ESTIMATION of ADVANCED DC/DC LUO-CONVERTERS BASED on ENERGY FACTOR and SUB-SEQUENTIAL PARAMETERS

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Abstract—The aim of this paper is to estimate and evaluate the dc/dc converters based on Energy factor and sub-sequential parameters to obtain mathematical model of power DC/DC converters (second order transfer function for any number of capacitors and inductors). The Elementary of positive output voltage-lift DC/DC Luo-converter and two stages positive output cascade boost converter super-lift DC/DC Luo-converter are chosen as the main focus case study of this paper. A computer simulation using NI SIMULINK results have been presented to verify the presented theoretical analysis.

Keywords—Estimation based on new energy concept, Advanced DC/DC converter, NI Simulation.

I. INTRODUCTION

Switching power circuits, such as power DC/DC converters, have pumping–filtering process, resonant process and voltage-lift operation. These circuits consist of several energy-storage elements. They are likely an energy container to store certain energy during performance. The stored energy will vary if the working condition changes [1]–[2].

DC/DC converters have been developed very quickly. The transient process from one steady state to another depends on the pumping energy and stored energy. Traditional parameters are not available to be used to describe the characteristics of power DC/DC converters and other high-frequency switching circuits and the traditional mathematical modelling is not available for complex structure converters because of the very high-order differential equations involved [1]–[2].

Traditional parameters used in power electronics are the power factor (PF), power transfer efficiency (η), total harmonic distortion (THD) and ripple factor (RF). Using these parameters has successfully described the characteristics of power systems [1]–[2].

Unfortunately, all these factors are not available to be used to describe the characteristics of power DC/DC converters and other high-frequency switching circuits. Power DC/DC converters have usually equipped by a DC power supply source, pump circuit, filter and load. The load can be of any type, but most of the investigations are concerned with resistive load, R, and back electromagnetic force (EMF) or battery. It means that the input and output voltages are nearly pure DC voltages with very small ripple (e.g. output voltage variation ratio is usually less than 1%). In this case, the corresponding RF is less than 0.001, which is always ignored [2].

Since all power is real power without reactive power, we cannot use power factor PF to describe the energy-transferring process [2].

Since DC components exist without harmonics in input and output voltage, THD is not available to be used to describe the energy-transferring process and waveform distortion [2].

To simplify the research and analysis, we usually assume the condition without power losses during power-transferring process to investigate power DC/DC converters. Consequently, the efficiency η is 100% for most of the description of power DC/DC investigation. Otherwise, efficiency η must be considered for special investigations regarding the power losses [2].

In general conditions, all four factors are not available to apply in the analysis of power DC/DC converters. This situation makes the designers of power DC/DC converters confusing for very long time. People would like to find other new parameters to describe the characteristics of power DC/DC converters [2]. So it is necessary to find other new parameters to describe the characteristics of power DC/DC converters [2].

The paper starts by describing the new energy parameters for dc/dc converter and then the mathematical model of dc/dc converters.

II. NEW ENERGY PARAMETERS FOR DC/DC CONVERTER.

Energy storage in power DC/DC converters has been paid attention long time ago. Unfortunately, there is no clear concept to describe the phenomena and reveal the relationship between the stored energy and the characteristics of power DC/DC converters.
Since 2005 a modern concept, “energy factor (EF)” is presented, and researched the relationship between EF and the mathematical modeling of power DC/DC converters.

EF is a modern concept in power electronics and conversion technology, which thoroughly differs from the traditional concepts such as power factor (PF), power transfer efficiency (η), total harmonic distortion (THD) and ripple factor (RF). EF and the sub-sequential other parameters can illustrate the system stability, reference response and interference recovery. This investigation is very helpful for system design and DC/DC converters characteristics foreseeing.

Assuming the instantaneous input voltage and current of a DC/DC converter are, v_in(t) and i_in(t), and their average values are \( V_{in} \) and \( I_{in} \), respectively. The instantaneous output voltage and current are \( V_o \) and \( I_o \), and their average values are \( V_o \) and \( I_o \) respectively. The switching frequency is \( f \), the switching period is \( T = 1/f \), the conduction duty cycle is \( k \) and the voltage transfer gain \( M = V_o/V_{in} \).

