SECTION IV

STATIC RELAYS

AND

STATIC PROTECTION SCHEMES

38-A

Introduction to Static and Microprocessor-based Integrated Programmable Protection, Monitoring and Control Systems

— Introduction to Static Relays and Integrated programmable Protective monitoring and control systems. Historical review — basic comparison, recent trends — Analogue Relays, Digital relays, Programmable Relays — Modular concept, Functional Modules and Assembly — Devices and components — Functional units in static relay system — Analogue circuits, Digital Circuits, Programmable Systems — AD Conversion — Applications of static relays — Components of Static Relays.

Ch. 25 gives Introduction to Protective Relaying. The principles described in Sec. 25.1 to 25.16 are applicable to Electromagnetic Relays and Static Relays. During 1980's Static relays and Microprocessor-based integrated, programmable protection, control and monitoring systems have been introduced. The versatile systems perform several tasks including monitoring, protection, data acquisition, display, control etc. Static relays and combined protection and control systems form an integral part of SCADA Systems. (Ch. 50)

38.1. INTRODUCTION AND DEFINITION

Static Relay (Solid State Relay) is an electrical relay in which the response is developed by electronic/magnetic/optical or other components, without mechanical motion of components.

Note. A relay which is composed of both static and electromechanical units in which the response is accomplished by static units is also called as a static relay.

In static relays, the measurement is performed by electronic/magnetic/optical or other components *without mechanical motion.* However additional electromechanical relay units may be used in output stage as auxiliary relays. *A protective system is formed by static relays and electromechanical auxiliary relays.*

Fig. 38.1 (*a*) illustrates the *essential components* in a static relays. The output of CT's of PT's or transducers is rectified in *rectifier.*

The rectified output is fed to the *measuring unit.* The measuring unit comprises comparators, level detectors, filters, logic circuits. *The output is initiated when input reaches the threshold value.*

The output of measuring unit is amplified by *Amplifier.*

The amplified output is given to the *output unit* which energizes the trip coil only when relay operates.

In conventional electromagnetic the measurement is carried out by comparing operating torque/force with restraining torque/force. The electro-mechanical relay operates when operating torque/force exceeds the restraining torque/force. The pick-up of relay is obtained by movement of movable element in the relay. In a static relay the measurement is performed by static circuits.

A simplified block diagram of single input static relay is given in Fig. 38.1 (*a*). In individual relays there is a wide variation. The quantities : voltage, current etc. is rectified and measured.

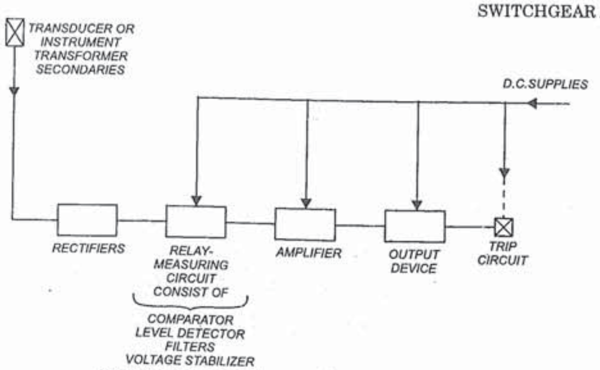


Fig. 38.1 (*a*). Block diagram of a static relay-simplified.

When the quantity to be measured reaches certain well defined value, the output device is triggered. Thereby current flows in the trip circuit of the circuit-breaker. Fig. 38.1 (*b*) gives a block diagram of a microprocessor based digital, programmable static relay.

Static relays can be arranged to respond to electrical inputs. The other forms of inputs such as heat, light, magnetic field, travelling waves etc. can be suitably converted into equivalent analogue or digital signals and then fed to the static relay. A multi-input static relay can accept several inputs. The logic circuit in the multi-input digital static relay can determine the conditions for relay response and sequence of events in the response.

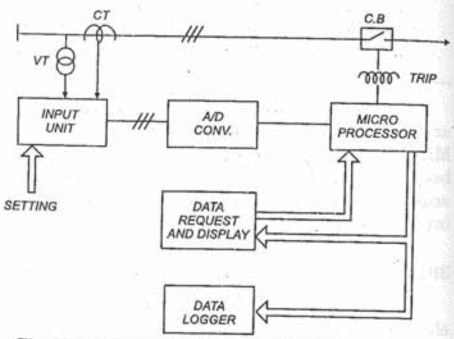


Fig. 38.1 (*b*). Block diagram of a simple Microprocessor Based Digital Static Relay.

A programmable protection and control system has a microprocessor or microcomputer in its circuit. *With the help of the logic circuits and the microprocessor the integrated protection and control system can perform several functions of data acquisition, data processing, data transmission, protection and control. Earlier, for each of these functions, separate electromechanical or static units were used along with complex wiring.*

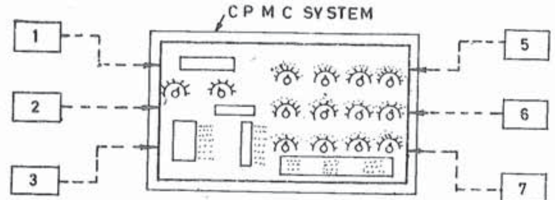
A *static relay* generally has several functional units. Some of the auxiliary functional units may be *electromechanical.*

The types of electronic circuits in static protection system include :

(1) Analogue circuits (2) Digital circuits (3) Hybrid circuits. For very simple functions, analogue circuits are preferred. For complex functions, digital circuits are preferred.

Advanced digital Static Relays may have Programmable System. Such relays are preferred for complex functions.

A *static relay may have one or more programmable units such as a microprocessor. Such relays are called programmable relays or microprocessor based relays or microprocessor controlled relays.* Programmable Static Relay system can perform several functions including protection, monitoring, data acquisition, control.



1. Data acquisition and Data processing System
2. Protection system
3. Control system
4. Data transmission system
5. Man-machine interface
6. Event recording
7. Additional required features.

