

Application of Power Electronics to Power System

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Abstract: Power electronics is the application of solid-state electronics for the control and conversion of electric power. It provides a basic knowledge of circuitry for the control and conversion of electrical power with high efficiency. The structure of Modern power systems have been separated in three different interlinked sections - generation, transmission and distribution likewise. Mostly the output of generator is always AC, but in some applications we need DC supply, where we get optimum utilization of efficient power with respect to applications example different types of sockets, connectors, switches, and fixtures. High-voltage direct current (HVDC) electric power transmission systems use DC for the bulk transmission of electrical power. Whereas, in some cases we need AC supply and we are supplied with DC quantity there, example transformers, 3 ϕ motor, etc. In such cases we need to convert AC to DC or DC to AC. This can be done using electronic devices such as SCR, Power BJT, Chopper, etc. In this paper we will study particularly application of SCR, TRIAC, GTO and IGBT in electrical power system.

Keywords: about four key words separated by commas.

1. Introduction

Power Electronics is a branch of Electrical engineering developed for conversion and control of electrical power using electronic converters. It also refers to a subject of research in electronic and electrical engineering which deals with the design, control, computation and integration of nonlinear, time-varying energy-processing electronic systems with fast dynamics. Now, coming towards power system, an electric power system is a network of electrical components deployed to supply, transfer, and use electric power. An example of an electric power system is the network that supplies a region's homes and industry with power—for sizeable regions, this power system is known as the grid and can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centres to the load centres and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. Power Electronics in Power system is mainly used for rectification, inversion, conversion, etc., and devices used for this are SCR, power BJT, Chopper, power MOSFET, IGBTs, etc. Mainly we will discuss about SCR, TRIAC, DTO and IGBT and their application in electrical power system.

2. Silicon Controlled Rectifier

The silicon control rectifier (SCR) consists of four layers of semiconductors, which form NPNP or PNP structures have three P-N junctions labelled J1, J2 and J3, and three terminals. The anode terminal of an SCR is connected to the p-type material of a PNP structure, and the cathode terminal is connected to the n-type layer, while the gate of the SCR is connected to the p-type material nearest to the cathode.

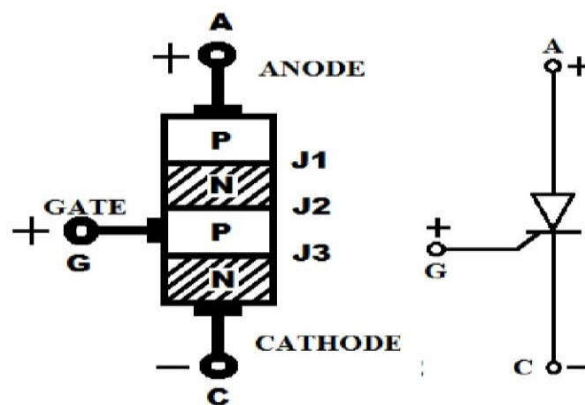


Figure 1: Schematic diagram of SCR and its symbol

There are three modes of operation for an SCR depending upon the biasing given to it:

2.1 Forward blocking mode

In this mode of operation, the anode is given a positive voltage while the cathode is given a negative voltage, keeping the gate at zero potential i.e. disconnected. In this case junction J1 and J3 are forward-biased, while J2 is reverse-biased, due to which only a small leakage current exists from the anode to the cathode until the applied voltage reaches its breakover value, at which J2 undergoes avalanche breakdown, and at this breakover voltage it starts conducting, but below breakover voltage it offers very high resistance to the current and is said to be in the off state.

2.2 Forward conduction mode

SCR can be brought from blocking mode to conduction mode in two ways: either by increasing the voltage across anode to cathode beyond breakover voltage or by applying positive pulse at gate. Once SCR starts conducting, no more gate voltage is required to maintain it in the ON state. There are two ways to turn it OFF:

1. Reduce the current through it below a minimum value called the holding current and
2. With the gate turned off, short out the anode and cathode

momentarily with a push-button switch or transistor across the junction.