Before the definition of EF some factors must be introduced:

A. Pumping Energy:

All power DC/DC converters have pumping circuit to transfer the energy from the source to some energy-storage passive elements, e.g., inductors and capacitors. The pumping energy \( PE \) is used to calculate the input energy in a switching period \( T \). Its calculation formula is:

\[
PE = \int_0^T P_{in}(t) \, dt = \int_0^T v_{in} i_{in}(t) \, dt = V_{in} I_{in} T
\]  

Where \( I_{in} = \frac{1}{T} \int_0^T i_{in}(t) \, dt \) is the average value of the input current if the input voltage \( V_{in} \) is constant. Usually, the input average current \( I_{in} \) depends on the conduction duty cycle [1]–[2].

B. Stored Energy:

Energy storage in power DC/DC converters studied for a long time ago. Unfortunately, there is no clear concept to describe the phenomena and reveal the relationship between the stored energy and the characteristics of power DC/DC converters.

If a power DC/DC converter works in the continuous conduction mode (CCM), then all inductor’s currents and capacitor’s voltages are continuous (not to be equal to zero). If there are \( n_l \) inductors and \( n_c \) capacitors, the total stored energy in a DC/DC converter is:

\[
SE = \sum_{j=1}^{n_l} W_{Lj} + \sum_{j=1}^{n_c} W_{Cj}
\]  

C. Capacitor–Inductor Stored Energy Ratio (CIR):

Most power DC/DC converters consist of inductors and capacitors. Therefore, the capacitor–inductor stored energy ratio (CIR) can be defined as follows:

\[
CIR = \frac{\sum_{j=1}^{n_c} W_{Cj}}{\sum_{j=1}^{n_l} W_{Lj}}
\]  

D. Energy Losses:

Usually, most of the analysis applied to DC/DC converters are assume no power losses, i.e. the input power is equal to the output power, \( P_{in} = P_o \), so that pumping energy is equal to output energy in a period \( PE = V_{in} I_{in} T = V_o I_o T \). It corresponds to the efficiency \( \eta = 100\% \).

Particularly, power losses always exist during the conversion process. They are caused by the resistance of the connection cables, resistance of the inductors and capacitors wires, and power losses across the semiconductor devices. We can sort them as the resistive power losses \( P_r \), passive element power losses \( P_p \) and device power losses \( P_d \). Then, the total power losses are:

\[
P_{\text{loss}} = P_r + P_p + P_d = P_{in} - P_o
\]

Therefore, the energy losses (EL) in a period \( T \) are:

\[
EL = \int_0^T P_{\text{loss}} \, dt = P_{\text{loss}} \times T = (P_r + P_p + P_d) T
\]

The efficiency can be defined as:

\[
\eta = \frac{P_o}{P_{in}} = \frac{P_{in} - P_{\text{loss}}}{P_{in}} = \frac{PE - EL}{PE}
\]

E. Energy Factor:

The energy factor (EF) is the ratio of the stored energy \( SE \) over the pumping energy (PE):

\[
EF = \frac{SE}{PE} = \frac{\sum_{j=1}^{n_l} W_{Lj} + \sum_{j=1}^{n_c} W_{Cj}}{V_{in} I_{in} T}
\]

Energy factor (EF) is a very important factor of a power DC/DC converter. It is usually independent from the conduction duty cycle \( k \), and proportional to the switching frequency \( f \) (inversely proportional to \( T \)) since the pumping energy (PE) is proportional to the switching period \( T \).

F. Variation Energy Factor:

The variation of stored energy (\( EF_V \)) is the ratio of the variation of stored energy over the pumping energy:

\[
EF_V = \frac{SE}{PE} = \frac{\sum_{j=1}^{n_l} \Delta W_{Lj} + \sum_{j=1}^{n_c} \Delta W_{Cj}}{V_{in} I_{in} T}
\]

Energy factor (EF) and variation energy factor (EFV) are available to be used to describe the characteristics of power DC/DC converters [1]–[2].

