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Current Power Electronics Research and Its Impact on Power Systems

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ABSTRACT : *Utilities may improve power delivery to their consumers and boost bulk power system dependability with the use of power electronics. Power electronics refers to the use of semiconductor switching devices for regulating and transforming the flow of electrical power to serve a variety of purposes. These methods of conversion have improved the quality of contemporary living by simplifying production, boosting product efficiency, and expanding the usefulness of numerous technological marvels like computers, and they may aid in the development of more trustworthy power supplies from utilities. In this study, we take a look at the ways in which power electronics have been implemented in various power infrastructures. The author describes the use of power semiconductors and power electronics in a few contexts. Classification, fundamental characteristics, key applications, and technological progress in power semiconductor devices will be discussed. As the efficiency and reliability of devices improves and the price of the switching megawatt decreases because to advancements in semiconductor and packaging technology, power electronics will be more used in distribution applications. At last, several power electronic converters and their respective uses are outlined and explored..*

Keywords: *Power Electronics Converter, FACTs, Voltage Source Inverter, Power Semiconductor Devices.*

INTRODUCTION

Power electronics, in its broadest sense, is the use of semiconductor devices to the management and transformation of electrical power. Power electronics allow for the regulation of current and voltage, respectively (AC or DC and the magnitude of currents and voltages). Power (electrical power), Electronics, and Control systems are all brought together in Power Electronics [1]. In the field of power electronics, both electrical and electronic engineers have a place. Generation, transmission, and distribution of electrical power are the main concerns of power engineers, and they focus on both stationary and mobile power systems. To achieve the necessary control goals, electronics involves the study of solid-state semiconductor power devices and circuits (to control the output voltage and output power).

The term "power electronics" refers to the field of study and technology that deals with the management and transformation of electrical power via the use of solid-state power semiconductor devices.

Several different types of power electronics exist in the electricity infrastructure. High-voltage direct current (HVDC) converter stations, flexible alternating current transmission system (FACTS) devices used to control and regulate alternating current (AC) power grids, variable-speed drives for motors, interfaces with various types of storage devices, interfacing distributed energy resources with the grid, electric drive in transportation systems, fault current-limiting devices, solid-state distribution transformers, and transfer switches are just a few examples[2,3].

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This document summarizes the most important power electronics applications for power systems in the following structure. In Section II, we see how power electronics has evolved and where it has found use thus far. Subsequently, semiconductor power devices are discussed. Classification, fundamental characteristics, key applications, and research and development are covered in Section III. Power electronic converters, as well as their benefits and drawbacks, are discussed in Section IV. It details power converter topologies, applications, kinds, and types of power electronic converters. Section V presents the last thoughts and tendencies for the future..

I. BRIEF HISTORY AND SOME APPLICATIONS OF POWER ELECTRONICS

A. ***Brief History of Power Electronics***

B. In the year 1900, the Mercury Arc Rectifier was created as the first power electronic gadget. Metal tank rectifiers, grid-controlled vacuum-tube rectifiers, ignitrons, phanotrons, thyratrons, and magnetic amplifiers were among the subsequent power devices to be invented and put into use for regulating electrical current.

C. till 1950. It was at Bell Labs in 1956 when the first silicon-controlled rectifier (SCR) or thyristor (first PNPN triggering transistor) was created.

D. In 1958, General Electric Company introduced the first commercial Thyristor, ushering in the second electronic revolution (GE). With this, a new age of power electronics was initiated. Subsequently, several varieties of power semiconductor devices and power conversion methods have been developed. Thanks to advancements in power electronics, we can now alter forms and exert finer control over massive volumes of energy.

E. ***Some Applications of Power Electronics [1,4,5,6]***

The most emerging renewable energy sources, wind energy, which by means of power electronics are changing from being minor energy sources to be acting as important power sources in the electrical network are described in [7]. Power electronics control of wind energy in distributed power systems and computer simulation of wind power systems can be found in [7,8].

There are two main trends in present development of power systems. First is a wide utilization of renewable power resources. The second is decentralization of power generation. Some applications of power electronics for power systems are presented in [9].

Power electronics covers a wide range of residential, commercial, and industrial applications, including computers, transportation, information processing, telecommunications, and power utilities. These applications may be classified into three categories:

Electrical applications:

Power electronics can be used to design AC and DC regulated power supplies for various electronic equipment, including consumer electronics, instrumentation devices, computers, and Uninterruptable Power Supply (UPS) applications. Power electronics is also used in the design of distributed power systems, electric heating and lighting control, power factor correction and Static Var Compensation (SVC).