Fig. 38.1 (*c*). Combined Protection, Monitoring and Control System (CPMC). CPMC has sub-systems (1 to 6) in a single unit.

An integrated static programmable protective and control system has one or more of the following subsytems (Fig. 38.1 (*c*)).

— Data acquisition and processing subsystem
— Protection system
— Control system
— Data transmission system

The required subsystems are assembled and mounted on a single panel to form an integrated modular programmable combined protection and control system. Fig. 38.1 (*c*) gives the concept of Combined Protection, Monitoring and Control System (CPMC) programmable system.

The total interconnected power system is managed by **Supervisory Control and Data Acquisition (SCADA) system, Energy Management Systems (EMS) and Automatic generation control systems (AGC).** *Integrated Protection and control programmable systems installed in generating station control rooms, substation control rooms and load control centres form the subsystems of the SCADA, EMS and AGC system. The programmable protection and control systems in different locations are linked by means of data transmission channels such as Power Line Carrier (PLC), Microwave, Fibre optic cables (For shorter lengths).*

The unit level has protective relays each of which performs one or more protective functions *e.g.* overcurrent protection, earth fault protection. Unit level is provided for each protected zone, *e.g.* bus zone, transformer zone, line zone.

At *substation or generating station level,* the microprocessor based system performs several protective functions and monitoring such as back up protection, autoreclosing sequence, sequential tripping, load shedding, remote signalling etc.

At *control centre level* the programmable system performs several functions of load management, load frequency control, planning operation, monitoring, economic loading, moral emergency and post-emergency actions.

In *electromechanical relays and systems,* a separate relay unit is required for each protective function. Several separate units are required in protective system of a greater or a large motor etc. And separate control systems are required for performing desired control and monitoring functions. This results in very large control panels and protection panels and complex wiring. Several operators are required in the control room to supervise the various control and protective panels.

With *microprocessor based combined protection, monitoring and control systems,* the complex tasks are performed automatically. The operator can get necessary information on the VDU (Video Display Unit) of the man-machine interface.

The electromagnetic units, hardwired static relay units and programmable units are used judiciously in the control and protective systems. *For simple functions electromagnetic units will con-*

tinue to be used. For multifunction relays, hardwired or programmable static relays are being preferred. For higher hierarchical levels at substation control rooms, power station control room and load control centres, the Combined Programmable Protection and Monitoring and Control Systems (CPMC) are preferred.

Table 38.1. Evolution of Static Relays and Integrated Protection and Control Systems

Type of Unit System	*Remarks*
Single function relays with : 1 Analogue Circuits 2 Digital circuits	— Performs one or more Protective functions. — Modular concept for subassemblies — Required functional block is assembled to form the relay unit.
Multifunction relays with : 1 Analogue Circuits 2 Digital Circuits	— One or more inputs — The relay unit may be hardwired or programmable.
Hardwired Digital or Analog Static Protective System	— Several relay units required for protection of a machine or power system component are assembled to form one protective system. *e.g.* Generator protection system, has overcurrent, reverse power, under voltage relay units.
Programmable Static Protective System	— It has additional logic circuit and programmable microprocessor.
Integrated Protection Monitoring and Control System. (IPMC)	— It has required functional subsystems such as data acquisition unit, protective unit data transmission unit, control unit. The microprocessor performs several functions.
Also called : Combined Protection Monitoring and Control Systems (CPMC) [Fig. 38.1 (*c*)]	— The protective functions may be segregated (separated) from control functions suitably. *e.g.* protective functions may deal with tripping of breakers whereas the control functions may deal with monitoring data processing and control.

With the developments in semiconductor technology, digital electronics, microprocessor technology and digital control systems fibre-optics data transmission etc. there has been a tremendous leap in the field of a digital static relays. The development of integrated circuits are more reliable and more compact. Furthermore, the microprocessor and digital computers are being increasingly used in power system protection, and control.

The static relays and static protection has grown into a special branch in its own right. This section covers principles and applications of static relays and static protection systems in details.

38.2. STATIC VERSUS ELECTROMAGNETIC RELAYS

The static relays compared to the corresponding electromagnetic relay have many advantages and a few limitations. The choice between an electromagnetic relay and a static relay depends upon

— Technical requirements of characteristics and protective functions.

— Overall cost.

For simple protective functions and for protection of simple low power equipment, electromechanical relays are preferred. Electromechanical units are also be used as components of total predominantly static relay e.g. for auxiliary relay functions, output functions.

For complex protective functions requiring accurate characteristics for various protective functions and for protection of costly, large equipment/machine, static relays are preferred. These may be hard-wired or programmable.

For integrated protection and monitoring systems programmable microprocessor controlled static relays are preferred.

(*a*) Advantages of Static Relays

1. **Low Power Consumption.** Static relays provide less burden on CT's and PT's as compared to conventional relays [Refer Table 38.2 (Also see Sec. 35.4 'Burden'].

In other words, the power consumption in the measuring circuits of Static Relays is generally much lower than for their electromechanical equivalents. The consumption of 1 milliwatt is quite common in static overcurrent relay. Whereas, an equivalent electromechanical relay can have consumption of about 2 watts. Reduced consumption has the following merits :

— CT's and PT's of less VA rating

— The accuracy of CT's and PT's increased.

— Air-gapped CT's can be used.

— Problems arising out of CT saturation are avoided

— Overall reduction in cost of CT's and PT's.

2. **Resetting Time and Overshoots.** By using special circuits, the resetting times and overshoot time can be reduced thereby the selectivity can be improved.

3. **No moving contacts** and associated problems of arcing, contact bounce, erosion, replacement of contacts etc.