III. MATHEMATICAL MODELING FOR POWER DC/DC CONVERTERS

We introduce the time constant \( \tau \), damping time constant \( \tau_d \), and time constant ratio \( \xi \), of power DC/DC converter as new parameters to describe the transient process and obtain the mathematical model of a DC/DC converter. They are defined as [1]–[2]:

\[
\tau = \frac{2T \times EF}{1 + CIR \left(1 + \frac{(1 - \eta)}{\eta}\right)}
\]
The time constant, damping time constant, and time constant ratio are independent from switching frequency f (or period T) and conduction duty cycle k. If there is no power loss and $\eta=1$. They are available to estimate the converter responses for a unit-step function and impulse interference. Usually higher power losses produces smaller time constant ratio ($\xi$) since usually CIR>1. From this analysis, most power DC/DC converters with lower power losses possess output voltage oscillation when the converter operation state changes. Vice versa, power DC/DC converters with high power losses will possess output voltage smoothening when the converter operation state changes. The unit-step function response can be estimated by using the ratio $\xi$. If the ratio $\xi$ is equal to or smaller than 0.25, then the corresponding unit-step function response has no oscillation and overshoot. Vice versa, if the ratio $\xi$ is greater than 0.25, then corresponding unit-step function response has oscillation and overshoot. The higher the value of ratio $\xi$, the heavier the oscillation with higher overshoot.

The mathematical model for all power DC/DC converters is [3]:

$$G(s) = \frac{M}{\tau_d s^2 + \xi s + 1}$$  \hspace{1cm} (12)

Where M is the voltage transfer gain (M = $V_o/V_{in}$), and S, the Laplace operator in the S-domain. Using this mathematical model of power DC/DC converters, it is significantly easy to describe the characteristics of power DC/DC converters for transient and steady state period [1].

IV. SIMULATED SCHEMATIC

In order to demonstrate the parameters’ calculation two examples are presented in this section. An Elementary of positive output voltage-lift DC/DC Luo-converter and two stages positive output cascade boost converter super-lift DC/DC Luo-converter are used for this purpose.

A. Elementary of Positive Output Voltage-lift DC/DC Luo-Converter:

Elementary circuit is shown in Fig. 1 [3].

![Elementary circuit of positive output voltage-lift Luo-converter](image1)

The general transfer gain M when inductors resistances have been taken into account is:

$$M = \frac{V_o}{V_{in}} = \frac{(K \frac{1-K}{R})}{1 + \frac{r_{L1} K}{R} (1-K) + \frac{r_{L2} K}{R}}$$  \hspace{1cm} (13)

Where $r_{L1}$ and $r_{L2}$ are a resistances of the inductors. The arrangement of current doesn’t change due to inductors resistances:

$$\frac{I_{in}}{I_o} = \frac{K}{1-K}$$  \hspace{1cm} (14)

Output voltage of the Positive output Luo-converter can be smaller, equal, or greater than the source or input voltage It depends on the duty cycle of the switch. The average capacitors voltages are:

$$V_c = V_{in} \left( \frac{K}{1-K} - r_{L1} \frac{1}{1-K} \right)$$  \hspace{1cm} (15)

$$V_{co} = V_o$$  \hspace{1cm} (16)

The average inductors currents for steady-state operation are:

$$I_{L2} = I_o = \left( \frac{1-K}{K} \right) I_{in}$$  \hspace{1cm} (17)

$$I_{L1} = I_{in}$$  \hspace{1cm} (18)

B. Two Stages of Positive Output Cascade Boost Converter Super-lift DC/DC Luo-Converter:

The circuit is shown in Fig. 2 [3].

![Two-stage positive output cascade boost converter super-lift DC/DC Luo-converter](image2)

The general transfer gain M if inductors resistances have been taken into account is:

$$M = \frac{V_o}{V_{in}} = \frac{1}{1 + \frac{r_{L1}}{R} (1-K)^2 + \frac{r_{L2}}{R} (1-K)^2}$$  \hspace{1cm} (19)

Where $r_{L1}$ and $r_{L2}$ are the resistances of inductors. The arrangement of current doesn’t change due to inductors resistances [3]:

$$\frac{I_{in}}{I_o} = \frac{1}{(1-K)^2}$$  \hspace{1cm} (20)

The average capacitors voltages are:

$$V_{C1} = V_{in} \frac{r_{L1}}{1-K}$$  \hspace{1cm} (21)

$$V_{co} = V_o$$  \hspace{1cm} (22)

The average inductors currents for steady-state operation are [3]:

$$I_{L1} = I_{in}$$  \hspace{1cm} (23)
\[ I_{L2} = \frac{i_0}{1 - \kappa} \]  \hspace{1cm} (24)

V. SIMULATIONS RESULTS

This section estimates and studies advanced dc/dc Luo-converters based on new energy factor (EF) and sub-sequential parameters using MATLAB (code given in the appendix). The parameters are extracted then compared with the results of NI MULTISIM modeling for transient and steady state period of output voltage. Fig.3 describes the flowchart of MATLAB’s code which is used to obtain new energy factor (EF), sub-sequential parameters, Mathematical modeling, and compute step response characteristic.

