Effect of Load Dynamic on Power Electronic System with Constant Power Load

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ABSTRACT

A switched-mode dc-dc converters are some of the most widely used power electronics circuits for its high conversion efficiency and flexible output voltage. These converters used for electronic devices are designed to regulate the output voltage against the changes of the input voltage and load current. This leads to the requirement of more advanced control methods to meet the real demand. Many control methods are developed for the control of dc-dc converters. To obtain a control method that has the best performances under any conditions is always in demand. Conventionally, the dc-dc converters have been controlled by linear voltage mode and current mode control methods. These controllers offer advantages such as fixed switching frequencies and zero steady-state error and gives a better small-signal performance at the designed operating point.In our power electronic circuit many types load are their like constant restive load and constant power load. The constant power load shows negative impedance instability. This resistive load and constant power are stabilized with buck and boost converter. By using the MATLAB Simulink platform.
Keywords:- MATLAB Simulink platform, DC- converters, linear voltage, steady-state error, buck and boost converter.

Introduction

DC-DC converters areanelectronic circuit which convert one level of electrical voltage into another level by switching action [1]. These converter's demands have an increase in many areas. This is due to their wide applications like power supplies for personal computers, office equipment, appliance control, DC motor drives, automotive aircraft, etc [1-2].

The analysis, control, and stabilization of switching converters are the main factors that need to be considered. Many control methods are used for the control of switch-mode DC-DC converters and the simple and low-cost controller structure is always in demand for most industrial and high-performance applications. Each control method has its advantages and drawbacks, and its effectiveness is determined by the application where it’s applied [3].

The designed PI controller would process the resultant error to generate a control signal is compared with a fixed frequency sawtooth waveform (in PWM modulator) to produce the switching pulses of the desired pulse width. The voltage mode controller only needs information about the output voltage to close the control loop and provide a regulated and stable output voltage [4].

Power electronic converters, when tightly regulated, behave as constant power loads [9]. Constant power loads have negative impedance characteristics. Voltage mode and current mode - controlled buck and boost converter with PI controller is used to stabilize the constant resistance load and constant power load.

Literature survey

The switching mode dc-dc converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower for buck converter [1]. The most used technique to control switching dc-dc converter is Pulse-width Modulation (PWM) [2].The conventional PWM controlled power electronics circuits are modelled based on averaging method and the system being controlled operates optimally only for a specific condition [3-4]. The output voltage of the power buckconverter is regulated using a PI controller. The closed loop performanceof the DC/DC power buckconverteris tested with operating point changes [5-6].Resistance load is constant when physical condition and temperature are constant [7].K. zenger et. al [8] discusses, the voltage mode control of the Buck converteroperating mainly in the continuous conduction mode [CCM]. And Small signalmodels were used to tune the proportional integral derivative controller(PID)controller,which was tested in the case of both resistiveload and constant power load [8]. S. radhika et.al [9] discuss the Current Mode Control of Boost Converter is an efficient step-up DC-DC converter used in numerous electronics devices. It is modeled and simulated using Matlab. A closed loop model is developed and used successfully for simulation. This converter has advantages like reduced hardware, high performance, less weight and accuracy. The simulation results are in line with the predictions. The same was implemented as a hardware project.A.Emadiet. al. [10discusses the concept of the negative impedance instability of the (constant power load) CPLs in advanced automotive systems. CPLs and their negative impedance instability characteristics were analysed with a different examples of constant power load and determine the condition of stability of constant power load.

Simulation Results

Buck converter feeding resistive load

The ideal buck converter has been modelled using the circuit diagram of fig 2.1 to create a MATLAB Simulink model as shown in fig 3.1.

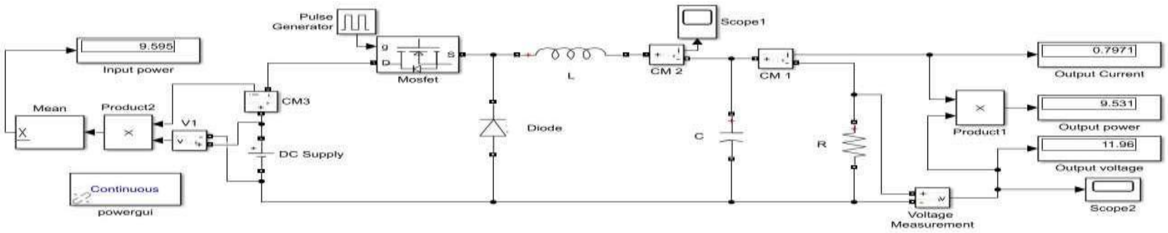


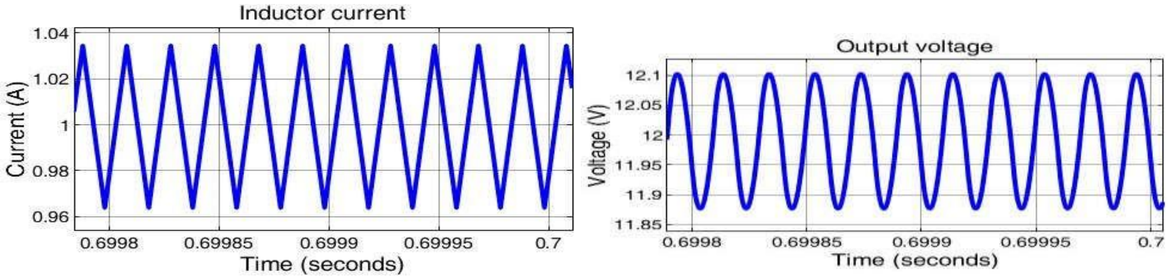
Fig. 3.1: Simulink model of voltage mode controlled buck converter feeding a Resistive load.

The simulation of the proposed Simulink model of a buck converter is carried out. under fixed duty cycle, where the inductor and capacitor are modelled as ideal elements. The inductor and capacitor value are selected as to ensure reliable operation in continuous conduction mode, resistance of constant resistance load (CRL) are varied. The parameters of the buck converter are listed in table 1.

