Quest Journals
Journal of Electronics and Communication Engineering Research
Volume1 ~ Issue1 (2013) pp: 43-52
ISSN(Online) :2321-5941 *www.questjournals.org*

Research Paper

A Review of the State-Of-The-Art of Power Electronics For Power System Applications

[1]Shazly A. Mohammed, [2]Abdel-Moamen M. A, [3]B. Hasanin

[1]Faculty of Engineering, South Valley University, Qena-Egypt
[2]Faculty of Energy Engineering, Aswan University, Aswan-Egypt
[3]Dean of Faculty of Engineering, Al-azhar University, Qena-Egypt

Received 21 September, 2013; **A**ccepted 07 October, 2013© The author(s) 2013. Published with open access at **www.questjournals.org**

ABSTRACT **:** *Power electronics can provide utilities the ability to more effectively deliver power to their customers while providing increased reliability to the bulk power system. In general, power electronics is the process of using semiconductor switching devices to control and convert electrical power flow from one form to another to meet a specific need. These conversion techniques have revolutionized modern life by streamlining manufacturing processes, increasing product efficiencies, and increasing the quality of life by enhancing many modern conveniences such as computers, and they can help to improve the delivery of reliable power from utilities. This paper gives a review on the power electronic applications for power systems. Some application of power electronics and power semiconductors are described. Classification, essential properties, important applications and development of power semiconductor devices will be explained. Moreover, developments in semiconductors and their packaging technology will drive power electronics into distribution applications as device efficiency and reliability increases whilst the cost of the switched megawatt falls. Finally, different types of power electronic converters and applications are described and discussed.*
Keywords: *Power Electronics Converter, FACTs, Voltage Source Inverter, Power Semiconductor Devices.*

I. INTRODUCTION

Generally, power electronics refers to the use of semiconductor devices to control and convert electrical power from one form to another one to meet a specific need. In other words, power electronics enables the control of the power flow as well as its form (AC or DC and the magnitude of currents and voltages). Power Electronics is a field which combines Power (electric power), Electronics and Control systems [1]. Power electronics belongs partly to power engineers and partly to electronics engineers. Power engineering deals with the static and rotating power equipment for the generation, transmission and distribution of electric power. Electronics deals with the study of solid state semiconductor power devices and circuits for power conversion to meet the desired control objectives (to control the output voltage and output power). Power electronics may be defined as the application of solid- state power semiconductor devices for the control and conversion of electric power.

Power electronics can be found in many forms within the power system. Some examples are: high-voltage direct current (HVDC) converter stations, flexible AC transmission system (FACTS) devices that are used to control and regulate AC power grids, variable-speed drives for motors, interfaces with storage devices of several types, interfacing of distributed energy resources with the grid, electric drive in transportation systems, fault current–limiting devices, solid-state distribution transformer and transfer switches[2,3].

This paper reviews the major applications of power electronics for power systems, and it is organized as follows. Section II shows a brief history and some applications of power electronics. Then, power semiconductor devices are presented. Section III discusses Classification, essential properties, important applications and development of power semiconductor devices. Section IV presents the power converter topologies, applications, types of power electronic converters, advantages and disadvantages of power electronic converters. Finally, in section V, the conclusions are drawn and the future trends are illustrated.

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

II. BRIEF HISTORY AND SOME APPLICATIONS OF POWER ELECTRONICS

A. Brief History of Power Electronics

The first power electronic device developed was the Mercury Arc Rectifier during the year of 1900. Then the other Power devices like metal tank rectifier, grid controlled vacuum tube rectifier, ignitron, phanotron, thyratron and magnetic amplifier, were developed & used gradually for power control applications until 1950. The first SCR (silicon controlled rectifier) or Thyristor was invented and developed by Bell Lab's in 1956 which was the first PNPN triggering transistor.

The second electronic revolution began in the year 1958 with the development of the commercial Thyristor by the General Electric Company (GE). Thus the new era of power electronics was born. After that many different types of power semiconductor devices & power conversion techniques have been introduced. The power electronics revolution is giving us the ability to convert shapes and control large amounts of power.