A. Results of the Elementary of Positive Output Voltage-lift Luo-Converter by using MATLAB:

The components of the converter are: \( V_{in}=20V \), \( C_1=C_2=1mF \), \( R=200\, \Omega \), the switching frequency \( f=10KHZ \), \( (T=1/f =100\, \mu s) \) and duty cycle \( K=0.6 \). The value of inductors \( L_1=L_2=10mH \) are suitable and larger than minimum inductors so this converter is stable and works in CCM. Three cases of different inductor resistances are modeled with results displayed in TABLE I.

<table>
<thead>
<tr>
<th>new energy parameters &amp; step response c/c</th>
<th>( r_L = 0, \Omega )</th>
<th>( r_L = 0.5, \Omega )</th>
<th>( r_L = 2.19, \Omega )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta ) (%)</td>
<td>1</td>
<td>99.19</td>
<td>96.56</td>
</tr>
<tr>
<td>( PE ) (J)</td>
<td>4.5*10^{-4}</td>
<td>4.4637*10^{-4}</td>
<td>4.354*10^{-4}</td>
</tr>
<tr>
<td>( SE ) (J)</td>
<td>0.9004</td>
<td>0.8881</td>
<td>0.8486</td>
</tr>
<tr>
<td>( CIR ) (J)</td>
<td>2.4615*10^{3}</td>
<td>2.4677*10^{3}</td>
<td>2.488*10^{3}</td>
</tr>
<tr>
<td>( EF ) (J)</td>
<td>2.008*10^{3}</td>
<td>1.9896*10^{3}</td>
<td>1.9528*10^{3}</td>
</tr>
<tr>
<td>( \tau ) (sec)</td>
<td>0.1625*10^{-3}</td>
<td>0.0034</td>
<td>0.0141</td>
</tr>
<tr>
<td>( \tau_d ) (sec)</td>
<td>0.4</td>
<td>0.019</td>
<td>0.0045</td>
</tr>
<tr>
<td>( \zeta = \tau_d / \tau )</td>
<td>2.4615*10^{3}</td>
<td>5.6144</td>
<td>0.3214</td>
</tr>
<tr>
<td>( Wn ) (rad/s)</td>
<td>124.0347</td>
<td>124.3829</td>
<td>125.5498</td>
</tr>
<tr>
<td>( Z )</td>
<td>0.0101</td>
<td>0.2110</td>
<td>0.8820</td>
</tr>
<tr>
<td>Settling Time ts(s)</td>
<td>0.0098</td>
<td>0.0116</td>
<td>0.0282</td>
</tr>
<tr>
<td>Min. Vo during ts (v)</td>
<td>1.8408</td>
<td>22.0978</td>
<td>27.5846</td>
</tr>
<tr>
<td>Max. Vo during ts (v)</td>
<td>59.0650</td>
<td>44.8590</td>
<td>29.0500</td>
</tr>
<tr>
<td>% overshoot</td>
<td>96.8834</td>
<td>50.7449</td>
<td>0.2794</td>
</tr>
<tr>
<td>% undershoot</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Peak (volt)</td>
<td>59.0650</td>
<td>44.859</td>
<td>29.0500</td>
</tr>
<tr>
<td>Peak time (sec)</td>
<td>0.0253</td>
<td>0.0260</td>
<td>0.0331</td>
</tr>
</tbody>
</table>

Where \( Wn \) is un-damped natural frequency and \( Z \) is damping ratio (if \( Z=0 \) system with no damped, \( 0<Z<1 \) under-damped, \( Z>1 \) over-damped, and \( Z=1 \) critical).

The mathematical modeling and step response of elementary P/O VL Luo-converter for three cases are:

1) At \( r_L = 0\, \Omega \):

\[
G(s) = \frac{1.5}{6.5 \times 10^{-5}s^2 + 0.1625 \times 10^{-3}s + 1} \quad (25)
\]

Fig. 3. Flowchart of MATLAB’s program

2) At \( r_L = 0.5\, \Omega \):

\[
G(s) = \frac{1.488}{6.646 \times 10^{-5}s^2 + 0.003393s + 1} \quad (26)
\]

Fig. 4. Step response for output voltage of P/O VL Luo-converter without energy losses \( (r =0\, \Omega) \).

