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Application Note AN-1040

System Simulation Using Power MOSFET Quasi-Dynamic Model

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The International Rectifier Automotive group explores the use of power MOSFET Quasi-Dynamic modeling of power MOSFETs and their effects on device thermal response. The simulation approach can show the system characteristics more accurately, so that the appropriate amounts of optimization can be designed into the system. Characterizing thermal performance is important, since Pspice and SABER device models display electrical behavior or physics modeling, and all parameters are considered thermally independent. This is not true in real system, because several key parameters change with temperature variation.

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APPLICATION NOTE

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System Simulation Using Power MOSFET Quasi-Dynamic Model

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Topics Covered

1. Objectives:

To examine the Quasi-Dynamic model of power MOSFET and its effects on device thermal response.

2.Introduction:

The design advantage of the simulation approach compared to analytic design is that it can reflect the system characteristics more accurately, for example: electric machine dynamic, parasitic parameters, MOSFET avalanche energy and switching loss. So it is more likely to have a suitable design basing on numerical analysis than analytic design using average method, which may end up with an over-designed system.

There are all kinds of Pspice and SABER device models on manufacture's websites. They provide great flexibility for circuit and system simulation, which can offer a good guidance for system design.

However, most of the MOSFET models are electrical behaviour or physics model. And all parameters are considered thermally independent. This is not true in real system, because several key parameters such as Rdson, Vth…would change following the temperature variation. So it wouldn't be appropriate to decouple the electrical and thermal design of a system. The thermal loop has to be closed in MOSFET level to reflect the device and system dynamics, which will improve the accuracy of the simulation and make the performance prediction reasonably close to the real system.

Several customers and manufactures are pushing for a more accurate dynamic MOSFET model and some results are available online. However, there are no widely accepted models and comprehensive device libraries in existance.

Various quasi-dynamic models have been published. This work builds on models originally proposed by Jim Bach of Delphi and published at the Saber Assure2000 users conference [1]. Dave Davins and John Ambrus at International Rectifier developed the quasi-dynamic model of IRF1404 as an example. In this study, the quasi-dynamic IRF1404 model is applied to an inverter system in a SABER environment to illustrate the advantage integrating thermal dynamics in a device electrical model. So this study is an extension of Dave and John's work.

3: Thermal Modelling:

Thermal Modelling means implementing thermal effects on device parameters. There are basically three levels of thermal modelling.

1: Static Thermal Model: Model equations are written such that during a simulation characteristics do not change as a function of temperature. However, temperature can be set to a value prior to a simulation and models, which have temperature dependency, will behave as if they are at the set temperature for the duration of simulation.

2: Quasi Dynamic Thermal Model: Model equations are written such that the temperature is calculated from the resulting power dissipation. However, the temperature does not effect any or some of model characteristics. Only the external connected components change with the temperature change.

3: Dynamic Thermal Model: Model equations are written such that during a simulation the characteristics of the model will change as the "self heating"

There are trade offs between using a dynamic and quasi-dynamic thermal models. Advantages for the quasi-dynamic approach are simulation speed and easy to create from any component, but the accuracy is lower than the dynamic model. On the other hand, it is harder to build the dynamic model because of the coding effort and simulation speed, which makes it the last choice for a designer to refine their design

The Quasi-Dynamic model of the IRF1404 is shown in Figure 1. The base model is the level 1 static model of the IRF1404 at 25°C. D_Rdson and D_Vt are external resistance and voltage source in serial with the device drain and gate pins respectively, which are temperature dependent and obtained from measurements.

Even though the idea of the quasi-dynamic model is simple, it can reflect the device thermal related behaviour more accurately through an iterative close loop process as shown in Figure 2. The device will finally work at the equilibrium point where the thermal effect and electrical response are balanced