Table: 1 Circuit Parameter

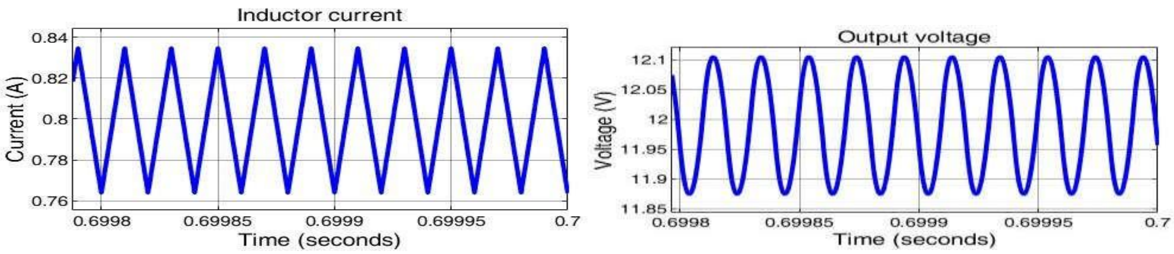
Parameter	Specification	Value/unit
	Input voltage	24 V
L	Inductor	1.7mH
C	Capacitor	0.75 µF
R	Resistiveload	12-15Ω
f	Switching frequency	50 kHz

The simulation results of the output voltage and inductor current for different resistance values of loads are displayed in fig respectively. In the steady-state, the waveform shows the stable period-1 behaviour and has minimum ripple content. The observed results are listed in table 2.



(a) (b)

Fig. Stable period-1 behaviour observed for3.2(a) Inductor current and 3.2(b) output voltage waveforms forR = 12 Ωload,Inductor current contains 3.55 % ripple and output voltage have 0.94% ripple.



(a) (b)

Fig.-Stable period-1 behaviour observed for3.3(a) Inductor current and3.3(b) output voltage waveforms for R = 15 Ωload,Inductor current contains 4.44 % ripple and output voltage have 0.94% ripple.

Table -2 Observation table

S.N.	V_{in}(V)	$_{in}$(W)	***R*(Ω)**	$_0$(V)	I_0(A)	$_0$(W)	%ΔV voltage ripple	%ΔICurrent ripple
1	24	11.99	12	11.97	0.9978	11.95	0.94	3.55
2	24	9.6	15	11.96	0.8	9.54	0.94	4.44

Boost converter feeding resistive load

The ideal boost converter has been modelled using the circuit diagram to create a MATLAB Simulink model as shown in fig 2.2.

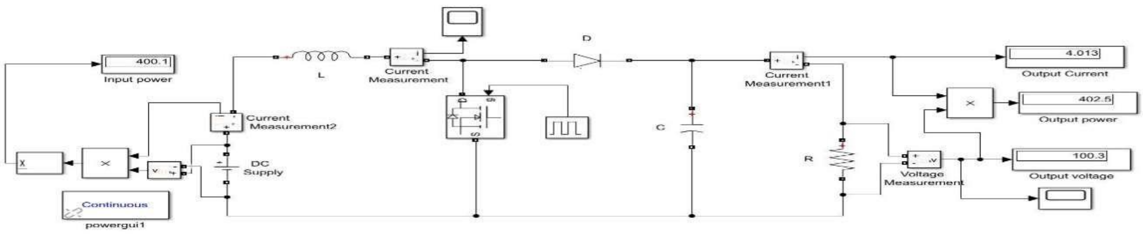
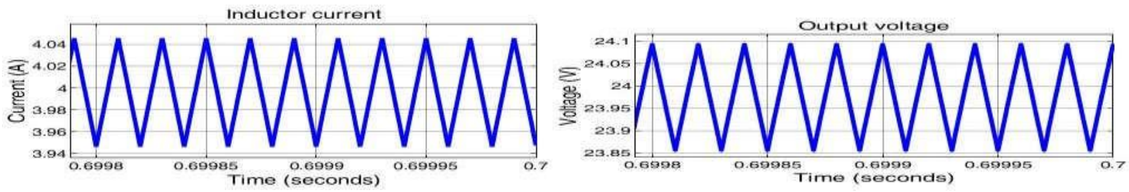


Fig: Simulink model of voltage mode- controlled boost converter feeding a Resistive load.

The simulation of the proposed Simulink model of a boost converter is carried out. under fixed duty cycle, where the inductor and capacitor are modelled as ideal elements. The inductor and capacitor value are selected as to ensure reliable operation in continuous conduction mode,resistance of constant resistance load (CRL) are varied. The parameters of the boost converter are listed in table 3.

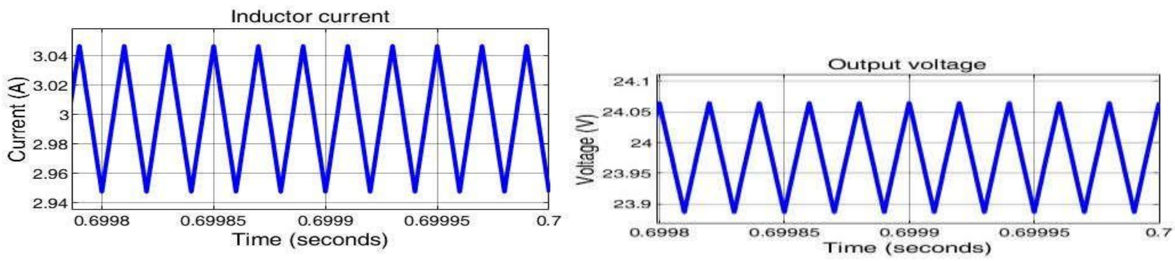
Table: 3 Circuit Parameter

Parameter	Specification	Value/unit
	Input voltage	24 V
L	Inductor	1.2mH
C	Capacitor	83.3 μF
R	Resistive load	12-16Ω
F	Switching frequency	50 kHz



(a) (b)

Fig. Stable period-1 behaviour observed for3.5(a) Inductor current and 3.5(b) output voltage waveforms for R = 12 Ωload,Inductor current contains 1.25 % ripple and output voltage have 0.35% ripple.



(a) (b)

Fig. Stable period-1 behaviour observed for3.6(a) Inductor current and 3.6(b) output voltage waveforms for R = 16 Ωload,Inductor current contains 1.67 % ripple and output voltage have 0.35% ripple.

From the above waveform, the system exhibits regular and desirable period-1 behaviour in the steady-state with a minimum amount of ripple, the observation results are listed in table.