Fig. 5. Step response for output voltage of P/O VL Luo-converter with energy losses \( (r =0.5\, \Omega) \).
3) At $r_L = 2.19\Omega$:

$$G(s) = \frac{1.4485}{6.344 \times 10^{-5}s^2 + 0.01405s + 1} \quad (27)$$

![Fig. 6. Step response for output voltage of P/O VL Luo-converter with energy losses ($r = 2.19\Omega$)](image)

**B. Results for the elementary of positive output voltage-lift Luo-converter by using NI MULTISIM**

In this section the output voltage for transient and steady state period for P/O VL Luo-converter are presented.

1) At $r_L = 1\mu\Omega \approx 0\Omega$:

![Fig. 7. Step response of output voltage for P/O VL Luo-converter (1µΩ=0Ω).](image)

2) At $r_L = 0.5\Omega$:

![Fig. 8. Step response of output voltage for P/O VL Luo-converter ($r = 0.5\Omega$).](image)

3) At $r_L = 2.19\Omega$:

![Fig. 9. Step response of output voltage for P/O VL Luo-converter ($r = 2.19\Omega$).](image)

**C. Results of Two stages positive output cascade boost converter super-lift DC/DC Luo-converter by using MATLAB**

The components of the converter are: $V_{in}=20V$, $C_1=C_2=1mF$, $R =800\Omega$, the switching frequency $f=10KHZ$, $(T=1/f =100\mu s)$ and duty cycle $K=0.5$. The value of inductors, $L_1=L_2=10mH$, are suitable and converter works in CCM. Three cases of different inductor resistances are modeled with results displayed in TABLE II.

<table>
<thead>
<tr>
<th>New energy parameters &amp; step response c/c</th>
<th>$r_L = 0\Omega$</th>
<th>$r_L = 0.5\Omega$</th>
<th>$r_L = 2.19\Omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$ (%)</td>
<td>1.0000</td>
<td>0.9877</td>
<td>0.9481</td>
</tr>
<tr>
<td>PE (J)</td>
<td>8.10×10^-4</td>
<td>7.901×10^-4</td>
<td>7.5847</td>
</tr>
<tr>
<td>SE (J)</td>
<td>4.001</td>
<td>3.9067</td>
<td>3.6122</td>
</tr>
<tr>
<td>CIR</td>
<td>4.00×10^3</td>
<td>4.004×10^3</td>
<td>4.0176</td>
</tr>
<tr>
<td>EF</td>
<td>5.001×10^3</td>
<td>4.9445×10^3</td>
<td>4.7625</td>
</tr>
<tr>
<td>$\tau$ (sec)</td>
<td>2.5×10^-4</td>
<td>0.0126</td>
<td>0.0524</td>
</tr>
<tr>
<td>$\tau_d$ (sec)</td>
<td>1.0000</td>
<td>0.0196</td>
<td>0.0045</td>
</tr>
<tr>
<td>$\zeta = \tau_d / \tau$</td>
<td>4.0000</td>
<td>1.5556</td>
<td>0.0868</td>
</tr>
<tr>
<td>Wn (rad/s)</td>
<td>0.0063</td>
<td>0.0063</td>
<td>0.0063</td>
</tr>
<tr>
<td>$Z$</td>
<td>63.2456</td>
<td>63.6078</td>
<td>21.1214/198.8742</td>
</tr>
<tr>
<td>Rise Time (sec)</td>
<td>0.0079</td>
<td>0.0126</td>
<td>0.0524</td>
</tr>
<tr>
<td>Settling Time (ts (s))</td>
<td>0.0191</td>
<td>0.0271</td>
<td>0.1412</td>
</tr>
<tr>
<td>Min. Vo during ts (v)</td>
<td>7.8000</td>
<td>0.1322</td>
<td>0.1905</td>
</tr>
<tr>
<td>Max. Vo during ts (v)</td>
<td>3.8769</td>
<td>73.9659</td>
<td>72.2020</td>
</tr>
<tr>
<td>% overshoot</td>
<td>158.0375</td>
<td>98.9880</td>
<td>75.7850</td>
</tr>
<tr>
<td>% undershoot</td>
<td>97.5469</td>
<td>25.2817</td>
<td>0</td>
</tr>
<tr>
<td>Peak (volt)</td>
<td>158.0375</td>
<td>98.9880</td>
<td>75.7850</td>
</tr>
<tr>
<td>Peak time (sec)</td>
<td>0.0497</td>
<td>0.0535</td>
<td>0.3416</td>
</tr>
</tbody>
</table>

Where $W_n$ is un-damped natural frequency and $Z$ is damping ratio (if $Z=0$ system with no damped, $0<Z<1$ under-damped, $Z=1$ over-damped, and $Z=1$ critical).