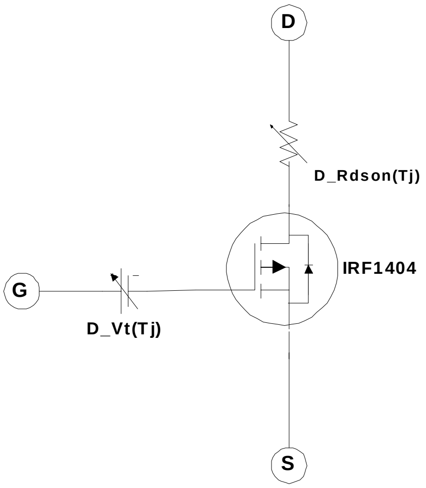

Figure 1: Quasi-Dynamic model of IRF1404

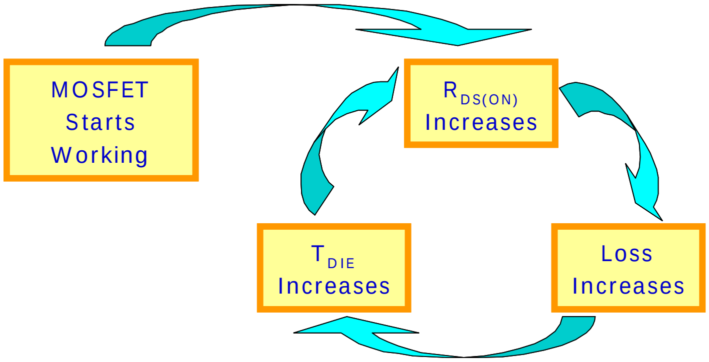

Figure 2: The self-heating process [1]

4. Simulation and Results:

A 14V ISA system is selected as a platform to illustrate the effect of the quasi-dynamic model of the IRF1404. As a starting point, three phase RL load is applied to simplify the analysis.

Both the static and quasi-dynamic models of the IRF1404 are employed in the system simulation. The MOSFET case temperature is fixed at 125^{o}C. In the case of the static model, the same thermal network as that in quasi-dynamic model is utilized to predict the junction temperature. The only difference is that its parameters are thermally independent.

The system schematic is in Figure 3 and Figure 4 shows the inverter circuit. In this study, each switch has one FET. The load is properly arranged to obtain the maximum datasheet current to the FET. This work can then be extended to multiple FETs per switch, which means multiple output power, and keeping each FET in the same maximum operating condition. The control of this inverter is six step drive. The operating frequency is 200Hz. The gate drive circuit is shown in Figure 5.

