Power Electronics

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About the Tutorial

Power Electronics refers to an interdisciplinary subject within electrical engineering that deals with the design, control and conversion of power in its electric form. A system that converts electric energy to an electric load through a control circuit is known as a **Power Electronic System.**

The purpose of this tutorial is to introduce and explain the main concepts in Power Electronics, which include Power Semi-Conductor Devices, Phase-Controlled Converters, DC to DC Converter, Inverters and AC to AC Converters.

Audience

The target of this tutorial is electrical engineering students. It is a good resource to help them gain knowledge on electronics and circuits as applied in power electronics.

Prerequisites

This tutorial is meant for novice readers. Almost anyone with a basic knowledge of electronics can make the most of this tutorial. It is difficult to avoid complex mathematics at some places, although we have tried to keep it at a minimum level. Therefore it is expected that the readers are comfortable with mathematical equations.

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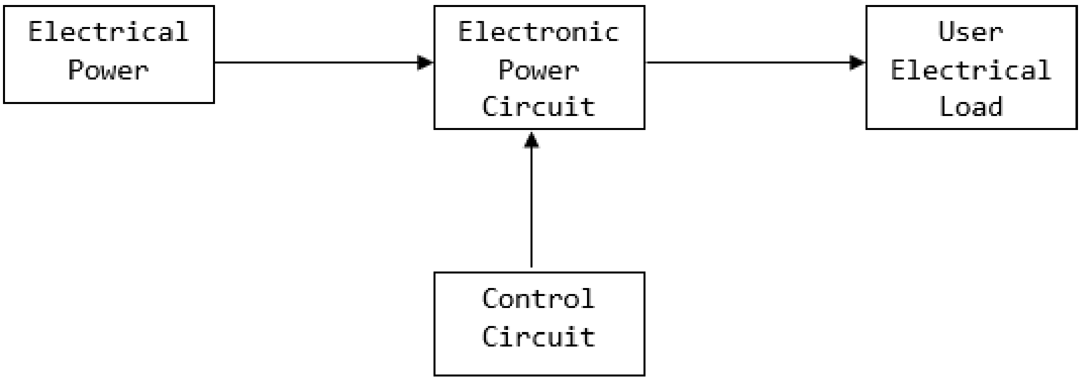
Unit 1: Basics

1. Power Electronics – Introduction

Power Electronics refers to the process of controlling the flow of current and voltage and converting it to a form that is suitable for user loads. The most desirable power electronic system is one whose efficiency and reliability is 100%.

Take a look at the following block diagram. It shows the components of a Power Electronic system and how they are interlinked.



A power electronic system converts electrical energy from one form to another and ensures the following is achieved-

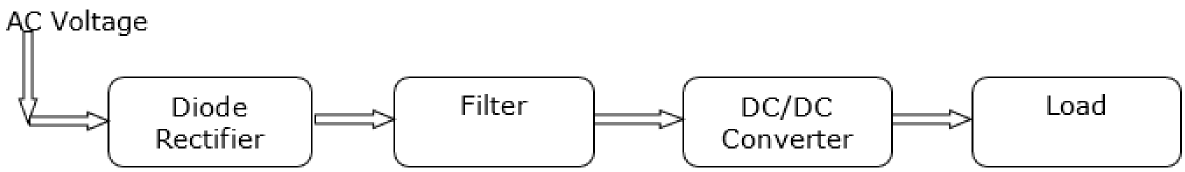
- Maximum efficiency
- Maximum reliability
- Maximum availability
- Minimum cost
- Least weight
- Small size

Applications of Power Electronics are classified into two types: Static Applications and Drive Applications.

Static Applications

This utilizes moving and/or rotating mechanical parts such as welding, heating, cooling, and electro-plating and DC power.