4. There is no effect of gravity on operation of a static relays. The relay can be installed in vessels, aircrafts etc.

Table 38.2. Reference Values of Burden of Static Ralays*

Item	*Conditions*	*Burden per phase*
1. Instantaneous Measuring Relay (*a*) Current Relay	Measuring circuit at lowest setting current ; 0.3 A to 20 continuous	7 to 100 mVA
(*b*) Voltage Relay	Measuring circuit at lowest setting voltage : 24 V/48, V/60 V, d.c.	20 mVA
2. Time-lag Over-current Relay	At rated current, given current, setting current 1 to 8 A	0.03 to 0.08 VA
3. Impedance Relay	At rated current, rated voltage (*a*) Current circuit (*b*) Voltage circuit	 0.2 to 0.3 VA 0.8 to 0.9 VA
4. Differential Relay for Transformer protection	(*a*) Normal current : 1 A (*b*) Normal current : 5 A	0.02 VA 0.18 VA

5. **Single Relay for Several Functions.** By combining various functional circuits, a single static relay can replace several conventional relays.

For example for motor-protection, a single static relay can provide over current, under voltage, single-phasing, short-circuit protection by incorporating respective functional blocks. This is not possible in electromechanical relays.

6. **Compactness.** Static relay are compact. A single relay performs several functions. A single Microprocessor based system can substitute several independent protection and control relay units. The space required for installing protective relay and control relays etc. is reduced. A single panel can incorporate a protection and control system for several functions.

7. **Superior Characteristic and Accuracy.** The characteristics of static relays are accurate and superior. They can be altered within certain range as per requirement of protection. *e.g.* static distance relay can have narrow rectangular characteristic on R-X plane. Several features can be incorporated depending upon the application requirements. Static relays of superior speed ($\frac{1}{2}$ cycle, 1 cycle) are available.

* As there are wide ranges and applications of static relays, the above mentioned values just for familiarity, not for application guidance.

8. **Transducers.** Several electrical or non-electrical quantities can be converted into electrical quantities and then fed to static relays.

9. **Static Relays can 'think'.** Complex protection schemes employ logic circuits. *Logic means the process of reasoning, induction or deduction.* Suppose, several conditions are imposed on a protective system such that for certain conditions, the relay should operate, and for some other conditions, the relay should remain stable; in such cases logic gates can be adopted.

Digital electronics and Logic circuits are used with multi-input static relays. The relay determines the response depending upon the conditions, of various inputs and the allocated logic.

e.g. Static distance relay can be given additional features of auto-reclosing unit. The relay can determine whether to give reclosing command or not depending upon the impedance measurement, synchronizing check, feature, etc.

10. **Programmable Operation.** The characteristic programmable relays can be altered by changing the programme. 'Programme' means sequential instructions that direct the microprocessor in the relay to perform specific functions.

11. **On-line computation and Functions.** The characteristics and functions of programmable relays can be altered on the basis of on-line computation of various variables.

e.g. which back-up breaker to operate with minimum outage can be decided by prevailing network configuration and on-line real time data.

12. **Interface with SCADA and EMS.** Static protection, control and monitoring system for substations, power stations etc. form a part of SCADA, EMS and AGC Systems which are indespansable in to-days AC Networks. (Ch. 50)

13. **Remote Back-up and Monitoring.** Static relays assisted by power line carrier can be used for remote back up and network monitoring.

In *centrally monitored systems,* the back-up protection is monitored by the digital computer. The switching is carried out in such a sequence that the stability is improved. (Ref. Sec. 43.10)

14. **Repeated Operations Possible.** Static relays can be designed for repeated operations as there are no moving parts in measuring circuits.

15. **Effect of Vibrations and Shocks.** Most of the components in static relays, including the auxiliary relays in the output stage are relatively indifferent to vibrations and shocks. The risk of unwanted tripping is less with static relays as compared to the corresponding electromechanical relays. This aspect makes the static relays suitable for earthquake prone areas, ships vehicles locomotives, aeroplanes etc.

16. **Self-supervision (monitoring) of the Relay.** Complex static relays have a facility of continuous and comprehensive self-monitoring by a special hardware called 'Watchdog' and test software. Any fault which occurs within the relay (*e.g.* failure of a component) are detected at once. Thus, periodic testing of the relay can be minimised.

17. **Simplified testing and servicing.** The static relays are provided with integrated features for self-monitoring, easy testing and servicing. Defective module can be replaced quickly.

18. **Extension of application by adding suitable modules.**

19. **Several functions.** A static protection control and monitoring system can perform several functions such as protection, monitoring, data-acquisition, measurement, memory, indication, data-communication etc.

38.3. LIMITATIONS OF STATIC RELAYS

1. **Auxiliary Voltage Requirement.** This disadvantage is now not of any importance as auxiliary voltage can be obtained from station battery supply and conveniently changed to suit local requirements.

2. **Electrostatic Discharges (ESD).** Semiconductor components are sensitive to electro-static discharges (ESD). Electrostatic charges are developed by rubbing of two insulating components. Some components are more sensitive than others. Even small discharges can damage the components which would normally withstand 100 V. Precautions are necessary in manufacturing of static relays to avoid ESD caused component failures.

3. **Voltage Transients.** The static relays are sensitive to voltage spikes or voltage transients. Such voltage transients are caused by operation of breaker and isolator in the primary circuit of CT's and PT's. Serious over voltage are also caused by breaking of control circuit, relay contacts etc. Such voltage spikes of small duration can damage the semiconductor components and can also cause maloperation of relays. Several relay failures were recorded during 1960 due to the above mentioned cause. The measurements showed that the voltage spikes in secondary circuits can attain an amplitude of 20 kV in rare cases and generally 12 kV.

Special measures are taken in static relays to overcome this difficulty. These include use of filter circuits in relays, screening the cable connected to the relays.

4. **Temperature Dependance of Static Relays.** The characteristics of semiconductor are influenced by ambient temperature. For example, the amplification factor of a transistor, the forward voltage drop of a diode, etc. change with temperature variation. This was a serious limitation of static relays in the beginning. Accurate measurement of relay should not be affected by temperature (–10°C to + 50°C). This difficulty is overcome by the following measures :

— Individual components in circuits are used in such a way that change in characteristic of components does not affect the characteristic of the complete relay.

