SIMULATION OF SOFT SWITCHING BASED RESONANT DC-DC CONVERTER

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ABSTRACT

This paper presents a soft switching DC-DC converter. Compared to the conventional bridge DC-DC converter for the similar applications, the new topology has the advantages over conventional circuit topology, soft switching implementation without additional devices, high efficiency and compact control. These advantages makes the new converter promising for high power applications, especially for auxiliary power supply in fuel cell vehicles and power generation where a high power density, low cost, low electromagnetic interference, high reliable power converters are required. The operating principle, theoretical analysis is provided in this research paper.

Keywords : Soft switching converter, DC-DC converter, SMPS, Efficient DC-DC converter, Soft switching converter.

1. INTRODUCTION

In recent years, the development of high power isolated bi-directional DC-DC converters has become an important topic because of the requirement in fuel cell applications and energy storage systems. The bi-directional DC-DC converter boosts the 12V battery voltage to a desired high voltage (normally 150-300V) for the cell to start. In order to increase the efficiency, soft switching technology has been widely used in DC to DC converters.

This bi-directional isolated DC to DC converter is based on the half bridge topology. Compared to the full bridge topologies it has half the component count for the same power rating with no total device rating penalty. In addition a unified ZVS is achieved in either direction of power flow without additional components. Therefore minimum number of devices are used in the proposed circuit. Also the design has less control and accessory power needs. All these features allow efficient power conversion, easy control leight weight and compacted packaging. This converter is a good alternative to the full bridge isolated DC to DC converter in high power applications and has distinct advantages for high power density and low cost applications.

2. POWER STAGE DISCRIPTION

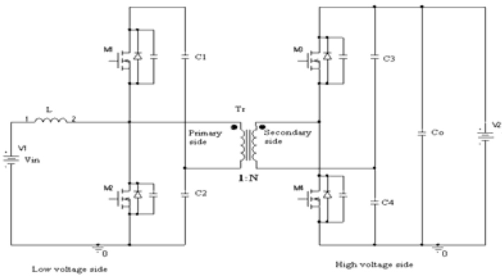

Fig.1 circuit diagram of bi-directional DC-DC converter

The circuit diagram for the bi-directional DC to DC converter is shown in figure. The circuit consists of four MOSFETs which are used as switching devices. Parallel to each MOSFET is connected a diode and a capacitor. The parallel capacitors are used for soft switching and each act as a loss less snubber. The circuit has

i. an inductor Ldc on the battery side.
ii. two half bridges namely LVS and HVS converters each placed on either side of the transformer.

Here a step up transformer of ratio 1:N is used to perform conversion Process. The transformer used to provide isolation and voltage matching. The leakage inductance is used as an interface and energy transfer between two voltage sources. The inverter side half bridges generates a square wave voltage applied to the primary of the transformer. The amount of power flow is determined by the phase shift when square wave voltage applied to primary and secondary of the transformer.

The LVS half bridge has double functions such as

- A boost converter to step up the voltage.
- An inverter to produce high frequency ac voltage.

The boost function is achieved by the Inductor and LVS half bridge. When power flow from low voltage side to high voltage side LVS converter acts as an inverter and HVS converter acts as rectifier. The circuit operates in the boost mode. When power flow from HVS to LVS, low voltage side converter operates as rectifier and HVS converter acts as an inverter. The circuit operates in the buck mode.

The conversion process is assisted by a high frequency transformer connected as shown in diagram. The reason for choosing the high frequency operation is that it reduces the ripples in the output voltage. In addition, it reduces the size of the filter circuits and transformer leading to considerable savings.

3. WORKING PRINCIPLE

A. BOOST MODE

Low voltage side act as inverter and High voltage side act as rectifier.

Mode 1

To produce positive half cycle of Vr1 (primary side voltage of transformer)

- Switch S1 is turned on.
- Voltage across capacitor Cl is V1 which is applied to the primary side of the transformer.
- The transformer step up the voltage and is given to the transformer secondary.
- HVS converter rectifies the voltage (V3) by forward biasing diode D3. So capacitor C3 gets charged and is given to the load

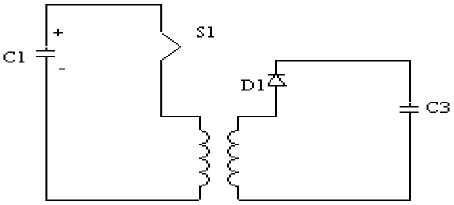

Fig. 2.a. Circuit diagram of mode1 positive half cycle Vr1=V1

Mode 2

Considering when S1 is conducting, the voltage across the resonating capacitor of switch S2 maintains voltage V1+V2 .When the switch S1 is turned off, the resonating capacitors Cr1,Cr2, transformer (Tr), resonate. Voltage Vr1 tend to shift from positive to negative.