Electromechanical applications:

Electromechanical conversion systems are widely used in industrial, residential, and commercial applications. These applications include AC and DC machine tools, robotic drives, pumps, textile and paper mills, peripheral drives, rolling mill drives and induction heating.

Electrochemical applications:

Electrochemical applications include chemical processing, electroplating, welding, metal refining, production of chemical gases and fluorescent lamp ballasts. Table (I) gives several power electronics applications in industrial, commercial, transportation, residential, utility systems, and telecommunication fields.

F. Power Semiconductor Devices

Modern power electronics rely on power semiconductor devices, which have been designed with two primary goals in mind.

1. Rate of transition (turn-on and turn-off times).

capacity for withstanding power (voltage-blocking capability and current-carrying capability).

Power semiconductor devices with high voltage and current ratings and quick turn-on and turn-off characteristics have been made possible by advances in semiconductor processing technology, as well as manufacturing and packaging methods. It is possible to cover a wide range of power electronic applications due to the wide variety of devices available; however, this diversity introduces trade-offs when it comes to selecting power devices due to their varying switching speeds, power handling capabilities, sizes, costs, and other characteristics.

Most systems and gadgets that use power electronics would be unable to function without power semiconductors. In the semiconductor industry, silicon has been and continues to be king. Power electronics systems are becoming more used in high-power utility and industrial applications due to the development of power semiconductor devices. An important part of the evolution of power electronics is due to the power semiconductor device's function as a central part of system architectures [10]. Power semiconductor devices vary in geometry from low-power devices due to the high voltages they must withstand while off and the enormous currents they must carry when on.

Based on the number of terminals, power semiconductors may be classified as either two-terminal devices or three-terminal devices [11]. Devices may also be divided into two groups depending on their functionality: those with a majority of carriers (Schottky diodes and MOSFETs) and those with a minority of carriers (Thyristors, bipolar transistors, and IGBTs), as seen in Figure 1. (1).

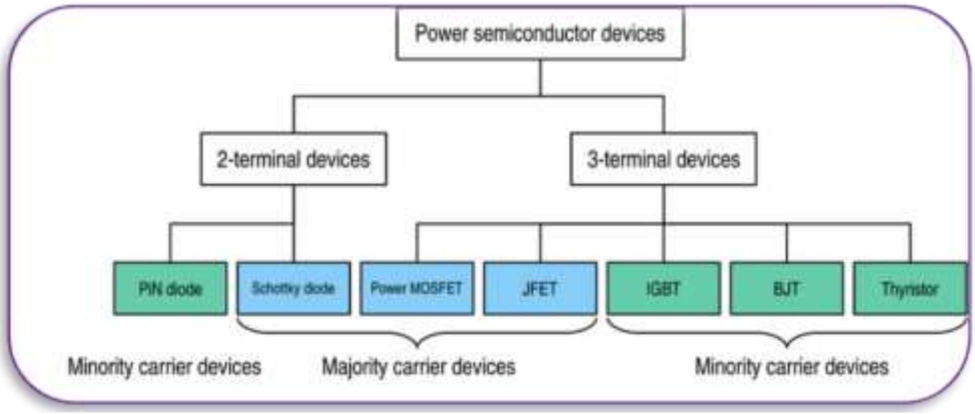


Figure 1: The Power Devices Family, Showing the Principal Power Switches

Power semiconductors devices exploit the electronic properties of semiconductor materials as Silicon, Germanium and Silicon Carbide. The revolution of power semiconductor devices started in 1958 when General Electric Company (GE) started to commercialize the first thyristors, the Silicon Controlled Rectifier (SCR). This was the beginning of a new era in power electronics that until that time had been based in vacuum tubes, ignotrons and phanotrons [1]. During the second half of the 1970's, two controllable non-latching type devices, the bipolar transistor module and the GTO, were developed and introduced on the market, starting a second era on the evolution of power semiconductor devices [12].

