Thermal Analysis of ZVS Switching Techniques on Semiconductor Devices Rating

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ABSTRACT
This paper endeavours to estimate the influence of soft switching on semi-conductor devices' rating, when they are subjected to high frequency applications. In order to find out the extent of saving in semiconductor devices losses, soft switched circuits were studied and analyzed. An experimental set up which could be operated both in hard-switching and soft-switching modes were chosen. Specific switching devices, namely MOSFETs were selected. The ageing of the semiconductor devices was correlated with the rise in temperature of the casing of the devices. The cutoff point for the experiment was the knee region where the thermal runaway would start. This experiment was conducted on two MOSFETs at two frequencies**.**

Keywords
Soft switching, hard switching, device ageing, temperature rise.

1. INTRODUCTION
Soft switching techniques are used to reduce the switching losses in power converters. Zero voltage transition and zero current transition are two recently proposed techniques to reduce the switching losses in the semiconductor switches. Pulse width modulated (PWM) DC-DC converters are widely used in industry due to their high power density, fast transient response and ease of control. Increasing the switching frequency achieves a higher power density and faster transient response. With implementation of a higher switching frequency, increased switching losses and electromagnetic interference (EMI) noises occur. To decrease the switching losses, active snubber circuit is used. In recent years a number of zero voltage transition (ZVT) PWM converters have been proposed by adding resonant active snubbers to conventional PWM converters. More recently, new power conversion topologies have been developed which dramatically reduce the power dissipated by the main power transistors during the switching interval, while at the same time minimising much of the generated radio frequency energy, or high frequency "noise". The most common technique employed has been a constant frequency resonant switching scheme, which ensures that the actual energy being dissipated by the active device is reduced to nearly zero. This method, commonly called "zero voltage switching" (ZVS) or "soft switching" uses the parasitic output capacitance of the power transistors (typically MOSFETs) and the parasitic leakage inductance of the power transformer as a resonant circuit. Using this resonant circuit, the output inductance, the parasitic drain-source body diodes of the MOSFETs, and an appropriate switching sequence allows the voltage across each transistor to swing to zero before the device turns on and current flows. Likewise, at turn-off, the current through the transistor swings to zero (ZCS) before it is driven to a non-conductive state. With this scheme, current is only flowing through the transistors when they are fully "on", and doing useful work transferring energy to the output of the supply. The power dissipation within the transistors that would normally occur during the switching interval has effectively been eliminated. Unwanted high-frequency voltage and current transients during the switching period- 'the culprits that supply much of the RF noise radiated and conducted out of the power supply'- are also dramatically reduced at its source, enhancing filtering at the input and output of the unit ensures that the unit is well within the noise limits set by international standards. Reducing the power here lowers their junction temperature, giving increased thermal operating margins and hence, a longer life for the power supply. Not only does a "soft switching" power supply generate significantly less electrical noise, it achieves greater efficiency, longer mean time between failures, and higher immunity to the effects of other equipment operating nearby.

In the conventional ZVT-PWM converter [1], the main switch is perfectly turned on under ZVS and ZCS by ZVT with a parallel resonance. The main diode is turned on and off with ZVS. The load current and the recovery current of the main diode and the energy of the resonant capacitor including the parasitic capacitor of the main switch are transferred to the resonant inductor by an auxiliary switch. However, the main switch is turned off with near ZCS. Moreover, the operation of the circuit is strongly dependent on line and load conditions. The turn off of the auxiliary switch with soft switching and the transfer of the energy stored in the inductor are very difficult to carry out and require additional circuits. There has been much research in this area to solve these problems [2] [3] [5] [7] [9].

In the normal ZCT-PWM converter, the main switch is perfectly turned off under ZCS and ZVS by ZCT with a serial resonance. The auxiliary switch is turned on with near ZCS. The operation of the circuit is very lightly dependent on line and load conditions. However, the main switch is turned on and main diode is turned off simultaneously with hard switching, so that a short circuit occurs at the same time. The prevention of this short circuit causing losses and EMI noise of large magnitudes is hard to realize. Also, the auxiliary switch is turned off with hard switching, and the parasitic capacitors of the switches discharge through the switches [3] [5].

