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SST Based Resonant Converter Applications to Hybrid Vehicles

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***Abstract*— The Soft-Switching Technique (SST) based isolated Full-Bridge DC/DC Converter (FBC) was designed to Electric Vehicle (E-V's) application. The proposed converter performance improved, due to reduced switching losses, stress, and with minimum number of switches. The constant switching frequency of 100 kHz maintained to Zero Switching Current (ZCS) of primary, Zero Voltage Switching (ZVS) of secondary of High Frequency Transformer (HFT), with 24V hydride input supply. The simulated results demonstrate the improved preformation.**

***Index Terms*— HFT, E-V's, ZCS ,SST, ZVS.**

I. Introduction

The contribution of CO_2 was more than 15% as per the survey of global warming in the past decade. Transportation system was the root cause for the same, due to usage of fossil based fuels like, petro-chemicals, coal, etc. Minimize the global warming issue by the researchers across the globe through the technological interpretation. The conventional petro-chemical fuel based vehicles contributing to the CO_2 was high, when compared with industrial usage. Reduction in the petro-chemical usage in the transportation system may address global worming scenario. The hybrid vehicles and electrical vehicle are alternating solution to the transportation system for the next generation.

Hybrid source like battery, fuel cell, DC source were combined and used to fill full the need of energy requirement of electrical transportation system.

The combination of oxygen from air with on board stored hydrogen gas from the fuel cell converts into electric energy. However, need of a supplement source of energy, due to FCVs suffers from the slowly transient (dynamic) response to variation load. The SST based isolated FBC fed with current source. Naturally commutated with minimize lose was proposed by authors [1-16], along with ZCS/ZVS switching. The proposed same converter operated as voltage fed FBC in the reverse direction. The author proposed the topology for Fuel Cell Electrical Vehicle.

The hybrid input source (24V), consist of parallel combination of battery, fuel cell and DC source with 24 V each by hybrid source as shown in circuit diagram Fig.1.

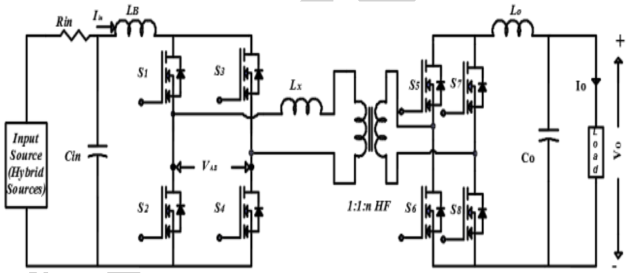

Fig.1 SST based isolated FCB for Hybrid E-V's

The hybrid source was regulated from 20-24V during the either direction of power flow shown Fig.1. in primary side, boost inductor L_B, R_{in} C_{in}, four number of semi-conductor switches are connected as full bridge converter type through transformer leakage inductance Lx of ZCS side of HF and in secondary side, four power switching devices are connected as ZVS type through active filter to load.

II. MATHEMATICAL DESIGN

From this section, the mathematical designed steps are explained by selected values based on converter ratings as following, Hybrid input voltage V_{in}=24V, Output V_o=60-70V, Output voltage (nominal=~45V), output power P_o=60-100W, and switching frequency of the power devices f_s=100kHz.

1). Input average current, $I_{in}=(P_o/\eta V_{in})$. Assumed efficiency value η of 95 % (ideally), I_{in} is 3.07A.

2). Conversion of voltage ratio or output to input voltage is given by,

$$V_o = \frac{n \cdot V_{in}}{2 \cdot (1-d)} \qquad (1)$$

Where, d= duty cycle of primary power switches.

3). The r.m.s current of primary power switches is given by,

$$I_{p,r.m.s} = I_{in}\sqrt{\frac{2-d}{3}} \qquad (2)$$

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4). Max. Voltage of primary power switches is,

$$V_{p,sw} = \frac{V_o}{n} \quad (3)$$

5). Boost leakage inductor LB is given by,

$$L_B = \frac{V_{in}\cdot(d-0.5)}{\Delta I_{in}\cdot f_s} \quad (4)$$

Where, ΔI_{in} is ripple current of boost inductor. ΔI_{in}=1A, L_B=22.5µH.