B. 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.

C. Power Semiconductor Devices

Power semiconductor devices represent the heart of modern power electronics, with two major desirable characteristics guiding their development:

1. Switching speed (turn-on and turn-off times).
2. Power handling capabilities (voltage-blocking capability and current-carrying capability).

Improvements in semiconductor processing technology as well as in manufacturing and packaging techniques have allowed the development of power semiconductor devices for high voltage and high current ratings and fast turn-on and turn-off Characteristics. The availability of different devices with different switching speeds, power handling capabilities, sizes, costs, and other factors makes it possible to cover many power electronic applications, so that trade-offs must be made when it comes to selecting power devices.

Power semiconductors are essential components of most power electronics devices and systems. Silicon is by far the most widely used semiconductor material. With the advance of power semiconductor devices, more and more power electronics systems are used in high-power utility and industry applications. Power semiconductor device has played an essential role in the development of power electronics as a key component in system topologies [10]. Compared to normal electronic devices, power semiconductor devices require to stand large voltages in the off state and to carry high currents in the on state, which demand geometry differences from the low-power devices.

Power semiconductor can be divided into two main categories based on terminal numbers: two-terminal devices and three-terminal devices [11]. A second classification can be based on the device performance: majority carrier devices (Schottky Diode, MOSFET) and minority carrier devices (Thyristor, bipolar transistor, IGBT), as shown in Figure (1).

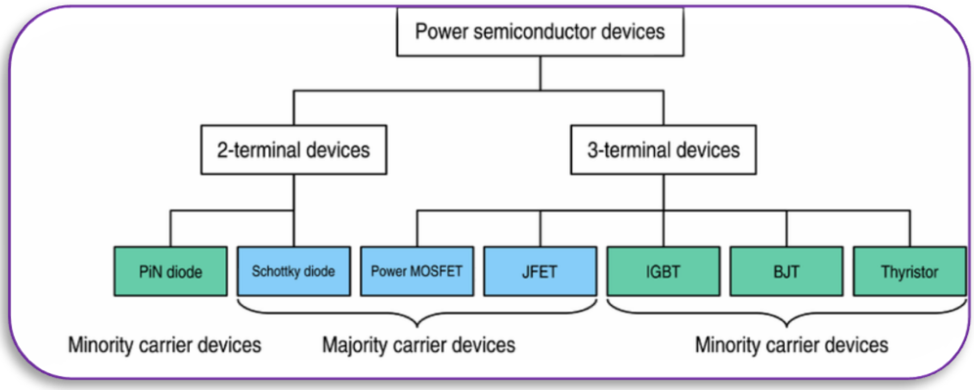


Figure 1: The Power Devices Family, Showing the Principal Power Switches

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].