2.3 Reverse blocking mode

SCRs are available with reverse blocking capability, which adds to the forward voltage drop because of the need to have a long, low-doped P1 region. (If one cannot determine which region is P1, a labelled diagram of layers and junctions can help). Usually, the reverse blocking voltage rating and forward blocking voltage rating are the same. The typical application for reverse blocking SCR is in current-source inverters.

2.4 V-I Characteristics of SCR

V-I: Curve between anode-cathode voltage (V) and anode current (I) of an SCR at constant Gate current.

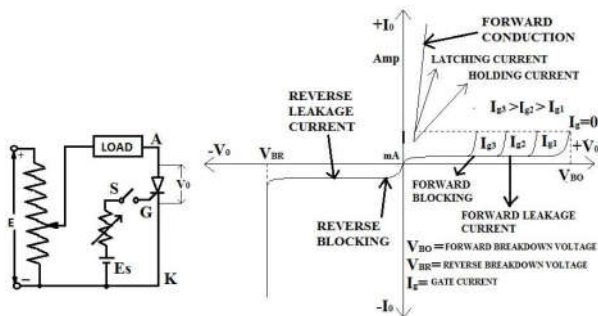


Figure 2: VI characteristics of SCR

2.4.1 Forward Characteristics

- Anode is +ve w.r.t. cathode
- When supply voltage is increased from zero, suddenly the SCR starts conducting => breakover voltage
- Voltage drops at this point suddenly as shown by the dotted line.
- If proper gate current is made to flow, then SCR can close at smaller supply voltage.

2.4.2 Reverse Characteristics

- Anode is -ve w.r.t. cathode
- Initially the anode current retains small (viz. leakage current)
- Beyond a particular reverse voltage, the SCR starts massive conduction (avalanche) => Reverse breakdown voltage

3. Application of SCR

3.1 A.C. Motor starters and regulators

Probably the simplest application of controlled rectifiers to motor control is in an A.C. static contactor circuit, which may be used as a direct-on-line starter for a squirrel-cage induction motor. Fig:(3) shows typical single-phase and 3phase circuits. The control unit in each case comprises a pulse generator which is switched by a bistable circuit of some kind in such a way as to give only 'off' and 'on' conditions without any phase control, so that the rectifier

groups function simply as open or continuously closed switches. Feedback into the pulse-generator control circuit from a current transformer in series with the motor provides automatic over-current protection by inhibiting the firing pulses in the event of an overload, conventional electronic principles being employed to obtain any inverse-time law required to correspond to the thermal ratings of the motor.

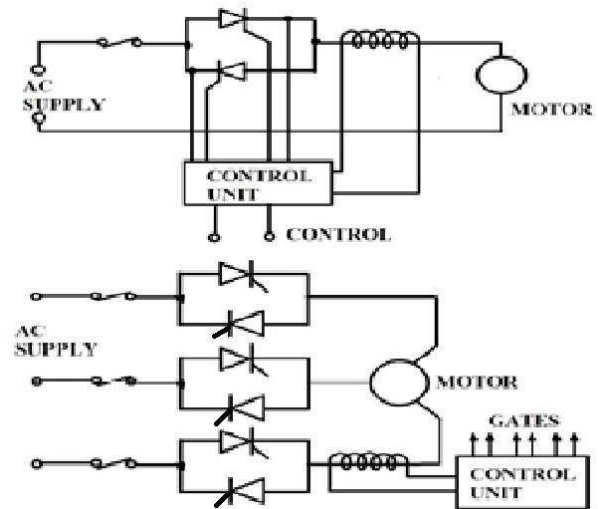


Figure 3: AC Motor Starter

Subject to manufacturers' overriding limits, the intermittent rating applicable to the starting condition can easily be estimated if the simplifying assumptions are made that the starting period may be considered long in relation to the thermal time-constant of the rectifier and short in relation to that of the cooling structure, and that starts are not excessively frequent. The rating then depends primarily on the device base temperature produced by the normal load current and the base-to-junction temperature rise produced by the starting current. On this basis, as an example, two 26 A controlled rectifiers will control a 3hp single-phase motor taking 15 A at full load and 80A on starting in an ambient temperature of 35°C.