6).Transformer leakage inductance or series inductance L_x is calculated by,

$$L_x = \frac{V_o\cdot(d-0.5)}{2\cdot n\cdot I_{in}\cdot f_s} \quad (5)$$

7). The r.m.s current of transformer leakage inductance L_x is given by,

$$I_{x,r.m.s} = I_{in}\sqrt{\frac{5-4d}{3}} \quad (6)$$

8). Average secondary current through power switching,

$$I_{avg} = \frac{P_o}{2\cdot V_o} \quad (7)$$

Here, $I_{avg} \cong$ 1.05A, The Voltage rating of switching devices at secondary V_o= 45V

9). The r.m.s current of secondary device is,

$$I_{s,r.m.s} = \frac{I_{in}}{2\cdot n}\sqrt{\frac{2d-1}{3}} \quad (8)$$

10. HF transformer rating in (VA-rating) is given by,

$$V\cdot A_{xmar} = \frac{V_o\cdot I_{in}\cdot}{n}\sqrt{\frac{2\cdot(5-4d)\cdot(1-d)}{3}} \quad (9)$$

The calculated values of HFT rating is always in 1500VA ratings.

These above relation are derivative with help of diode of power switches conduction time is pretty short (interval 6) and insignificant with the help of aim to make ensure that in the ZCS of primary power switching devices without knowingly cumulative their highest current. However, at the light converter load, conduction time the body diode is relatively more, with equation is (1) is not valid. Because, the body diode conduction extended for longer, load voltage can stepped to a more than of minimal step-up converter. For the such cases, (1) is simplified equations are,

$$V_o = \frac{n\cdot V_{in}}{2\cdot(1-d-d')} \quad (10)$$

$$\text{Where, } d' = d - 0.5 - \frac{2\cdot n\cdot I_{in}\cdot L_x\cdot f_s}{V_o} \quad (11)$$

From, (11), it can be observed that, load as decreases with d′ is increases, for a given values of transformer leakage inductance L_x and V_o, at the full load, d′=0. And equation (11) is converted from equation (1).

11. The output power and duty cycle, the relation is,

$$P = \frac{n\cdot V^2{}_{in} - V_o\cdot V_{in}\cdot(3-4\cdot d)}{4\cdot n\cdot L_x\cdot f_s} \quad (12)$$

III. Converter Operation

In this section, explaining the converter operation, a ZCS of the primary, ZVS of secondary of HFT. Power switches of Primary side are turned off and turned on by ZCS technique and the output voltage appears across a HFT is V_o/n. The MOSFET's are the primary power switches with the pair of S_1, S_4 and S_2, S_3. The PWM for S_1=S_4=25%, S_2=S_3=75% maintained in this topology.

Power switches of Secondary side are turned off and turned on by ZVS technique and the output voltage appears across (R/ RL) load, through active filter. The MOSFET's are the secondary power switches with the pair of S_5, S_8 and S_6, S_7. The PWM for S_5=S_6=S_7=S_8=20% maintained, connected as bridge rectifier.

The assumptions are made as follows for converters,

i) Input boost leakage inductances are L_B large, assumed kept current constant through them.

ii) The transformer leakage inductance or magnetizing inductance kept assumed to be infinitely.

iii) The components of all are ideal.

iv) L_x is the transformer leakage inductance or series inductance which is includes the leakage of transformer.

The steady-state operating waveforms[1], in a half cycle of HF, during altered intervals of operating converter is explained [1] and primary switching devices such as, S_1, and S_2 are controlled by pulsating gates signals shifted with the phase angle of 180^0 along in similarity(or overlap). The similarity varies with the pulse width modulation of duty cycle with fixed high frequency is fixed at 100kHz [1-5], the pulse width of Switches are S_1, S_4<25% and S_2, S_3>75% and fixed switching frequency 100kHz selected to get desired output level.

IV. Simulation

The proposed topology was designed, analyzed and simulated for R-Load and RL-load using Matlab-2009a. it consisting of input hybrid input source(V_{in}=24V), which parallel combination of Fuel cell, DC voltage, Battery=24V, two pair arm of power switches are S_1, S_4 and S_2, S_3 , which are connected as bridge type rectifier through input boost leakage inductance L_B , and through transformer leakage inductance L_x, ZCS of primary side HFT .