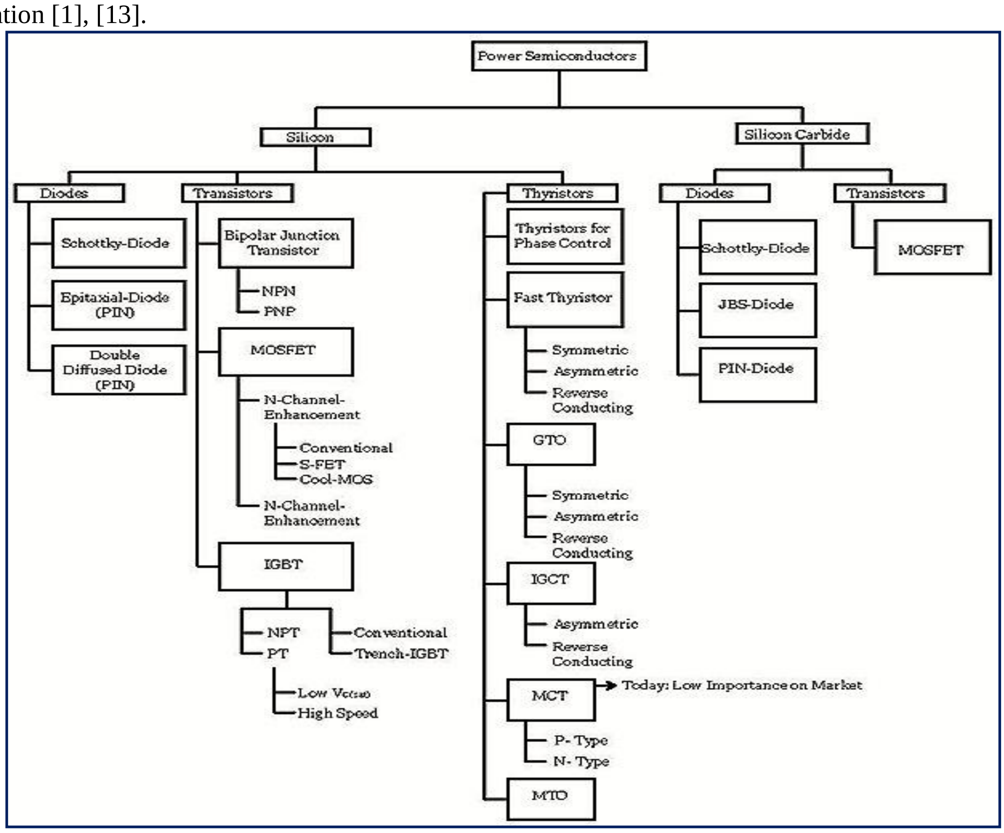
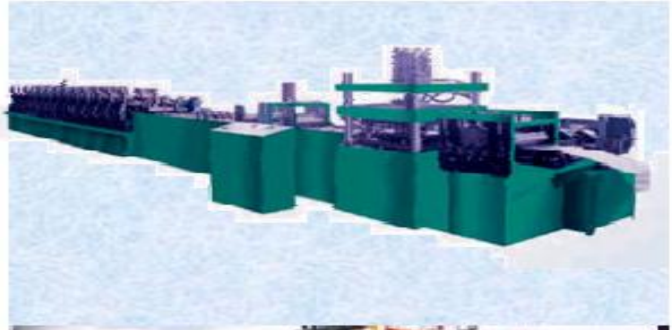


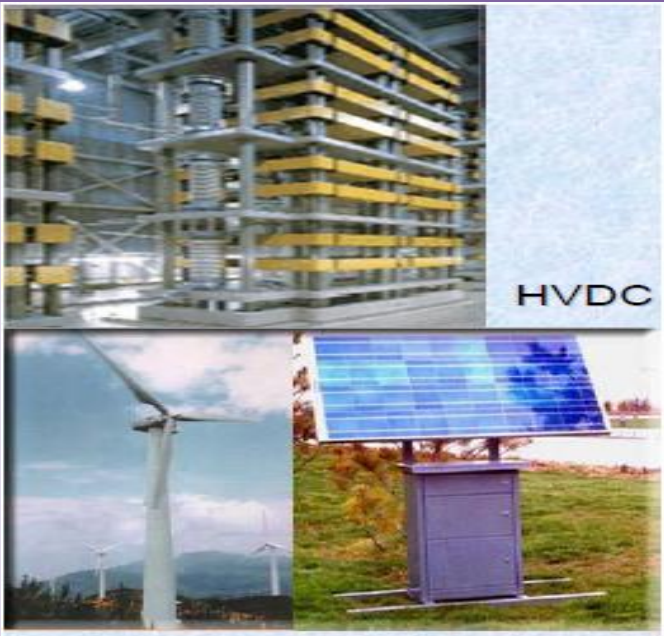
Figure 2: Classification of Power Semiconductor Devices [1], [13]

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

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**	

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

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**	

III. CLASSIFICATION, APPLICATIONS AND DEVELOPMENT OF POWER SEMICONDUCTOR DEVICES

A. Some Devices and Applications of Power Semiconductors

Recent technology advances in power electronics have been made by improvements in controllable power semiconductor devices. Figure (2) and Figure (3) summarize the most important power semiconductors on the market and their rated voltages and currents [14], [15]. The device characteristics for medium voltage power semiconductors are shown in Table (II) [16]. Metal Oxide Semiconductor Field Effect Transistors (MOSFET) and IGBTs have replaced Bipolar Junction Transistors (BJT) almost completely. Conventional GTOs are available with a maximum device voltage of 6kV in traction and industrial converters [16]. The high on- state current density, the high blocking voltages and the possibilities to integrate an inverse diode are considerable advantages of these devices. IGBTs were introduced on the market in 1988. IGBTs from 1.7kV up to 6.5kV with DC current ratings up to 3kA are commercially available Table (II) [15], [16]. They have been optimized to satisfy the specifications of the high-power motor drives for industrial and traction applications.