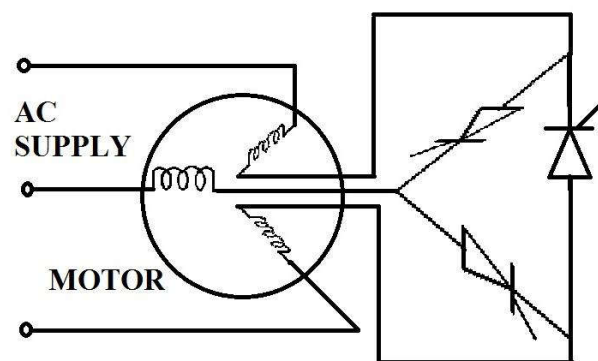


Figure 4: Alternative 3 phase contactor circuit

Fig:(4) shows an example of the economy that can sometimes be made by suiting the load to the control gear, as distinct from suiting the control gear to the load. By opening, as it were, the star point of a 3-phase motor winding it is possible to insert an assembly of only three controlled rectifiers and

achieve the same result as with the six devices shown in Fig:(3). If the simple on/off pulse generators are replaced by drivers with phase control, the voltage applied to the motor may be reduced for starting to limit the starting current and gradually increased to the normal level. The principal other application of such A.C. regulators to machine control is to the control of ordinary rectifier circuits, for which purpose they may be considered together with non inverting controllable rectifiers.

4. TRIAC

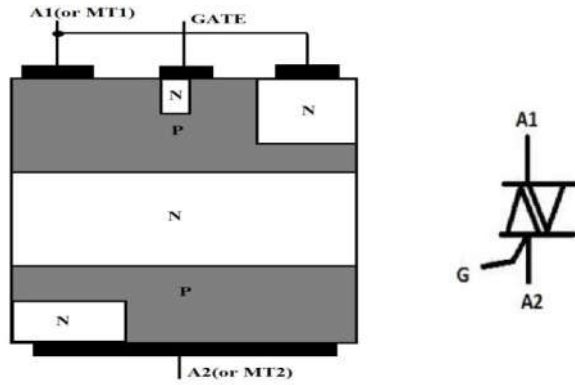


Figure 5: Schematic diagram of TRIAC and its symbol

TRIAC, from triode for alternating current, is a generic trademark for a three terminal electronic component that conducts current in either direction when triggered. Its formal name is bidirectional triode thyristor or bilateral triode thyristor. A thyristor is analogous to a relay in that a small voltage and current can control a much larger voltage and current. The illustration on Fig:(5) shows the circuit symbol for a TRIAC where A1 is Anode 1, A2 is Anode 2, and G is Gate. Anode 1 and Anode 2 are normally termed Main Terminal 1 (MT1) and Main Terminal 2 (MT2) respectively. TRIACs differ from SCRs in that they allow current flow in both directions, whereas an SCR can only conduct current in a single direction. Most TRIACs can be triggered by applying either a positive or negative voltage to the gate (an SCR requires a positive voltage). Once triggered, SCRs and TRIACs continue to conduct, even if the gate current ceases, until the main current drops below a certain level called the holding current.

4.1 Modes of operation of TRIAC

In quadrants 1 and 2, MT2 is positive, and current flows from MT2 to MT1 through P, N, P and N layers. The N region attached to MT2 does not participate significantly. In quadrants 3 and 4, MT2 is negative, and current flows from MT1 to MT2, also through P, N, P and N layers. The N region attached to MT2 is active, but the N region attached to MT1 only participates in the initial triggering, not the bulk current flow. In most applications, the gate current comes from MT2, so quadrants 1 and 3 are the only operating modes (both gate and MT2 positive or negative against MT1). Other applications with single polarity triggering from an IC or digital drive circuit operate in quadrants 2 and 3,

then MT1 is usually connected to positive voltage (e.g. +5V) and gate is pulled down to 0V (ground).

4.2 V-I characteristics of TRIAC

The TRIAC characteristics is similar to SCR but it is applicable to both positive and negative TRIAC voltages. When the device gets turned on, a heavy current flows through it which may damage the device, hence in order to limit the current a current limiting resistor should be connected externally to it.

