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Effect of ambient temperature on the performance of power electronic converters

Vani Vijay*, Giridhar Kini P**, Viswanatha C*** Pradeep K****

Efficiency of power electronics devices are highly dependent on temperature. Hence temperature compensation and heat sink design are very important factors in maintaining the performance quality of power electronic converters. Thus the ambient temperature at which the device is operating also effects the performance since the heat removal by heat sinks or cooling fans is affected by the ambient temperature. Here a detailed analysis of the dependency of losses in power electronic switches on the junction temperature and in turn ambient temperature is presented. A theoretical Analysis of conduction losses and effect of ambient temperature on it is presented along with a set of experimental results by analyzing the performance of a 850W Solar PV inverter at various ambient temperatures. The results are satisfactorily explaining the effect of ambient temperature on converter efficiency.

Keywords: *Solar PV inverters, conduction Losses, heat sink, ambient temperature*

1.0. INTRODUCTION

Power electronic converters find application in almost all fields of electrical utility from simple inverters and choppers to high speed electrical drives. Power electronic converters are sensitive to temperature and heat sink design for the switches is a very important factor in ensuring best performance. Due to the rising energy crisis, the utilization of renewable energy sources is of prime importance and performance of related converters should be improved so as to ensure maximum energy harnessing. Solar PV inverters may be subjected to various atmospheric conditions depending on the application [1-3].. hence the performance analysis at field conditions is required for effective design and utilization of such converters.

The effect of ambient temperature in the operation of Power MOSFETs can be explained based on the relationship between variation in conduction losses, internal parasitic parameters and junction temperature in MOSFETs and IGBTs [4-7]. By analyzing the heatsink design and heat flow equations, the relationship between switch losses and ambient temperature variations can be found [8-10]. Various studies have been conducted to study the effect of ambient temperature in various power electronic applications. Results with prominent effects in lower rating devices

This paper presents the effect of ambient temperature on the converter performance in an 850 VA Solar PV inverter. The theoretical explanation is given in section 3 and 4 followed by experimental evaluation in section 5 [12-13].

*Energy Efficiency and Renewable Enenrgy Division, Central Power Research Institute, Bangalore- 560080. E-mail: vani.cpri@gmail.com
**E&E Department, Manipal Institute of Technology, Manipal - 576104
***Diagnostics Cables and capacitors Division, Central Power Research Institute, Bangalore - 560080
****Energy Efficiency and Renewable Energy Division, Central Power Research Institute, Bangalore - 560080

The results are found to be matching pronouncing the effect of ambient temperature conditions in the performance of power electronic converters.

2.0 SOLAR PV INVERTERS

Solar PV inverters convert the DC input from solar panels to AC output for utility. They can be broadly classified as Standalone inverters, grid connected inverters and micro inverters. Even though term inverter implies DC-AC conversion, Solar PV inverters are incorporated with some other functions also according to the application. Stand alone inverters use DC power from Solar panel to charge battery.

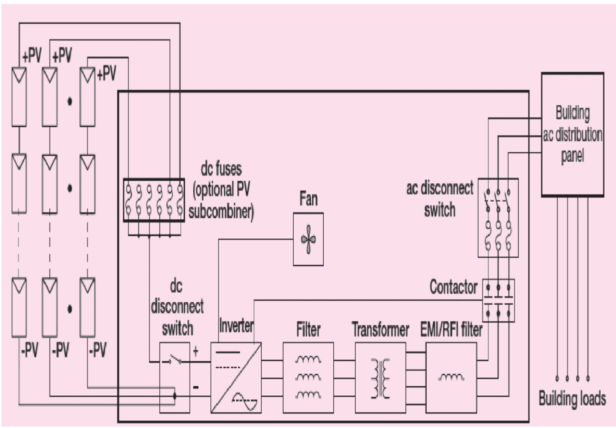

FIG. 1 STANDALONE SOLAR PV INVERTER SCHEMATIC

This is the converted to AC and directly used to supply the AC loads without any connection to the grid. So a DC-DC converter is incorporated along MPPT (Maximum Power Point Tracking) for optimum charging of the battery. In the case of grid connected inverter, the generated power is directly supplied to the grid without battery. Therefore here grid synchronization and islanding protection is required [1-2].