The introduction of the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) led to the development of the so-called third stage of power semiconductors. At the end of the 1980's and the beginning of the 1990's with the combination of the best features of the MOS (Metal Oxide Semiconductors) and bipolar devices, revolutionary IGBT (Insulated Gate Bipolar Transistor) was developed. More recently a new type of thyristor has been inserted to the market, the IGCT (Integrated Gate Commutated Thyristor), representing the state of the art and probably opening a new era the field. Figure (2) shows power semiconductor devices classification [1], [13].

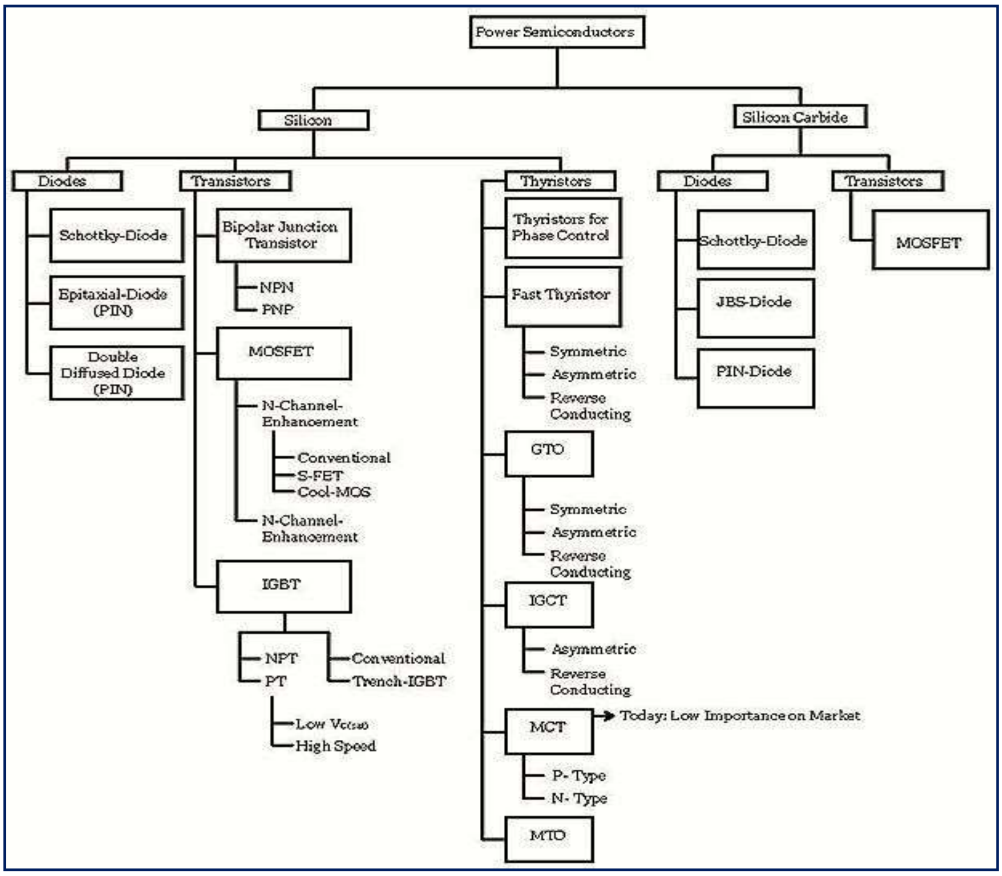
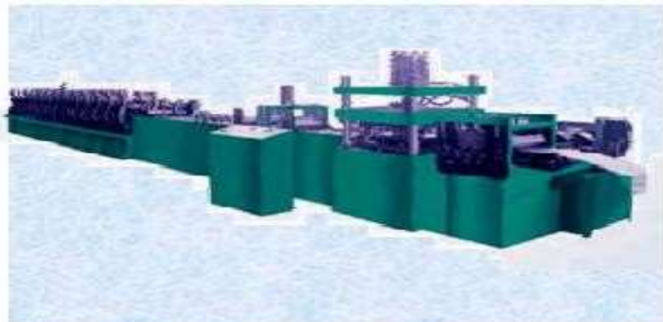
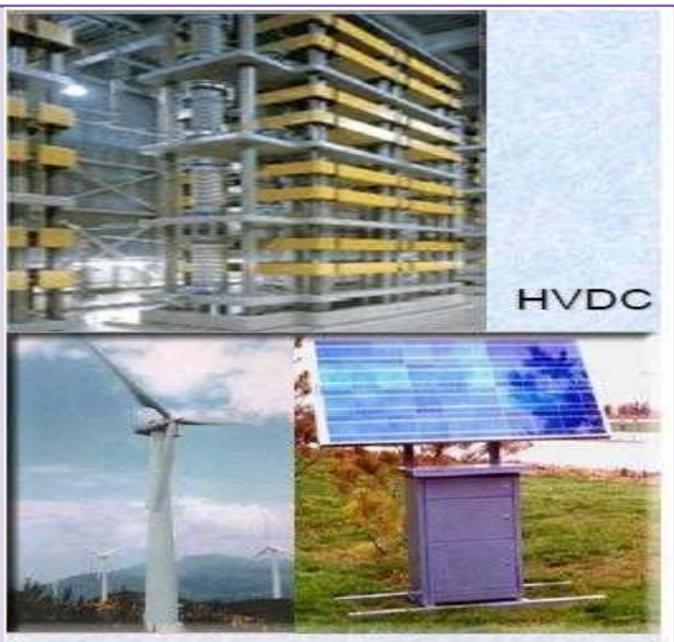