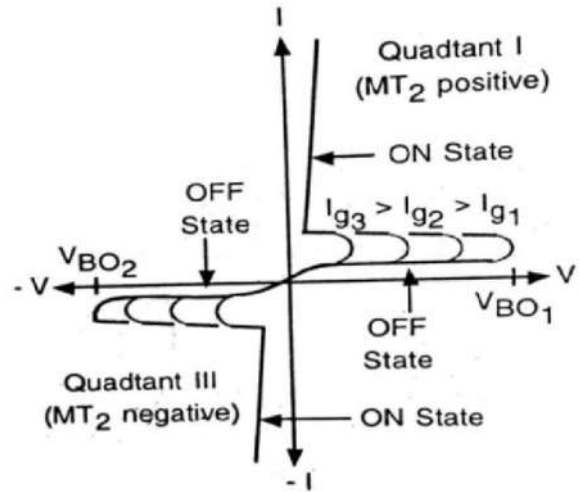


Figure 6: VI characteristics of TRIAC

By applying proper gate signal, firing angle of the device may be controlled. The gate triggering circuits should be used for proper gate triggering. We can use DIAC for triggering the gate pulse. For firing of the device with proper firing angle, a gate pulse may be applied up to a duration of 35 μ s.

4.3 Application of triac

4.3.1 Proposed real time based led driver for street lighting

Real time based systems are not reliable in outdoor environment. Proper design efforts are required to meet the real time specification. Fig:(7) shows the functional block diagram of proposed system. Proposed system limelight on phase angle detection of TRIAC and regulation of output current using single controller in real time to enhance the energy efficiency of street lighting and loop stability. Microcontroller is used to control the phase angle and LED current which ensure the operation in real time environment. PWM controller in feedback loop uses extra circuitry conventionally which is reduced same operating on microcontroller.

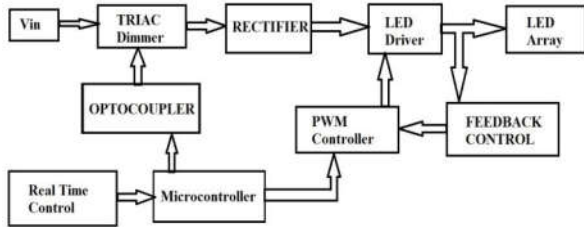


Figure 7: Proposed schematic of Dimmable LED driver with time based control

In the given block schematic additional circuits required for phase angle detection, primary side regulation integrated circuit, LED current adjusting circuits are reduced. Digital controller plays vital roles to drive both TRIAC and current regulation circuit in the feedback, though design considerations are not particularized for specific application. Adoptive timing design is challenge in real time embedded system. Adoptive timing interfacing with digital controller replenishes the design considerations accessible in such real time applications. The following section introduces the main system function employing controller.

4.3.2 Phase angle detection using microcontroller

TRIAC is an inexpensive solution for controlling the ac power delivered to load. TRIAC has three terminals namely MT1, MT2 and gate. During each half cycle of AC, a gate pulse is required to turn on. Fig:(8) shows block diagram of microcontroller pin can drive TRIAC gate. The waveform across load is shown in fig. 3. Real time clock feed timing to microcontroller, based on timing, pulse is generated in microsecond. TRIAC required that firing pulse in millisecond for that gate driving circuit needed. One can use transistorized pulse transformer or opto-coupler in gate driving circuit TRIAC.

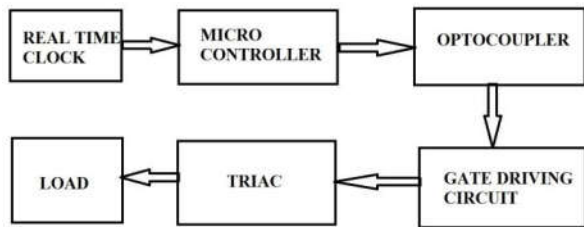


Figure 8: Block diagram of Microcontroller driving a TRIAC gate

Current Regulation for Brightness control using Microcontroller Adjustment of LED current is done very precisely, as LEDs are current controlled devices.