- During this resonating period, the voltage across Cr2 drop from V1+V2 and Vr1 also drop from V1 to V2.
- When Cr2 tend to overshoot the negative rail, the diode D2 is forward biased.
- By turning ON the switch S2 turned during the conduction of the diode we can obtain ZVS.

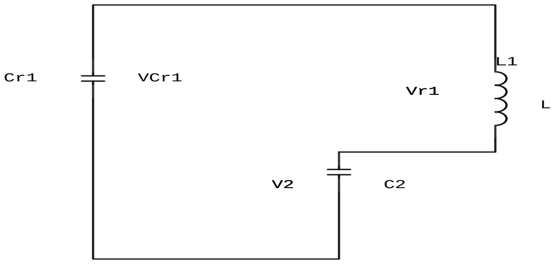

Fig 2.b.Circuit diagram of mode 2

Mode 3

To produce negative half cycle of Vr1 Switch S2 is turned on. Voltage across C2 is V2 which is applied to the primary side of the transformer to get the negative half. The secondary of the transformer V4 forward biases the diode D4 and capacitor C4 gets charge

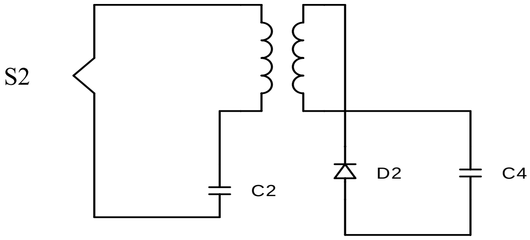

Fig. 2.c. Circuit diagram of mode 3 Negative half cycle

Mode 4

During the conduction of the switch2, the resonating capacitor of switch maintains V1+V2.

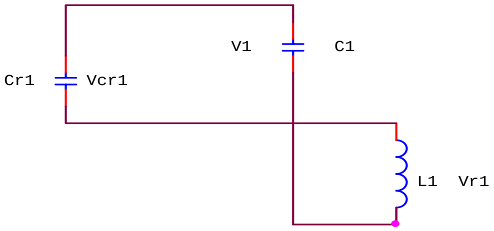

Fig 2.d. Circuit diagram of Mode 4

- When the switch S2 is turned OFF, the resonating capacitors Cr1, Cr2, transformer (Tr), resonate. Voltage Vr1 tend to shift from negative to positive.
- During this resonating period, the voltage across Cr1 drop from V1+V2 and Vr2 also raise from V2 to V1.
- When Cr1 tend to overshoot the positive rail, the diode D1 is forward biased.
- By turning ON the switch S1 turned during the conduction of the diode we can obtain ZVS.

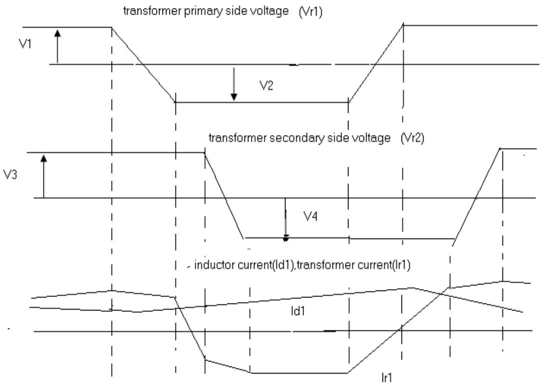

Fig. 3 Waveform for boost mode

B. BUCK MODE

Similar to boost mode S3 and S4 perform inverter operation like S1 and S2 in the boost mode. And Diodes D1 and D2 perform the rectifier mode operation like D3 and D4 in the boost mode. The waveforms for buck mode is shown below.