Figure 2: Classification of Power Semiconductor Devices [1], [13]

Table (I) Power Electronics Applications [1,4,5,6]

1- Industrial-Commercial Applications **Motor drives** **Electrolysis** **Electroplating** **Pumps** **Compressors** **Blowers and fans** **Machine tools** **Arc furnaces** **Induction furnaces** **Lighting** **Industrial lasers** **Process control** **Induction heating** **Factory automation** **Welding equipments** **Rolling mills** **Excavators Transformer-tap changers**	

2- Transportation Applications **Trains** **Trolley buses** **Subways** **Magnetic levitation** **Electric vehicles** **Electric Trucks** **Traction control** **Battery chargers** **Electric locomotives** **Street cars** **Automotive electronics** **Ship power systems** **Aircraft power systems**	
3- Residential Applications **Refrigeration and freezing** **Space heating** **Entertaining** **Air conditioning** **Cooking** **Lighting** **Electronics** **Uninterruptible power supplies** **Personal computers** **Vacuum cleaners** **Washing machines** **Fans** **Light dimmers** **Food mixers** **Electric door openers**	

4- Utility Systems Applications **High-Voltage DC transmission(HVDC)** **Flexible ac transmission(FACTS)** **Static VAR compensation(SVC)** **Custom power & power quality control** **Supplemental energy sources like: (wind, photovoltaic, fuel cells)** **Energy storage systems** **Induced-draft fans** **Line transformers** **Generating systems** **Solid state transformer** **Solid state fault current limiter** **Boiler feed water pumps** **Excitation systems** **Static circuit breakers**	
5- Power supplies for electronic equipment **Telecommunications** **Battery chargers** **Office equipment** **Computers** **Lighting** **Appliances** **Portable or mobile electronics** **Electronic instruments** **Power supplies(DC and UPS)** **Mobile cell phone battery chargers**	

II. CLASSIFICATION, APPLICATIONS AND DEVELOPMENT OF POWER SEMICONDUCTOR DEVICES

A. Some Devices and Applications of Power Semiconductors

Enhancements in programmable power semiconductor devices have been at the heart of recent developments in power electronics. The most popular power semiconductors and their operating voltages and current ratings are shown in Figures 2 and 3, respectively [14], [15]. Table (II) [16] lists the devices' specs for medium-voltage power semiconductors. Bipolar Junction Transistors (BJTs) have been mostly phased out in favor of Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Insulated-Gate Bipolar Transistors (IGBTs). The highest device voltage for conventional GTOs used in traction and industrial converters is 6kV [16]. Significant benefits of these devices include high on-state current densities, high blocking voltages, and the potential for integrated inverse diodes. In 1988, IGBTs first appeared on store shelves. Table (II) [15], [16] lists the DC current ratings of commercially available IGBTs, which range from 1.7kV to 6.5kV and up to 3kA. The standards of the high-power motor drives used in industrial and traction applications have been met with their development.