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

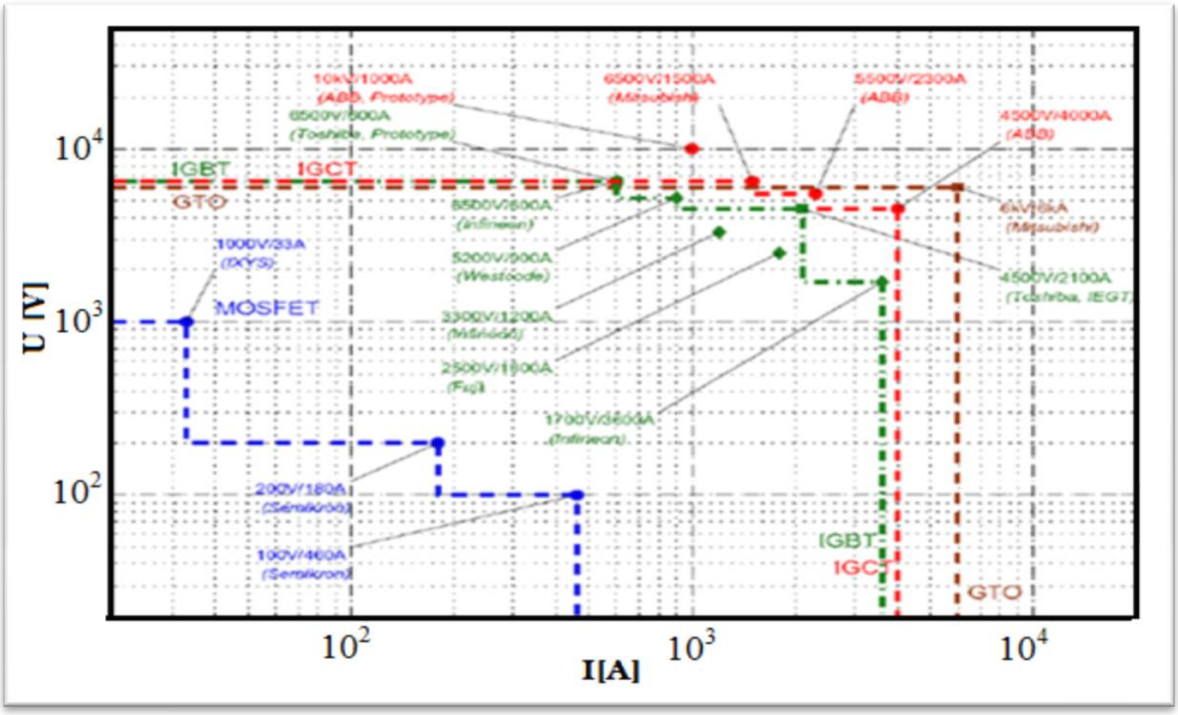


Figure 3: Power Range of Commercially Available Power Semiconductors [14], [15]

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

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

In [17], the main advantages of the IGBT over a Power MOSFET and a BJT are explained as follows:
1. It has a very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.
2. Low driving power and a simple drive circuit due to the input MOS gate structure. It can be easily controlled as compared to current controlled devices (thyristor, BJT) in high voltage and high current applications.

