International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 8, August 2020 ||

A Unique Converter Based on Control of the Energy Injection

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ABSTRACT: In comparison to the conventional converter, this article examines the characteristics of a converter associated with energy injection control which can be used for the transform of $\boldsymbol{AC-AC, AC-DC, DC-DC\ and\ DC-AC}$.It accomplishes energy transformation in a single stage. The detailed operation of switches is defined in the mode of energy injection and the free mode of oscillation. Converter work, every time in a soft switch state and output current, will remain unchanged when the load is altered. Simulations are evolved to investigate the characteristics of the all four conversions and also verifies that the converter can accomplish single stage transformation and bidirectional energy flow. The outcomes of the simulation evaluate the accurateness and effectiveness of the converter. The proposed study was simulated and implemented with the $\boldsymbol{MATLAB\ /\ Simulink\ R2020a}$.

KEYWORDS: Inductive Power Transfer(**IPT**),Zero Current Switching(**ZCS**),Energy Injection Control, Energy Injection, $\mathbf{DC-DC}$ converter, $\mathbf{AC-AC}$ converter,$\mathbf{DC-AC}$ converter,$\mathbf{AC-DC}$ converter, Electronic Power Transformer(**EPT**) ;

I.INTRODUCTION

The power electronics ($\boldsymbol{PE}$) area focuses primarily on transferring power from one base to the other and switching from one level to another level of voltage using different power electronic converters. There are many control mechanisms used to make this conversion simpler in converters. And signal conditioning helps us to confirm that the input and output signals are free from harmonics. It is not likely to get clean signals, but there are numerous ways to decrease the harmonics, the easiest way is to use a low-pass $\boldsymbol{LC}$ filter.

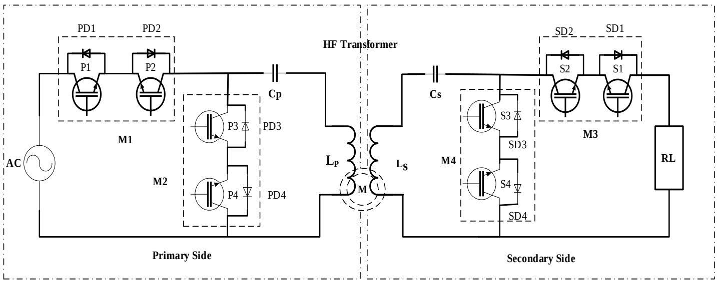
Power electronics converters generally consist of solid-state switches for example IGBT & lossless components for example inductor and capacitor. To use in power converters, inductors and capacitors are well suited since the power loss in these components is null relative to the resistance.

Solid-state devices are used as switches in the power electronics sector. And the frequency at which the solid-state systems are turned on and off is called the frequency of switching. The capacitor and inductor used will contribute to a large weight gain as well as a rise in the volume of power converters, resulting in a reduction in the converters' power density. This could be mitigated with a high switching frequency that decreases the converter component size — However, a high switching frequency fallout in high switching losses.

Nowadays, a power converter is commonly used in the industrial sectors with the growing development of power electronics, involving drives and renewable energy. As the electrical system 's essential connector, it realizes energy conversion.Several topologies have been projected to please the different needs of industrial applications. There are usually four classes of power conversions, such as $\boldsymbol{AC-AC, DC-DC, AC-DC}$, and $\boldsymbol{DC-AC}$. Typically, only one transformation can be made by one power converter. To increase the application range of the power converter, more and more care is paid to the study of multi-functional topology. i.e. An Electronic Power Transformer ($\boldsymbol{EPT}$) is proposed which would likely replace the conventional electromagnetic transformer. Electronic Power Transformer can accomplish conversion of voltage and effectively deliver power to the secondary track without direct electrical contact through magnetic coupling from the primary. This removes the vital drawbacks of conventional transformers like DC bias and no-load loss. This also offers a safe and efficient means of accessing a renewable resource.

This article proposes an EPT relying on a unique converter revealed in Figure 1 which has symmetrical topology. The unique converter consists mainly of a transformer with high-frequency (HF) and two buck converters. The HF transformer provides electrical separation for the two Buck converters. This unique power converter can accomplish direct current generation with a high frequency from an alternating current (AC) power source without a direct current (DC)

Figure 1. The Unique Converter



Link relying on the control of free oscillation & the energy injection. By the use of a distinct control of the energy injection scheme, High-Frequency resonance is maintained. The primary inductor (L_P) and primary capacitor (C_P) of the converter are active to establish the series resonant tank, even the secondary inductor (L_S) and secondary capacitor (C_S). Resonant tank decreases Electron-Magnetic Interference (EMI), switching stresses, and the power losses. Each Buck converter involves two bi-directional switches ($M1 - M4$), & each bi-directional switches is comprehended by two IGBT's ($P1 - P4$ or $S1 - S4$) with anti-parallel diodes ($PD1 - PD4$ or $SD1 - SD4$).