The power electronic switches which are the main components in this system, are designed with heat sinks in order to dissipate the heat due to conduction loss and switching losses. For higher rating inverters, cooling fans will be provided to ensure operating temperatures. The schematic diagram of a solar PV inverter is shown in Figure 1. Figure 2 shows typical input and output Voltage and current waveforms on an inverter under test. The input current is supposed to be pure DC but distortion is due to the converter operation [3].

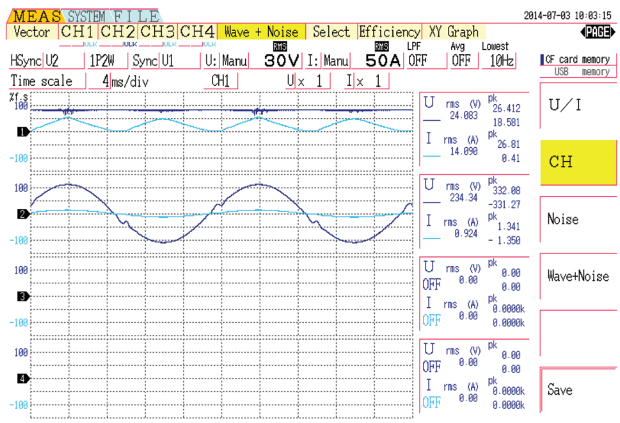

FIG. 2 STANDALONE SOLAR PV INVERTER WAVEFORMS

3.0 LOSSES IN POWER MOSFETS AND EFFECT OF TEMPERATURE

The losses in Power MOSFET are mainly of 3 types, that is conduction losses, Switching losses and blocking losses, out of which blocking losses which happen during off state are normally neglected.

3.1. Conduction Losses

Conduction loss is the most important loss in operation of power MOSFET. It depends mainly on the ON state drain-Source resistance RDSON. The voltage drop during conduction state is given by,

$$U_{DS}(i_D) = R_{DSON}(i_D).(i_D) \qquad ....(1)$$

Where, U_{DSON} and i_D are the drain source voltage and current respectively and R_{DSON} can be obtained from device datasheet. R_{DSON} is highly variable with respect to i_D and temperature, which can be obtained from MOSFET datasheet [4] [5].

Figure 3 shows typical RDS variation with respect to iD are various gate to source voltages.

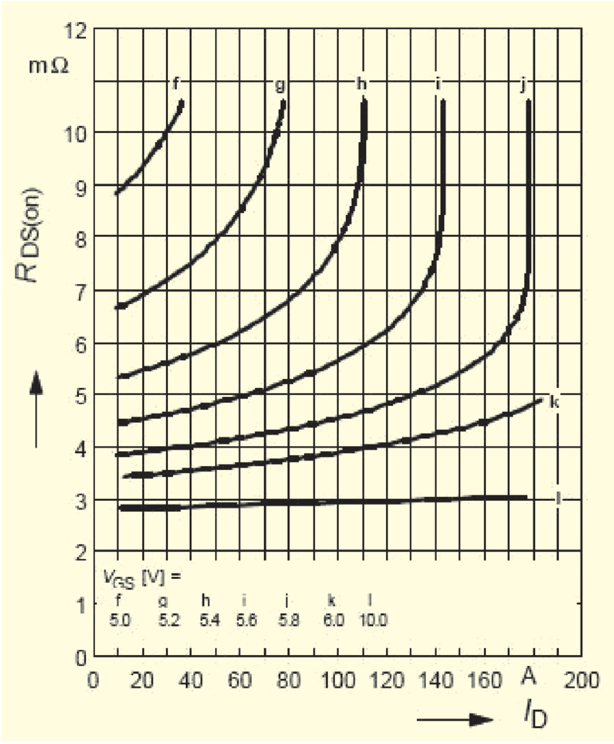

FIG. 3 VARIATION OF RDS ON WITH RESPECT TO CURRENT IDS

Instantaneous value of MOSFET conduction loss is given by,

$$P_{CM} = U_{DS}(t).i_D(t) = R_{DSON}.i_D^2(t) \qquad ....(2)$$

Integration over switching cycle gives conduction loss PCM

$$P_{CM} = \frac{1}{T_{sw}} \int P_{CM}(t)dt = R_{DSON}.I_{D\_rms}^2(t) \qquad ....(3)$$