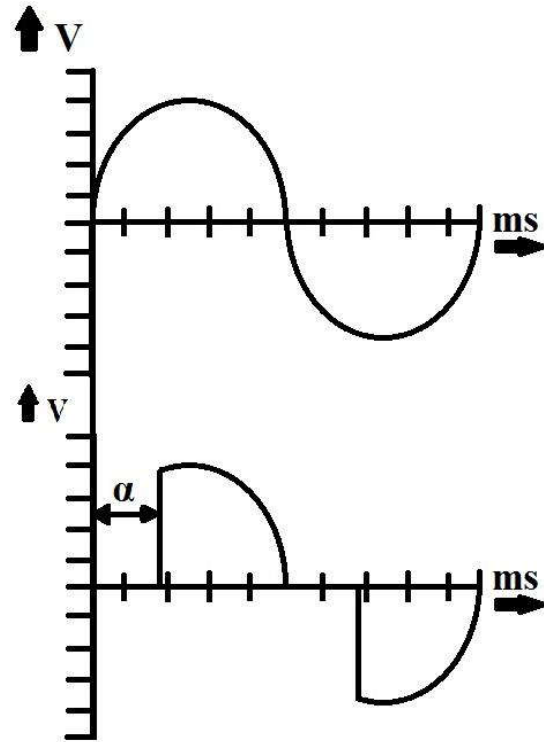


Figure 9: Mains supply waveform and TRIAC dimmer output waveform.

Brightness of LED is analogous to LED current. While using PWM dimming accurate controlling of current is important. Accurate current regulation used to minimize shifts in colour, variations in supply voltage. The proposed system designed to achieve high efficiency while controlling the LED current at different real time levels. The time levels are decided by considering standard time in which street light dimming is done. Soft control dimming is presented in proposed system results in an increased efficiency. For achieving high efficiency wide range of dimming is essential for high voltage street lighting. As shown in fig:(7), PWM dimming can be achieved through controller with negative feedback system, for this linear current regulator is used with fly-back topology.

5. Insulated Gate Bipolar Transistor (IGBT)

An insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch which, as it was developed, came to combine high efficiency and fast switching. It switches electric power in many modern appliances: variable-frequency drives (VFDs), electric cars, trains, variable speed refrigerators, lamp ballasts, air-conditioners and even stereo systems with switching amplifiers.

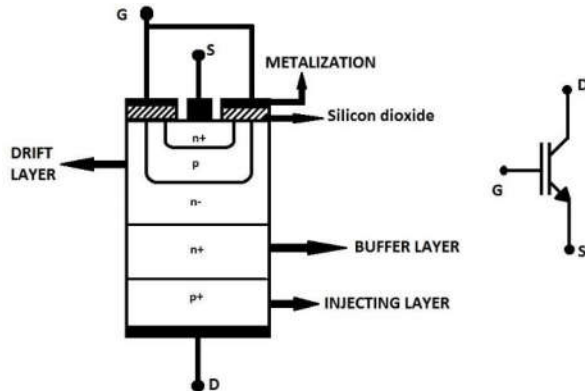


Figure 10: Schematic diagram and symbol of IGBT

The IGBT is a semiconductor device with four alternating layers (P-N-P-N) that are controlled by a metal-oxide-semiconductor (MOS) gate structure without regenerative action. The characteristics is same as that of normal MOSFET but and the end part its current increases due to its BJT characteristics.

5.1 Application of IGBT

5.1.1 DC transmission system

Conventional HVDC transmission employs line commutated, current-source converters requiring a synchronous voltage source in order to operate. The conversion process demands reactive power from filters, shunt banks, or series capacitors which are part of the converter station. Any surplus or deficit in reactive power must be accommodated by the ac system. This difference in reactive power needs to be kept within a given band to keep the ac voltage within the desired tolerance. The weaker the system or the further away from generation, the tighter the reactive power exchange must be to stay within the desired voltage tolerance.

Proper control of the converter and its associated reactive power compensation allows the ac system voltage to be held within a fairly tight and acceptable range. Unlike a generator or static variable compensator, however, a conventional HVDC converter cannot provide much dynamic voltage support to the ac network. HVDC conversion technology using voltage source converters, however, can not only control the power flow but also provide dynamic voltage regulation to the ac system. Fig:(11) depicts the P – Q characteristics for a VSC designed for HVDC transmission. The capacitive limit is due to imposing a voltage limitation. If the system voltage is reduced, this limit increases. The reactive power control range available depends on the active power operating point.

