MODIFIED SEPIC CONVERTER FOR HIGH STATIC GAIN

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Abstract:
This paper presents a high step-up DC-DC converter based on the modified Single Ended Primary Inductance Converter (SEPIC) for achieving high static gain. This converter topology is the combination of a classical boost converter and a conventional SEPIC converter. The modified SEPIC converter used for low input voltage and high output voltage application to get desired characteristic like High static gain, High efficiency with ZCS turn on. The modified SEPIC converter can be analysed with two types of configurations namely with magnetic coupling and without magnetic coupling. The magnetic coupling allows the increase of the static gain maintaining a reduced switch voltage. Two configurations operating with an input voltage equal to 15V and an output power equal to 100W. The configuration without magnetic coupling operating with an output voltage equal to 150V and with magnetic coupling operating with an output voltage equal to 300V. For a qualitative analysis, simulations of both topologies were performed, and compared, result show SEPIC with magnetic coupling give desired gain.

Index Terms— SEPIC converter, Topology of SEPIC, Simulation Results

I. INTRODUCTION

One of the major concerns in the power sector is the day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. So, the development of high static gain (G) dc–dc converters is an important design due to present's demand of low voltage renewable sources like solar PV, wind energy, fuel cell applications in portable electronic equipment, uninterruptable power supply, and battery powered equipment.

Classical non isolated Boost converter gives limited voltage gain of about G=5 with duty ratio of 0.8 and normally can operate with an adequate static and dynamic performance. A dc–dc converter operating with a static gain range until $G = 5$ is considered a standard static gain, a static gain range higher than $G = 10$ is considered a high static gain solution and an operation with static gain higher than $G = 20$ is considered a very high static gain.

Many techniques are used to get High static gain in classical DC-DC converter. Techniques applied on non-isolated converter like Voltage multiplier cells, Switched Capacitor/Inductor technique, magnetic coupling, interleaved technique and also combination of these gives dual benefits of High static gain with isolation other desired characteristics.

CONVERTER	GAIN	TECHNOLOGY	POWER ELE S/W		Energy storage element
			CONTROLLED	UNCONTROLLED	
Boost	5	-	1	1	2
Boost with voltage multiplier cell	20	Voltage multiplier = 3	1	7	8
SEPIC	5	-	1	2	3
SEPIC without magnetic coupling	10	Voltage multiplier = 1/2	1	2	4
Transformer less DC-DC converter	12	Switched Inductor + Two voltage lift	2	3	4
ISD, NSD	10, 6.50	Switched Capacitor	1	3	3,3
SIB	18	Interleaved + Magnetic coupling	1	2	4+HFT
Extend SEPIC derived	36	Switched Capacitor + Voltage multiplier	1	5	7
Modified SEPIC with magnetic coupling	20	Voltage multiplier + Magnetic coupling	1	3	4,HFT

Table-1 Summery of different converter and there technique

The base topology is here considered as a SEPIC DC-DC converter. But it generates limited gain same as boost converter also has high input ripple current. So to increase the gain above techniques is used and from that two topologies are derived that are converter without magnetic coupling and with magnetic coupling. Table show modified SEPIC converter topologies uses less number of switches and less passive elements among other DC-DC converters with same technique. to get desired characteristics like High static gain, high efficiency, low input current ripple, soft switching.

The basic structure without magnetic coupling presents a static gain close to twice of the classical boost converter and the switch voltage is close to half of the value obtained with the classical boost converter in the operation with high values of the duty cycle. The structure with magnetic coupling is derived by including secondary winding as high frequency fly-back transformer. Leakage inductance of transformer has some benefits & some problems.

II. CONVERTER WITHOUT MAGNETIC COUPLING:

In classical SEPIC converter give low gain about of five with high ripple current also have switch voltage which is nearly half of output voltage. To increase gain modification is done as diode D_m and capacitor C_m in between inductor and switch. This modification cell called Voltage multiplier Cell. So by accomplishing this cell, modified converter give gain twice of that classical SEPIC converter. Here capacitor C_m is operated as output of classical Boost converter and capacitor C_s polarity is inverted.