This article is organized as follows. In Part II, the Description and Basic Circuit Operation of the Unique Converter are added. Part III, About Loosely Coupled Transformer. A simulation study is given out in Part IV to verify the functionality of the circuit and the effectiveness of the unique converter. The conclusions are ultimately made in Part V.

II.STUDY OF THE UNIQUE CONVERTER

1. Portrayal of the Unique Converter

By activating switches in various combinations, we can enable the converter operates in the energy injection and the free oscillation configurations. To retain full of energy in converter's resonant tank is the main key. In free oscillation configuration, there is energy loss in the resonant circuit tank due to the non-ideal components, and the circuit cannot oscillate continuously. The resonant circuit tank is driven by the power source in the energy injection configuration. Energy is introduced to the tank and resonant current is boosted. With the precise discovery of resonant current (I_R), zero current switching's are ensured and the high performance of the unique converter is achieved.

As we have shown, the Converter topology is symmetrical. There is no constraint on the source & load of the converter. It can be changed. For the sake of study, V is assumed as source and that R as load. Because of the special feature of the topology, converter can convert to $AC - AC, AC - DC, DC - DC, DC - AC$.

2. AC − AC Conversion

When the input power supply is AC. Based on the polarity of input power supply and the pathway of resonant current, the converter operations are split into IV modes, which is revealed in Figure. 2. Fig. 2.1, 2.3 are energy injection mode and Fig. 2.2, 2.4 are free oscillation mode.$I_R$resonant current, T_R resonant current period, T_I Input cycle, I_L Load current.

During the positive half-cycle of V_{AC}, the prime side switches ($P2$ and $P4$) and secondary side switches ($S1$ and $S3$) are permanently switched off, while the remaining switches $P1, S2, P3,$ and $S4$ function in line with the resonant current direction. when I_R is more than zero. In Prime side, $P1$ is switched on and $P3$ is switched off. The input supply current enters into the resonant tank and increases the I_R which is the energy injection mode. In the secondary side, the $S2$ is switched on and $S4$ is switched off. I_R drifts over the load R_L. when I_R is less than zero. In Primary side, $P1$ is switched off and the $P3$ is switched on. In secondary side, the $S2$ is switched off and $S4$ is switched on. $I_R$drifts over the tank which is free oscillation mode. Fig. 3 illustrates the actions of the consistent switches in detail.

During the negative half-cycle of V_{AC},the prime side switches ($P1$ and $P3$) and secondary side switches ($S2$ and $S4$) are permanently switched off, while the remaining switches $P2, S1, P4,$ and $S3$function in line with the resonant current direction. when I_R is more than zero.In the Primary side, $P2$ is switched on and $P4$ is switched off. The input supply current enters into the resonant tank and increases the I_R which is the energy injection mode. In the secondary side, the $S1$ is switched on and $S3$ is switched off. I_R drifts over the load R_L. When I_R is less than zero. In the Primary side, $P4$ is switched off and $P2$ is switched on. In the secondary side, the $S1$ is switched off and $S3$ is switched on. I_R drifts over the tank which is free oscillation mode.

3. AC − DC Conversion

The prime side is the similar as the $AC - AC$ conversion for $AC - DC$ conversion, and secondary side is altered to get DC output.Fig. 4 illustrates the actions of the consistent secondary side switches in detail.

During the positive half-cycle of V_{AC}, the prime side switches ($P2$ and $P4$) and secondary side switches ($S1$ and $S3$) are permanently switched off, while the remaining switches $P1, S2, P3,$ and $S4$ function in line with the resonant current direction. when I_R is more than zero.In Prime side, $P1$ is switched on and $P3$ is switched off. The input supply current enters into the resonant tank and increases the I_R which is the energy injection mode. In the secondary side, the $S2$ is switched on and $S4$ is switched off. I_R drifts over the load R_L. when I_R is less than zero. In Prime side, $P1$ is switched off and the $P3$ is switched on. In secondary side, the $S2$ is switched off and $S4$ is switched on. $I_R$drifts over the tank which is free oscillation mode. Fig. 3 illustrates the actions of the consistent switches in detail.