The mathematical modeling and step response of two stage P/O CBC SL Luo-converter is presented here for three specific cases:

1) At $r_L = 0\Omega$:

$$G(s) = \frac{4}{0.00025s^2 + 0.00025s + 1} \quad (28)$$

![Fig. 10. Step response for output voltage of P/O VL Luo-converter without energy losses ($r =0\Omega$).](image)
$2) r_L = 0.5\Omega$:

$$G(s) = \frac{3.951}{2.472 \times 10^{-4}s^2 + 0.0126s + 1}$$  \hspace{1cm} (29)$$

Fig. 11. Step response for output voltage of P/O VL Luo-converter with energy losses ($r = 0.5\Omega$).

$3) r_L = 2.19\Omega$.

$$G(s) = \frac{3.792}{2.381 \times 10^{-2}s^2 + 0.005237s + 1}$$  \hspace{1cm} (30)$$

Fig. 12. Step response for output voltage of P/O VL Luo-converter with energy losses ($r = 2.19\Omega$).

Based on the work presented here for the both types of the converters, one can deduce the following points:

- The mathematical model of dc/dc converters has been successfully developed using the approach of energy factor and sub-sequential parameters.
- TABLE I, TABLE II, and simulation results (section V) clearly demonstrate that the transient period, percentage overshoot oscillation, and efficiency is non-directly proportional to the resistance of the inductors, but in same time the voltage drop of the output voltage is directly proportional to the resistance of the inductors.
- Practical results have not yet been demonstrated to verify the presented theoretical analysis because of the difficulty to obtain the transient period via the available instruments.

VI. CONCLUSION AND FUTURE WORK

We presented an estimation of the dc/dc converters based on Energy factor and sub-sequential parameters. Then the mathematical model of power DC/DC converters as second order transfer function for any number of capacitors and inductors is presented in this paper. The study has been compared against theoretical simulations to confirm its validity. The results are consistent for different variable parameters of the system.

The Future works include implementing one of the advanced dc/dc converter in renewable energy system, using random PWM by using computer program or micro-controller to control the advanced dc/dc converter and compare with normal PWM, study the soft-switching advanced dc/dc Luo-converters, and implementing the Maximum Power Point Tracking for advanced DC/DC converters in renewable energy system.

APPENDIX

A. The MATLAB program for elementary P/O VL Luo-converter is:

```matlab
clc
clear
Y=2;
while Y==2;
x=menu('menu','Ren Hammouda program','Thanks');
if(x==1);
```
Vin=input('Vin='); R=input('R=');
L1=input('L1=');L2=input('L2='); r=input('r=');
C1=input('C1=');C2=input('C2=');
f=input('f=');K=input('K=');
Wn=(K/(1-K))/((1+((r*R)/(K*(1-K))))^2+((r*R)/(K*(1-K))));
Vo=M*Vin; Io=Vo/R;
IL1=Io*(K/(1-K)); IL2=Io;
VC1=((K/(1-K))*Vin)/(1+((r*R)/(K*(1-K))))^2; VC2=Vo;
WL=0.5*IL1^2*L1+0.5*IL2^2*L2;
WC=0.5*C1*VC1^2+0.5*C2*VC2^2;
T=1/f;
Po=Vo*Io; Ploss=r*IL1^2+r*IL2^2;
Iin=(Po+Ploss)/Vin;
disp('The efficiency')
eff=abs((Vo*Io)/(Vin*Iin))
disp('pumping Energy')
PE=abs(Vo*Vin*T);
disp('undamped natural frequency = ') Wn
disp('damping ratio =') Z
S = stepinfo(sys*Vin,'RiseTimeLimits',[0.05,0.95])
disp('percentage peak to peak output Voltage ripple')
100*(1-K)/(R*C2*f)
end
Y=menu('Repeat run', 'Quit', 'repeat run');
if Y==1
end
end

REFERENCES