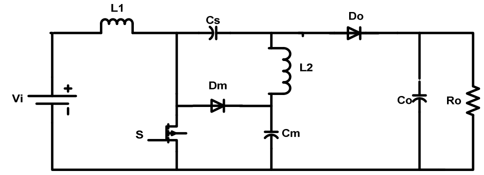


Fig.1 Modified SEPIC Converter without Magnetic Coupling

The continuous conduction mode of this topology has two operation stages. Here all capacitor consider as voltage source and switch as ideal in theoretical analysis.

1) *First Stage [t0−t1] (Fig. 4):*

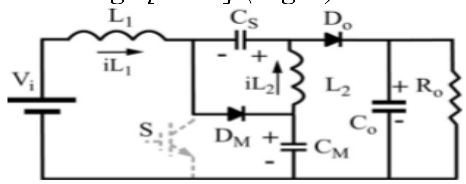


Fig.2 First stage

At the instant $t0$, switch S is turned-off and the energy stored in the input inductor $L1$ is transferred to the output through the CS capacitor and output diode Do and also is transferred to the CM capacitor through the diode DM . Therefore, the switch voltage is equal to the CM capacitor voltage. The energy stored in the inductor $L2$ is transferred to the output through the diode Do.

2) *Second Stage [t1−t2] (Fig. 4):*

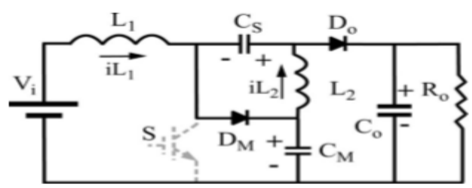
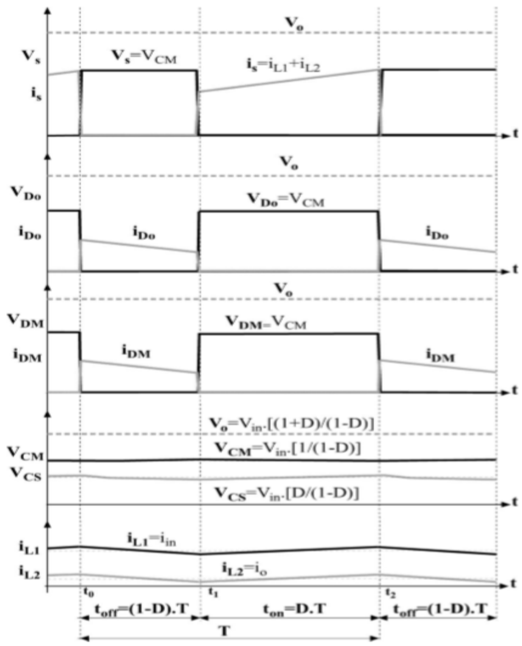


Fig.3 Second stage

At the instant $t1$, switch S is turned-on and the diodes DM and Do are blocked and the inductors $L1$ and $L2$ store energy. The input voltage is applied to the input inductor $L1$ and the voltage $VCS-VCM$ is applied to the inductor $L2$. The VCM voltage is higher than the VCS voltage.



Static gain is a measure of the ability of a circuit to increase the power from the input to the output. It is usually defined as the ratio of the output to the input of a system. At the steady state for the inductor L_1, the relation presented in (1) occurs:

$$V_i * (t_{on} + t_{off}) = V_{CM} * t_{off} \tag{1}$$

$$V_i * D = (V_{CM} - V_i) * (1-D) \tag{2}$$

Therefore, the C_M capacitor voltage is defined by (3), which is the same equation of the classical boost static gain given by

$$\frac{V_{CM}}{V_i} = \frac{1}{1-D} \tag{3}$$

During the period where the power switch is turned-off (t off), the diodes D_M and D_0 are in conduction state, and the following relation can be defined:

$$V_0 = V_{CS} + V_{CM} \tag{4}$$

$$V_{CS} = V_0 - V_{CM} \tag{5}$$

The L_2 average voltage is zero at the steady state, and the following relations can be considered.