Table 4: Observation Table

S.N.	V_{in}(V)	$_{in}$(W)	***R(Ω)***	$_0$(V)	I_0(A)	$_0$(W)	%ΔV voltage ripple	%ΔICurrent ripple
1	12	49.95	12	24.09	2.00	48.38	0.35	1.25
2	12	37.97	16	24.07	1.5	36.2	0.35	1.67

Voltage mode-controlled Buck converter feeding resistance load

The ideal buck converter has been modelled using the circuit diagram of fig 2.3 to create a closed-loop MATLAB Simulink model as shown in fig 3.7

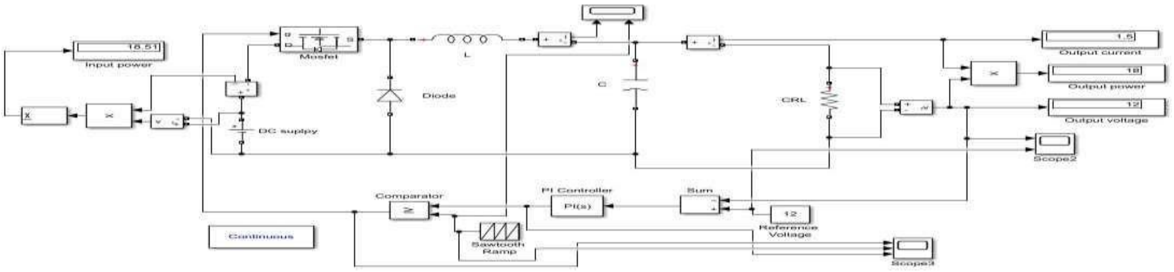


Fig.: Simulink model of voltage mode controlled buck converter feeding a Resistive load.

The simulation of the proposed Simulink model of a buck converter is carried out under fixed reference voltage where the inductor and capacitor are modelled as ideal elements. The inductor and capacitor value are selected to ensure reliable operation in continuous conduction mode, the value of the resistive load is varied and the switching frequency (f) is set to 50 kHz the parameters of the buck are listed in table 5.

In this model the reference voltage is used to get the desired value of output voltage an error voltage signal is generated by subtracting the output voltage from the reference voltage. The error signal is processed by the PI controller and generates the control signal by comparing the control signal and sawtooth ramp signal, gate pulse signal is generated as shown in fig. The simulation results of the output voltage, and inductor current for different values of load resistance are displayed in fig.

.

Table 5: Circuit parameters

Parameter	Specification	Value/unit
	Input voltage	24 V
L	Inductor	1 mH
C	Capacitor	4.7 μF
R	Resistance load	6-8 Ω
	Reference voltage	12 V
f	Switching frequency	50 kHz
	Proportional gain	1
	Integral gain	100 S^{-1}

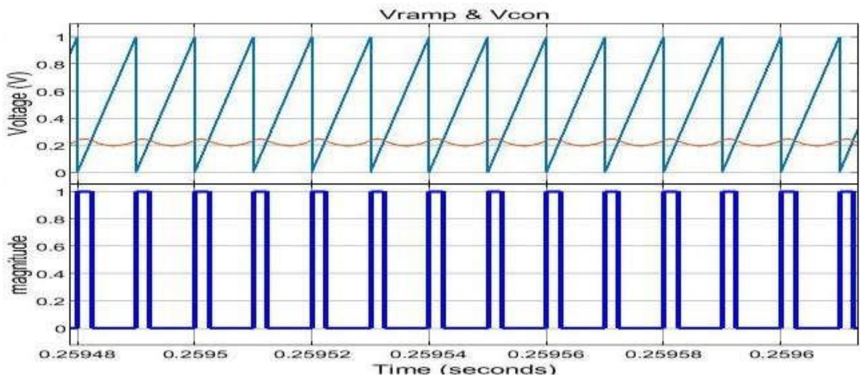
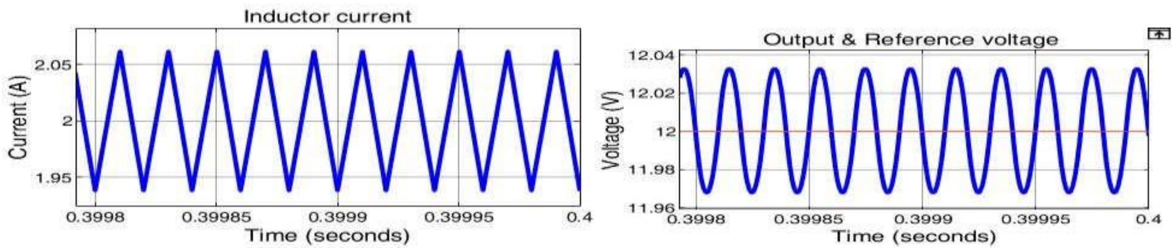
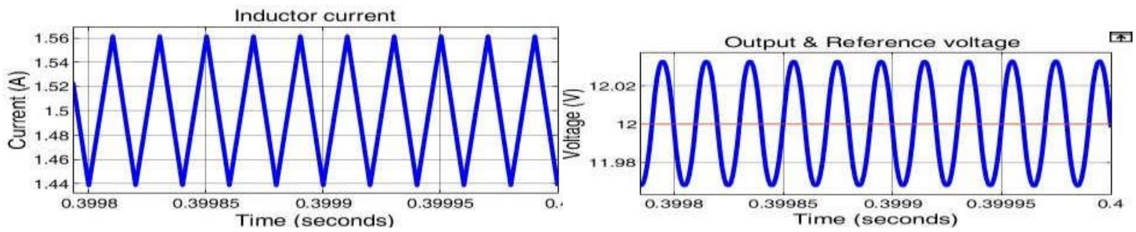


Fig.3.8: Ramp signal, control signal and gate pulse



(a) (b)

Fig.: Stable period-1 behaviour observed for3.9(a) Inductor current and 3.9(b) output voltage waveforms forR = 6 Ωload,Inductor current contains 3 % ripple and output voltage have 0.27% ripple.



(a) (b)

Fig.: Stable period-1 behaviour observed for3.10(a) Inductor current and 3.10(b) output voltage waveforms for R = 8 Ωload.Inductor current contains 4.1 % ripple and capacitor/output voltage have 0.27% ripple.

From the above waveform, the output voltage tracks the reference voltage and the system exhibits regular and desirable period-1 behaviour in the steady-state with a minimum amount of ripple, the observation results are listed in table 6.