In addition, most active snubber cells are seriously criticized due to their complexity and thus high cost and difficult control a large amount of circulating energy and so excessive voltage and current stresses, and also narrow line and load ranges [3] [5].

Nearly all these papers concentrate more on the efficiency of the converter and its power consumptions. The emphasis of this paper is to calculate the amount of stress applied on the switching devices and possible thermal runaway of the devices with these soft switching snubbers and their effect on the devices.

2. OBJECTIVE OF THE PROPOSED EXPERIMENT

The recent papers on soft switching with active snubber circuits [1] [2] [3], lay emphasis on the efficiency of the converter to improve the output power and to reduce the snubber components thereby reducing the net power losses. The main objective of the proposed experiment is to show the level to which the soft switching can protect the device and the conditions at which it can really provide reduced thermal losses in the device to have a realistic difference in ageing.

The proposed experimental setup has been made to prove the influence of soft switching on semi conductor devices rating.

3. EXPERIMENTAL SETUP

The design of the circuit is partially taken from the reference [1]. The soft switching DC-DC converter described in this paper is far more efficient and practical than the previous circuits. The circuit contains less number of components. The circuit can be a hard switched circuit without dismantling the circuit. When the auxiliary switch is not given a triggering pulse it works as an ordinary converter that is switched under hard switching mode. When the auxiliary is given a gate pulse with respect to the main device, it operates as soft switching circuit.

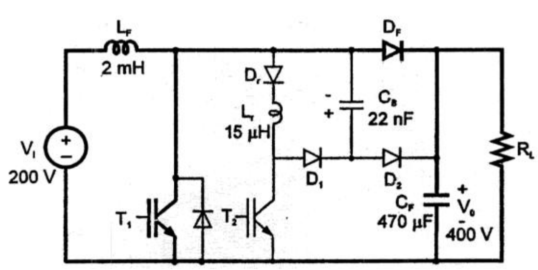

Fig. 1 Experimental circuit

The switching devices (MOSFETs) were attached with heat sink and are kept so that they can be removed and replaced easily. The casing temperature of the device is the one which is taken into consideration in our experiment to know the aging of device through thermal run away. The casing temperature is noted by a remote temperature sensing device which works by IR radiations.

The experiments were purely done with resistive load as this emphasis on the stress applied to the devices due to high frequency switching.

4. EXPERIMENTAL RESULT

Experiments were conducted using the DC-DC converter, which can work, both with soft switching snubber and without soft switching snubber. Experiments on the same switch performance were conducted in both modes. The casing temperature of the device was taken into consideration for calculation of the device ageing. The devices were operated at different load currents and the variation in temperature noted.

The safe temperature limit for the device was taken as 100^{o}C. This value was obtained from the data sheet of the manufacturer, namely International Rectifier.The same device was cooled and the device was operated under soft switching mode. The experiment was repeated and the graphs were plotted.

The experiment was repeated with a few ratings of MOSFETs to check repeatability (IRF 620 and IRF 610).The same experiments were repeated with a higher frequency of 30 kHz and the readings were noted for both hard and soft switching and the graphs were plotted.

5. INFERENCES

The graphs plotted (figs.2 & 3), from the readings obtained by the experiments show clearly that soft switching definitely saves the device from quick ageing than hard switching but the effect is pronounced when it is operated near its rating and at a relatively higher frequency. When the rated current is low both hard and soft switching have nearly the same performance. Similarly at lower operating frequency they don't show much difference in their performance.