$$(V_{CM} - V_{CS}) * t_{on} = (V_O - V_{CM}) * t_{off} \tag{6}$$

$$(V_{CM} - V_{CS}) D = (V_O - V_{CM}) * (1-D) \tag{7}$$

From equations (3), (5) and (6) the static gain of the proposed converter is obtained and presented in (8)

$$\frac{V_O}{V_i} = \frac{1+D}{1-D} \tag{8}$$

The voltage of the series capacitor V_{CS} is defined by substituting (3) and (8) in (7), resulting the following equation.

$$\frac{V_{CS}}{V_i} = \frac{D}{1-D}$$

It can be observed from gain equation that with duty ratio D=0.82 it give gain of G=10 and switch voltage nearly 6 time of that input voltage. But this topology has some problem like hard switching, overvoltage.

III. CONVERTER WITH MAGNETIC COUPLING:

Modified SEPIC without magnetic coupling give maximum gain (G) of 12.5 with maximum duty ratio (D) of 0.86. However in some application very high gain is necessary which can be solved by accomplishing magnetic coupling to elevate static gain without increase duty ratio and switch voltage. So inductor L2 replace by including magnetic coupling. Inductor L2 on primary side operated as buck-boost inductor and secondary side winding increase output voltage by inductor winding turns ratio (n), operating as flyback transformer. Fig. 5 can be used as alterative circuit compare to previous without magnetic coupling topology.

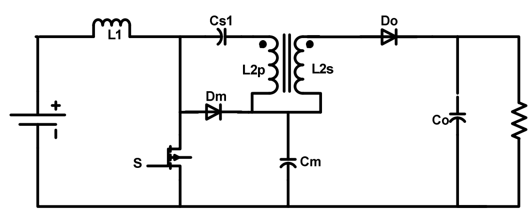


Fig.4 Modified SEPIC Converter without Magnetic Coupling

However above converter structure has some problems due to leakage inductance like overvoltage across output diode. But leakage inductance has some benefits like ZCS commutation, reduce diode reverse recovery current and increase converter efficiency. The energy stored in leakage inductance, due to the reverse recovery current result in voltage ring across diode Do.

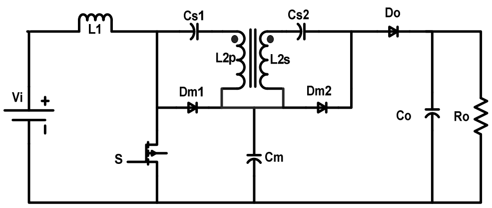


Fig.5 Modified SEPIC Converter without Magnetic Coupling and voltage multiplier at sec. side

To get rid the problems of leakage inductance voltage multiplier at secondary side include as Diode Dm2 and clamp capacitor Cs2. This Voltage multiplier cell increase converter static gain with reduce voltage across output diode Do and operated as nondissipative clamping circuit for Do show I fig.

Many isolated Boost converter with magnetic coupling are used which give very high static gain but this type topology give high input current ripple due to magnetic coupling is in directly connect with dc source. This input current ripple is increase with transformer turns ratio which give problems in fuel cell application and reduce life span of fuel cell. But in SEPIC with magnetic coupling not give high input ripple current.

The CCM operation of the modified SEPIC converter with magnetic coupling and voltage multiplier cell give five operation stages.

1) *First Stage [t0−t1] (Fig. 10):*

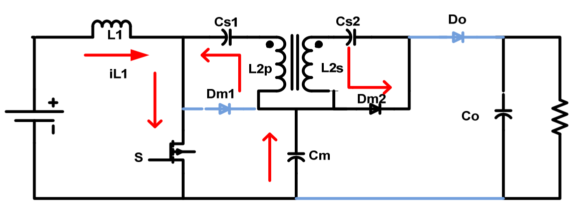


Fig.6 First stage

As power switch is turn on inductor L_1 stores energy linearly. At same time on both side primary & secondary resonance occurs, so at secondary side winding L_{2s} release energy & charge capacitor C_{S2}. Same way C_{S1} is charge but current is in opposite direction of that dot rule. Now current through switch is sum of IL_r & IL_{S2}. The leakage inductance limits the current and the energy transference occurs in a resonant way. The output diode D_O is blocked, and the maximum diode voltage is equal to (V_0−V_{CM}).

