Power Semiconductors

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Abstract: The objective of this paper is present the data requirements for modeling power electronic devices to aid in modeling power converters for transient simulation studies. The presentation will target applications of power semiconductor devices commonly used in medium to high power applications: insulated gate bipolar transistors (IGBTs), Thyristors (SCR), and Gate Turn-Off Thyristors (GTOs) and power diodes. The intended audience is power engineers modeling converters for transient simulations rather more than converter designers. Low power, single-phase loads are beyond the scope of the presentation.

Keywords: Power Electronics, Transient Simulation

I. INTRODUCTION

Power converters are used in many applications in power systems, both in the power delivery system and as part of the end use applications. Power delivery applications include HVdc transmission, flexible ac transmission system (FACTS) devices at the transmission level and Custom Power devices at the distribution level. Many distributed generation and storage devices also incorporate power electronic interfaces. Load-based applications include motor drives, and reactive compensators.

Models of the power converters and their control systems are needed with the appropriate degree of detail for performing transient simulations. Power electronic devices introduce non-linearities to the computer simulation. Representing this non-linear behavior in sufficient detail to produce results with the desired degree of accuracy represents a significant challenge. In many cases, approximations in the converter modeling can be made without impacting accuracy too significantly. In other cases, more exact detail is needed. Also in some situations, data sufficient to model the power semiconductor devices and related components is lacking. This could result from using a converter built and installed by another party who prefers you to view it as a "black box."

Different models for power converters and the power electronic devices will be presented along with guidelines for when different levels of modeling should be used will be presented. A description of detailed device models will be presented. This will be followed by a discussion on where to get appropriate device data for different levels of modeling and how to convert it for use in the device models.

II. CONVERTER MODELS:

Averaged Models

For many studies, averaged or steady state models of the converters can be used. The power semiconductor devices are not modeled in these studies, although the internal device characteristics can be incorporated into the model. Instead an averaged behavior for the converter based on terminal characteristics is developed. The converter is often represented as either a dependent current source or a dependent voltage source. These models are typically used for steady-state operation points and to study the response of slower converter control schemes.

Switching Models

The degree of detail in the converter model often depends on the relationship between frequency of interest in the simulation results and the switching speeds in the converter. If the dynamic or transient response of the converter is required, a converter model that represents the switching of the power electronic devices is used. The control model now must include gating circuits and the sychronization scheme. In some cases a model of the snubber circuits is also appropriate, in other cases the snubber circuit can be ignored. In some cases the converter can be reduced to a simpler equivalent. For example, a HVdc converter could have 50 or 60 thyristors connected in series, but a model including one thyristor may be equivalent.

III. SWITCH MODELING

A. *Ideal Device Models*

Converter terminal characteristics are often sufficient for many simulations involving power converters. In such cases, it could be appropriate to model series and parallel connected power electronic devices as one or two equivalent devices. Or a 48-pulse voltage source converter could be represented with a simpler, lower pulse order model if response is sufficient.

In addition, if the converter is connected to a system where the time scales of the dynamic response of interest are very long compared to the device turn-on and turn-off times, ideal switch models can be used. In this case, the power electronic device is assumed to open or close in one time-step as the simulation progresses (or essentially instantly as far as the external system is concerned).

B. *Detailed Device Models*

More detailed device models are needed in other circumstances, generally in cases where the transient response of the converter and the immediate converter subsystems are of interest. Examples of situations where more detailed switch models are needed include:

- Studies for switching and conduction loss prediction
- Simulations to evaluate voltage and current stresses on the power electronic devices

- Simulations to study voltage stresses seen by rotating machines or transformers fed by the transformer.
- Electromagnetic interference studies

In such cases, a more accurate device model that includes turn-on/turn-off behavior as well as conduction behavior when the device is on or off are needed. In addition, if one is going to the effort to model the characteristics of the switching devices, need more detail in other aspects of the switching circuit is needed, including: parasitic inductances and resistance in the wiring, snubber circuit characteristics, and accurate gate circuit models.

IV POWER SEMICONDUCTOR DEVICES

The following power semiconductor devices are most common in power system simulations: power diodes, thyristors, gate turn off (GTO) thyristors, insulated gate bipolar transistors (IGBT), and in the near future gate commutated thyristors (GCT) and MOS-controlled thyristors (MCT) may see increased use.

Each of the types of devices listed above has specific turn-on and turn-off characteristics that are visible in the voltage and current characteristics. In addition, each will have conduction losses while the device is turned on. In some devices, the conduction losses are best modeled as a steady-state voltage drop, in others it appears more as a somewhat non-linear temperature dependent resistance.

Models representing these characteristics can be added to emtp-like programs. However, some degree of approximation will be necessary in most cases. In some cases resistances, inductances and dependent voltage sources are sufficient, in other cases equations describing the behavior are developed and used to create devices to include in the circuit.

VI. GATHERING MODEL DATA

The first step is to determine the level of detail needed for the simulation studies to be performed. For studies of the impact of the power converter on real or reactive power flows, voltage magnitude control, or motor control ideal device models are often sufficient. In such studies, choosing the appropriate converter topology and control scheme to model is the main concern. Emtp-like programs have built-in switch models adequate to represent diodes, thyristors, and self-commutating devices such as IGBTs, GTOs, and GCTs.

If studies requiring detailed converter and device models are required, obtaining device data can be more difficult. Simulations conducted by the parties designing and building the converter can be conducted with knowledge of the specific devices used, and values of resistance, inductance and capacitance for the passive components in the circuit. The main source of data will be the manufacturers specification sheets for the devices. Tabular data will be available describing turn-on and turn-off behavior and on-state conduction behavior. The turn-on and turn-off characteristics are generally approximated with piecewise linear approximations of the curves or with equation models. It will also be necessary to include the external snubber circuits, and any circuits to control voltage sharing in series connected devices and current sharing in parallel connected devices.

Access to the data necessary to model the power converters for detailed transient simulations can be difficult to obtain for parties without access to the details of the converter topology and design. However, the device data may be easier to determine than the details of the control scheme. In some cases, the devices themselves are visible in the package or on design drawings. Then model data can again be determined by looking at the device manufacturer's specifications. However, data on the resistances, inductances, and capacitances may be more difficult to obtain without contacting the converter manufacturer. Approximations can be made, but be aware, that these values can have a significant impact on voltage and current stresses seen by the devices and external circuit.

If the device data is lacking, it may be possible to develop a reasonable approximation based on converter voltage and current ratings. With this knowledge, one can estimate the voltage and current ratings of the devices used and look up the specifications for similar devices. Be aware that this approximation can lead to significant error.

VIII. REFERENCES

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