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Performance Analysis of Power Devices

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The increasing focus on electrification for a cleaner environment has fueled the need for electric power in different forms. Power electronics is the branch of electrical engineering that deals with the processing of high voltages and currents to deliver power that supports a variety of needs. From household electronics to equipment in space applications, these areas all need stable and reliable electric power with the desired specifications. Power supply in one form is processed using power semiconductor switches and control mechanisms to another form, supplying a regulated and controlled power. While switched-mode power supplies are a common application of power electronics where power density, reliability, and efficiency are of prime importance, motor control is gearing up with more electrification in transportation systems. Precise control and efficiency are key characteristics for power control applications. The study of power electronics is thus multidisciplinary, involving semiconductor physics, electrical motors, mechanical actuators, electromagnetic devices, control systems, and so on.

In power generation, especially in renewable energy, the generated power must be processed to meet the AC voltage specification of the power grid. For instance, a solar cell generates DC power whose output power varies with the operating voltage and incident solar irradiation. It is important to extract the maximum power available at the output of the cell and transfer it to the grid with the highest possible efficiency. So, the interface that connects the solar cell to the grid should provide AC power that matches the grid specifications and draws input power that operates the solar cell at its maximum power point. In addition to this, the conversion of this DC power to AC power should be with higher efficiency to minimize the losses in power generation. This is possible using power semiconductor devices with advanced control mechanisms that monitor the output and input parameters and control the switches.

Advancements in power semiconductor devices have paved the path for newer devices such as silicon carbide, gallium nitride field effect transistors (FETs), and power diodes. These devices have superior characteristics in terms of wide band gap that allows for high-voltage operation, thermal management, and efficiency. This has resulted in widespread usage of power electronics even in noise-sensitive areas, replacing the lossy linear power supplies and voltage regulators. The main advantage of these devices is that they can withstand high voltage when compared to the silicon devices. Thus, the systems can be designed with high-voltage capabilities, which, in turn, reduces the current and improves efficiency, for the same power to be delivered. In addition to this, operating the devices at higher switching frequencies helps in reducing the size of passive components, making the systems compact. The ability to handle higher temperatures simplifies thermal designs.

How Do Power Electronics Work?

Power electronic systems are used in a variety of applications, such as:

- Power Generation
- Power Transmission
- Power Distribution
- Power Control

In all these applications, the input voltages and currents are switched using power semiconductor devices to provide desired outputs. The construction of basic semiconductor devices such as diodes, FETs, and bipolar junction transistors (BJTs) are altered to withstand high voltages and currents. As a result, we have silicon-controlled thyristors (SCRs), power diodes, power metal oxide semiconductor field effect transistors (MOSFETs), power BJTs, insulated gate bipolar transistors (IGBTs), gate turn-off thyristors (GTOs), and so on. The device selection is based on the power levels, the switching frequency requirements, efficiency, and the nature of inputs and outputs. For instance, in an EV powertrain, the power handled is of the order of kW. In such applications, power MOSFETs which can withstand the high voltage and switch at higher frequencies are commonly used. In the case of power transmission, where the handled power is of the order of few megawatts, silicon-controlled rectifiers (SCRs) are used.

The block diagram of a typical power electronic system is shown in the figure below.

Click to see the detail The primary element in a power electronic system is a switching power converter. The power converter consists of power semiconductor devices that are turned on and off at high frequencies. This operation switches the voltage and current through the devices, delivering a controlled power at the output. In addition to this, the power drawn from the input can also be controlled. An ideal device switches the voltage and current instantaneously and offers zero resistance once turned on and infinite resistance when turned off. But in the real world, no device can be switched instantaneously. The switching converters are associated with two types of power losses in the devices: Switching Losses Conduction Losses

The switching losses occur during turn on and off. For instance, when a switch turns on, the voltage across the switch goes to a low value from the voltage that was being blocked when it was in the off state. At the same time, the current through the device goes from zero to the load current level. Since this process takes finite time and the voltage and current are transitioning, power loss takes place. The transition is reversed when the switch is turning off. These losses constitute the switching losses. The switching losses increase with the switching frequency. To minimize these losses, several methods, such as zero voltage switching and zero current switching, are implemented using additional capacitors and inductors.

Conduction losses are a result of the finite on-state voltage drop across the switches during conduction. Availability of newer semiconductor devices and advancements in device structures are helping to reduce the conduction losses.

To control the switches, a control circuit, commonly known as a compensation circuit, is used. This block plays a pivotal role in minimizing the losses, delivering power efficiently and with good quality. The control block gets the reference and feedback signals as input and gives switching signals as outputs. Present-day controllers are mostly digital where the feedback is converted from an analog to digital signal and input to a signal processor. Compensation logic is implemented in the software that runs on the processor, and appropriate switching signals are generated. These signals are passed through drivers to provide sufficient power to drive the switching devices. Traditionally, analog circuits using operational amplifiers and comparators are used in compensation circuits. While providing appropriate gating signals to the switches, the control circuits also monitor the health of the system and inhibit the power output when faults occur.

Types of Power Electronic Circuits

As mentioned in the previous sections, power electronic circuits control the input and output power. There are several types of power converters based on the type of application. When we consider the power source, there are two main types of power sources, namely alternating current (AC) and direct current (DC). This forms four basic types of power electronics circuits shown in the figure below. .

1. AC-to-DC Converters

The input AC voltage is converted to DC voltage at required levels. A diode bridge rectifier is traditionally used for these applications. But this configuration results in currents that have high peak values and high harmonic content. Boost converters are commonly used to draw currents that are in phase with the AC voltage.

2. DC-to-DC Converters

The DC power input, whether unregulated or regulated, is converted to regulated DC power at the output. Without power electronic converters, it is very difficult to generate variable DC power. With the availability of different configurations of DC-to-DC converters, DC power at desired levels has become indispensable. Buck, boost, and buck-boost converters are three basic converters that can step down, step up, and provide both levels, respectively.

3. DC-to-AC Converters (commonly known as inverters)

The input DC power from batteries is inverted to provide AC power. This AC power is used to control AC motors with precision and efficiency. A combination of AC-to-DC and DC-to-AC converters are used in high-power transmission where two different grids are connected without worrying about synchronization.

4. AC-to-AC Converters (commonly known as cycloconverters)

The AC input that has a variable magnitude and frequency is processed to provide an AC output that has both regulated magnitude and frequency. Wind power generation is a popular application of these types of converters. The output of the wind generator varies in both magnitude and frequency depending on the wind speed. To connect this power to the grid or a load, the voltage and frequency need regulation. This functionality is provided by the AC-to-AC converters.

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