2) *Second Stage [t1−t2] (Fig. 11):*

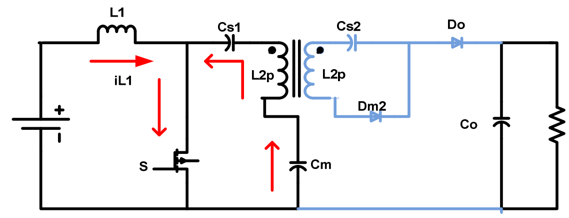


Fig.7 Second stage

At the instant t1, the energy transference to the capacitor C_{S2} is finished so the diode D_{M2} is blocked. When the diode D_{M2} is blocked, to the instant t2 when the power switch is turned OFF, the inductors L_1 and L_2 store energy from input dc source and Capacitor D_{M2} and the currents linearly increase.

3) *Third Stage [t2−t3] (Fig. 12):*

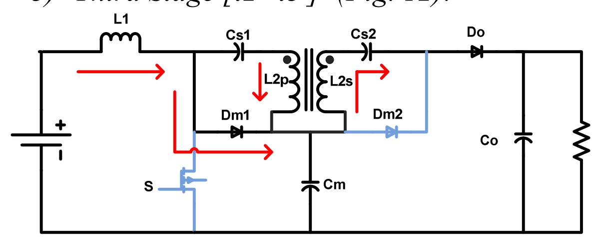


Fig.8 Third stage

At the instant t2 the power switch S is turned OFF. The energy stored in the L_1 inductor is transferred to the C_M capacitor. Now also L_{2P} is charge from capacitor C_{S1}. There is the energy transference to the output through the capacitors C_{S1}, C_{S2} inductor L_2 and output diode D_O.

4) *Fourth Stage [t3−t4] (Fig. 13):*

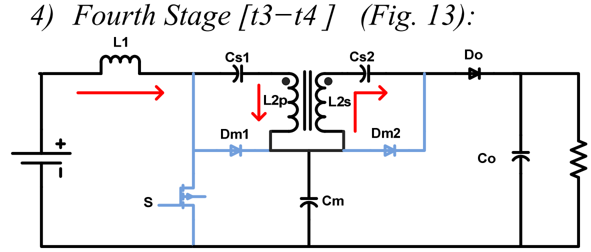


Fig.9 Fourth stage

At the instant t3, the energy transference to the capacitor C_M is finish and also as IL_1 is equals to IL_{2P} the diode D_{M1} is blocked. The energy transference to the output is maintained until the instant t4, when the power switch is turned ON. Current through D_o is decrease.

5) Fifth Stage [t4−t5] (Fig. 14):

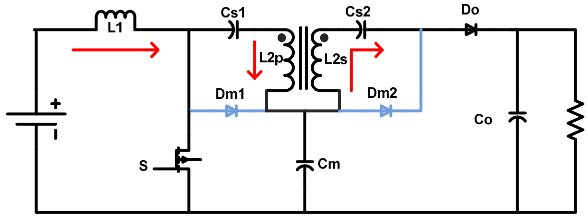


Fig.10 Fifth stage

When the power switch is turned ON at the instant t4, the current at the output diode D_o linearly decreases and the di/dt is limited by the transformer leakage inductance, reducing the diode reverse recovery current problems. When the output diode is blocked, the converter returns to the first operation stage.

The main theoretical waveforms of the modified SEPIC converter with magnetic coupling and with the voltage multiplier at the secondary side are presented in Fig. 15. Power switch is turn on with ZCS due to leakage inductance result in reduce losses and increase converter efficiency. This topology gives lower switch voltage and output diode voltage. Large rate of change of current through output diode is limited by leakage inductance.

$$\frac{V_{CM}}{Vi} = \frac{1}{1\text{-}D} \tag{10}$$

$$\frac{V_{DO}}{Vi} = \frac{n}{1\text{-}D} \tag{11}$$

$$V_o = V_{CM} + V_{Do} \tag{12}$$

So, the static gain of the modified SEPIC converter with magnetic coupling and voltage multiplier is calculated by

$$\frac{V_o}{V_i} = \frac{(1+n)}{1\text{-}D} \tag{13}$$

Where the inductor windings turns ratio (n) is calculated by,

$$n = \frac{N_{L2s}}{N_{L2P}} \tag{14}$$

Static gain of converter is increase by increment of transformer turns ratio 'n'.