Similarly, another four power switches (S_5 to S_8) are connected as bridge rectifier type, which has connected through active filter circuit under the ZVS of secondary side of HFT and resistive (R-load) load. Similarly, R-load is replaced by R-L-load (R=21.62Ω, 100mH) as shown in Fig.2.

Fig.3 shown, input waveforms are closely coincide for the both R-load and R-L Load as shown for hybrid input

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voltage (V_{in}) =24V, with respect to time as shown in Fig.3(a), input current I_{in} is linearly increases from 3A to reach peak value of 5.5A and again linearly decreases peak value to 3A w.r.t. time during this period 0 to 0.0499 seconds and repeated same previous steps w.r.t time up to 0.05seconds as shown in Fig.3(b).

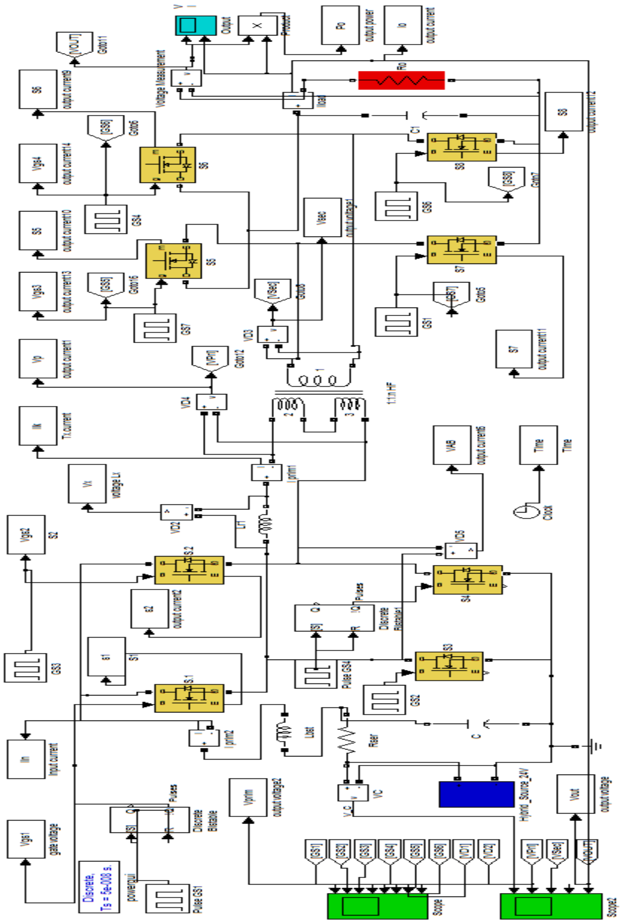

Fig.2 Simulated module for SST based isolated FBC with R-load(R=21.62 Ω,) and with R-L-load(R=21.62 Ω, L=100mH, with input hybrid source=24V).

Input power P_{in}, the product of input of voltage and current, is linearly increases from 35 to 130W and again linearly decreased from peak to 40W w.r.t. time during this period 0 to 0.0499 seconds and same procedure were repeated previous steps up to time period 0.05s time as shown in Fig.3(c), when these are zoom out in scope, its results are noting that like as triangular in the nature.

Fig.4 shows, output waveforms for R-Load (R=21.62 Ω) , output voltage(V_o) is linearly increases to reach peak value of nearly below ~45V with in time period is 0.05seconds after this time voltage is to reach stable of 45V w.r.t time up to 0.5seconds as shown in Fig.4(a) ,

Output current (I_o) is linearly increases to reach peak value of nearly above 2A with in time period is 0.05seconds after this time, current is to reach stable of above 2A w.r.t time up to 0.5seconds as shown in Fig.4 (b).

Output power (P_o) is product of current and voltage, linearly increases to reach peak value of nearly above 70W with in time period is 0.05seconds after this time, power is to reach stable of below 100W w.r.t time up to 0.5seconds as shown in Fig.4(c).