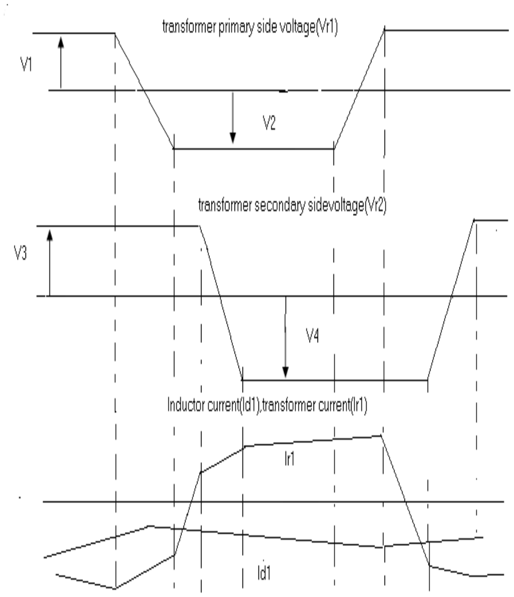

Fig. 4 Waveforms for buck mode

4. CIRCUIT ANALYSISOF BIDIRECTIONAL DC-DC CONVERTER

CIRCUIT DESIGN

A. Inductor (L dc)

$Ldc = (Vin\,\Delta t)/\Delta I$

Δt - Switching time of switch S2

ΔI - Ripple current

B. ZVS circuit

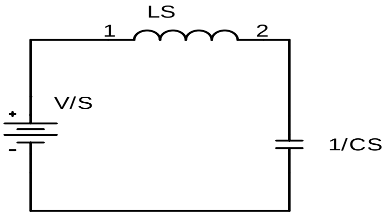

Fig 5.a. ZVS Circuit Diagram

From the figure,

$$I(S) = \frac{V/S}{LS + \frac{1}{CS}}$$

$$= \frac{V/S}{\frac{LCS^2 + 1}{CS}}$$

$$I(S) = \frac{VC}{LC(S^2 + \frac{1}{LC})}.\frac{\omega}{\omega}$$

$$I(S) = \frac{V}{\omega L}.\frac{\omega}{S^2 + \omega^2}$$

Taking laplace inverse

$$I(t) = V.\sqrt{C/L}.Sin\ \omega t$$

$$Vc = \frac{1}{C}\int i.dt$$

$$Vc = \frac{1}{C}\int_0^t V.\sqrt{C/L}.Sin\omega t.dt$$

$$Vc = V(1 - Cos\ \omega t)$$

If $\omega t=0$ $V_C = 0$
If $\omega t=90^o$ $V_C = V$
If $\omega t=180^o$ $V_C = 2V$

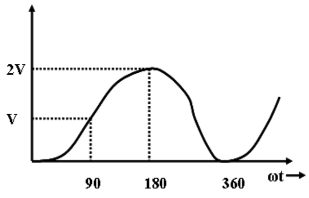

Fig. 5.b. ZVS curve

Under resonance,

$X_L = X_C$

$f=1/2\sqrt{\ }(LC)$

C. Current through load

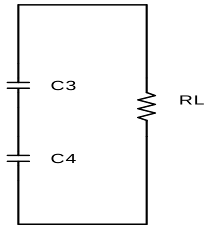

Fig 6.a. Load circuit

The above circuit can be reduced as shown below. It shows the equivalent circuit to find the current through the load.

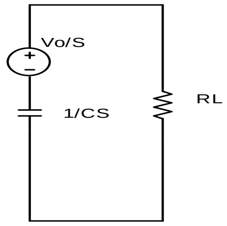

Fig 6.b. Equivalent Circuit

Here we take $C = \frac{C_3.C_4}{C_3 + C_4}$

Therefore $I(s) = \frac{Vo/S}{R+\frac{1}{CS}}$

$$I(s) = \frac{Vo/S}{\frac{RCS+1}{CS}}$$

$$I(s) = \frac{Vo.C}{RC(S+\frac{1}{RC})}$$

Taking Laplace Transform

$$I(t) = \frac{Vo}{R}e^{-t/RC}$$

$$Vo = R.i(t)$$

$$V = Vo.e^{-t/RC}$$

Where $\mathbf{C} = \frac{C_3.C_4}{C_3+C_4}$

D. Transformer designed as T-Network

The transformer circuit is shown below. It can be modeled a T- network.