Similarly average diode conduction loss is given by,

$$P_{CD} = R_{DSON}.I_{rms}^2(t) \qquad ....(4)$$

R_{DSON} varies extensively with temperature and proportionally the conduction losses also varies. The variation od R_{DSON} with temperature is shown in Figure 4. [6] [7]

The variation in R_{DSON} with respect to change in junction temperature is given by,

$$R_{DSON}(T_J) = R_{DSON\_MAX}(25^o)\left(1+\frac{\alpha}{100}\right) \qquad ....(5)$$

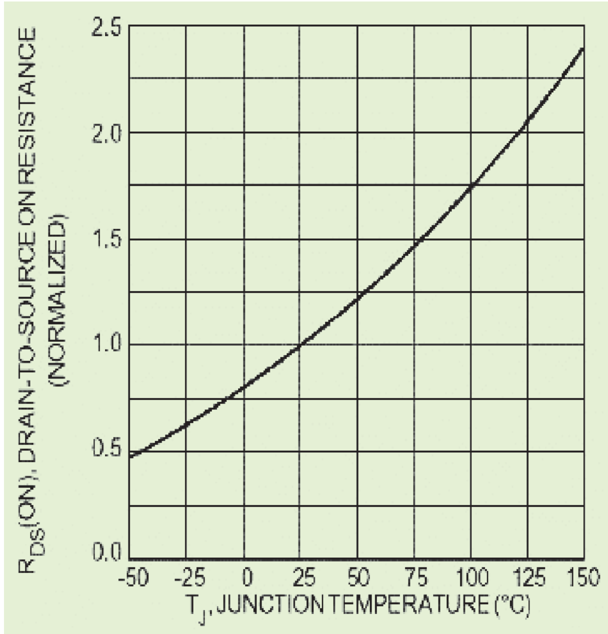

FIG. 4 VARIATION OF RDS ON WITH RESPECT TO JUNCTION TEMPERATURE

3.2. Switching Losses

Switching losses include energy loss during turn ON transient and turn OFF transients. These values depend mainly on the internal capacitance between drain-gate, drain-source and gate-source. When it comes to the effect of temperature, these capacitances are not much affected with the variation in temperature.

4.0. RELATION WITH AMBIENT TEMPERATURE

As discussed in previous section, the conduction losses depend on R_{DSON} which in turn depends on the temperature. Heat snks are to be designed so as to keep the MOSFEET temperature within tolerable limits. Heat sink is designed based on the maximum allowable junction temperature.

If θJA is the thermal resistance between MOSFET Junction and atmosphere, TJ is the junction temperature, TA is the ambient temperature and PD is the power dissipation.

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \qquad ....(6)$$

i.e. $$P_D = \frac{T_{JMAX} - T_A}{\theta_{JA}} \qquad ....(7)$$

Using different ambient temperature power dissipated can be calculated using θ_{JA} and T_{JMAX} from data sheet. From this, derating factor can be calculated. Ie, power dissipation per degree Celsius rise in temperature.

Therefore, junction temperature can be calculated as,

$$T_J = (\theta_{JA} x P_D) T_A \qquad ....(8)$$

Thermal resistance θ_{JA} can be considered to be θ_{JA} comprised of θ_{JC} between junction and and case and θ_{CA} between case and atmosphere.