Table 1 Observations made at 15 kHz

Load current (A)	Time (min.)	Soft switching (Temp)	Hard switching (Temp)
1	0	28	28
1	3	32	33
1	6	32	43.7
1	9	32	48.2
1	12	32	48.3
1	15	47.9	50
1	18	48	57
1	21	48	62.5
2	24	52.6	67
2	27	56.5	67.8
2	30	61.5	68.2
2	33	65.7	74
2	36	65.8	76.5
2	39	65.8	78
3	42	72	81.6
3	45	74.6	88.5
3	48	77.3	94.6
3	51	78.3	98.3
3	54	82.5	104.3
3	57	87.6	*
3	60	93.4	*
3	63	94.6	*
3	66	94.6	*
3	69	98.1	*
3	72	101.7	*

* tests stopped due to temperature >100°C
*test result may vary with ambient temperature

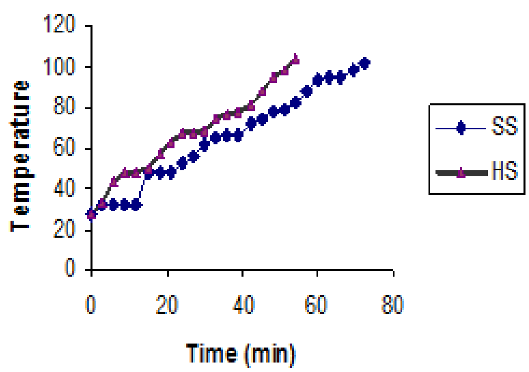

Fig.2 Hard switching Vs Soft switching at 15 kHz

Table 2 Observation made at 30 kHz

Load current (A)	Time (min.)	S.S. mode (°C)	H.S.mode (°C)
1	0	28	28
1	3	32	33
1	6	32	43.7
1	9	32	48.2
1	12	32	48.3
1	15	47.9	50
1	18	48	57.4
1	21	48	64.5
2	24	52.6	71.3
2	27	56.5	78.9
2	30	61.5	82.2
2	33	65.7	89.6
2	36	65.8	93.2
2	39	65.8	98.4
3	42	72	102.3
3	45	74.6	106.5
3	48	77.3	111.7
3	51	78.3	116.1
3	54	82.5	119.2
3	57	87.6	122.4
3	60	93.4	124.6
3	63	94.6	126.8
3	66	94.6	*
3	69	98.1	*
3	72	101.7	*

* tests stopped due to temperature >100°C.
*test result may vary with ambient temperature

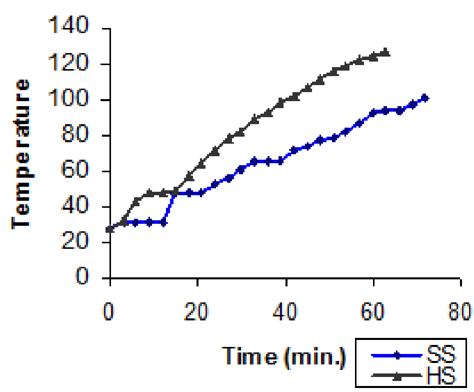

Fig.3 Hard switching Vs Soft switching at 30 kHz

As per the results from the papers [1] [2] [5], the proposed converter is said to deliver 97% efficiency but this does not hold true under all conditions. Only when operated at the near rating of the device and the specified frequencies these converters can provide the specified efficiency or else, the active snubbers do not produce much difference between them in output efficiency.

6. CONCLUSION

The results on the performance of the recently proposed converters with active snubbers have been analyzed with the results given in the respective papers. The experiments conducted prove that the influence of soft switching on semiconductor devices is not predominant when the devices are derated below 60% of their rating and the saving due to soft switching is insignificant. Soft switching when used at lower frequency (like 10 kHz) does not have positive effect in decreasing the device ageing. Only when the device is used at its nearly full-rating and relatively higher frequencies, soft-switching results in reduced losses and hence reduced ageing of the device; and increased efficiency of the converter. This would pose a limitation for IGBTs, which are generally used at relatively lower switching frequencies due to their high current carrying capacity.

7. REFERENCES

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