Table 6: Observation table

SN.	(V)	(W)	**R(Ω)**	(V)	(V)	(A)	(W)	%ΔI	%ΔV
1	24	18.51	8	12	12	1.5	18	3	0.27
2	24	24.69	6	12	12	2	24	4.1	0.27

Based on the inductor current and capacitor voltage waveforms shown in figure 3.9 to 3.10the following calculations can be made [1]

Ripple in inductor current

$$\%\ \Delta i = \frac{\text{Peak to peak value of inductor current}}{2 * i_L}$$

Ripple in capacitor voltage

$$\%\ \Delta v_C = \frac{\text{Peak to peak value of capacitor voltage}}{2 * v_C}$$

Where, is inductor current and is capacitor voltage.[1-2]

From the observation table, when decreasing the resistance of constant resistance load it extracts more power from the source. Resistance is decreased again; it again extracts more power from the source.

Voltage mode-controlled Buck converter feeding constant power load

The ideal buck converter has been modelled using the circuit diagram of fig 2.3 to create a closed-loop MATLAB Simulink model as shown in fig.

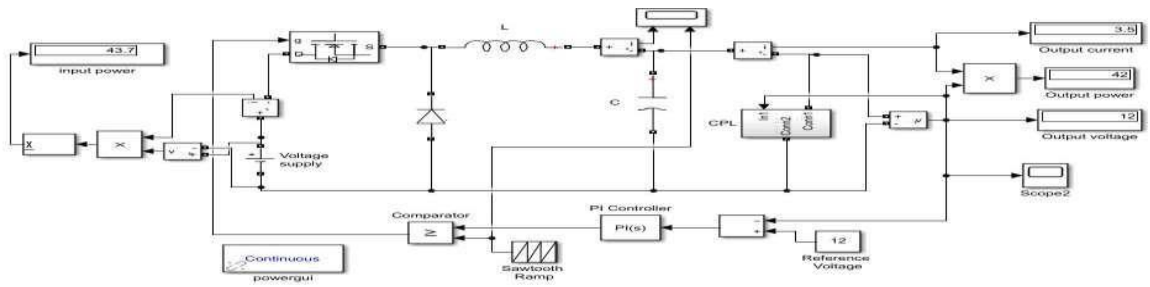


Fig.: Simulink model of voltage mode controlled buck converter feeding CPL.

The simulation of the proposed Simulink model of a buck converter feeding CPL is carried out, the parameters of the buck are listed in table 7.

Table 7 - Circuit parameters

Parameter	**Specification**	**Value/unit**
	Input voltage	20 V
L	Inductor	1 mH

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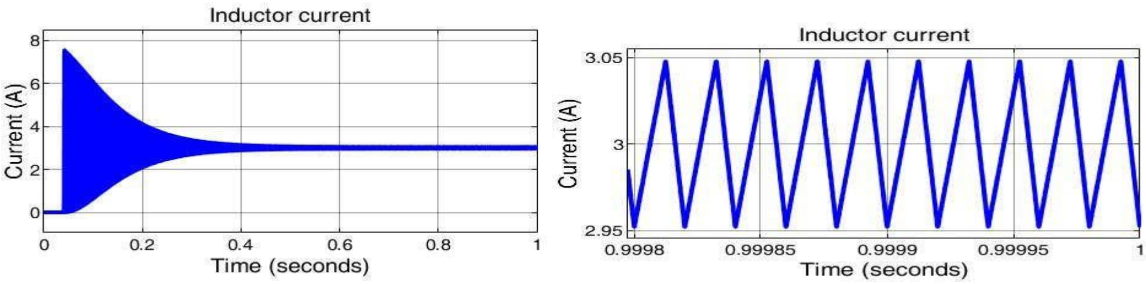
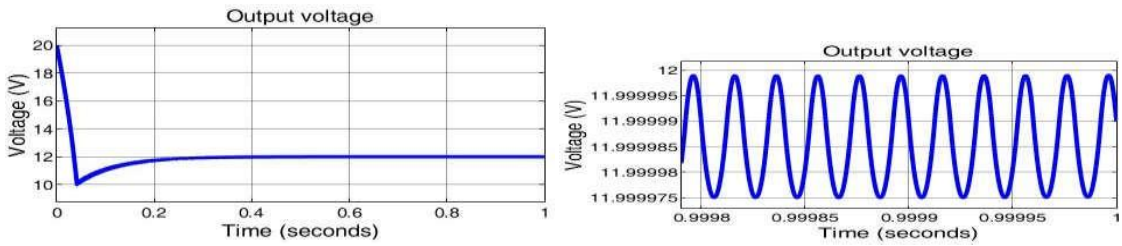
C	Capacitor	10 mF
CPL	Constant power load	36-42 W
	Reference voltage	12 V
f	Switching frequency	50 kHz

The simulation results of the output voltage and inductor current for different values of constant power load are displayed in fig 3.12 to 3.15 respectively. In the steady-state, the waveform shows the stable period-1 behaviour with a minimum ripple content, the observed results are listed in table 8.



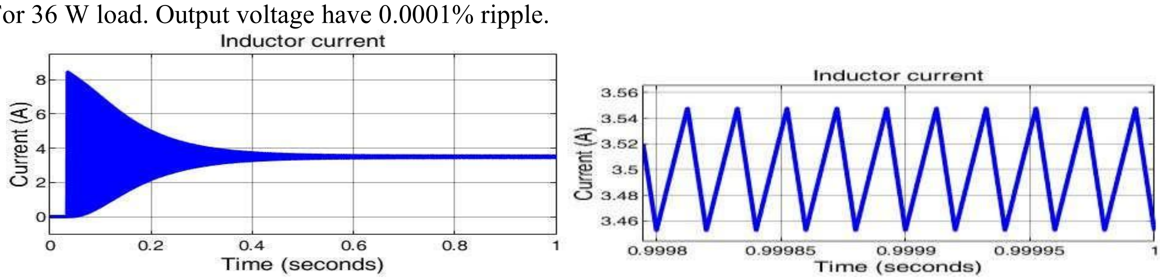
(a) (b)

Fig.: Shows the inductor current waveform (a) Inductor current with transient and (b) Stable period-1 behaviour. For36 Wload.Inductor current contains 1.6 % ripple.