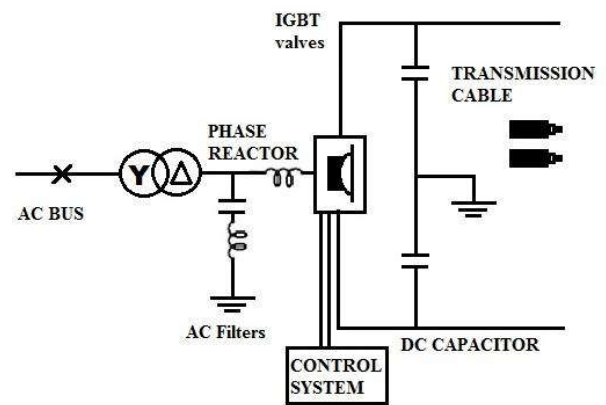


Figure 11: VSC Transmission

5.1.2 vsc converter design

VSC-based HVDC transmission utilizes several important technological developments:

- High voltage valves with series-connected IGBTs
- Compact, dry, high-voltage dc capacitors
- High capacity control system
- Solid dielectric DC cable

A special gate unit and voltage divider across each IGBT maintain an even voltage distribution across the series connected IGBTs. The gate unit not only maintains proper voltage sharing within the valve during normal switching conditions but also during system disturbances and fault conditions. A reliable short circuit failure mode exists for individual IGBTs within each valve position. Depending on the converter rating, series-connected IGBT valves are arranged in either a three-phase two-level or three-level bridge. In three-level converters, IGBT valves may also be used in place of diodes for neutral point clamping. Each IGBT position is individually controlled and monitored via fibre optics and equipped with integrated antiparallel, free-wheeling diodes. Each IGBT has a rated voltage of 2.5 kV with rated currents up to 1500 A. Each VSC station is built up with modular valve housings which are constructed to shield electromagnetic interference (EMI). The valves are cooled with circulating water and water to air heat exchangers. PWM switching frequencies for the VSC typically range between 1-2 kHz depending on the converter topology, system frequency and specific application.

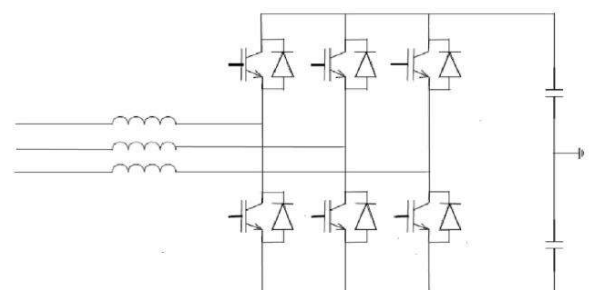


Figure 12: pwm signal for 2-level vsc

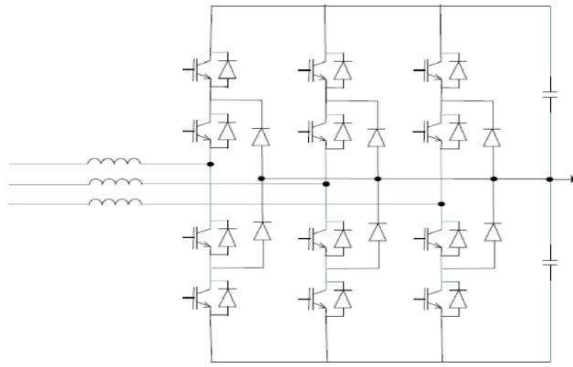


Figure 13: pwm signal for 2-level vsc

Each vsc is effectively mid-point grounded and coupled to the ac bus via phase reactors and a power transformer with intermediary shunt ac filters. the ac filters are tuned to multiples of the switching frequency. this arrangement minimizes harmonic content and avoids dc voltage stresses in the transformer which allows use of a standard ac power transformer for matching the ac network voltage to the converter ac voltage necessary to produce the desired dc transmission voltage. dc capacitors are used across the dc side of the vsc. for transmission applications there may also be dc filters and a zero-sequence blocking reactor. the filters and zero sequence reactor are used to mitigate interference on any metallic telephone circuits that run adjacent to the dc cables. the total capacitance of the pole to ground dc capacitors vary with the application. dc capacitance is higher for vsc used for flicker mitigation.

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