DC Power Supply

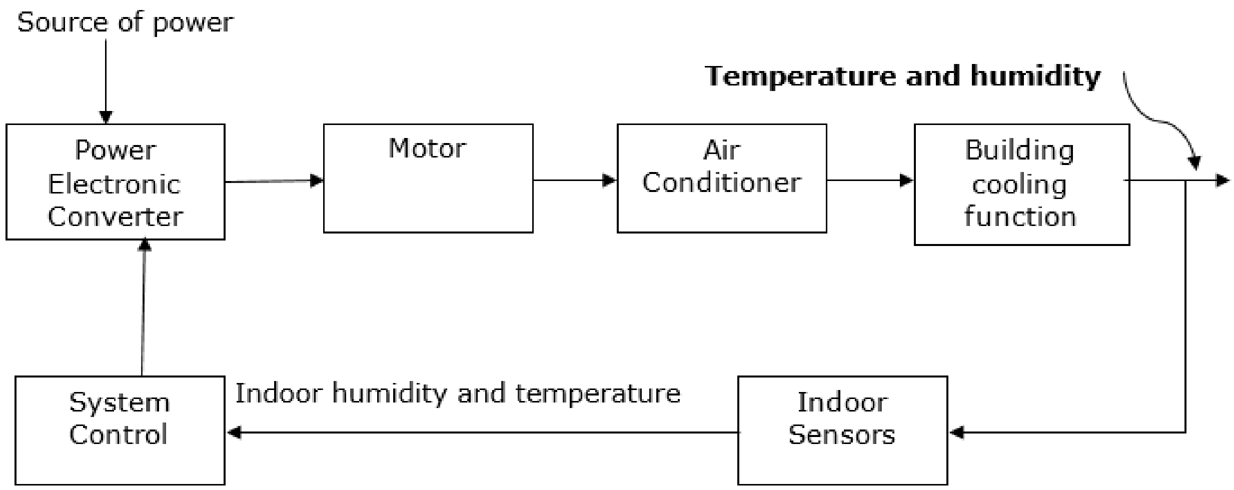


Drive Applications

Drive applications have rotating parts such as motors. Examples include compressors, pumps, conveyer belts and air conditioning systems.

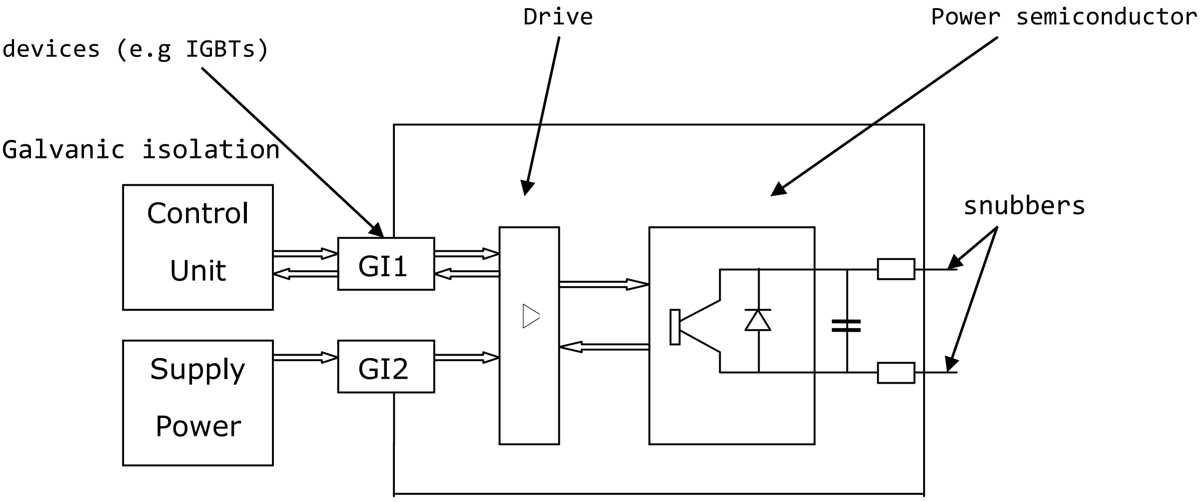
Air Conditioning System

Power electronics is extensively used in air conditioners to control elements such as compressors. A schematic diagram that shows how power electronics is used in air conditioners is shown below.



2. Power Electronics – Switching Devices

A power electronic switching device is a combination of active switchable power semiconductor drivers that have been integrated into one. The main characteristics of the switch are determined by internal correlation of functions and interactions of its integrated system. The figure given below shows how a power electronic switch system works.