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

3. Wide Safe Operating Area (SOA). It has superior current conduction capability compared with the bipolar transistor. It also has excellent forward and reverse blocking capabilities.
The main drawbacks are:
1. Switching speed is inferior to that of a Power MOSFET and superior to that of a BJT. The collector current tailing due to the minority carrier causes the turn-off speed to be slow.
2. There is a possibility of latch up due to the internal PNPN thyristor structure.
In [18], there is an overview of semiconductor components utilized in power systems applications and key AC & DC systems available to improve transmission and distribution of electrical power. Because power semiconductors have a very wide-range of applications, the most desirable type for a given application comes down to several factors: the amplification, the switching speed and the power class. Trends in particular types can be seen in applications in industry, the consumer market and transportation [19]. The Integrated Gate Commutated Thyristor (IGCT) was developed to be a new high-power semiconductor based on the developing experience of SCR and GTO which combines the advantage of IGBT and GTO [20]. IGCT has these characteristic such as high current, high voltage, high frequency, high reliability, compact structure and low consumption. It is a strong candidate to be the power semiconductor of choice in Medium Voltage Industrial Applications. Nowadays, IGCT is increasingly applied in Static Var Generator (SVG), Static Var Compensation (SVC) Equipment, Management Energy of Super conduction Storage System and DC High Voltage Power Transmission [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).

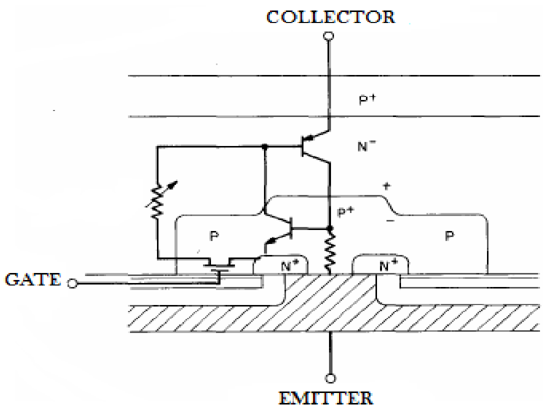


Figure 4: Basic Structure of IGBT

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:

Silicon based power switching devices are reaching fundamental limits imposed by the low breakdown field of the material. Silicon carbide, with a higher field characteristic, is a promising choice for high power, high temperature and high frequency applications [25], [26], [27] due to the reasons below:
1) Sic has a high electric breakdown property, which will support a very high voltage across a thin layer.
2) Sic has a high carrier drift velocity, which is essential for high frequency operation particularly for minority carrier driven bipolar devices.
3) Sic has a high thermal conductivity realizing high temperature operation and better thermal management of power control applications. Due to the superior material properties, Sic power devices can give a much better performance than silicon power devices, e.g., the on-resistance of Sic can be 700 times lower than similar silicon devices.

Faculty of Engineering, South Valley University, Qena-Egypt

IV. POWER CONVERTER TOPOLOGIES

Power converters are used in many applications in power systems, both in the power delivery system and as part of the end user 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.

In [28], for high power applications, such as flexible AC transmission systems (FACTS) devices and energy storage systems, power converters with high voltage, high current, low harmonics and fast dynamic response speed are required.

Multi-level voltage source converters have been studied intensively for high-power applications [29], [30]. Depending on the application, different topologies of power electronic converters are used in renewable energy generation systems [31]. New converters are developed to increase efficiency of power conversion stage, improve its reliability or decrease initial cost.

In [32], a new control method for balancing the DC buses of cascaded H-bridge rectifier has been introduced. The cascaded H-bridge converter is extremely modular and makes possibility for connecting to medium voltage levels directly. Using this structure together with the series-parallel connection of isolated DC/DC converters and a voltage source inverter, the power electronic transformer (PET) structure is achieved. Currently, there is an increasing interest in multilevel power converters especially for medium to high-power, high-voltage wind turbine applications [33] and [34].

A. 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 can be 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 system applications. 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).

B. 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 converter systems.
(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 line can 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.