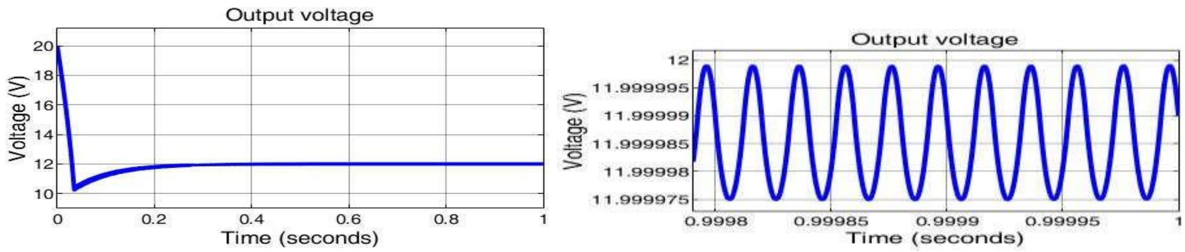
(a) (b)

Fig.: Shows the output voltage waveforms(a) Output voltage with transient and (b) Stable period-1 behaviour. For 36 W load. Output voltage have 0.0001% ripple.



(a) (b)

Fig.: Shows the inductor current waveformsa) Inductor current with transient and (b) Stable period-1 behaviour. For 42 Wload.Inductor current contains 1.37 % ripple.



(a) (b)

Fig.: Shows the output voltage waveforms3.15(a) Output voltage with transient and 3.15(b) Stable period-1 behaviour. For 42 W load. Output voltage have 0.0001% ripple.

Table 8 - Observation Table

SN.	(V)	(W)	(V)	(W)	(V)	(A)	(W)	%ΔI	%ΔV
1	20	37.36	12	36	12	3	36	1.6	0.0001
2	20	43.7	12	42	12	3.5	42	1.37	0.0001

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Current mode-controlled Buck converter feeding resistance load

The ideal buck converter has been modelled using the circuit diagram to create a closed-loop MATLAB Simulink model as shown in fig .

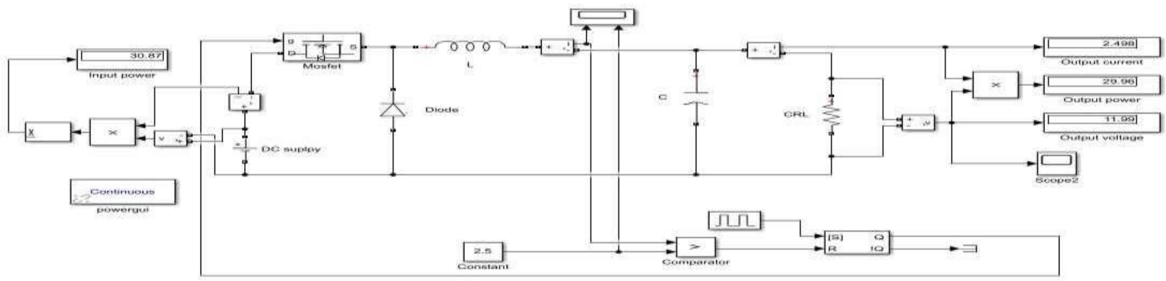


Fig.: Simulink model of current mode controlled buck converter feeding resistive load.

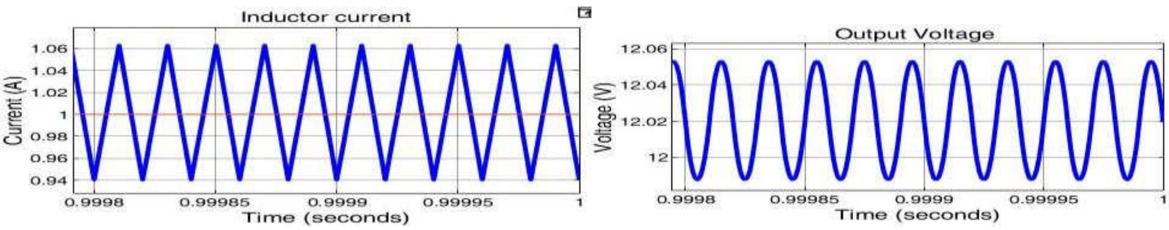
The simulation of the proposed Simulink model of a buck converter feeding resistive load is carried out, the parameters of the buck are listed in table 9.

Table 9 - Circuit parameters

Parameter	Specification	Value/unit
	Input voltage	12 V
L	Inductor	1 mH

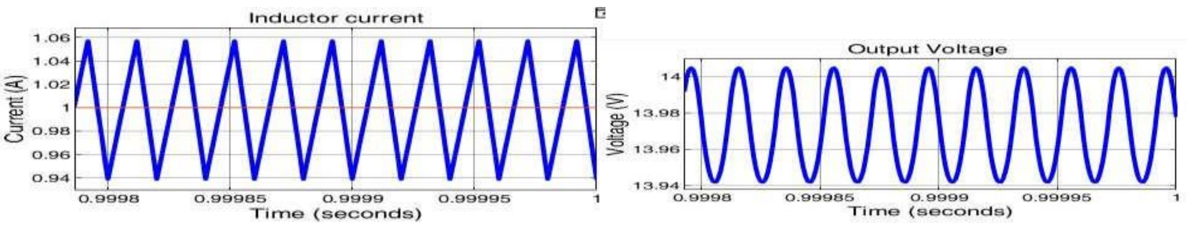
C	Capacitor	4.7 µF
R	Resistive load	12-14Ω
	Reference voltage	1 A
f	Switching frequency	50 kHz

The simulation results of the output voltage and inductor current for different values of constant power load are displayed in fig 3.17 to 3.18 respectively. In the steady-state, the waveform shows the stable period-1 behaviour with a minimum ripple content, and the observed results are listed in table 10.



(a) (b)

Fig: Stable period-1 behaviour observed for (a) Inductor current and (b) output voltage waveforms forR = 12 Ωload,Inductor current contains 6 % ripple and output voltage have 0.27% ripple.



(a) (b)

Fig.: Stable period-1 behaviour observed for3.18(a) Inductor current and (b) output voltage waveforms forR = 14 Ωload,Inductor current contains 6 % ripple and output voltage have 0.27% ripple.

