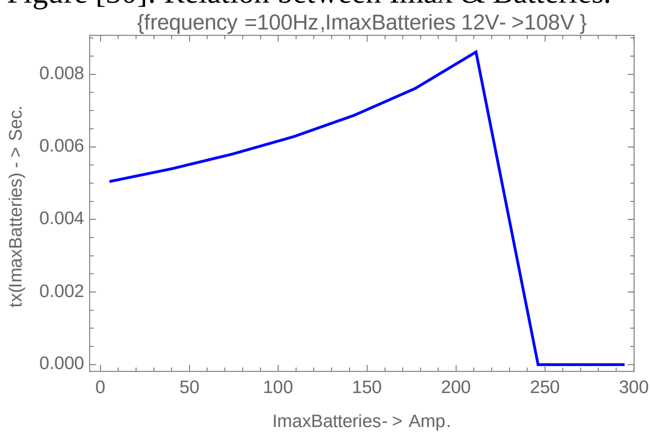

Figure [31]: Relation Between Imax of Batteries &tx of Maximum Currents of Batteries.

Conclusions

In this research, the program is written by the Mathematica Program Language. This program valid for any DC motor parameters. By this program, continuous and discontinuous mode of operations are obtained for any DC motor. In this paper, continuous mode of operation is obtained only at 12V and 24V when Imax is taken as a parameter. Imax is decreasing when extra battery is injected into the system.

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