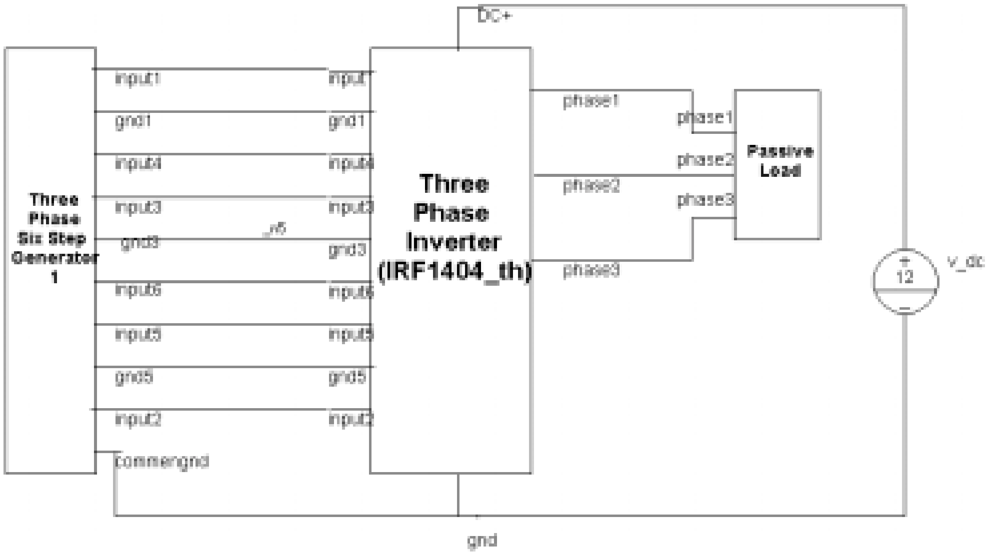

Figure 3: System Schematic

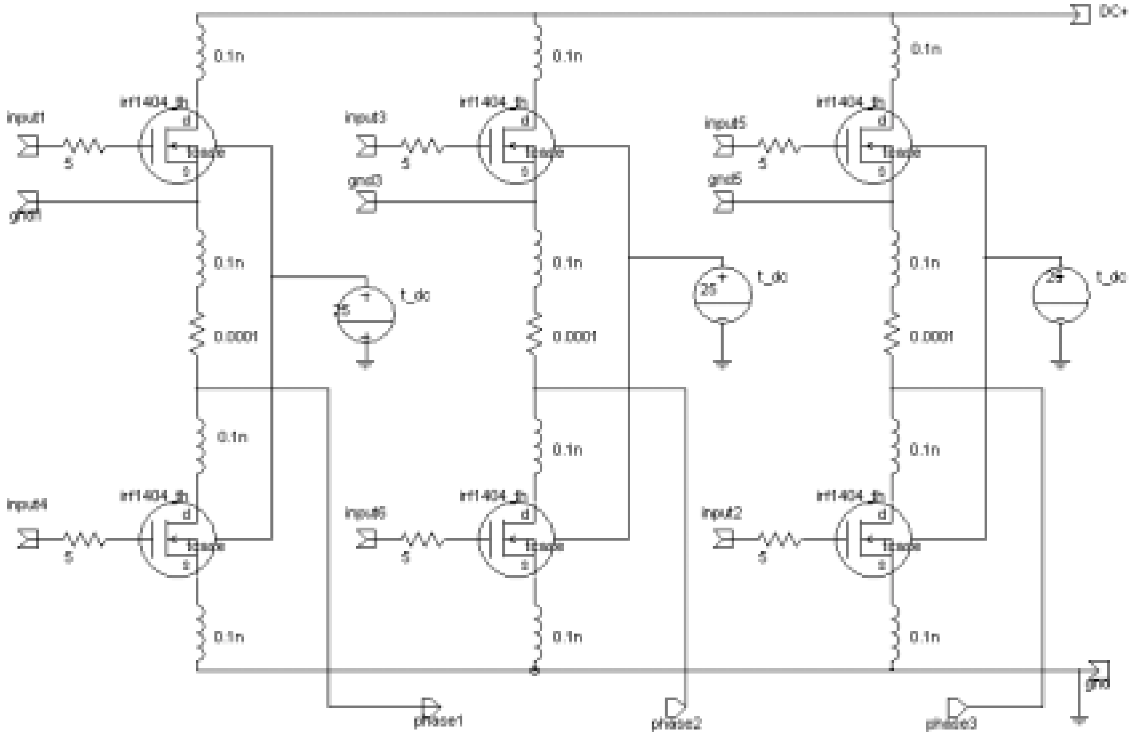

Figure 4: Inverter Circuit Schematic

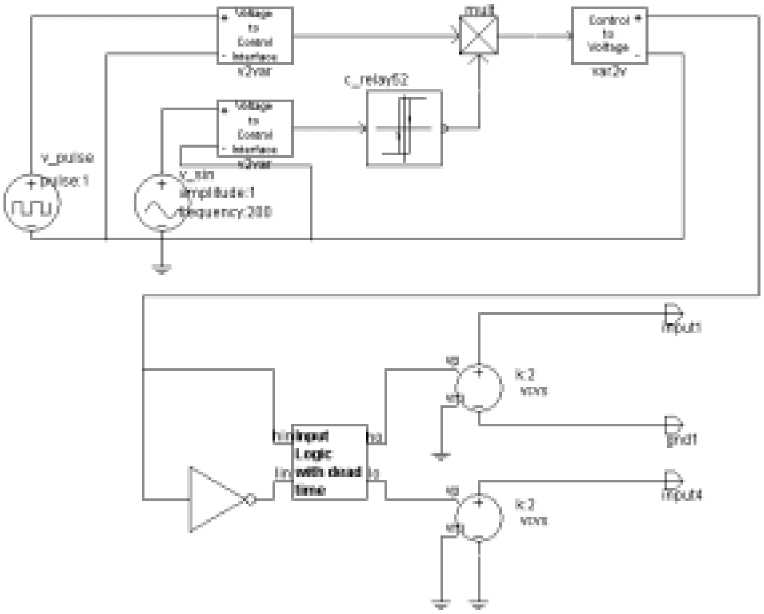

Figure 5: Gate drive circuit for one half-bridge

The three phase RL load is illustrated in Figure 6. The load is selected in order to pump 160amp peak (around 110 amp rms) through the MOSFET. This load current is close to the rated maximum continuous load current in IRF1404's datasheet. To avoid a numerical problem, a big resistor is connected from the neutral point to ground.