During the negative half-cycle of the input,the prime side switches ($P1$ and $P3$) and secondary side switches ($S2$ and $S4$) are permanently switched off, while the remaining switches $P2,\ S2,\ P4,$ and $S4$ function in line with the resonant current direction. when I_R is more than zero.In the Prime side, $P2$ is switched on and $P4$ is switched off. The input supply current enters into the resonant tank and increases the I_R which is the energy injection mode. In the secondary side, the $S2$ is switched on and $S4$ is switched off $I_R$drifts over the load RL. whenI_R is less than zero. In the Prime side, $P4$ is switched off and $P2$ is switched on. In the secondary side, the $S2$ is switched off and $S4$ is switched on. s$I_R$drifts over the tank which is free oscillation mode.

Figure. 2. Switching actions of the unique converter for $AC - AC$ conversion

Figure. 3. Switching actions of the unique converter for $AC - AC$ conversion

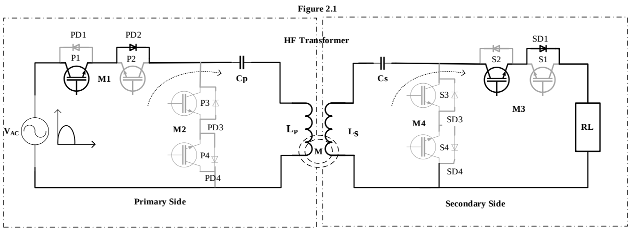


Fig 2.1 During positive half cycle in energy injection mode

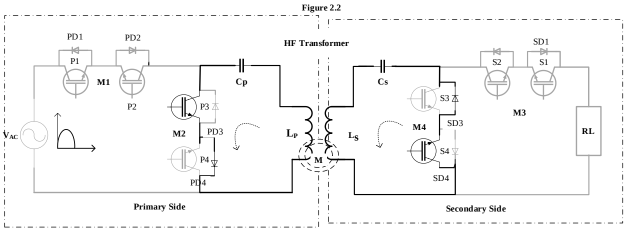


Fig 2.2 During positive half cycle in free oscillation mode

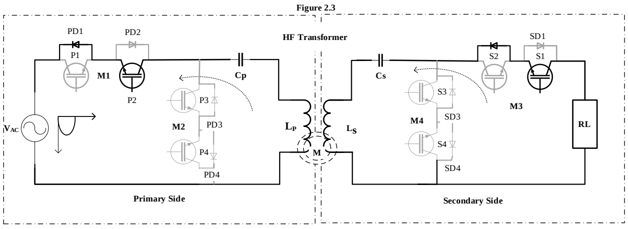


Fig 2.3 During negative half cycle in energy injection mode

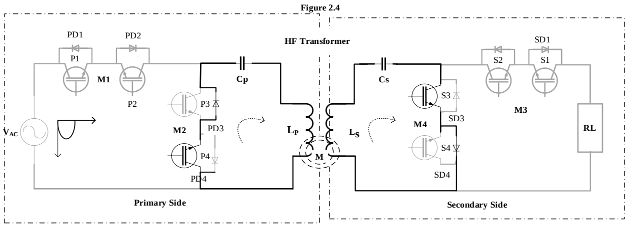
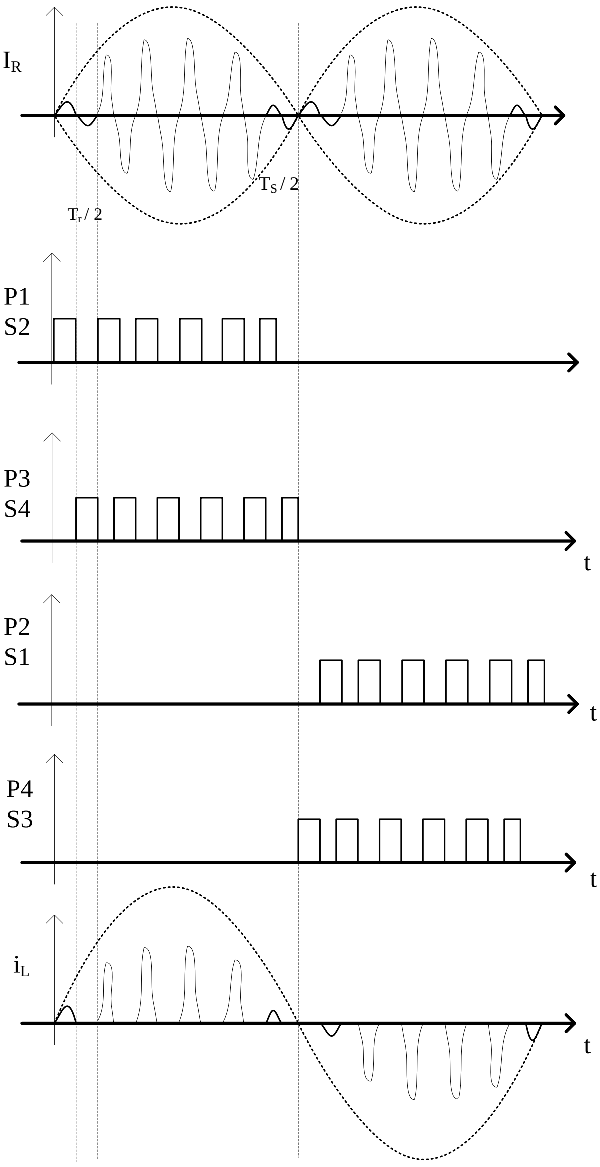