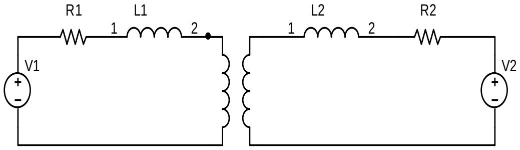

Fig 7.a. Transformer circuit

L1 – Inductance of primary winding
L2 – Inductance of secondary winding
K = (N1/N2)
K – turns ratio
N1, N2 - Number of turns of primary and secondary windings
$E1=4.44f\phi N1$
$E2=4.44f\phi vN2$
$L2=L1/K^2$
To find the value of M
$M = k \sqrt{(L1L2)}$
It can be modeled a T- network as shown in figure.
L1 = L1-M
L2 = L2-M

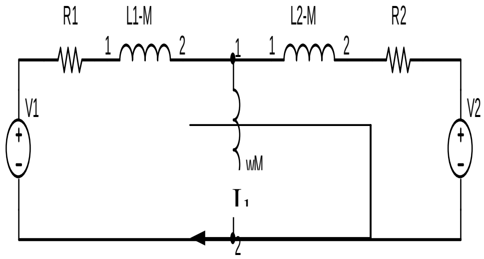

Fig 7.b. Transformer designed as T network

E. Design of load resistance

From the ripple factor the load resistance can be calculated as follows

$$r = \frac{1}{4\sqrt{3}\ f\ c\ R}$$

The system specifications specifies the value of r as .04

$$R = \frac{1}{r\ 4\sqrt{3}\ f\ c}$$

5. SIMULATION RESULTS

A. Boost mode with transformer and leakage inductance

The circuit diagram of boost mode of DC to DC converter with transformer and leakage inductance is shown in figure. For boost operation the dc source is connected on the LVS side and the load is connected to the HVS side.