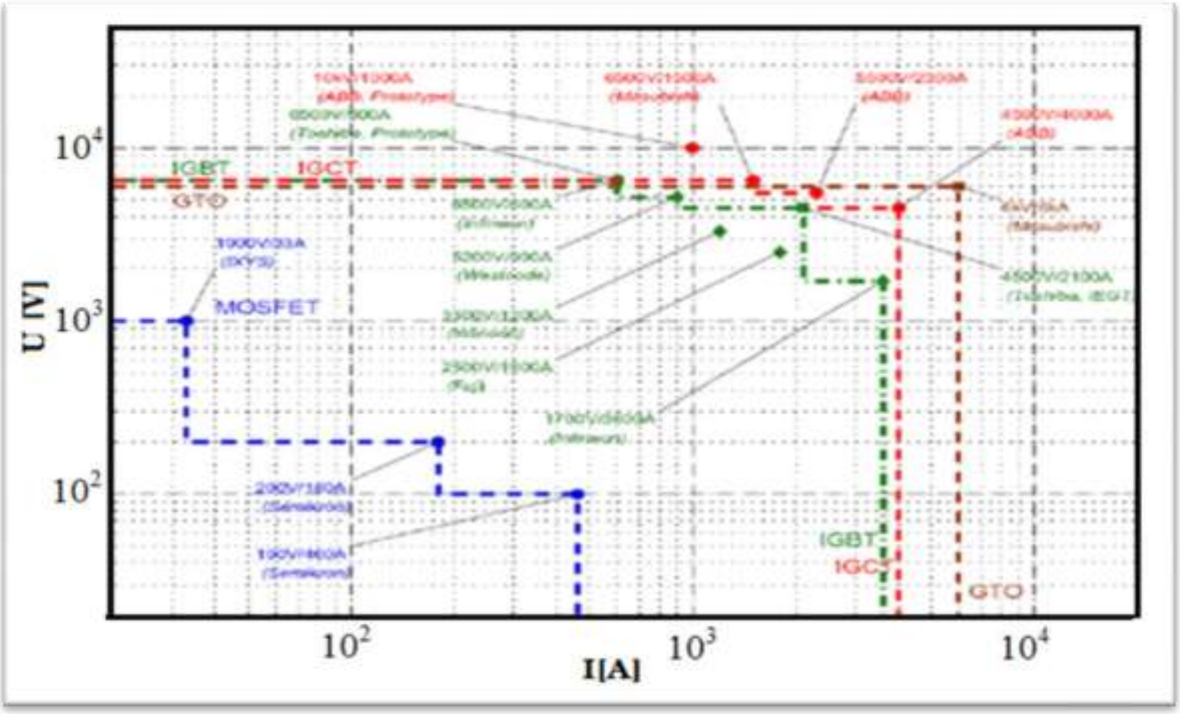


Figure 3: Power Range of Commercially Available Power Semiconductors [14], [15]

Table (II) Devices Rating and Package Types MV Power Semiconductors [15], [16].

Power Semiconductors	Manufacturer	Voltage Ratings	Current Ratings	Case
GTO	MITSUBISHI	6kV	6000A	Presspack
		4.5kV	1000-4000A	Presspack
	ABB	4.5kV	600-4000A	Presspack
		6kV	30000A	Presspack
IGBT	EUPEC	3.3kV	400-1200A	Module
		6kV	200-600A	Module
	MITSUBISHI	3.3kV	800-1200A	Module
		4.5kV	400-900A	Module
		6kV	600A	Module
	HITACHI	3.3kV	400-1200A	Module
	TOSHIBA	3.3kV	400-1200A	Presspack
		4.5kV	1200-2100A	Module
	ABB	3.3kV	1200A	Module
		4.5kV	600-3000A	Presspack
		6kV	600A	Module
IGCT	ABB	4.5kV	3800-4000A	Presspack
		4.5kV	340-2200A	Presspack
		5.5kV	280-1800A	Presspack
		6kV	3000A	Presspack
	MITSUBISHI	4.5kV	4000A	Presspack
		6kV	3500-6000A	Presspack
		6.5kV	400-1500A	Presspack

In [17], the main advantages of the IGBT over a Power MOSFET and a BJT are explained as follows:

The modification of the conductivity results in a very small on-state voltage drop and a high on-state current density. As a result, both the size and price of chips may be lowered.

A low input MOS gate structure driving power and a straightforward drive circuit. When compared to devices that rely on current control (such as a thyristor or BJT), it is much simpler to operate at high voltage and current levels.

A Large Margin of Safety (SOA). When compared to the bipolar transistor, it may conduct more current. In addition, it is a formidable defensive barrier, both in front of and behind the target.