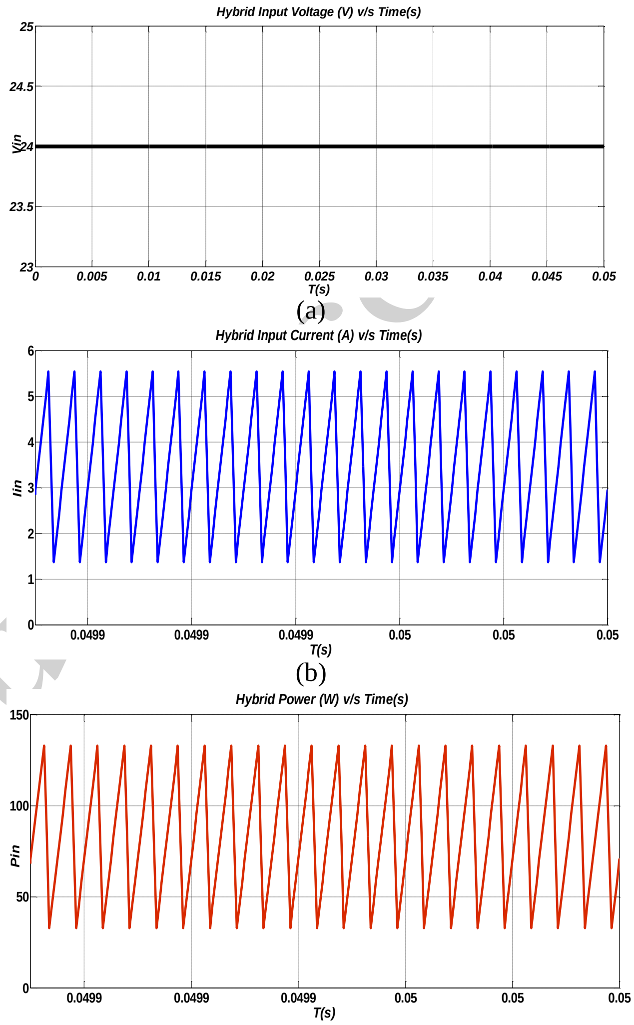

Fig.3. Simulated input Results for R-Load (R=21.62 Ω,) R-L load(R=21.62 Ω,L=100mH) and (a)V_{in} (b) I_{in} (c) P_{in}

Fig.5 shows, output waveforms for R-L-Load (R=21.62 Ω, L=100mH), output voltage(Vo) is linearly increases to reach peak value of near about 60V and it oscillates/ fluctuate to below 40V with in time period is 0.05seconds after this time, voltage is to reach stable below 40V w.r.t time upto 0.5seconds as shown in Fig.5(a).

Output current (I_o) is linearly increases to reach peak value of near about 2A and it oscillates/ fluctuate to above 2A with in time period is 0.05seconds after this time, current is to reach stable below 1.8A w.r.t time up to 0.5seconds as shown in Fig.5(b).

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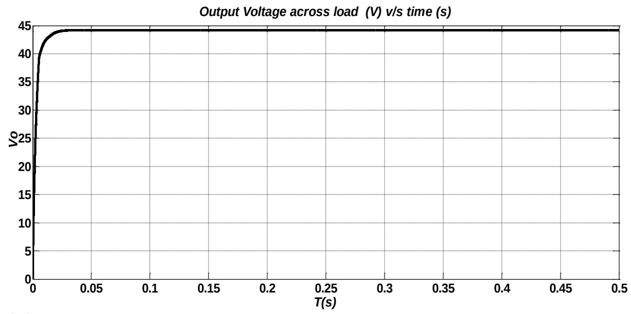
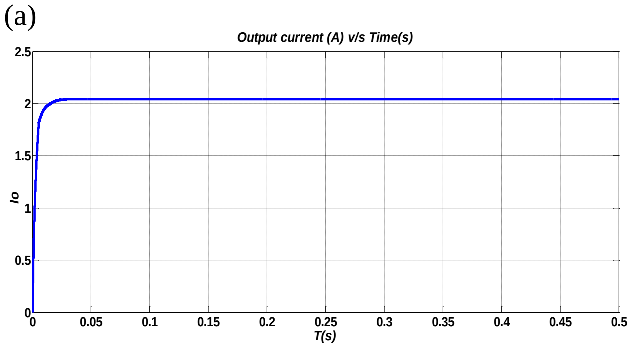
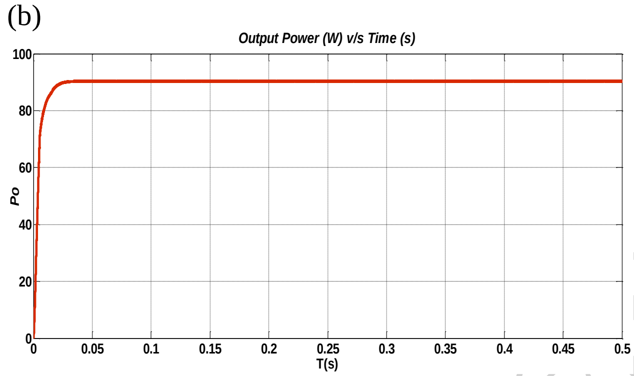