Fig 2.4 During negative half cycle in free oscillation mode



4. DC − DC Conversion

For $DC - DC$ conversion, The prime side switches ($P2$ and $P4$) and secondary side switches ($S1$ and $S3$) are permanently switched off, while the remaining switches $P1,\ S2,\ P3,$ and $S4$function in line with the resonant current direction. when I_R is more than zero.In the Prime side, $P1$ is switched on and $P3$ is switched off. The input supply current enters into the resonant tank and increases the I_R which is the energy injection mode. In the secondary side, the

$S2$ is switched on and $S4$ is switched off. I_R drifts over the load R_L. when I_R is less than zero.In the Prime side, $P1$ is switched off and the $P3$ is switched on. In the secondary side, the $S2$ is switched off and $S4$ is switched on. $I_R$drifts over the tank which is free oscillation mode. Figure. 5 illustrates the actions of the consistent switches in detail.

Figure. 4. Switching actions of the unique converter for $AC - DC$ conversion

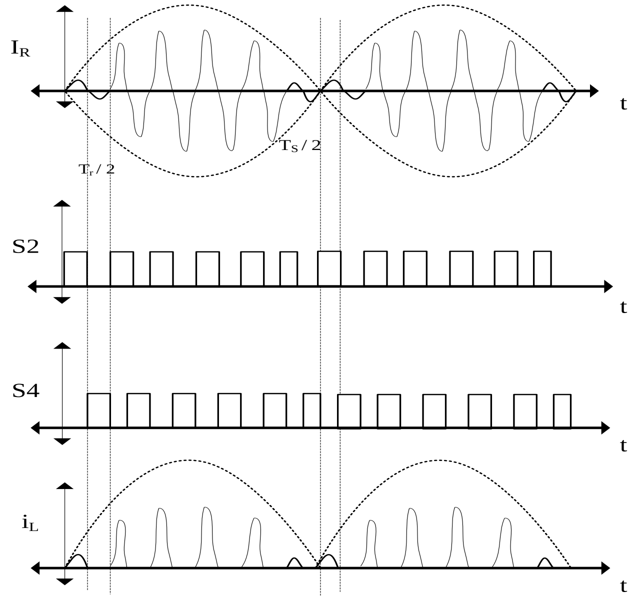
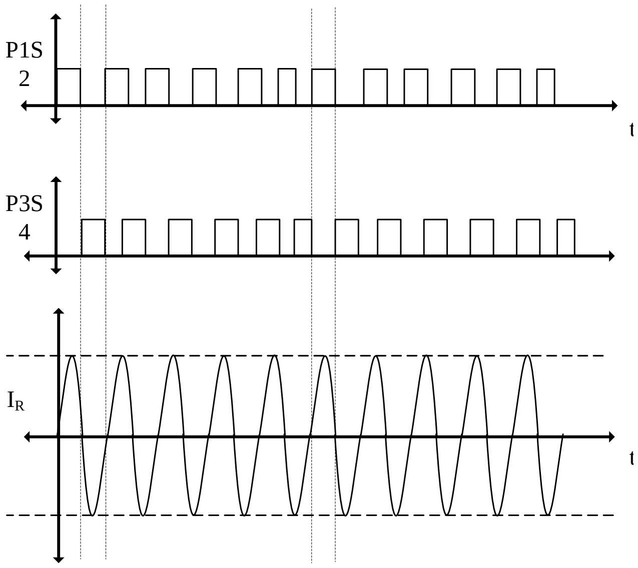


Figure. 5. Switching actions of the unique converter for $DC - DC$ conversion



5. DC − AC Conversion

For $DC - AC$ conversion, the $DC - AC$ switching operation is the same as the $AC - DC$ switching operation due to the similarity of the topology.