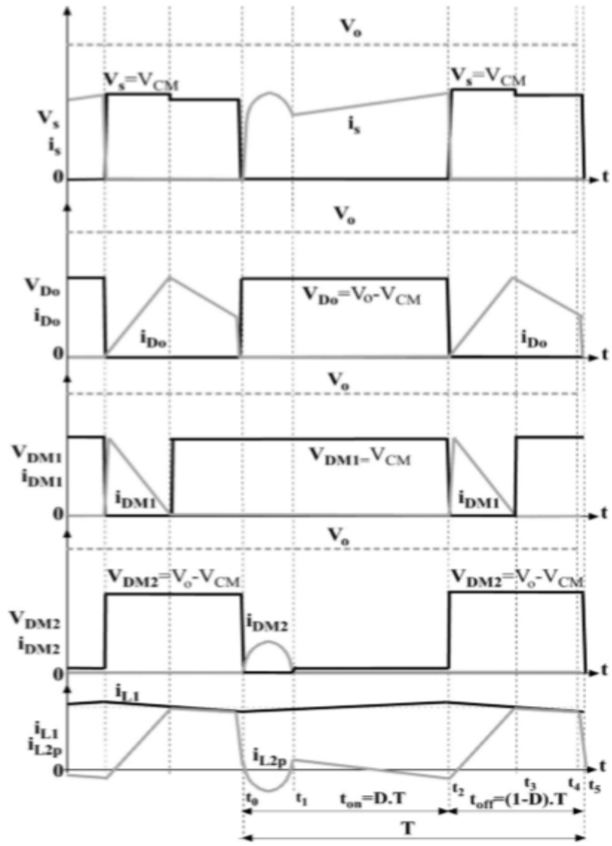


Fig.11 Theoretical waveform

Third operation stage gives maximum switch voltage equal to V_{CM}. In fourth operation stage V_{CM} is reduce slightly due to energy stored in L_{lkg} is released which is small.

IV. DESIGN CONSIDERATIONS OF THE PROPOSED CONVERTER WITH MAGNETIC COUPLING:

1. Duty ratio :
   By considering static gain equal to 20 with turn ratio n=2.6, duty ratio as function of input/output voltage given below

$$D = 1 + \frac{Vi}{Vo} * (1+n)$$

$$= 1 + \frac{15}{300} * (1+2.6)$$

$$= 0.82$$

2. Switch and diode Voltage :

   Voltage across switch (V_S) and diode (V_{DM1}) is equal to voltage across C_M (V_{CM}).

$$V_S = \frac{V_{CM}}{(1\text{-}D)} \tag{16}$$

$$= \frac{15}{(1\text{-}0.82)}$$

$$= 83.5 \text{ V}$$

The diode $DM2$ voltage () and the output diode voltage (VDo) are equal and are calculated as

$$V_{DO} = \frac{n * V_i}{(1\text{-}D)} \qquad (17)$$

$$= \frac{2.6 * 15}{(1\text{-}0.82)} = \quad 216\ V$$

3. L_1, L_{2P} *and* L_{2S} :

Considering $L1$ equal to $L2$p and an input current ripple equal to 5 A
So,

$$L_1 = L_{2p} = \frac{V_i * T_s * D}{\Delta_i}$$

$$L_1 = L_{2p} = \frac{V_i * D}{\Delta_i * F_s}$$

$$L_1 = L_{2p} = \frac{15 * 0.82}{5 * 24000}$$
$$= 103\mu H$$

$$L_{2S} = \ n * L_{2P}$$
$$= 2.6 * 103\ \mu H$$
$$= 700\ \mu H$$

V. SIMULATION OF BOTH CONVERTER TOPOLOGY

1) Modified SEPIC without magnetic coupling:

Vi	15 V
Vout	150 V
Po	100 W
Io	0.666 A
Ro	900 Ω
Cm = Cs	3.3 µH
Co	1000 µH

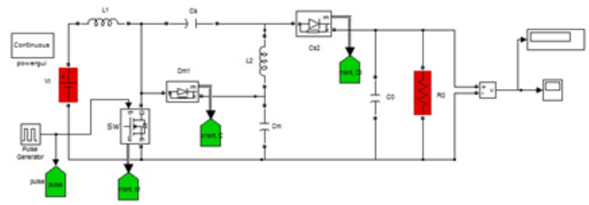


Fig.12 Simulation of converter without magnetic coupling

Fig.12 shows the topology without magnetic coupling with input voltage of 15 V and output voltage of 150.

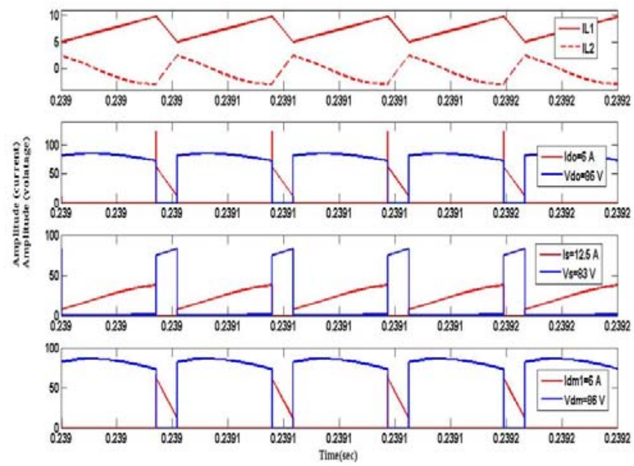


Fig.13 Results of converter without magnetic coupling

Fig (13) show voltage across and current through each inductor and diode. In this switch turn on with hard commutation and switching spike across output diode.

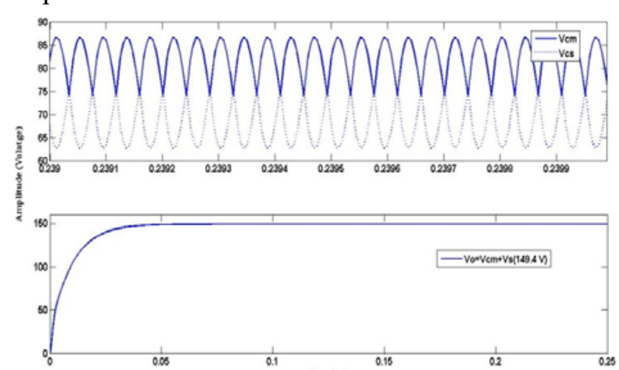
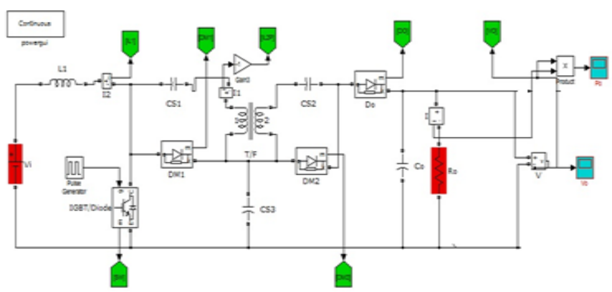


Fig.14 Output voltage Vo =150 V

Fig.(14) show output voltage which is sum of voltage across diode C_M and voltage across switch S. So, converter without magnetic coupling give output voltage of 149.5 V with input of 15 V. Simulation result of Converter is give gain of 10.