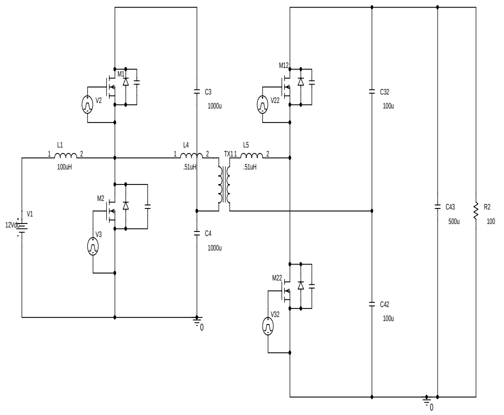

Fig 8.a. Boost mode with transformer and leakage inductances

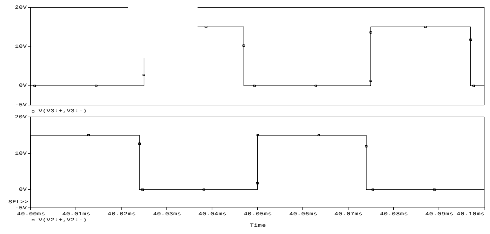

Fig 8.b.Gate pulses for switches S1 and S2

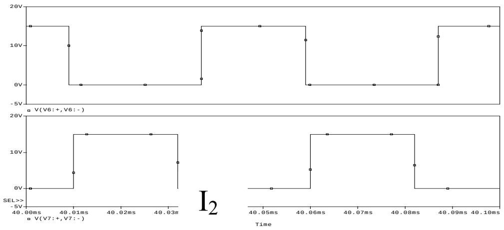

Fig8.c.Gate pulses for S3 and S4

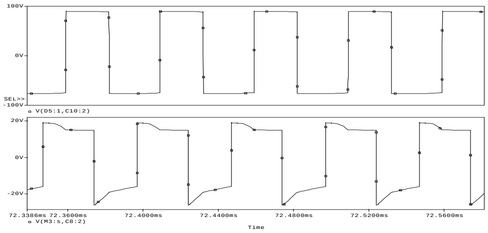

Fig 8.d Transformer primary and secondary voltages

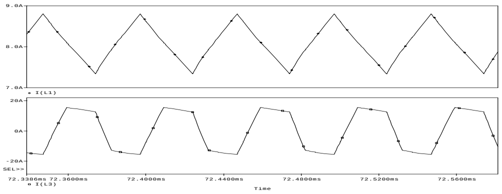

Fig 8.e Inductor current and Transformer current

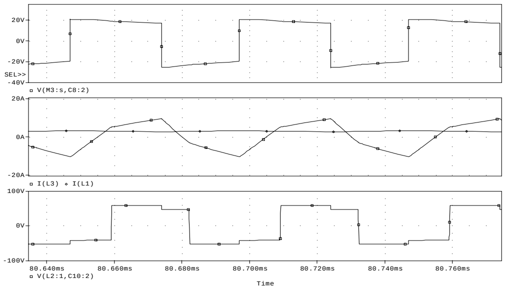

Fig 8.f. Steady state operation of Boost mode

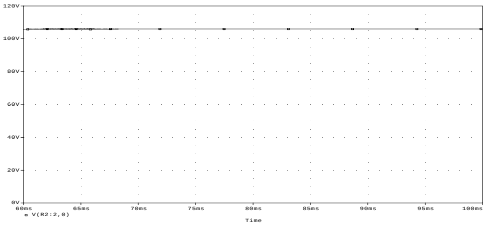

Fig 8.g. Output voltage

B. Buck mode with transformer and leakage inductances

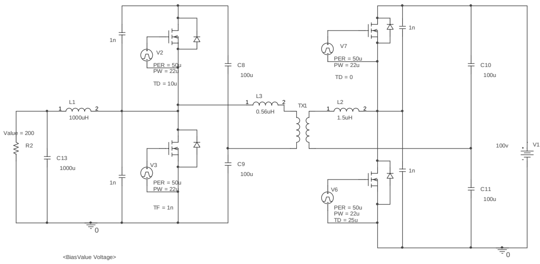

Fig 9.a. Buck mode with transformer and leakage inductances

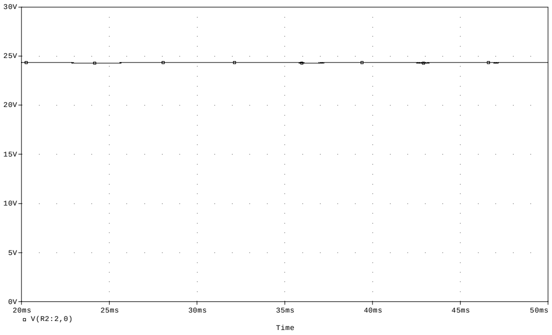

Fig 9.b. Output voltage

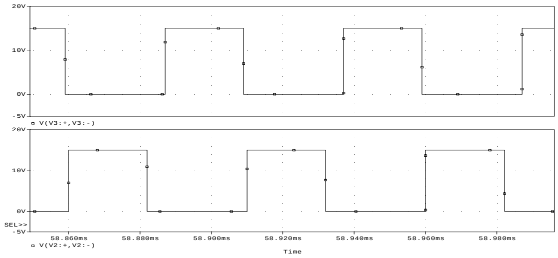

Fig 9.c Gate pulses for S1 S2 pulse

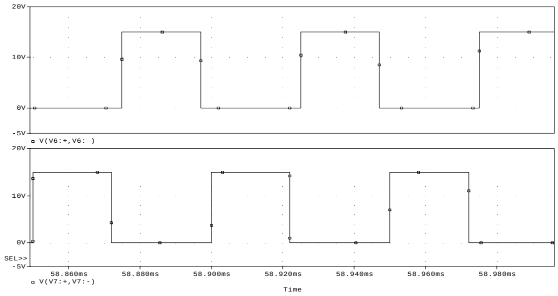

Fig 9.d. Gate pulses for S3 and S4

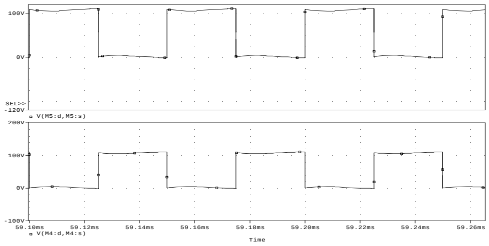

Fig 9.eVoltages across the switches

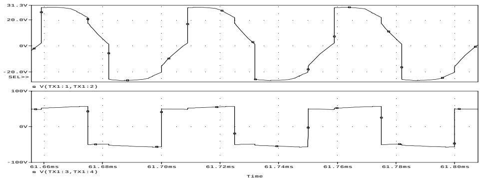

Fig 9.f. Primary and Secondary side voltage of transformer

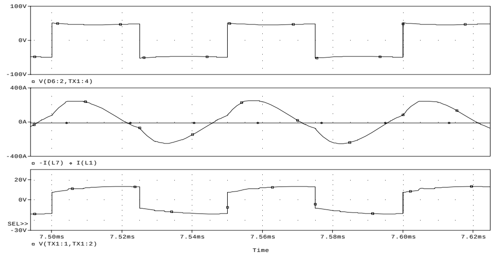

Fig.9.g Steady state operation for buck operation

C. Boost mode with T network

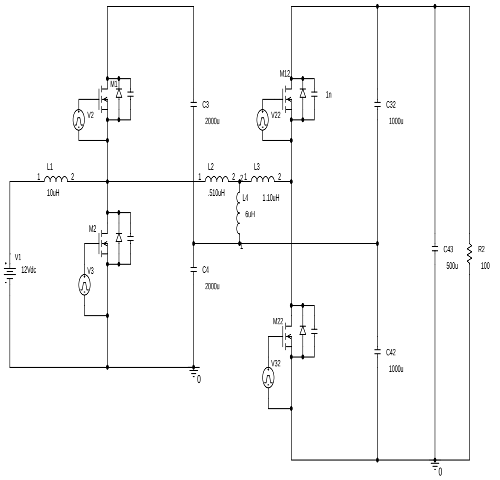

Fig.10.a. Boost mode with transformer as T network