Further when heat sink is used,

$$\theta_{CA} = \theta_{CS} + \theta_{SA} \qquad ....(9)$$

where, θ_{CS} is the thermal resistance between case and sink and θ_{SA} is the thermal resistance between sink and atmosphere [8] [9]

Thus,

$$\frac{T_J - T_A}{P_D} = \theta_{JC} + \theta_{CS} + \theta_{SA} \qquad ....(10)$$

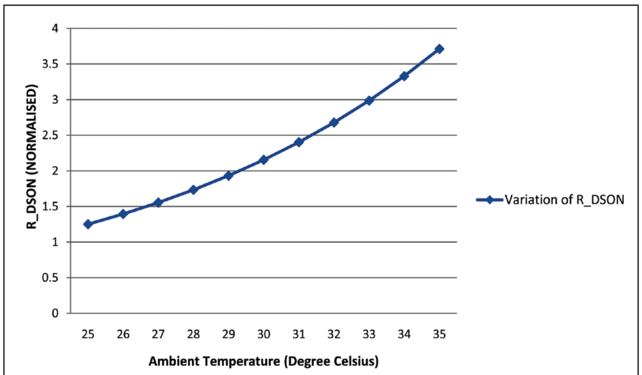

FIG. 5 INCREASE IN R_{DSON} WITH RESPECT TO AMBIENT TEMPERATURE

Heat sink is designed for a particular ambient temperature and thus heat dissipation varies with change in ambient temperature. Amount of heat removed from the junction decreases there by causing temperature rise resulting in increase in R_{DSON} as shown in Figure 6. It is calculated for 1 kW rated switch from temperatures 25° C to 35° C using constants from datasheet. Thus it can be seen that conduction losses increase resulting in reduced efficiency with rise in ambient temperature [10].

5.0. EXPERIMENTAL RESULTS

In order to substantiate the theoretical analysis given in section 3 and 4, an experimental analysis of inverter performance at different temperatures is conducted as per the schematic diagram shown in Figure 6.

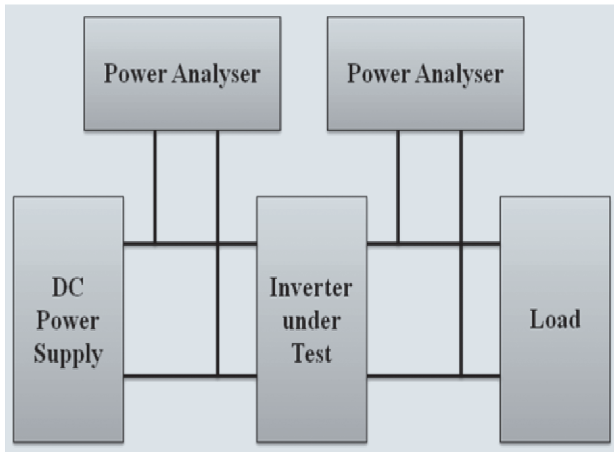

FIG. 6 EXPERIMENTAL SETUP TO ANALYSE THE EFFICIENCY OF SPV INVERTER

This test is conducted to study the variation under slight atmospheric temperature changes around standard value. Extreme conditions can be analysed using an environmental chamber to simulate very high and very low temperature and humidity in which the inverters may respond differently. IEC 60068-2 explains the requirements to test inverter under such conditions [10] [11].

The inverter under test is 850 VA , 24V DC input inverter. Rated Output is 220 V ± 2 % AC, 45-55 Hz. High precision power analyzers are used to obtain the input and output values as shown in Tables below.

TABLE 1

EXPERIMENTAL RESULTS AT 25° C

	AC SIDE			DC SIDE		
% load	Voltage, V	Voltage THD, %	Current, A	Current THD, %	Current, A	Efficiency, %
120	234	2.8	4.36	1.85	49.1	85.76
100	234.02	2.84	3.64	2.21	40.7	86.03
75	234.97	2.16	2.71	2.75	29.74	87.17
50	235.02	2.38	1.82	2.98	19.93	87.04
25	235.21	2.94	0.91	3.14	10.06	85.19
10	233.07	3.41	0.37	5.67	4.29	79.26