2) Modified SEPIC with magnetic coupling:

Vi	15 V
Vout	300 V
Po	100 W
Io	0.333 A
n	2.6
Ro	900 Ω
Cm = Cs1=Cs2	3.3 µH
Co	100 µH



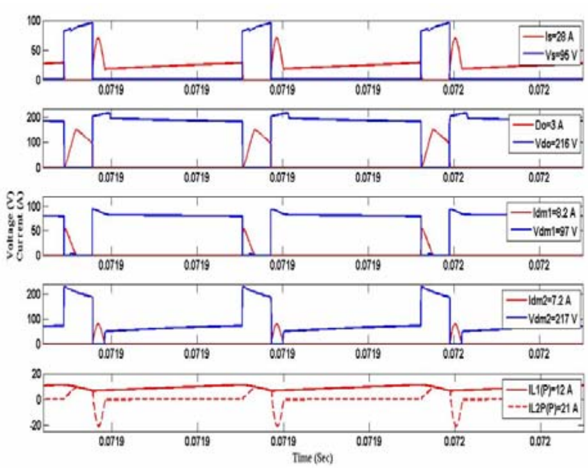


Fig15. Results of converter with magnetic coupling

Fig (15) show simulation result of that switch is turn on with ZCS commutation which increase converter efficiency. Intially due to leakage inductance give resonance period with Fr=250 kHz also current through Do limited by Llkg.

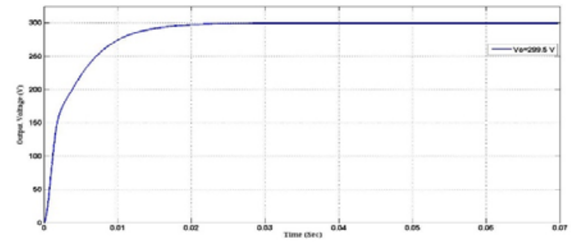


Fig.16 Output voltage Vo=299.5

Fig(16) show simulatioe waveform of converter with magnetic coupling which give output voltage equal to 299.5 V. So, converter with magnetic coupling give gain of 20. Fig (17) show, When input volatge is change from 15 V to 13 V in that case to keep output voltage constant, duty ratio is varying and incrase gain automatically through use of PI controller. As in fig (18) static gain is function of duty ratioin by considering D=0.80, static gain G=10 for N=1 same for G=20 for N=3.

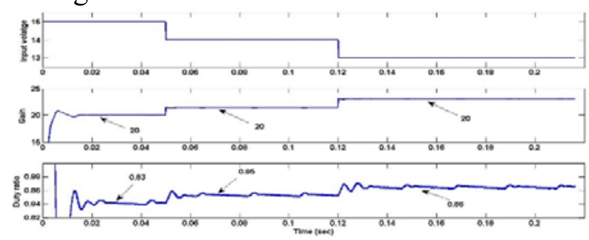


Fig.17 Change in input voltage with constant load

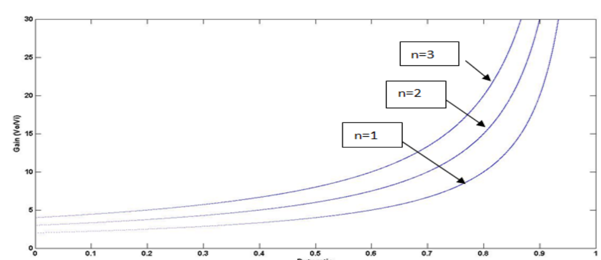


Fig.18 Plot of Duty ratio v/s Gain

PARAMETER	WITHOUT MAGNETIC COUPLING		WITH MAGNETIC COUPLING	
	THEORETICAL	SIMULATION	THEORETICAL	SIMULATION
V_{in}	15 v	15 v	15 v	15 v
V_{out}	**150 v**	**149.4 v**	**300 v**	**299.5**
Gain	**10**	**9.5**	**20**	**19.5**
$V_{s/w}$	82.5 v	83.5 v	83 v	95 v
$I_{s/w}$	13.02 A	12.5 A	29 A	28.5 A
V_{DM1}	82.5 v	83.5 v	83 v	97 v
V_{DM2}	-	-	216 v	217 v
V_{D0}	82.5 v	83.5 v	216 v	217 v

Fig.19 Comparison table

VI. CONCLUSION

Modified SEPIC with magnetic coupling offers advantages like Low Input current ripple, Non-inverting output, less switching voltage stress and high-efficiency. The performance of Modified SEPIC Topologies is compared from that modified SEPIC converter with magnetic coupling offer high static gain which is twice of that without magnetic coupling. Modified SEPIC with magnetic coupling can be used as an alternative for the SEPIC converter.

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