Major downsides include:

One, it has slower switching speeds than Power MOSFETs and faster speeds than BJTs. The minority carrier causes the collector current to tail off, which in turn slows the turn-off speed.

Second, the thyristor's intrinsic PNPN structure might cause latch up.

In [18], you'll find a review of the semiconductor components used in power systems applications, as well as a summary of the most important AC and DC systems on the market today that are designed to enhance the transmission and distribution of electrical power. Due to their versatility, power semiconductors exist in a broad variety of forms, each with its own optimal combination of characteristics. These include amplification, switching speed, and power class. Applications in business, the consumer sector, and transportation all show trends in certain kinds [19]. Using the knowledge gained from constructing both the silicon controlled rectifier (SCR) and the germanium tunnel junction (GTO), a new high-power semiconductor called the integrated gate commutated thyristor (IGCT) was created [20]. IGCT is distinguished by its high current, high voltage, high frequency, high reliability, compact construction, and low consumption. It has excellent potential to replace conventional power semiconductors in MV industrial applications. Static var generators (SVGs), static var compensation (SVC) equipment, energy management for super conduction storage systems, and direct current (DC) high voltage transmission are just some of the places you may find IGCT being used today [21], [22].

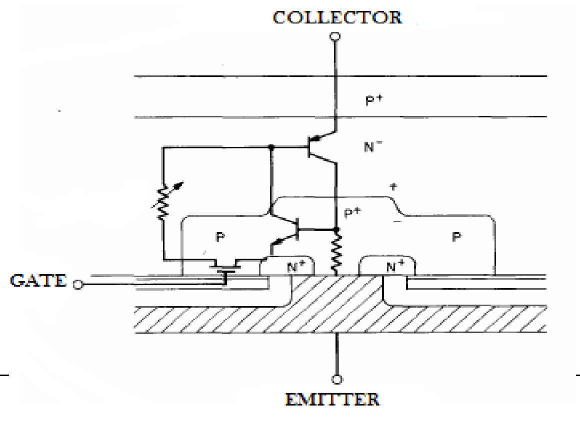
B. Future Developments of Power Semiconductors

For future power conversion applications, new structures or semiconductor materials can be investigated for prospective power semiconductor devices [23], [24].

1. Structure Improvement:

Insulated gate bipolar transistors (IGBT), Integrated Gate Commutated Thyristor (IGCT) and MOS- controlled thyristor (MCT) [10] are three new structures of power devices. IGBT is most common used power electronic devices nowadays, whose structure is shown in Figure (4).

Figure4:Basic Structure of IGBT



An IGBT is basically a hybrid MOS-gated turn on/off bipolar transistor that combines the attributes of a MOSFET, BJT and thyristor.

2. Materials Improvement:

The low breakdown field of silicon is putting serious constraints on power switching devices made from the material. Given its greater field characteristic, silicon carbide is a suitable material for high power, high temperature, and high frequency applications [25], [26], [27]:

1) Sic can withstand an extremely high voltage over a very thin layer because to its strong electric breakdown capability.

Secondly, Sic's fast carrier drift velocity is crucial for high frequency operation, especially in minority carrier driven bipolar devices.

Sic's strong thermal conductivity allows it to function at high temperatures and improves thermal management in power control applications. The on-resistance of Sic power devices, for example, may be 700 times lower than equivalent silicon devices because to the superior material characteristics.

POWER CONVERTER TOPOLOGIES

A. Power converters have numerous uses in power systems, both in the power distribution infrastructure and in the many end-user appliances and electronics that rely on electrical power. HVDC transmission, flexible AC transmission system (FACTS) devices, and bespoke power devices are all examples of power delivery applications. Power electronic interfaces are found in many devices for distributed generation and storage. The use of motor drives and reactive compensators are examples of load-based applications.

B. Power converters with high voltage, high current, low harmonics, and quick dynamic reaction speed are needed for high power applications in [28], such as flexible AC transmission systems (FACTS) devices and energy storage systems.

C. For high-power applications, researchers have focused heavily on multi-level voltage source converters [29, 30]. It is important to note that the topology of the power electronic converter utilized in a renewable energy generating system is highly dependent on the specifics of the application [31]. To boost the power conversion stage's efficiency, boost its dependability, or lower its initial cost, new converters are always being developed.

D.