(a)



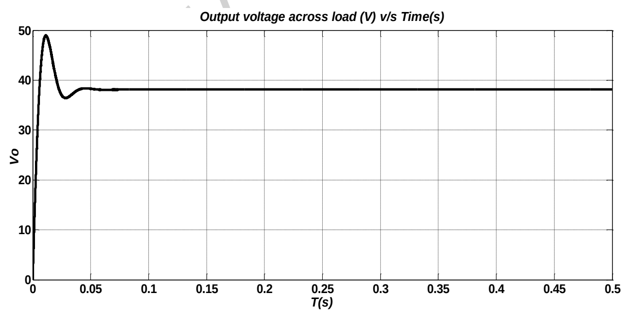
(b)



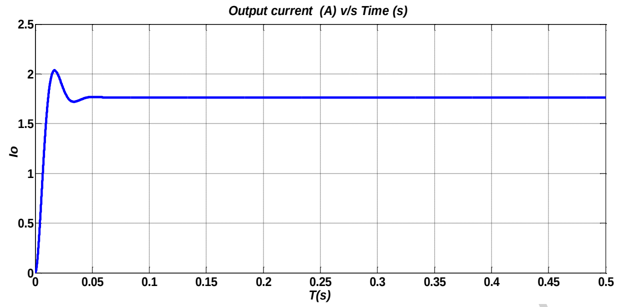
(c)

Fig.4. Simulation Results for out-put R-Load (R=21.62 Ω,), (a)V_o (b) I_o(c) P_o

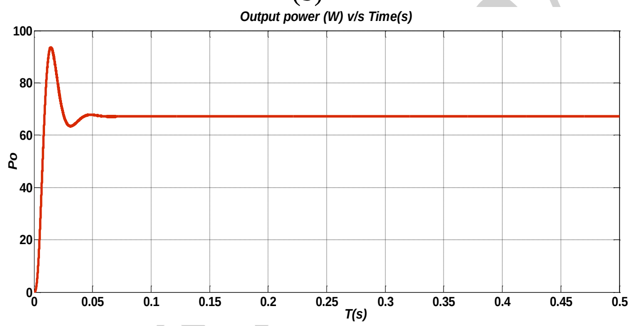
Output power (P_o) is product of output current and voltage , linearly increases to reach peak value of nearly above 80W and it oscillates/ fluctuates to below 70W with in time period is 0.05seconds after this time, power is to reach stable of above 60W w.r.t time up to 0.5seconds as shown in Fig.5(c).



(a)



(b)



(c)

Fig.5 Simulation Results for out-put R-L load (R=21.62 Ω,L=100mH) (a)V_o (b) I_o(c) P_o

V. Conclusion

The proposed topology was designed, developed simulink module and simulated in Matlab2009a, with SST based isolated FBC for E-V's. The hybrid input source of 24V, with constant switching frequency of 100 kHz maintained throughout the simulation with R-load and RL-load. The performance of the system improved due to various factors. The system performance has demonstrated with improved results depicted with R/RL-load conditions.

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