REFERENCES

[1]. M.H.Rashid, “Power Electronics Circuits, Devices and Applications”, 3rd Ed. Upper saddle, NJ: Pearson Prentice Hall. 2006.
[2]. Rishabh Dev Shukla, R. K. Tripathi and Sandeep Gupta, “Power Electronics Applications in Wind Energy Conversion System: A Review”, International Conference on Power, Control and Embedded Systems (ICPCES), pp. 1-6, Nov. 29 2010-Dec. 1 2010.
[3]. G.K. Andersen, C. Klumpner, S.B. Kjaer, F. Blaabjerg, “A New Green Power Inverter for Fuel Cells”, IEEE 33rd Annual Conference of Power Electronics Specialists Conference (PESC), Vol. 2, pp. 727–733, 2002.
[4]. N.Mohan, T.M. Undeland and W.P.Robbins, “Power Electronics: Converters, Applications and Design”, 3rd Ed, ISBN: 978-0-471-22693-2, Nov. 2003.
[5]. E.I.Carroll, “Power Electronics for Very High Power Applications", Power Engineering Journal, Vol. 13, Issue 2, pp. 81-87, April 1999.
[6]. Zhe Chen, J. M.Guerrero and F. Blaabjerg, “A Review of the State of the Art of Power Electronics for Wind Turbines”, IEEE Transaction on Power Electronics, Vol. 24, Issue 8, pp. 1859-1875, Aug. 2009.
[7]. F. Iov, M. Ciobotaru and F. Blaabjerg, “Power Electronics Control of Wind Energy in Distributed Power Systems", International Conference on Optimization of Electrical and Electronic Equipment, pp. XXIX-XLIV, 22-24 May 2008.
[8]. R. Melício, V. M. F. Mendes and J. P. S. Catalão, “Computer Simulation of Wind Power Systems: Power Electronics and Transient Stability Analysis", International Conference on Power Systems Transient (IPST 2009), in Kyoto, Japan, June 3-6, 2009.
[9]. P. Biczel, A. Jasinski and J. Lachecki, “Power Electronic Devices in Modern Power Systems", the International Conference on Computer as a Tool, EUROCON, 9-12 Sept. 2007.
[10]. B. K. Bose, “Evaluation of Modern Power Semiconductor Devices and Future Trends of Converters”, IEEE Transactions on Industry Applications, Vol. 28, Issue 2, pp. 403-413, 1992.
[11]. Tanya Kirilova Gachovska, “Modeling of Power Semiconductor Devices”, PhD thesis, University of Nebraska, December 2012.
[12]. C. C. Davidson, “The Future of High Power Electronics in Transmission and Distribution Power Systems”, European Conference on Power Electronics and Applications (EPE’09), pp. 1-14, 8-10 Sept. 2009.
[13]. S. Bernet, “Recent Developments of High Power Converters for Industry and Traction Applications,” IEEE Transactions on Power Electronics, Vol. 15, No. 6, pp. 1-14, Nov. 2000.
[14]. Seyed Saeed Fazel, “Investigation and Comparison of Multi-Level Converters for Medium Voltage Applications", Technical University of Berlin, 2007.
[15]. Arash A. Boora, Firuz Zare, Arindam Ghosh and Gerard Ledwich, “Applications of Power Electronics in Railway Systems”, In Proceedings Australasian Universities Power Engineering Conference (AUPEC 2007), Western Australia, pp. 113-121, 2007.
[16]. S. Bernet, “State of the Art and Developments of Medium Voltage Converters-An Overview”, Przeglad Elektrotechniczny (Electrical Review), Vol. 82, No. 5, pp. 1-10, May 2006.
[17]. IXYS, “Power Semiconductors Application Notes”, IXYS Corporation, 3540 Bassett Street, Santa Clara CA 95054, and Phone: 408-982-0700, 2002.
[18]. B. K. Bose, “Energy, Environment and Advances in Power Electronics”, IEEE Transactions on Power Electronics, Vol. 15, Issue 4, pp. 688-701, Jul. 2000.