Table 10: Observation Table

SN.	(V)	(W)	**R(Ω)**	(V)	(V)	(A)	(W)	%ΔI	%ΔV
1	24	12.38	12	1	12	1	12	6	0.27
2	24	14.23	14	1	12	1	14	6	0.27

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Current mode-controlled Buck converter feeding constant power load

The ideal buck converter has been modelled using the circuit diagram of fig 2.6 to create a closed-loop MATLAB Simulink model as shown in fig.

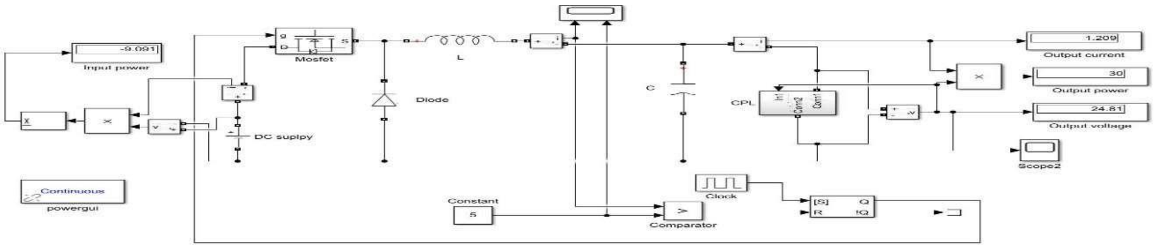


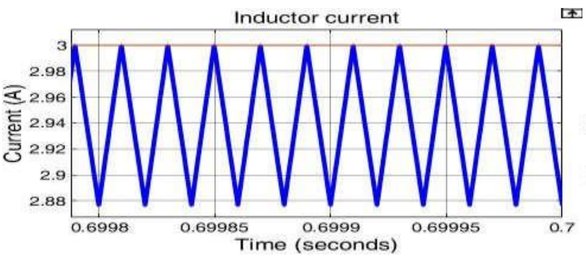
Fig.: Simulink model of current mode controlled buck converter feeding CPL.

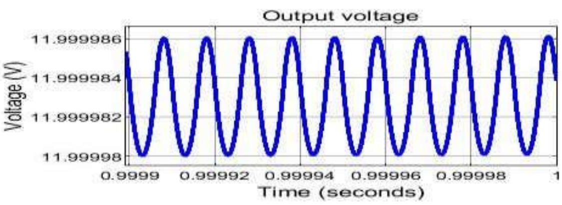
The simulation of the proposed Simulink model of a buck converter feeding CPL is carried out, the parameters of the buck are listed in table 11.

Table 11 - Circuit parameters

Parameter	Specification	Value/unit
	Input voltage	20 V
L	Inductor	1 mH
C	Capacitor	10 mF
CPL	Constant power load	30-36 W
	Reference voltage	3 A
f	Switching frequency	50 kHz

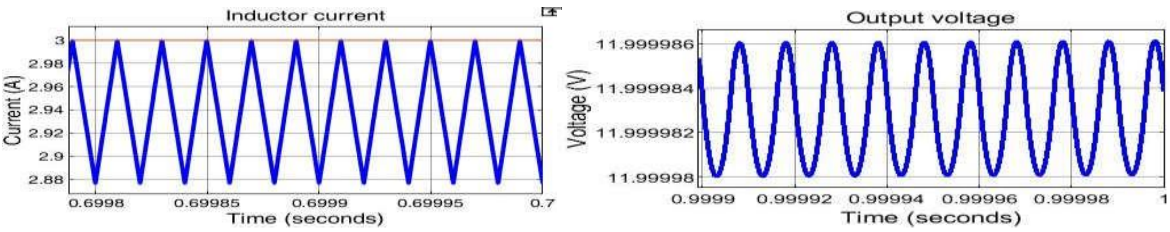
The simulation results of the output voltage and inductor current for different values of constant power load are displayed in figures respectively. In the steady-state, the waveform shows the stable period-1 behavior with a minimum ripple content, the observed results are listed in table 12.





(a) (b)

Fig: Stable period-1 behaviour observed for(a) Inductor current and (b) output voltage waveforms forP = 36 Wload,Inductor current contains 1.08 % ripple and output voltage have 0.27% ripple.



(a) (b)

Fig.: Stable period-1 behaviour observed for (a) Inductor current and (b) output voltage waveforms forP = 42 Wload,Inductor current contains 1.06 % ripple and output voltage have 0.27% ripple.

Table 12 - Observation Table

SN.	(V)	(W)	(V)	(W)	(V)	(A)	(W)	%ΔI	%ΔV
1	24	37.36	3	36	12	3	36	1.08	0.27
2	24	43.23	3	42	14	3	42	1.06	0.27

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Voltage mode-controlled Boost converter feeding resistance load

The ideal boost converter has been modelled using the circuit diagram of fig 2.7 to create a closed-loop MATLAB Simulink model as shown in fig 3.22.

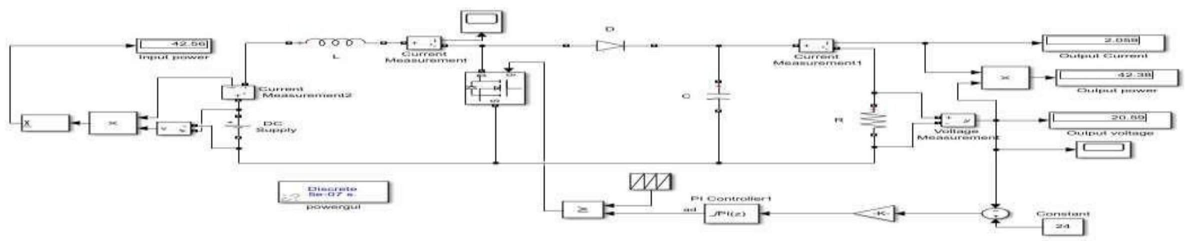


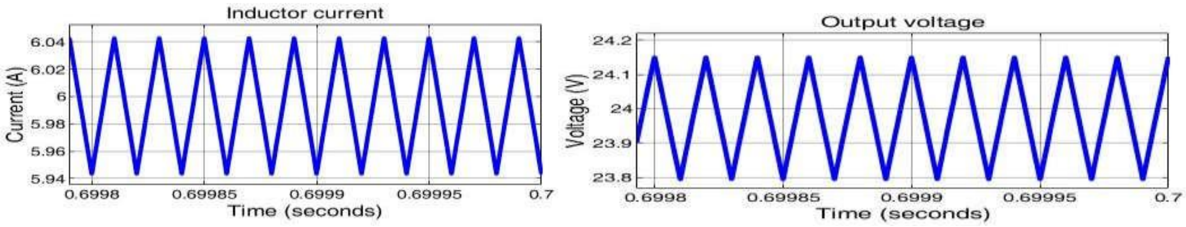
Fig.: Simulink model of voltage mode-controlled boost converter feeding resistive load.