E. Cascaded H-bridge rectifiers have a novel DC bus-balancing control mechanism announced in [32]. As a result of its modular design, the cascaded H-bridge converter may be directly connected to medium voltage sources. The power electronic transformer (PET) construction may be achieved by connecting isolated DC/DC converters in series and parallel with a voltage source inverter in this way. The use of multilayer power converters in high-voltage, medium-to-high-power applications like wind turbines is gaining popularity at the moment [33, 34].***Types of Power Electronic Converters and its Applications [1, 15, 16, 35]***

A power electronic system consists of one or more power electronic converters. A power electronic converter is made up of some power semiconductor devices controlled by integrated circuits. The switching characteristics of power semiconductor devices permit a power electronic converter to shape the input power of one form to output power of some other form. Static power converters perform these functions of power conversion very efficiently. Broadly speaking, power electronic converters (or circuits) for power systems canbe classified into:

1. AC to DC converters (phase-controlled rectifiers)

These convert constant AC voltage to variable dc output voltage. These rectifiers use line voltage for their commutation and therefore they are also called line-commutated or naturally-commutated AC to DC converters. Phase-controlled converters may be fed from a 1-phase or 3-phase source. They are seen by the grid as current sources. These are used in DC drives, chemical industries and excitation systems for synchronous machines etc.

2. DC to AC converters (Inverters)

An inverter convert's fixed DC voltage to a variable AC voltage. The output may be a variable voltage and variable frequency. These converters use line, load or forced commutation for turning-off the switches. They can be seen as voltage sources or as current sources. The former are the latest candidates for most power systemapplications. Inverters find wide use in induction-motor, synchronous-motor drives, induction heating, UPS and HVDC transmission etc.

3. AC to AC converters

These convert fixed AC input voltage into variable AC output voltage. These are of two types as under:

I. AC voltage controllers (AC voltage regulators)

These converter circuits convert fixed AC voltage directly to a variable AC voltage at the same frequency. AC voltage controllers are widely used for lighting control, speed control of fans and pumps etc.

II. Cycloconverters

These circuits convert input power at one frequency to output power at a different frequency through one-stage conversion. Line commutation is more common in these converters, though forced and load commutated cycloconverters are also employed. These are primarily used for slow-speed large AC drives like rotary kiln etc.

4. DC to DC converters

Converts input DC to variable magnitude DC, e.g., voltage regulators. Like (DC Chopper-Buck/Boost/Buck- Boost Converter).

F. Advantages and Disadvantages of Power Electronic Converters [1]

(i) High efficiency due to low loss in power-semiconductor devices.

(ii) High reliability of power-electronic converter systems.

(iii) Long life and less maintenance due to the absence of any moving parts.

(iv) Fast dynamic response of the power-electronic systems as compared to electromechanical convertersystems.

(v) Small size and less weight result in less floor space and therefore lower installation cost.

(vi) Mass production of power-semiconductor devices has resulted in lower Cost of the converter equipment. Systems based on power electronics, however, suffer from the following disadvantages:

(a) Power-electronic converter circuits have a tendency to generate harmonics in the supply system, as well as in the load circuit. In the load circuit, the performance of the load is influenced, for example, a high harmonic content in the load circuit causes commutation problems in DC machines, increased motor heating and more acoustical noise in both DC and AC machines. So steps must be taken to filter these out from the output side of a converter. In the supply system, the harmonics distort the voltage waveform and seriously influence the performance of other equipment connected to the same supply line. In addition, the harmonics in the supply linecan also cause interference with communication lines. It is, therefore necessary to insert filters at the input side of a converter.

(b) AC to DC and AC to AC converters operate at a low input power factor under certain operating conditions. In order to avoid a low pf, some special measures have to be adopted.

(c)Power-electronic controllers have low overload capacity. These converters must, therefore, be rated to take momentary overloads. As such, cost of power electronic controller may increase.

(d)Regeneration of power is difficult in power electronic converter systems.

V. CONCLUSIONS

This paper has reviewed the power electronic applications for power systems. Classification, some devices and applications of power semiconductors are described. Development of power semiconductor devices is very essential for modern electronics devices.

The advantages possessed by power electronic converters far outweigh their disadvantages. As a consequence, semiconductor-based converters are being extensively employed in systems, where power flow is to be regulated. As already stated, conventional power controllers used in many installations have already been replaced by semiconductor-based power electronic controllers.

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