The external circuit of the above diagram is usually held at a high potential relative to the control unit. Inductive transmitters are used to support the required potential difference between the two interfaces.

Power switching devices are normally selected based on the rating at which they handle power, that is, the product of their current and voltage rating instead of their power dissipation rate. Consequently, the major attractive feature in a power electronic switch is its capability to dissipate low or almost no power. As a result, the electronic switch able to achieve a low and continuous surge of power.

3. Power Electronics – Linear Circuit Elements

Linear circuit elements refer to the components in an electrical circuit that exhibit a linear relationship between the current input and the voltage output. Examples of elements with linear circuits include;

- Resistors
- Capacitors
- Inductors
- Transformers

To get a better understanding of linear circuit elements, an analysis of resistor elements is necessary.

Resistors

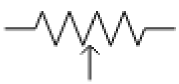
A resistor is a device in which the flow of an electric current is restricted resulting in an energy conversion. For example, when electricity flows through a light bulb, the electricity is converted into a different form of energy such as heat and/or light. The resistance of an element is measured in ohms (Ω).

The measure of resistance in a given circuit is given by:

$$\boldsymbol{R = \rho \frac{L}{A}}$$

Where **R** - resistance; **ρ** – resistivity; **L** - length of wire; and **A** - cross-sectional area of wire

Symbol of Various Resistors

Resistor	
A variable resistor	
A potentiometer	

Capacitors

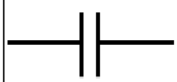
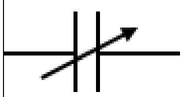
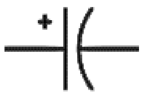
A capacitor refers to an electrical device that has two conducting materials (also known as plates) separated by an insulator known as a dielectric. It uses electric field to store electric energy. The electric field is developed when the capacitor is connected to a battery, thus making positive electric charges accumulate on one plate and negative electric charges on the other plate.

When energy is stored in the electrical field of a capacitor, the process is called charging, and when energy is removed, the process is called discharging. The level of electrical energy stored in a capacitor is called capacitance and is measured in farads (F). One farad is the same as one coulomb per unit volt given by 1 C/V.

The difference between a capacitor and a battery is that a capacitor stores electrical energy while a battery stores chemical energy and releases the energy at a slow rate.

Symbol of Various Capacitors

The various symbols of a capacitor are given in the table below.

Fixed Capacitor	
Variable Capacitor	
Polarized Capacitor	

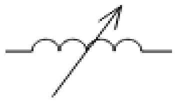
Inductors

Inductors are electronic devices that use magnetic field to store electric energy. The simplest form of an inductor is a coil or a wire in loop form where the inductance is directly proportional to the number of loops in the wire. In addition, the inductance depends on the type of material in the wire and the radius of the loop.

Given a certain number of turns and radius size, only the air core can result in the least inductance. The dielectric materials, which serve the same purpose as air include wood, glass, and plastic. These materials help in the process of winding the inductor. The shape of the windings (donut shape) as well as ferromagnetic substances, for example, iron increase the total inductance.

The amount of energy that an inductor can store is known as inductance. It is measured in Henry (H).

Symbol of Various Inductors

Fixed inductor	
Variable inductor	

Transformers

This refers to a device that alters energy from one level to another through a process known as electromagnetic induction. It is usually used to raise or lower AC voltages in applications utilizing electric power.

When the current on the primary side of the transformer is varied, a varied magnetic flux is created on its core, which spreads out to the secondary windings of the transformer in form of magnetic fields.

The operation principle of a transformer relies on Faraday's law of electromagnetic induction. The law states that the rate of change of the flux linking with respect to time is directly related to the EMF induced in a conductor.