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt

[19]. Jai P. Agrawal, Marie Crothers and Tony M. Keaveny, “Power electronic systems: theory and design”, 1st Edition, Category: Science and Technology, 2001.
[20]. Abraham I. Pressman, “Switching Power Supply Design”, 2nd Edition, Beijing: Publishing house of electronics industry, 2005.
[21]. T. Adhikari, “Application of Power Electronics in the Transmission of Electrical Energy”, TENCON’98, IEEE International Conference on Global Connectivity in Energy, Computer, Communication and Control, Vol. 2, pp. 522-530, 1998.
[22]. S. Klaka, M. Frecker and H. Gruening, “The Integrated Gate-Commutated Thyristor: A New High-Efficiency, High-Power Switch for Series or Snubberless Operation”, Power Conversion June 1997 Proceedings, pp. 1-8, 1997.
[23]. B.J. Baliga, “Power IC’s in the Saddle”, Journal IEEE Spectrum,Vol. 32, Issue 7, pp. 34-49, July 1995.
[24]. F.Blaabjerg and M. Liserre, “Power Electronics Converters for Wind Turbine Systems", IEEE Transactions on Industry Applications, Vol. 48, Issue 2, pp. 708-719, March- April 2012.
[25]. G. Majumdar, “Future of Power Semiconductors”, IEEE 35th Annual Power Electronics Specialists Conference (PESC 04), Vol. 1, pp. 10-15, 20-25 June 2004.
[26]. J. Wang and A. Q. Huang, “Design and Characterization of High-Voltage Silicon Carbide Emitter Turn-off Thyristor”, IEEE Transactions on Power Electronics, Vol. 24, No. 5, pp.1189-1197, 2009.
[27]. T. F. Zhao, J. Wang, A. Q. Huang, and A. Agarwal, “Comparisons of SiC MOSFET and Si IGBT Based Motor Drive Systems”, Proceeding of the 42nd Annual Meeting IEEE Industry Application Conference, pp. 331-335, 2007.
[28]. J. J. Shea, “Understanding FACTS, Concepts and Technology of Flexible AC Transmission Systems”, IEEE Electrical Insulation Magazine, Vol. 18, Issue 1, Jan.-Feb. 2002.
[29]. F. Z. Peng, “A Generalized Multilevel Inverter Topology with Self Voltage Balancing”, IEEE Transactions Industry Applications, Vol. 37, No. 2, pp. 611-618, Mar/Apr 2001.
[30]. T. Meynard, H. Foch, F. Forest, C. Turpin, F. Richardeau, L. Delmas, G. Gateau and E. Lefeuvre, “Multicell Converters: Derived Topologies”, IEEE Transactions Industrial Electronics, Vol. 49, No. 5, pp. 978-987, Oct. 2002.
[31]. F. Blaabjerg, F. Iov, R. Teodorescu and Z. Chen, “Power Electronics in Renewable Energy Systems”, 12th International Conference on Power Electronics and Motion Control (EPE-PEMC 2006), pp. 1-17, Aug. 30 2006-Sept. 1 2006.
[32]. H. Iman-Eini, Sh. Farhangi, J-L. Schanen and J. Aime, “Design of Power Electronic Transformer Based on Cascaded H-bridge Multilevel Converter”, IEEE International Symposium on Industrial Electronics (ISIE 2007), pp.877-882, 4-7 June 2007.
[33]. J.M. Carrasco, E. Galvan, R. Portillo, L.G. Franquelo and J.T. Bialasiewicz, “Power Electronics System for the Grid Integration of Wind Turbines”, IEEE 32nd Annual Industrial Electronics Conference (IECON 2006), pp. 4182-4188, 6-10 Nov. 2006.
[34]. R. Portillo, M. Prats, J.I. Leon, J.A. Sanchez, J.M. Carrasco, E. Galvan, L.G. Franquelo. “Modelling Strategy for Back-to-Back Three-Level Converters Applied to High-Power Wind Turbines”, IEEE Transactions on Industrial Electronics, Vol. 53, No. 5, pp. 1483-1491, Oct. 2006.
[35]. M. Hiller, R. Sommer, M. Beuermann, “Converter Topologies and Power Semiconductors for Industrial Medium Voltage Converters”, IEEE Industry Applications Society Annual Meeting (IAS’08), pp. 1-8, 5-9 Oct. 2008.

*Corresponding Author: Shazly A. Mohammed
Faculty of Engineering, South Valley University, Qena-Egypt