TABLE 2

EXPERIMENTAL RESULTS AT 35° C

	AC SIDE			DC SIDE		
% load	Voltage, V	Voltage THD, %	Current, A	Current THD, %	Current, A	Efficiency, %
1.2	233.28	3.93	4.37	1.92	52.84	80.09
1	234.40	4.07	3.62	2.18	42.96	81.80
0.75	234.70	4.16	2.71	2.69	31.96	82.48
0.5	234.94	4.33	1.83	3.95	22.09	80.37
0.25	234.71	3.87	0.90	7.48	11.35	77.01
0.1	235.49	2.50	0.36	14.36	5.64	62.03

Table 1 and Table 2 give the Voltage, current, THD and efficiency of the inverter at 25° C to 35° C respectively. It can be seen that Efficiency is reduced and THD in voltage and current has increased with increase in temperature. Figure 7 shows the comparison of inverter efficiencies at 25° C and 35° C and Figure 8 shows the comparison of losses. An average increase of 45W loss is found from 25° C and 35° C. The rate of increase is found to be proportional to the rate of increase of R_{DSON} with respect to ambient temperature as per Figure 5 multiplied by the square of average drain- Source current. Hence the theoretical explanation holds good.

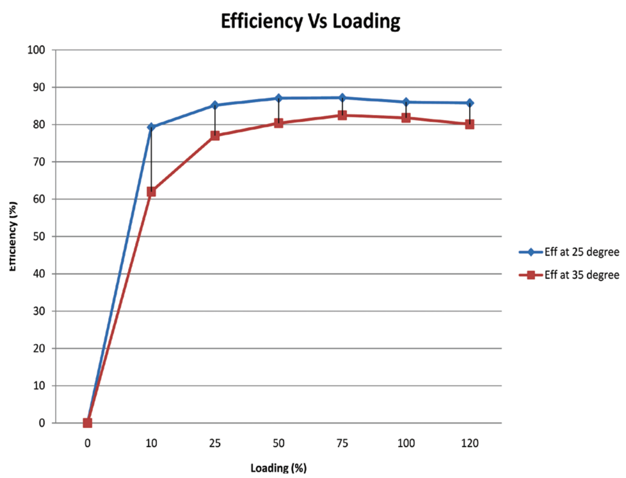

FIG. 7 EFFICIENCY COMPARISON AT 25° C AND 35° C

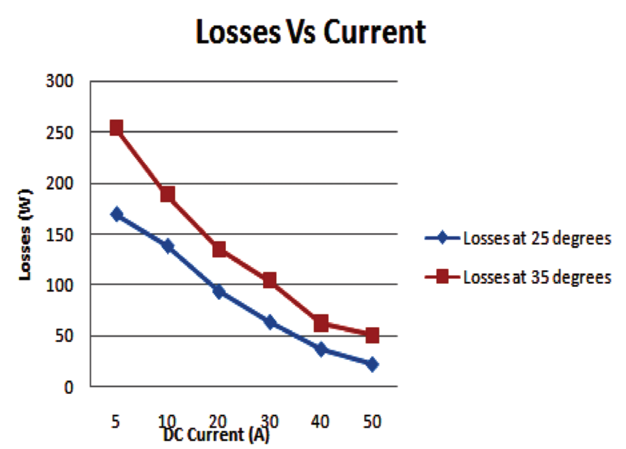

FIG. 8 INCREASE IN LOSSES WITH RESPECT TO INCREASE IN AMBIENT TEMPERATURE.

6.0 CONCLUSIONS

The performance of power electronic converters is highly dependent upon the junction temperature which is to be maintained below the maximum allowable value. The amount of heat removed from the junction depends on heat sink design and is related to the ambient temperature at which the equipment is working. The efficiency of the converter designed for 25° C ambient temperature is found to reduce at a higher temperature. This is due to the increase in conduction losses caused by rise in forward conduction resistance with increase in junction temperature. Hence power electronic equipments should be operated at the ambient temperature for which it is designed to obtain optimum performance.

7.0. ACKNOWLEDGEMENT

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