— Temperature compensation is provided by means of thermistor circuits, digital measuring techniques, etc. Thus modern static relays are designed to suit wide limits of temperatures (–10°C to + 50°C).

5. **Price.** For simple, single function relays the price of static relays is higher than the equivalent electromechanical types. [Fig. 38.1 (*d*)]. For multifunction protection, static relays provide economical solution. The production technology of plug-in type static relays on the panel (Sec. 38.7) permits manufacture of standard relays on large scale. The customer's requirements can be fulfilled quickly by incorporating required relay units on the panel.

6. In electromagnetic relay, the pick-up relays or reset of relays does not affect the relay characteristic since the operation is based on the comparison between operating torques. However, the statics relay characteristic is likely to be affected by the operation of output device.

For simple protective functions, conventional electromechanical relays provide economic and satisfactory choice. For complex protection systems static relays are preferred technically and economically. As static relays perform protective and monitoring functions, the additional cost is justified on the basis of improved system stability, reliability and availability of electric power.

38.4. RELIABILITY AND SECURITY OF STATIC RELAYS

Reliability is defined as the likelyhood of that the device will perform as expected at all times. This includes (1) Security to not operate incorrectly and (2) Dependability to operate correctly when expected.

Security of a Relay or Protection system is the factor of reliability which relates to the degree of certainty that the relay will not operate incorrectly.

Reliability of protective relaying is very important. Electromechanical relays have high reliability, due to (1) precision, manufacture (2) few, reliable components in their construction (3) experience gained in designing manufacturing testing and maintenance Static Relays are in infant stage and have to prove their reliability. As the static relays have several discrete components such as resistors, capacitors, semi-conductors in their construction, reliability depends on reliability of these components and reliability of the total assembly. It is therefore, necessary to choose the components with great care. Each components should be type tested. Care should be taken in connections, soldering etc. The ambient conditions, voltage spike, should also be considered. The use of integrated circuits increases reliability of static relays. *Integrated circuits are much more reliable* *than the equivalent discrete component circuits.* Reliability of components is improved by strict quality control, presoaking the components to improve temperature response presoaking of a relay means, operating the relay under service conditions for certain time with current and voltage connected to it. With this method, bad components and poor joints can be detected.

Self monitoring feature in modern micro-processor based relays ensures indication of failed internal component. Thereby the failed component/circuit can be replaced. This increases the reliability and security of static relays.

38.5. HISTORICAL REVIEW IN BRIEF

— The major break-through in the application of electronics in power system protection occurred in 1928 when carrier current protection system was introduced for the protection of transmission lines. Earlier schemes were with vacuum tubes.

— The protective relays employing the vacuum tubes and gas tubes were not popular due to the short life of tubes, need of heater supply, slow speed, less reliability etc. Their use was mainly in control circuits. Protective relays employing vacuum tubes did not find any commercial success, except for carrier current protection systems.

— Transistors were invented in 1941 which led to a revolution in electronic technology. The development of static relays employing semi-conductor devices such as diodes, transistors, thyristors etc. was started in 1950's.

— The first generation of static relays were with discrete (independent, separately identifiable) component fitted on printed circuit boards (PCB). Relays with PCBs are manufactured even now.

— During the period 1958-1974, many leading manufacturers in the world have conducted research and development in static relays technology. The static relays of second generation employ Integrated Circuits (IC). The ICs may be small scale (SSIC), Medium Scale (MSIC) or large scale (LSIC)

— At present schemes of generator protection, bus-bar protection, transmission line protection etc. employing static relays are being used. These are with IC's and PCBs and are very compact (1980's). The ICs are available for Analogue and Digital Circuits.

— Fibre optic relays (1980's) use fibre optic circuits for conduction of light pulses. Fibre-optic relays and central circuit pilot wiring is gaining commercially success. (1990)

— Earlier generation of static relays (1970s) were with Analogue Circuits. Now Digital circuits are preferred. Such relays are called 'Digital Relays' or 'Numerical Relays'.

— Development of digital Electronics and Microprocessor (1980s) has resulted in programmable multi-function systems. The functions include measurement, data transmission, protection and control. Microprocessor controlled relays have become popular. (1990's)

— **Communication.** During 1980s, power system data communication systems with (1) carrier communication (2) Microwave radio communication (3) Telephone communication (4) FASIMILE transmission (5) Satellite communication systems, have been introduced for protection, monitoring and control.

38.6. RECENT DEVELOPMENT OF STATIC RELAYS

The present trends in static relays indicate the following aspects :

— *Miniaturization.* Due to change-over from discrete components to integrated circuits, the measuring parts of static relays are compact. The size of the complete relaying system will be influenced by the size of the transformers.

— *Increased reliability and reduced price.* Static relays with ICs are cheaper than these with discrete components.

— Use of digital techniques for measurements, instead of analogue techniques, used earlier. Thereby the tolerance of individual components will not influence measurement.

— Use of new type of instrument transformers instead of conventional CT's and PT's in ultra-high voltage networks. Development of optoelectric components for protection is in progress. We can expect the development of static relays to suit such devices.

— Increasing use of digital computers and microprocessors in power system protection. A closer co-operation of static relays and Energy Management Systems, Scada Systems etc. is in the offing.

— Programmable Relays, instead of Fixed-wired Relays. This gives 'flexibility' to the protection system.

— Combined Programmable Protection, Monitoring and Control Systems. (CPMC) have been introduced for Protection and Control of EHV-Substation.

— Use of fibre-optic cables in pilot wire differential protection.

— Ultra high speed directional wave relay (5ms) for protection of UHV AC lines and EHV-AC lines.

— Power system simulator for realistic testing of static protection systems.

— Protection and control system for HVDC-Substations.