The simulation of the proposed Simulink model of a boost converter feeding resistive load is carried out, the parameters of the boost are listed in table 13.

Table 13: Circuit parameters

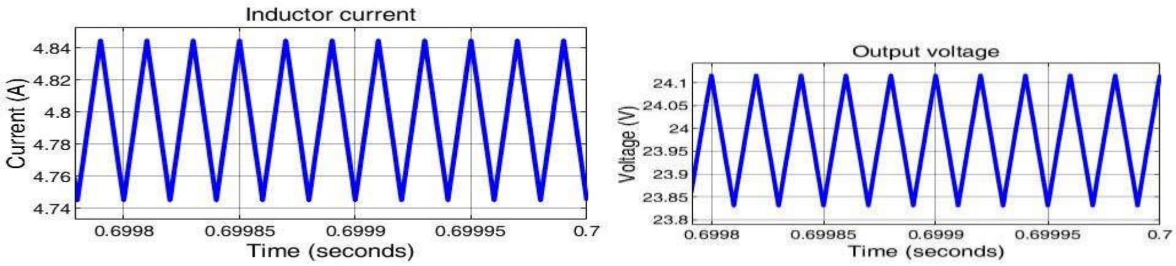
Parameter	Specification	Value/unit
	Input voltage	12 V
L	Inductor	1.2mH
C	Capacitor	83.3μF
Resistive load	Resistive load	8-10Ω
	Reference voltage	24 V
f	Switching frequency	50 kHz
	Proportional gain	0.7
	Integral gain	100 S^{-1}

The simulation results of the output voltage and inductor current for different values of constant power load are displayed in figures respectively. In the steady-state, the waveform shows the stable period-1 behaviour with a minimum ripple content, and the observed results are listed in table 14.



(a) (b)

Fig.: Stable period-1 behaviour observed for(a) Inductor current and (b) output voltage waveforms for R = 8 Ωload.Inductor current contains 1.25 % ripple and capacitor/output voltage have 0.75% ripple.



(a) (b)

Fig.: Stable period-1 behaviour observed for(a) Inductor current and (b) output voltage waveforms for R = 8 Ωload.Inductor current contains 1.25 % ripple and capacitor/output voltage have 0.75% ripple.

Table 14 - Observation Table

SN.	(V)	(W)	**R(Ω)**	(V)	(V)	(A)	(W)	%ΔI	%ΔV
1	12	72.91	8	24	24	3	72	1.25	0.75
2	12	60	10	24	24	2.4	57.6	1.25	0.75

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Voltage mode-controlled Boost converter feeding constant power load

The ideal boost converter has been modelled using the circuit diagram of fig 2.7 to create a closed-loop MATLAB Simulink model as shown in fig.

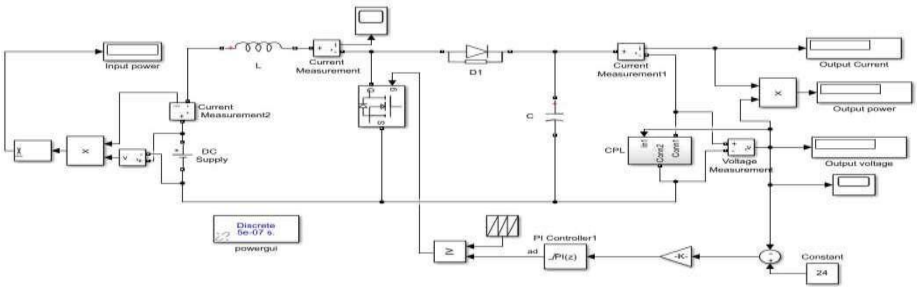


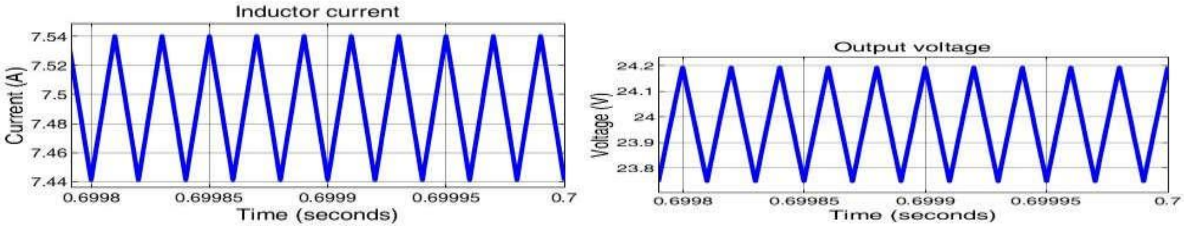
Fig.: Simulink model of voltage mode-controlled boost converter feeding CPL.

The simulation of the proposed Simulink model of a boost converter feeding CPL is carried out, the parameters of the boost are listed in table 15.

Table 15 - Circuit parameters

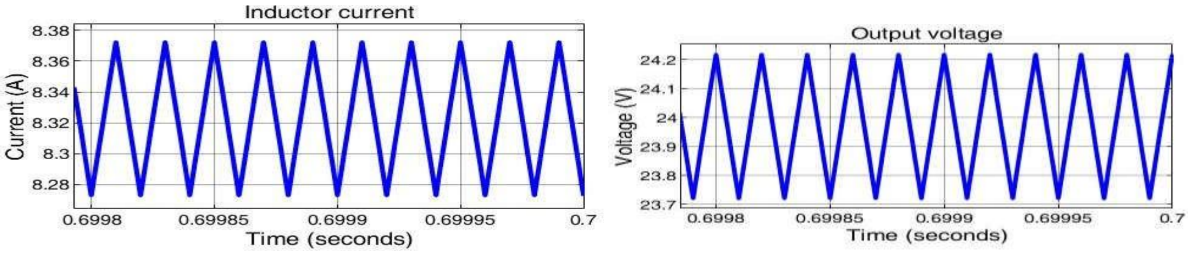
Parameter	**Specification**	**Value/unit**
	Input voltage	12 V
L	Inductor	1.2mH
C	Capacitor	83.3µF
CPL	Constant power load	90-100 W
	Reference voltage	24 V
f	Switching frequency	50 kHz
	Proportional gain	8
	Integral gain	100 S^{-1}

The simulation results of the output voltage and inductor current for different values of constant power load are displayed in fig 3.26 to 3.27 respectively. In the steady-state, the waveform shows the stable period-1 behaviour with a minimum ripple content, the observed results are listed in table 16.