In theprime side of $DC - AC$ conversion, the prime side switches $P2$ and $P4$ switched off in one output voltage set. when I_R is more than zero. $P1$ is switched on and $P3$ is switched off.when $I_R$is less than zero. P1 is switched off and the P3 is switched on. Fig. 6.1. illustrates switching actions of the unique converter for $DC - AC$ conversion for prime side.

In the secondary side of the $DC - AC$ conversion, the secondary side switches $S1$ and $S3$ are switched off during the positive half-cycle of the output voltage. when I_R is more than zero, the $S2$ switched on and the $S4$ switched off. when I_R is less than zero, the $S2$ switched off and the $S4$ switched on. In the negative half-cycle of the output voltage, the$S2$ and $S4$ are always switched off. when I_R is more than zero, $S1$ is switched off and $S3$ is switched on. when I_R is less than zero, $S1$ is switched on and the switch $S3$ is switched off. Fig. 6.2. illustrates the switching actions of the unique converter for $DC - AC$ conversion for secondary side.

III.STRATEGY OF LOOSELY COUPLED TRANSFORMER

Fig. 1 illustrates that the prime side converter & the secondary side converter is linked through a high-frequency transformer and configured as a loosely coupled Transformer. It has a leakage inductance more with coefficient of low coupling. The equivalent circuit is shown in Figure 7. $L_A$and L_B are prime & secondary winding leakage inductance and R_A and R_B are prime & secondary winding resistance. M is Mutual Inductance. It is a sort of transformer that can be defined as two inductors are series linked on each side.

As per the transformer equivalent circuit, the large leakage inductances$L_A$and L_B will substitute the resonant inductances $L_P$and L_S correspondingly, which prevents the use of the additional inductor. Mutual inductance M accomplishes electrical energy isolation and transmission.

Figure. 6.1. Switching actions of the unique converter for $DC - AC$ conversion for primary side

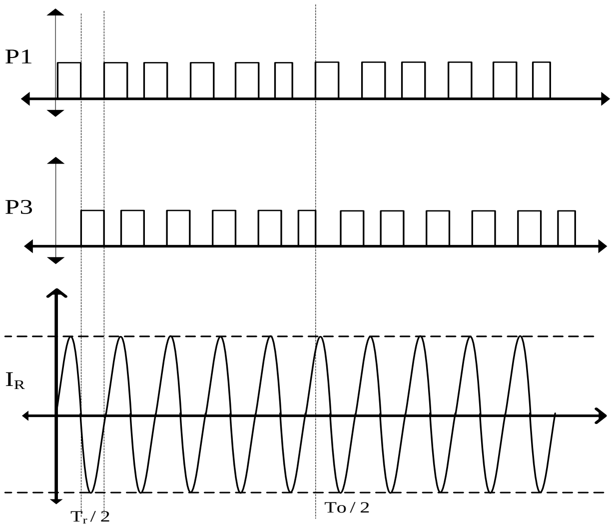


Figure.7. The equivalent circuit of Loosely Coupled Transformer

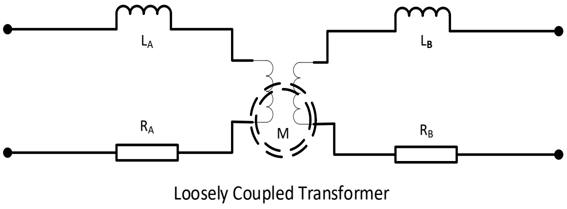
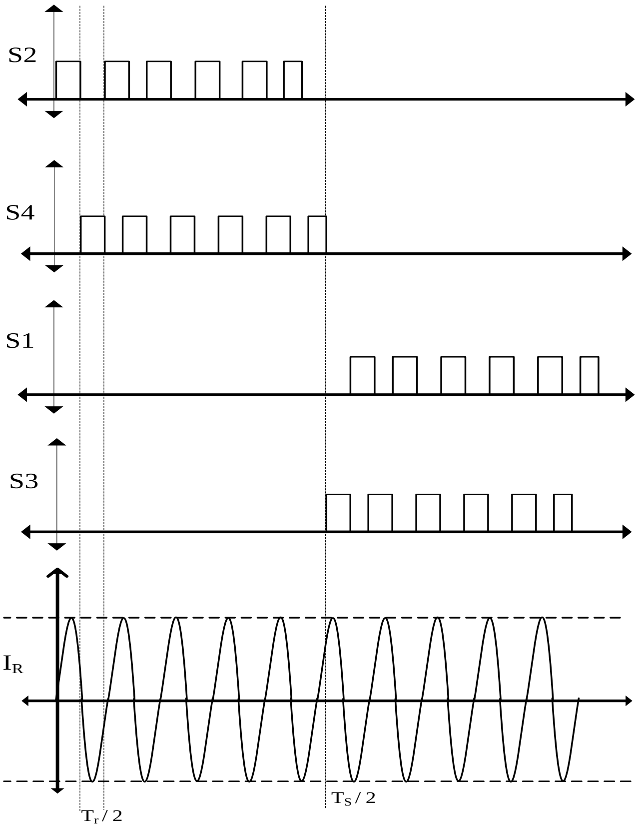