Table 38.3
Electromagnetic Versus Static Relays

Function	Conventional Relay	Static Relay	
		Without Thyristor	With Thyristor
1. Input	1-3 W	10 mW	20 mW
2. Switching capacity	30 W	10 W	100 W
3. Power gain	8-32	1000	500
4. Continuous current rating	5 A	1 A	1 A
5. Time	10 m sec	20 sec	50 sec
6. Effect of vibration	Bearing affected	No effect	No effect
7. Ambient temperature range	No effect 5 to 70° C	Needs compensation	Needs compensation − 20°C to 100°C
8. Operations	Above 10^6	No limit	No limit
9. Effect of pollution	Yes	No	No
10. Testing	Easier	Difficult	Difficult

38.7. PRESENT TRENDS IN PROTECTION AND CONTROL TECHNOLOGY (1997)

The trends have been from *simple electromechanical relays, to Microprocessor-based Digital Relays* and finally Combined (Integrated) Protection. Monitoring and Control Systems for substations, generating stations and load control centres.

These trends have followed the advances in digital electronics, digital computer technology, microprocessor technology etc. and are listed in Table 38.4. The details have been covered in subsequent chapters.

The application of electromechanical, static, digital static, microprocessor based relays depends upon *complexity of protective functions.* For simpler single functions, electromechanical relays may be preferred. For complex, multi-functions microprocessor based relays may be preferred Ref. Fig. 38.3.

Table 38.4. Historical Trends in the Protection and Control Technology

Years	*Product description*	*Remarks*
1880—1940	Electromechanical relays of various types for : — Protective functions — Control functions	Used even today for simpler protection functions and simpler control functions.
1940—1960	Static Relays with vacuum tubes for carrier differential protection and microwave protection of transmission lines	Lateron replaced by static relays with semiconductors.
1960—1970	Static Relays (Analog) for protection of motors, generators, transformers, busbars transmission lines etc.	Analog relays may have a PCB and IC.
1965—70	Digital static relays	Used A/D conversion and digital Electronics Techniques IC, LSIC's used.
1968—75	Digital computer based static protection systems used for transmission systems for main and backup protection.	On-line digital computer used for protection type prodar 70 installed by westinghouse USA (Ref. Sec. 46.15)
	Proved costly for simpler protective functions.	Used in Generating stations, substations control centres etc. (Ref. sec. 46.4)
	Digital computer based systems for — Data Acquisition — Data monitoring — Data transmission — Data processing — Data display.	Integral part of Network control (Ref. Sec. 50.4).
1968—75	Various types of Digital computers installed in generating station control room, substation control room and Load control centres for Network monitoring and Network Automation.	— Large computers for load control centres. — Medium computers for Generating stations and substations. — Minicomputers for small substations. (Ref. Sec. 46.9)
1975—85	Microprocessors introduced for power system control and power system protection *Proved cost effective and advantageous for protective relays and control.*	Each individual protective system or control system can have its own microprocessor. Becoming increasingly popular. Ref. Ch. 43.B
1985—95	Combined (Integrated) Protection, Control and Monitoring systems based on Digital Computers, Microprocessors.	— For integrated substation control and protection — For integrated generating station protection and control. — For system control from load control centres.
1985—95	Introduction of SCADA systems AGC Systems EMS system etc.	Supervisory control and Data Acquisition systems (SCADA) are applied to AC Network. The protection and control functions are sub-divided at various levels in — Load control centre — Generating station control room. — Substation control room. — Major load centres etc.

Ref. Fig. 38.1 (*d*) which gives the trends over the years.

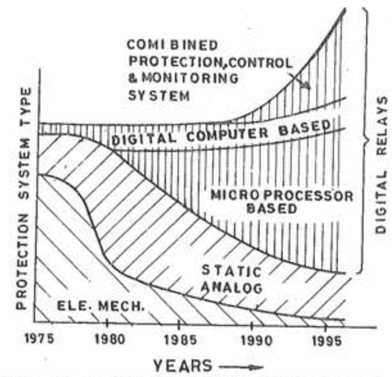


Fig. 38.1 (*d*). Application trends of the various alternative types of protective relays over the years.

(In 1975 the Static Relays were used only for complex functions such as a generator protection, EHV-line protection etc. Today Static Relays have replaced electromechanical relays in al-

Electromechanical Relays. These are ideally suitable for simple protective functions of individual loads. They are least costly in such applications. However for complex protective systems such as protection of transmission lines, protection of generators, protection of large motors etc. electromechanical relays are technically not preferred Several relays are necessary in the protection system the cost of protection with electromechanical relays increases rapidly with the complexity of protection (in terms of speed, characteristic number of functions etc.)

Static Relays (Analog). These are suitable for more complex functions and are preferred for almost all protective systems. With the use of printed circuit boards (PCB) and single chip IC's the cost of static relays has reduced rapidly and they are used for a wide range of applications.

Digital Static Relays. The logic circuits and digital electronics are used in relay circuits involving several functions. Such relays are preferred for complex protective systems. The relays may have PCB or IC having fixed circuit.

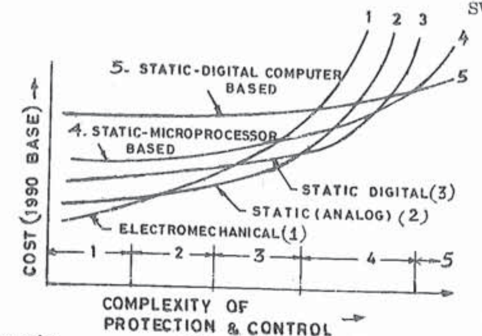
Programmable Relays with Microprocessors. These were developed during 1975-95 and have become *extremely popular* over a very wide range of applications. The microprocessor is provided within the relay. The relay can therefore perform logical functions. *The relays may be with fixed programme or variable programme. Cost of microprocessor based relays is much less than the earlier computer based protective relays.*

Digital Computer based Protective System. These were developed during 1968 in USA. However they are costly and can be justified for very complex multifunction EMS and SCADA systems. They are not preferred for individual protection systems.