The simulated gate drive signals are shown in Figure 7. Note at the start of the simulation, all low side switches have to be turned on to set a valid initial condition. Otherwise, a numerical problem may occur. Load current and voltage are given in Figures 8, 9 and 10.

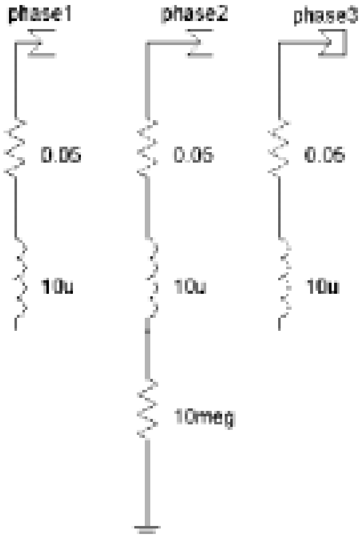

Figure 6: RL three phase load

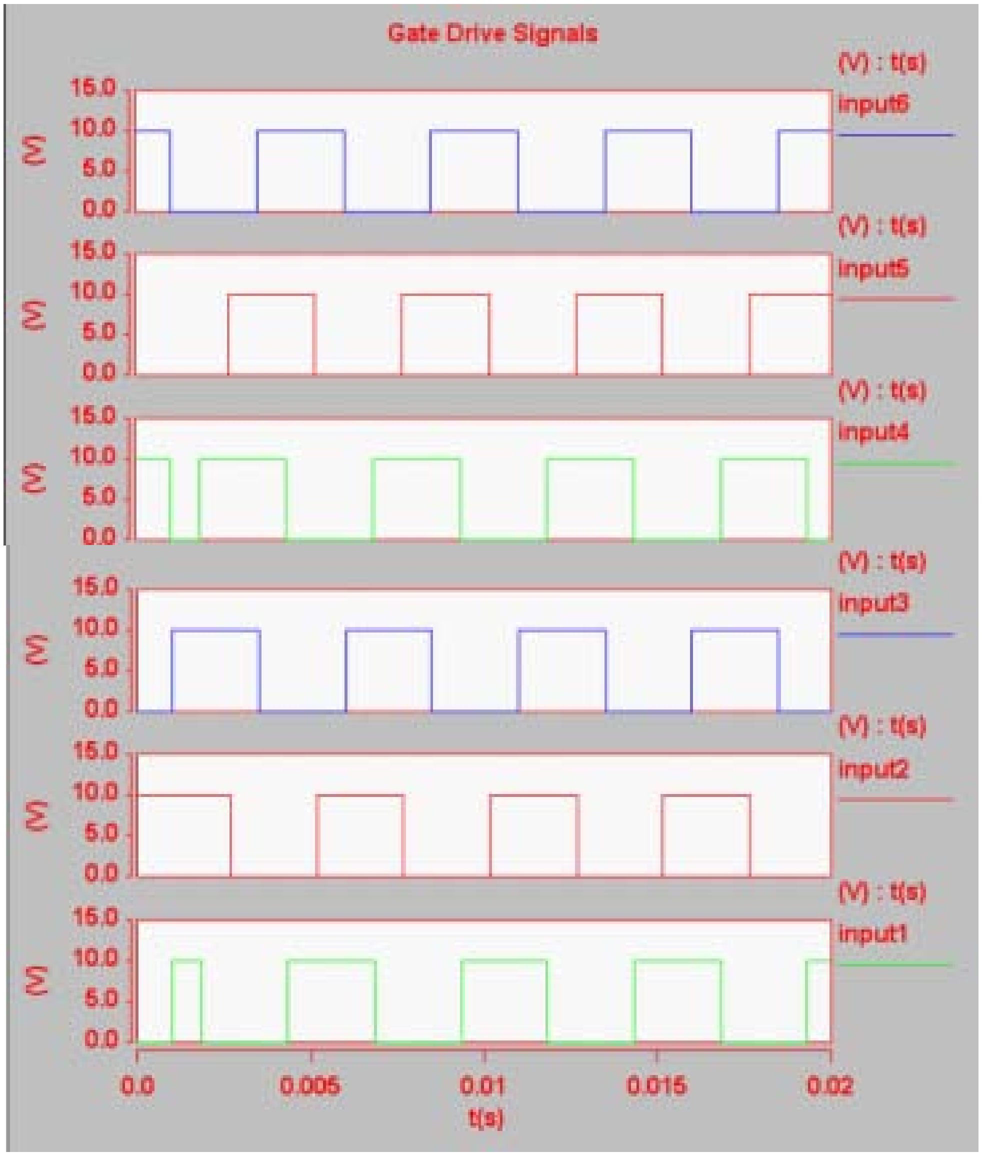

Figure 7: Gate drive signals

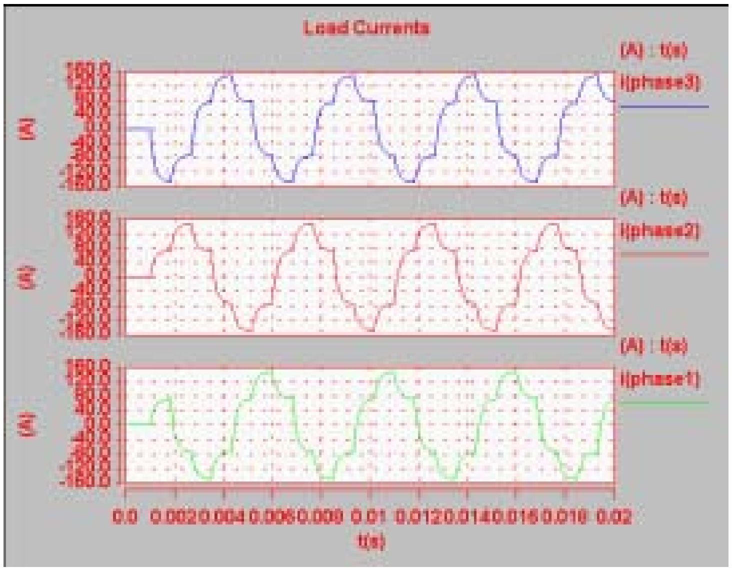

Figure 8: Three Phase Load Currents

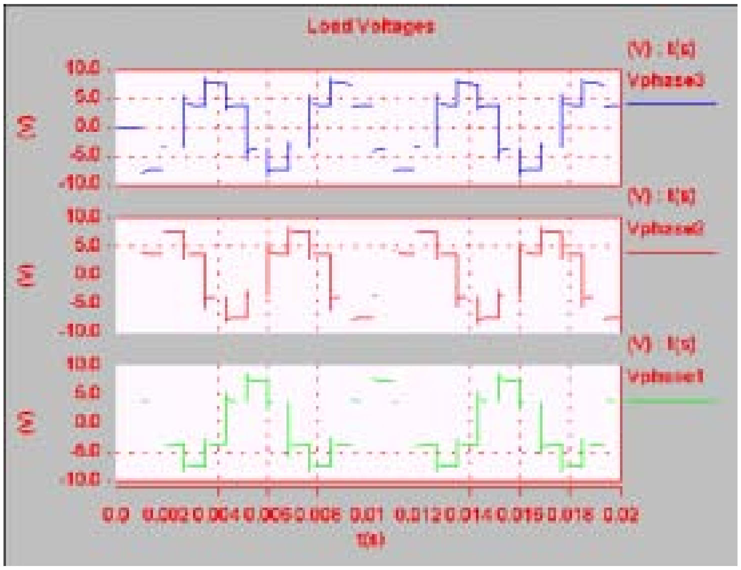

Figure 9: Three Phase Voltages