Figure. 6.2. Switching actions of the unique converter for $DC - AC$ conversion for secondary side



IV.MATLAB SIMULATION STUDY

The simulation has been carried out in $MATLABSimulink\ R2020a$ to evaluate the functionality and efficiency of the proposed unique converter. The Simulation parameters and the values are recorded.

$$V_{AC}(\mathrm{RMS}) = 50\ \mathrm{Hz},\ V_{DC} = 100\mathrm{V}, L_P = 423\ \mu\mathrm{H}, L_S = 423\ \mu\mathrm{H}, C_P = 0.15\ \mu\mathrm{H}, C_S = 0.15\ \mu\mathrm{H}, M = 211\ \mu\mathrm{H},$$
$$R_{Load} = \text{Variable from 100 to 400}\ \Omega, C_O = \text{Output Filter}.$$

Figure.8, Fig.8.1. displays the circuit diagram of $AC - AC$ Conversion.

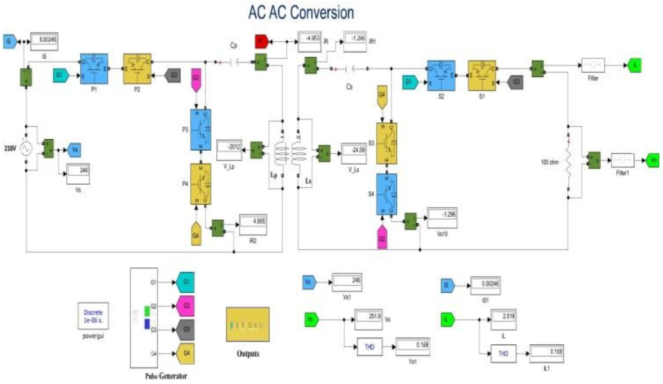
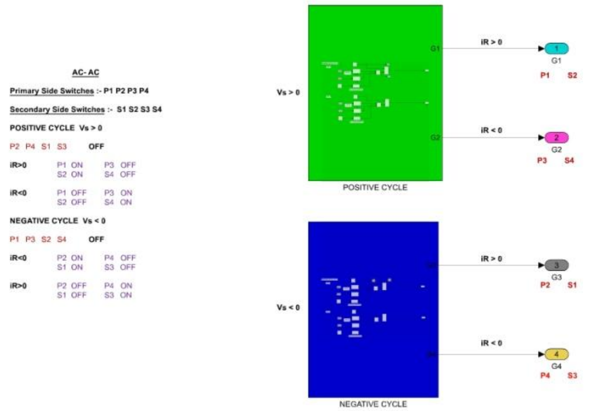


Fig.8.2. shows the switching condition control block for$AC - AC$ Conversion.



AC- AC

Primary Side Switches :- P1 P2 P3 P4

Secondary Side Switches :- S1 S2 S3 S4

POSITIVE CYCLE Vs > 0

P2 P4 S1 S3 OFF

iR>0	P1 ON S2 ON	P3 OFF S4 OFF
iR<0	P1 OFF S2 OFF	P3 ON S4 ON

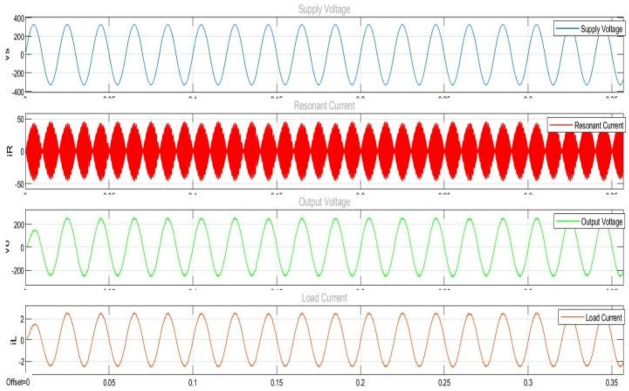
NEGATIVE CYCLE Vs < 0

P1 P3 S2 S4 OFF

iR<0	P2 ON S1 ON	P4 OFF S3 OFF
iR>0	P2 OFF S1 OFF	P4 ON S3 ON

Fig.8.3. shows waveform of V_S, I_R, V_O, $I_O$for$AC - AC$ Conversion.