Combined Protection, Monitoring and Control Systems (CPMC). These are being used for substation protection and protection in generating stations, protection of HVDC systems etc. They are generally microprocessor based. They simplify the entire protection and control system and they prove less costly for more complex and remote unattended power stations/substations.

Fig. 38.1 (*e*) and 38.1 (*f*) illustrate the applications and cost aspects of the above types of protection devices.

Combination of Static and Electromechanical Relays. At present both static and electromagnetic units are used in protection systems. 'All-or-nothing' relays are generally electromechanical type and measuring relays are either static or electromechanical. For simple



1. Least complex : Electro-mechanical relays
2. Slightly complex : Static (analogue)
3. More complex : Static (digital)
4. Very complex : Static-Microprocessor based
5. Extremely complex : Static-Digital Computer Based.

Fig. 38.1 (e). Preference of type of relay system with reference to *cost* and *complexity*.

protective measuring functions, electromechanical relays are preferred. For complex protective measuring functions, static relays are preferred. Hence, the electromechanical and static relays are equally important. Electromechanical relays are not obsolete.

38.8. MODULAR CONCEPT, BUILDING-BLOCK PRINCIPLE USED IN PREDOMINANTLY STATIC PROTECTION SYSTEMS

Modern protective measuring relays, all-or-nothing relays and other auxiliary devices are generally of plug-in-type. The required modules are plugged into terminal base. The terminal base fits into the switchboard cases and rackmounted frames. The required plug-in-devices are selected to form the required protective and control systems. *e.g.* app. 50 cm × 20 cm panel space can accommodate upto twenty relay modules with individual targets and 120 contacts. With plug-in type modules, the time required for screwing is avoided. The wiring is also minimised. *The required electromechanical or static relay modules and other auxiliary devices are plugged in to form the protective and control system.*

38.9. STATIC RELAY FUNCTIONAL CIRCUITS AND INDEX OF FUNCTIONS

The various functional requirements for measuring units, all-or-nothing units, auxiliary units and components are defined, standardised and each unit given certain index number. The index of functions consists of over 300 identified and standard functions.

The *predominantly static relay* is formed by combining required protective and auxiliary relay functions with one or more static relay unit.

The basis protective functions *required for protection of Generators, Motors, Transformers Lines, busbars etc. are identical with those studied in earlier chapters. Only the range and characteristics differ with each application, e.g.* consider overcurrent protective function which is used in generator protection, motor protection, transformer protection. The *overcurrent protection* may be further subclassified into :

— Instantaneous overcurrent
— Inverse time overcurrent
— Directional overcurrent
— Definite time overcurrent
— Under current
— Phase fault, Ground fault functions.

The basic overcurrent functional circuit or unit is used in respective static protection system for achieving overcurrent function. In static relays a large number of protective functions can be combined in one relay unit. In static protective systems, several protective relay units can be combined on one protection panel.

The principles of basic protective functions, *viz*. overcurrent, differential, distance etc. and the basic principles of protective zones main and back-up protection, desirable aspects of protective relays with respect to speed, accuracy, selectivity, discrimination sensitivity, reliability, adequateness, characteristic CT and VT connections etc. described in Ch. 25 to 37 apply to static protection systems. However, measurements in static relays is performed by electronic circuit and not by an electromechanical unit.

The standard terms and definitions (Sec. 25.8) have been evolved based on electromechanical relays and their protective systems. These terms are generally applicable to predominantly static relays with certain restructuring wherever necessary. *Terms and definitions used with Digital Computers and Microprocessor (Sec. 46.2) are applicable in the terminologies for Microprocessor based protective and control relays.*

The following sections and Chapters have a reference to predominantly static relays.

38.10. TYPES OF MEASURING AND ALL-OR-NOTHING RELAY UNITS (Ref. Sec. 25.8.3)

1. **Measuring Relay.** The relay which responds to an electrical quantity (or one of its parameters the name of which characteristics of the relay) and the response of the relay depends upon the measurement of the characteristics quantity and the response characteristics of the relay.

2. **All-or-nothing Relays and Auxiliary Relays.** All-or-nothing relay is an electrical relay which is intended to be energized by a quantity, whose value is either

— higher than that at which is picks up
— or, lower than that at which it drops out.

Note. The adjective 'All-or-nothing' can be deleted when no ambiguity will result. Auxiliary relays, latching and time delay relays fall into the category of All-or-nothing relays.

3. **Latching Relay (Bistable Relay).** It is an electrical relay which having responded to an input energizing quantity (or characteristic quantity) and having switched, remains in that condition after that quantity has been removed.

The position of a bistable relay can be controlled by two input circuits (*A* and *B*) or by two methods of connections of one input circuit (*A*)

— The *A* condition is that condition which corresponds to the energized condition related to *A* input circuit.
— *B* condition corresponds to energized condition of *B* input circuit.

4. **Monostable Relay (Self-reset relay).** A relay which having responded (to an input energizing quantity or characteristic quantity) and having changed its condition returns to its previous condition when the quantity is removed.

5. **Timing Relay or Time Delay Relay.** A *time-delay relay* that introduces a fixed or set-time delay into the operation of associated function. *Non-specified-time relay* has no accurate time.

6. **Static Relay.** An electrical relay in which the response is developed by electronic, magnetic, optical or other components without mechanical motion.

Note. A relay which is composed of both static and electromechanical units and which is designed to achieve the response by means of static units is also called a static relay. In static relays the measuring relays are static. The all-or-nothing relays are either static or electromechanical.

7. **Starting Relay or Starting Unit (Element).** The element (unit) or a protection system which responds to faults or abnormal service conditions and initiates operation of other elements (units) of protection system.