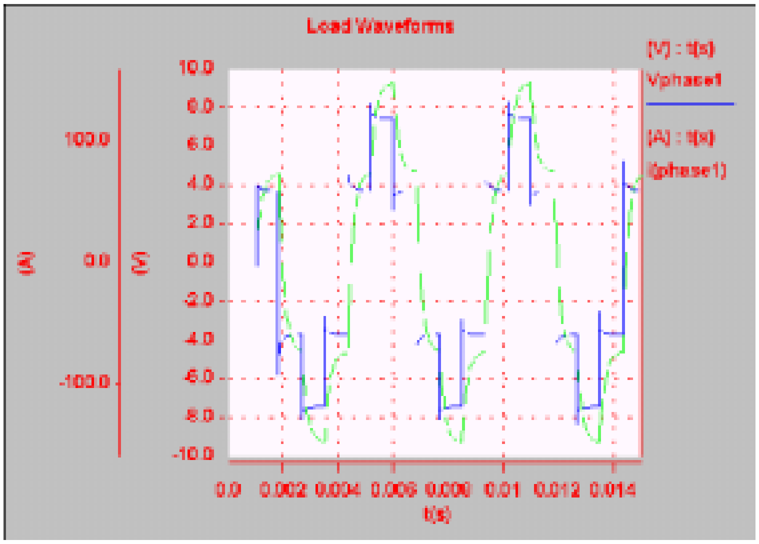

Figure 10: Current and voltage of one phase

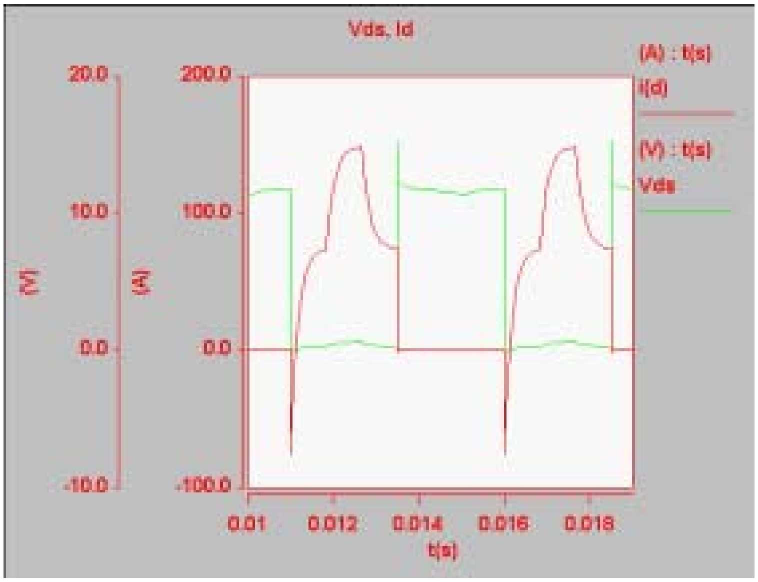

Figure 11: Vds and Id of one MOSFET

MOSFET Vds and Id are shown in Figure 11. When the FET turns on, load current already flows through its body diode because of the commutation. Therefore, the MOSFET works at synchronous mode. Load current goes through source to drain. No turn-on loss for the FET. After the current becomes positive (from drain to source), the MOSFET works in normal conduction mode