A transformer has three main parts;

- Primary winding
- Magnetic core
- Secondary winding

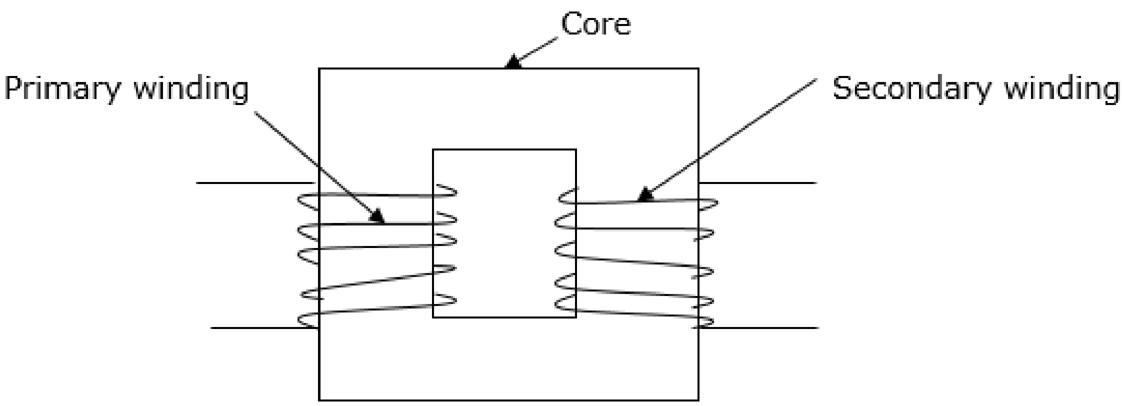
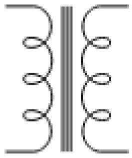


Figure: Schematic of a transformer

Symbol of a Transformer



Additional Devices

Electromagnetic Devices

The concept of electromagnetism is widely used in technology and it is applied in motors, generators and electric bells. For example, in a doorbell, the electromagnetic component attracts a clapper that hits the bell and causes it to ring.

Controllers

Controllers are devices that receive electronic signals transferred from a measured variable in a process and compare the value obtained with a set point of control. It utilizes digital algorithms to correlate and compare functions.

Sensors

Sensors are used to determine current, which constantly varies to provide feedback for purposes of control. Sensing current makes it possible to achieve a smooth and accurate converter function. Current sensors are critical in converters such that the information in parallel or multiphase converters is easily shared.

Filters

Electronic filters are also used to carry out processing of signals to remove undesired frequencies. They are analog circuits and exist in either active or passive state.

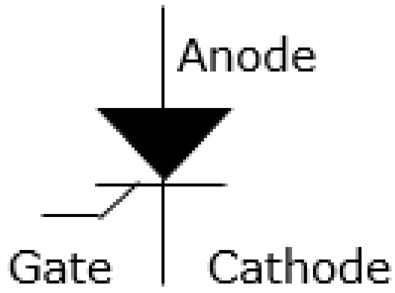
Unit 2: Power Semiconductor Devices

4. Power Electronics – Silicon Controlled Rectifier (SCR)

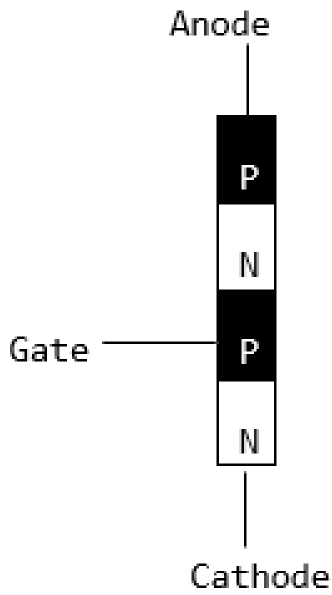
A silicon controlled rectifier or semiconductor-controlled rectifier is a four-layer solid-state current-controlling device. The name "silicon controlled rectifier" is General Electric's trade name for a type of thyristor.

SCRs are mainly used in electronic devices that require control of high voltage and power. This makes them applicable in medium and high AC power operations such as motor control function.

An SCR conducts when a gate pulse is applied to it, just like a diode. It has four layers of semiconductors that form two structures namely; NPNP or PNPN. In addition, it has three junctions labeled as J1, J2 and J3 and three terminals(anode, cathode and a gate). An SCR is diagramatically represented as shown below.



The anode connects to the P-type, cathode to the N-type and the gate to the P-type as shown below.



In an SCR, the intrinsic semiconductor is silicon to which the required dopants are infused. However, doping a PNPN junction is dependent on the SCR application.

End of ebook preview

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