Figure.9, Fig.9.1. displays the circuit diagram of $AC - DC$ Conversion.



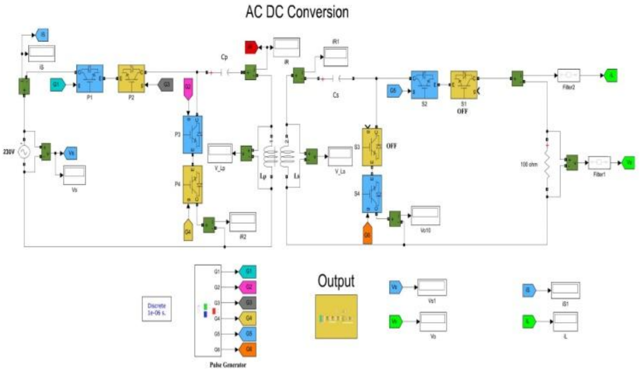


Fig.9.2. shows the switching condition control block for $AC - DC$ Conversion.

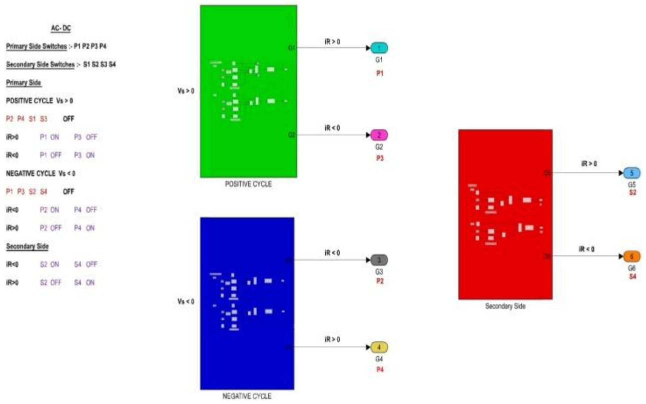


Fig.9.3. shows waveform of V_S, I_R, V_O, I_O for $AC - DC$ Conversio

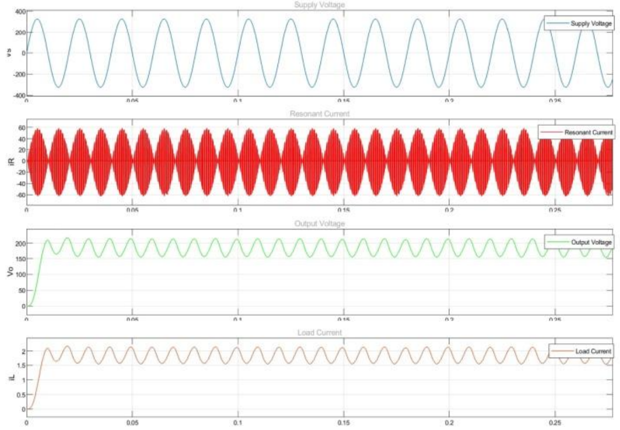


Figure.10, Fig.10.1. shows the circuit diagram of $DC - DC$ Conversion.

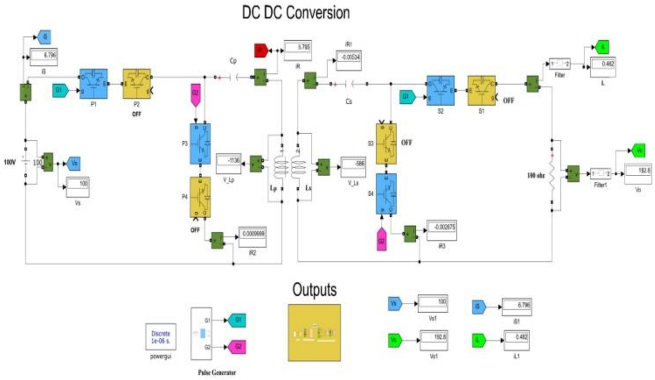
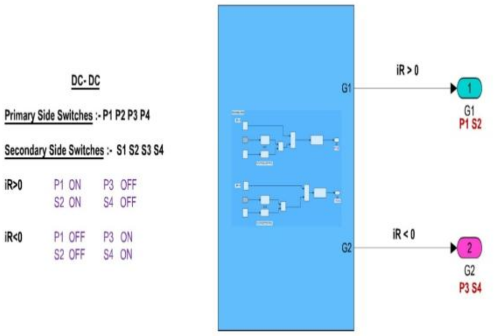


Fig.10.2. shows the switching condition control block for $DC - DC$ Conversion.