Because the switching frequency in this application is only 200Hz, the conduction loss dominates the total FET loss. The thermal dependent Rdson will change with the device junction temperature, which in turn will cause different conduction loss. Figure 12 shows the loss difference between static and quasi-dynamic models.

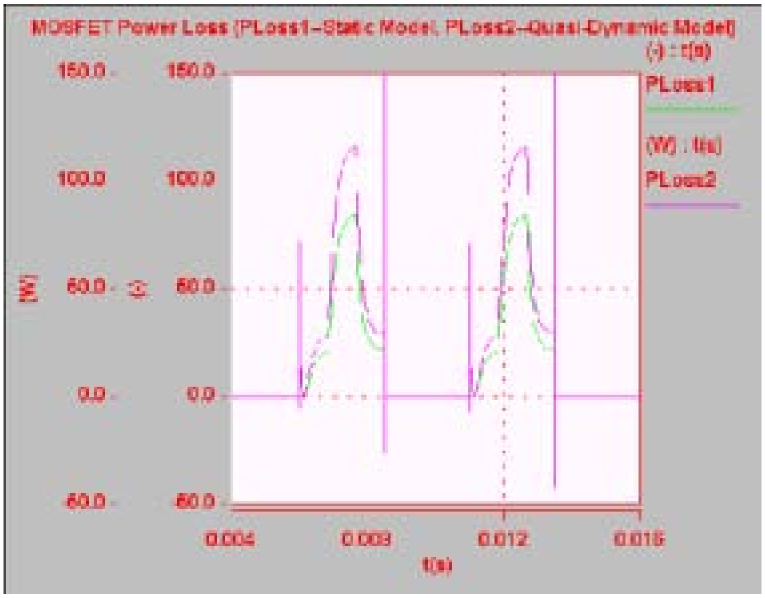

Figure 12: MOSFET Power Loss

Figure 13 shows the predicted junction temperatures for both static and quasi-dynamic models. The peak ΔT is 14^{o}C in the quasi-dynamic case, compared to 10^{o}C in static case.The difference is 40%