8. **Polarisation.** A term applied to input that provides reference for establishing the direction of system phenomena (such as direction of real power, direction of reactive power, direction of fault, direction of disturbance).

9. **Biased (Restraint) Static Relay.** Bias (restraint) means the action of input quantity which when present results in increase in the threshold value of another input quantity or otherwise limits the operation of the relay. Biased Relay is a relay in which the operating value is modified by means of additional electronic circuit which provides restraining rendency.

10. **Blocking Element (unit or relay).** An element (unit or relay) of a protection which under certain conditions limits or prevents the operation of other elements.

11. **Programme.** A sequential instructions that direct a microprocessor or computer to perform desired arithmetic and logical operations to perform specific tasks. Programmes form the software.

Programmable Relay : Flexible Relay, Microprocessor Based Relay.

A relay which responds to electrical quantities in accordance with the programme.

A programmable relay (or system) has a microprocessor or a microcomputer its functional system. The programmable relay (system) performs protection functions/control functions/data transmission functions/memory functions/self monitoring functions etc. by means of digital measuring techniques, programmable logic. The type of characteristic (*e.g.* inverse, very inverse, extremely inverse, definite time) can be selected directly of the relay in accordance with the changes in the network.

12. **Real Time (On line).** The actual time during which the relay/protective systems is in the state such that it can respond in accordance with the programme. On line protective and control system is a programmable system which takes into account the actual quantities on the line in real time.

38.11. ANALOGUE AND DIGITAL SUB-SYSTEMS IN PROTECTIVE RELAYING

The hardware used in the protective relaying system can be divided in the following three major classes :

(1) Analogue (2) Digital (3) Hybrid

All the three types of hardware are now commonly encountered in the power system protection, monitoring, control and also in various branches of power system engineering. Whereas during 1960's analogue and digital computation hardware was not introduced in stand-alone functional assemblies, the situation has changed rapidly during 1970's and 80's. The development of Large Scale Integrated Circuits (LSI) technology has resulted in development of both *Analogue and Digital* functional devices called *'Microchips'.* (Ref. Sec. 38.9)

The microchips (either Analogue or Digital) are functionally powerful (can perform several functions) and relatively cheap (as compared with earlier PCB circuits) (Ref. Sec. 38.9)

The protection/monitoring/control system has several functional systems (modules)

The functional modules can be either analogue or digital and in the form of :

Table 38.5. Forms of Functional Modules

- Discrete components connected by hardwire**
- Printed Circuit Board (PCB)**
- Integrated Circuits (ICs)**
- Large Scale Integrated Circuits (LSIs)**
- Microprocessor-based circuits*
- Digital computer based circuits*.

38.12. ANALOGUE PROTECTION SYSTEMS

In the engineering practice, analogue electronic circuits are used universally. These may be in form of PCB's or IC's. The required relay characteristics with certain variables (*e.g.* I and t for over-

*These are Digital type fixed programme or may be programmable.

** These are either analog or digital.

current relay) are represented by equations. The analogue circuits are formed by resistance capacitance, inductances, and protective features are added by using comparators. The analogues quantities are compared in comparators and the comparator distinguishes between the healthy and abnormal condition in the protected circuit. The analogue circuits can be used for solution of differential equations, for integrating current/voltage, for scating, for amplifying, for summing, for comparing and for obtaining more complex characteristics. Table 38.6 gives summary of important analogue circuits used in protective relays.

Table 38.6. Standard Analogue Electronic Circuits used in Static Relays

Analogue circuit	*Remarks*	*Reference*
1. Operational Amplifiers	— Basic element in analogue computation.	Sec. 38.21
	— Represented by a triangle.	Fig. 38.29
	— Used in circuits for addition, subtraction, integration, differentiation, and other combinations.	
	— Available in the form of IC, L.S.C.	Table 38.3
	— Available in very wide range of specs.	
	— Has limitations.	Table 38.13
2. Inverting Amplifiers	$V_0 = \frac{R_2}{R_1} V_1$	Sec. 38.24
3. Analogue Addition Summer.	$V_0 = -(V_1 + V_2)$	Sec. 38.24
4. Analogue subtraction (subtractor)	$V_0 = V_2 - V_1$	Sec. 38.24
5. Analogue Integrator	$V_0 = \frac{1}{RC} \int V_s \, dt$	Sec. 38.24
6. Analogue Differentiator	$V_0 = -RC \frac{dV_s}{dt}$	Sec. 38.24
7. Analogue Level detector.	$V_s = \pm V_\alpha$	Sec. 38.24
8. Analogue Comparator	$V_s > V_\alpha$ output V_0 positive $V_s < V_\alpha$ output V_0 negative Alternatively Output V_0, $V_0 = O$ for $(V_2 - V_1)$ Positive $V_0 = V_\alpha$ for $(V_2 - V_1)$ Negative.	Sec. 38.24
9. Function Generator	Generator certain well defined forms of functions *e.g.* steps, ramps, square wave triangular wave, sine wave. Standard function generators are commercially available.	
10. Multifunction convertors.	Several standard combinations of available commercially which provide a range of non-linear analogue functions *e.g.* a typical convertor may provide : Multiplication, division, square, square root, exponential, roots, sines, cosine, $\tan^{-1}(y/x)$, $\sqrt{x^2 + y^2}$, $\log x$ etc.	
11. Analogue computer.	It comprises several operational amplifiers circuits such as summer, inverter etc. The analogue computers are used for power system studies and in real time computing.	
12. Digital to Analogue Converters (DAC)	Gives Analogue output V_0 proportional to the digital input (V_1).	
13. Analogue to Digital Convertor (DAC).	Gives Digital output V_0 proportional to analogue input V_s.	Sec. 31.25
14. Analogue Multiplexers.	Used for converting a number of Analogue signals to a single ADC.	
15. Hybrid circuits	By use of ADC and DAC the analogue and digital circuits are combined to get Hyb.	