Simulations Results: -

From Figure.8, the AC peak output voltage is $270V$ in source voltage phase $(230V, 50Hz)$

From Figure 9.3, The DC peak output voltage is $220V$ is gained by rectification of the output voltage of AC.

From Figure.10, The DC peak output voltage is $200V$

From Figure.11, The AC peak output voltage is $450V$

Fig.10.3. shows waveform of V_S, I_R, V_O, I_O for $DC-DC$ Conversion.

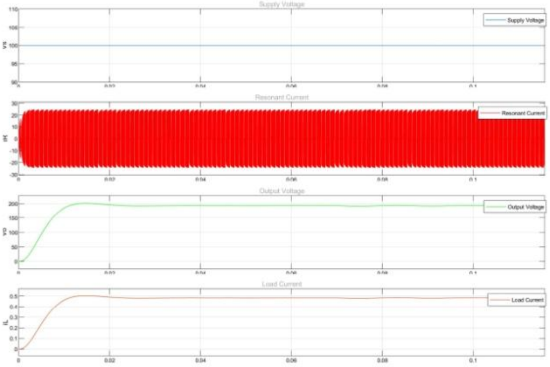


Figure.11, Fig.11.1. shows the circuit diagram of $AC-DC$ Conversion.

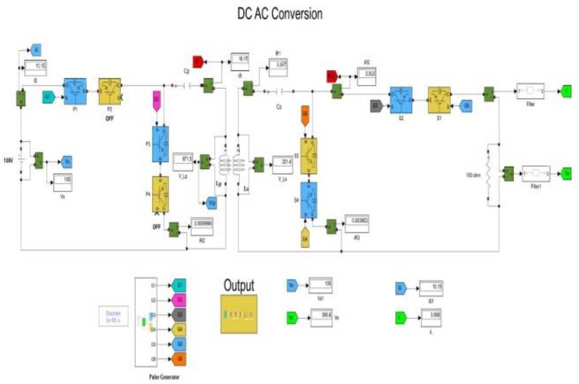


Fig.11.2. shows the switching condition control block for $AC-DC$ Conversion.

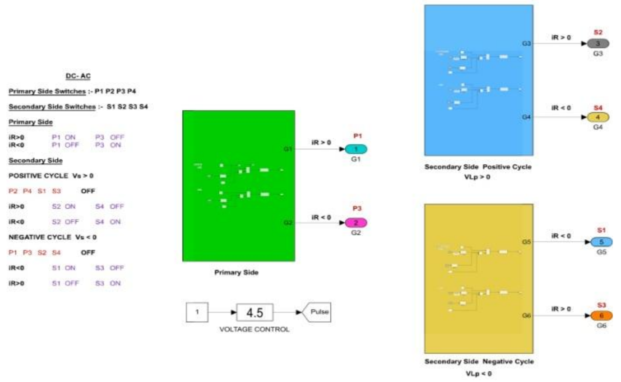
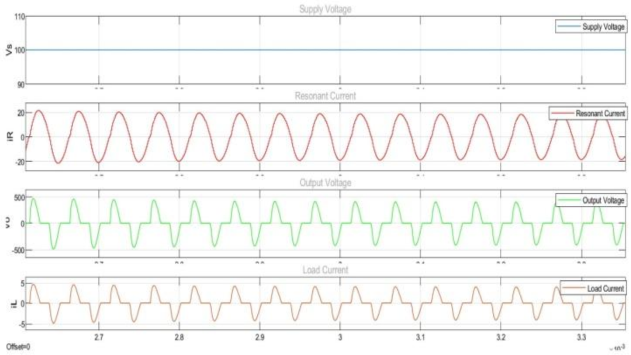


Fig.11.3. shows waveform of V_S, I_R, V_O, I_O for $AC-DC$ Conversion.



V.CONCLUSION

This paper evaluates the unique converter relying on energy injection that can accomplish the $AC-AC, AC-DC, DC-DC, DC-AC$ conversion. The detailed activity of the switches is portrayed. Detailed analysis of Energy Injection and free oscillation mode is revealed. Simulations are made in $MATLAB-Simulink$ and the simulation result have verified that the unique converter can comprehend the IV conversion and effectiveness of the Unique Converter are also studied.

ACKNOWLEDGMENT

The publishers would like to specially thank Dr. Ambedkar Institute of Technology, Malathalli, Bengaluru for providing the technical support.

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