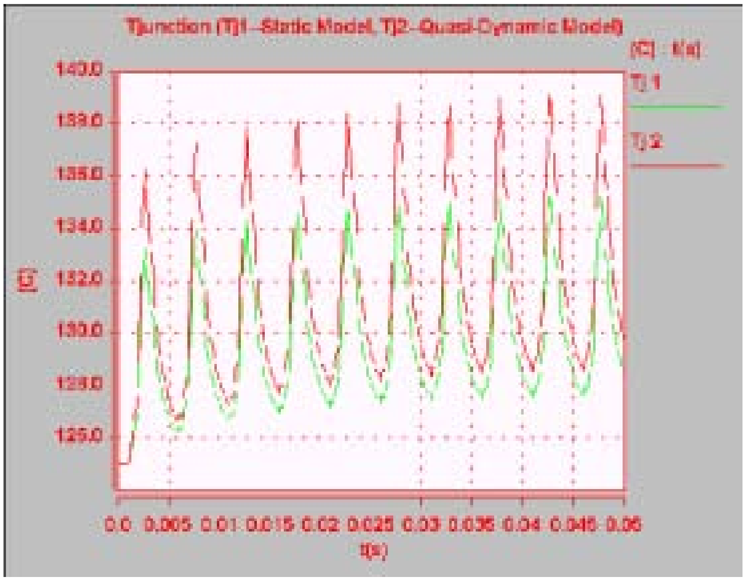

Figure 13: Device Junction Temperature

In Figure 14, the peak Δ Rdson is 1.8mΩ, which is 45% increase compared to the datasheet Rdson rating 4mΩ. The difference can be from the load current change, because the Rdson change is 3% of the load resistance 60mΩ, which would cause a smaller load current. The decrease of the current and the increase of the Rdson generate the final temperature variation.

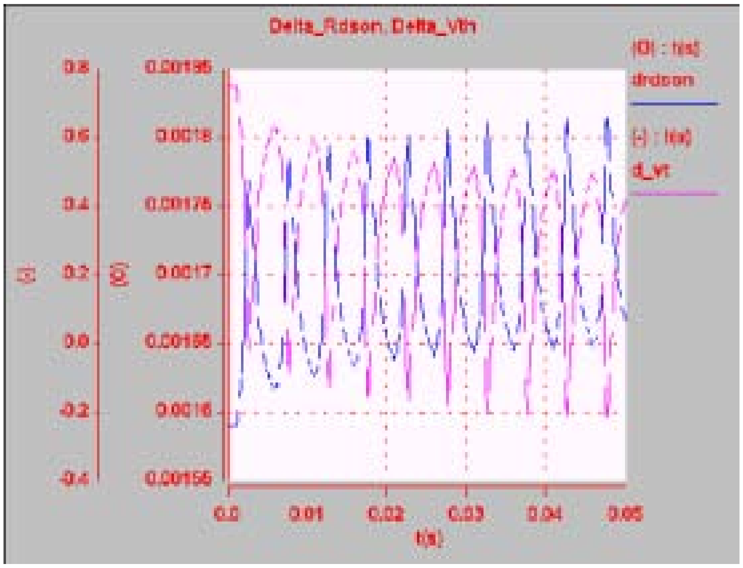

Figure 14: Rdson and Vt variation

5: Conclusion and Discussion:

1: The Quasi-dynamic MOSFET model can help predict the junction temperature, coupling the thermal and system dynamics.
2: The predicted junction temperature by quasi-dynamic model and static model has big difference.
3: Compared to analytic design, this numerical approach can easily integrate electric machine, parasitic parameters and control schemes, which can reflect whole system performance.
4: Some device characteristics such as avalanche energy, switching loss are circuit related, which can be easily examined through simulation.

References:

[1] James C. Bach, “Developement of an Electro-Thermal Power MOSFET Macro-Model”, Saber Assure2000 users conference, May 10-12, 2000

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