(a) (b)

Fig.: Stable period-1 behaviour observed for(a) Inductor current and (b) output voltage waveforms for P = 90 Wload.Inductor current contains 3% ripple and capacitor/output voltage have 0.93% ripple.



(a) (b)

Fig. 3.27: Stable period-1 behaviour observed for3.27(a) Inductor current and 3.27(b) output voltage waveforms for P = 100 Wload.Inductor current contains 2.6% ripple and capacitor/output voltage have 1.02% ripple.

Table 16 - Observation Table

SN.	(Volt)	(W)	(V)	(W)	(Volt)	(amp)	(watt)	ΔI%	ΔV%
1	12	91.4	24	90	24	3.75	90	3	0.93
2	12	101	24	100	24	4.2	100	2.6	1.02

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Current mode-controlled Boost converter feeding resistance load

The ideal boost converter has been modelled using the circuit diagram of fig to create a closed-loop MATLAB Simulink model as shown in fig.

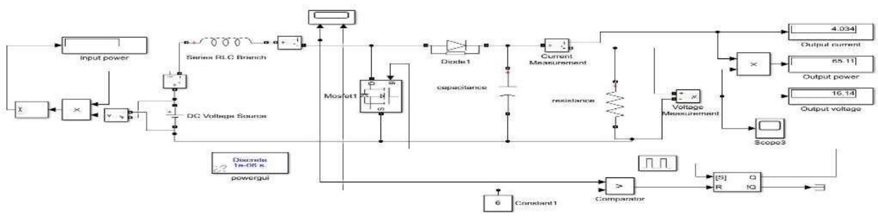


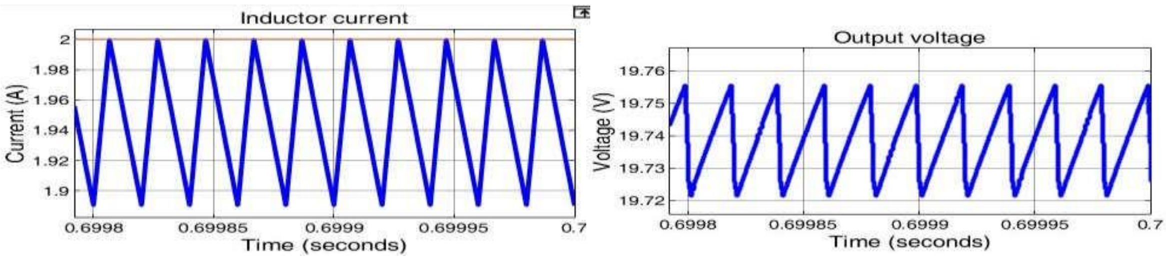
Fig.: Simulink model of currentmode-controlled boost converter feeding resistive load.

The simulation of the proposed Simulink model of a boost converter feeding resistive load is carried out, the parameters of the boost are listed in table 17.

Table 17 - Circuit parameters

Parameter	Specification	Value/unit
	Input voltage	12 V
L	Inductor	76.8µH
C	Capacitor	400µF
R	Resistive load	30-36 Ω
	Referencecurrent	2A
f	Switching frequency	50 kHz

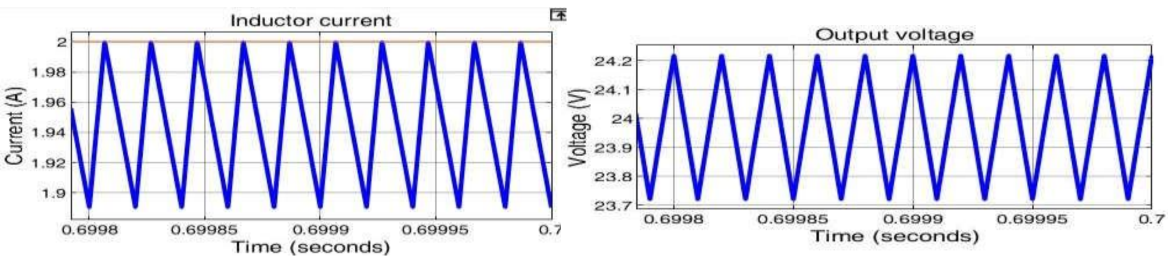
The simulation results of the output voltage and inductor current for different values of constant power load are displayed in fig 3.29 to 3.30 respectively. In the steady-state, the waveform shows the stable period-1 behaviour with a minimum ripple content, and the observed results are listed in table 18.



(a)

(b)

Fig.: Stable period-1 behaviour observed (a) Inductor current and (b) output voltage waveforms for R = 20 Ωload.Inductor current contains 2.745 % ripple and capacitor/output voltage have 0.08% ripple.



(a) (b)

Fig: Stable period-1 behaviour observed for3.30(a) Inductor current and 3.30(b) output voltage waveforms for R = 24 Ωload.Inductor current contains 2.745 % ripple and capacitor/output voltage have 0.75% ripple.

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Table 18 - Observation Table

SN.	(V)	(W)	**R(Ω)**	(V)	(V)	(A)	(W)	%ΔI	%ΔV
1	12	21.2	20	2	20	1	20	2.745	0.08
2	12	25.1	24	2	24	1	24	2.745	0.75

From the observation table, when increasing the power of constant power load, it extracts more power from the source.

Conclusion

The operation of a voltage mode and current mode-controlled buck and boost converter has been explored when the converter is connected to two types of load – constant resistance and constant power load. With the proper choice of the converter and controllers parameters, the converter is found to exhibit stable period-1 behaviour with negligible amount of ripple content in inductor current and capacitor voltage.

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