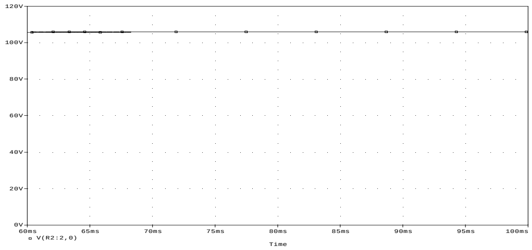

Fig.10.b. Output voltage

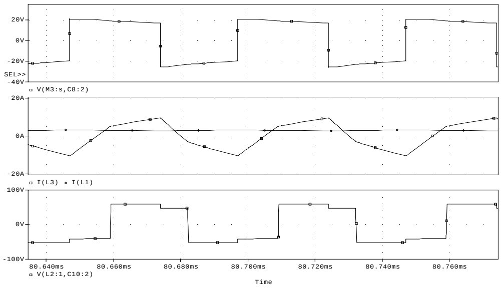

Fig 10.c.Steady state operation of Boost mode

D. Buck mode with T network

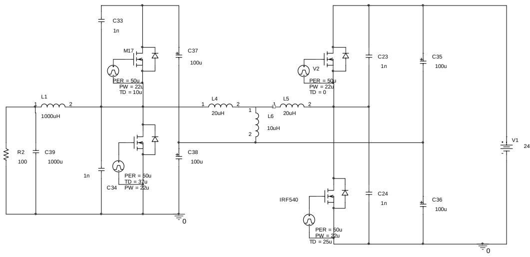

Fig.11.a. Boost mode with transformer as T network

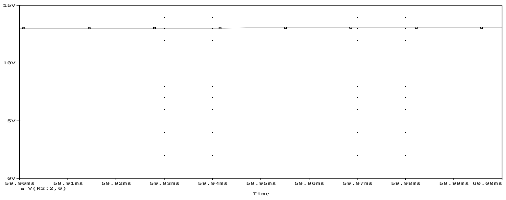

Fig.11.b.output voltage

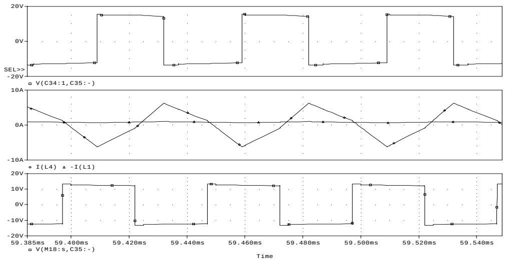

Fig.11.c.Steady state operation for buck mode

6. CONCLUSION

A new soft switching based DC to DC converter has been presented. The operation, analysis, design consideration were depicited. Simulation results were shown to verify the operating principle. The circuit analysis is presented and the results are obtained. It is shown that ZVS is obtained in either direction of power flow is achieved in a flexible manner. The high switching frequency involved in this scheme is for less switching stresses and losses.

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Biography

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S.Rama Reddy has obtained AMIE in 1984 from institution of engineers. He has obtained his M.E degree from Anna University in the year 1987. He has done his Ph.D in the area of resonant converters in the year 1995. He has 18 years of teaching experience and 2 years of industrial experience. He is a life member of IEEE, IETE, SSI and SPE. His research areas are FACTS and Power Electronic Converters.