38.13. LIMITATIONS OF ANALOGUE SYSTEMS

— Analogue computation has lesser accuracy. The accuracy is limited by resolution with which the chosen analogue quantity (*e.g.* current) can be measured. Analogue quantities are, in principle, continuous and the limits of resolution are physical effects such as wire-to-wire spacing of potentiometers, random circuit noise etc.

— Operational amplifier have following limitations :

1. Voltage gain falls and phase shift is produced between input and output signals for frequencies beyond the range.
2. The transient response to step functions in sluggish.
3. Output impedance is low.
4. With feedback, operational instability may be introduced.
5. Logic operations are difficult to be obtained.

— Digital and *programmable operations* are not possible. This presents a seniors limitation in complex protective functions. Hence, analogue protective relays are used for less complex functions.

— *Digital techniques* are being used increasingly and are replacing analogue techniques for many protective functions and this trend with continue.

38.14. DIGITAL AND PROGRAMMABLE ELECTRONIC STATIC RELAYS

Digital electronic circuits process the information by processing descrete electrical signals in digital form. They can perform simple logic and arithmetic operations and can therefore be used to construct the basis functional circuits required for protective relaying system. The digital electronic circuits can be used to hold and store discrete information by means of 'memory'. The ability to store the information or data and to process the data by logical and arithmatical means is the inherent feature of digital data processing systems including microprocessor and digital computers.

The protective relaying functions require sequential operations depending upon information being processed. The digital protective relaying has ability to determine the sequence of operations which are performed on the basis of the information or data being processed. A digital system can be classified by the wave in which the sequence of operation is to be implemented.

Presently three forms of digital systems have become commercial successful :

1. Hardwired logic is used extensively for performing combination and sequential logic operations.
2. Microprocessor
3. Very large scale Integrated devices (VLSI)

38.15. HARDWIRE DIGITAL SYSTEMS

A digital system is called *hard-wired* if the sequence of operation is governed by physical interconnections of the digital processing elements by means of solid conducting paths (hard-wires). For example in a hard-wired logic system, physical interconnections of elements, determine the route by which the data flow between processing elements. The physical interconnection (hard-wired) determine the sequence or processing operations performed on the data. Thus the hard-wired digital protection and control system has fixed sequence of digital computation process and fixed sequence of operations.

This type of system is designed for specific protective or control function and is therefore inflexible. If the processing function has changed and the sequence process of logical operation is to be charged the processing elements and their interconnections (wiring) also need to be altered.

38.16. PROGRAMMABLE DIGITAL PROTECTIVE AND CONTROL SYSTEMS

A digital protective and control system is called 'Programmable' if the data processing function in the systems can follow a 'Programme' *i.e.* the sequential instructions to perform specific tasks (Sec. 43.28)

Programmable Digital system incorporates a general purpose processing element (Microprocessor or Digital computer) to which a programme (instructions in particular required-fashion) are fed. The programme has a purpose to implement specific functions in predetermined way.

The coded instructions are normally stored in the memory part of the system and the program forms an integral part of the system.

The ability to define the digital functions by programming gives a significant 'flexibility' into the system. It also enables an identical programmable hardware to be used for several different applications by using appropriate programmes.

38.17. FORMS OF DIGITAL ELECTRONIC CIRCUITS

1. For less complex functions, hard-wired digital logic circuits are used extensively to perform several logical functions. The integrated circuits may be called :

— Small Scale Integrated Circuits (SSTC)
— Medium Scale Integrated Circuits (MSIC)
— Large Scale Integrated Circuits (LSI)
— Very Large Scale Integrated Circuits (VLSI)

2. For complex functions where flexibility is required programmable devices are used.

The programmes may be of following types :

— Microprocessor based for complex functions
— Digital computer based for very complex functions.

The trend is toward increasing use of microprocessor based protection systems with each individual protected system.

38.18. INTEGRATION A CONTROL AND PROTECTION FOR HIGH VOLTAGE AC SUBSTATION

The modern AC Networks are formed by interconnections two or more independently controlled AC Networks (Areas). The hierarchical levels of control include (1) National Load control centre (2) Regional load control Centres (3) Power Station Control Rooms (4) Substation Control Rooms (Sec. 46.1, 50.4). Several supervisory, control and protection functions are performed from substation control room.

Before 1985, the protective functions were segregated (separated) from control functions, with traditional electromechanical relays and earlier generation of hard-wired static relays, the functions of protection systems were limited to (1) Sensing faults and abnormal conditions (2) Giving alarm (3) Tripping circuit-breakers (4) Autoreclosing of Circuit-breakers. *The substation supervisory functions and control functions were independent of the above protective functions.*

With the development of Programmable Digital Systems *i.e.* Microprocessor Based Systems, the entire supervisory functions, control functions, protective functions can be combined (integrated). The microprocessor based or Microcomputer based Integrated or Combined Protection, Monitoring and Control Systems (CPMC) have been introduced for EHV Substation and HVDC Substation during 1985-90 and are capable of performing the following functions.

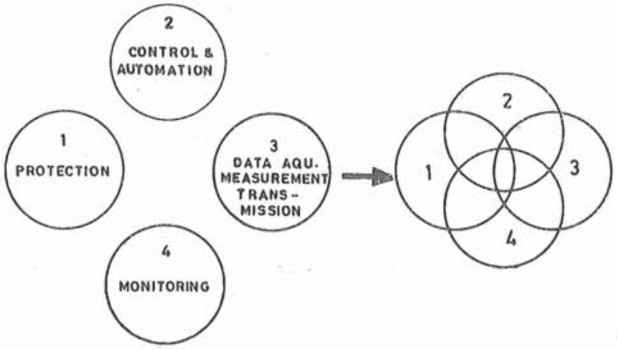


Fig. 38.1 (*f*) Concept of combined Protection, Monitoring and Control System (CPMC) with modern microprocessor-based Digital Relays.

Table 38.7. Functions of Combined Protection, Monitoring and Control (CPML) in EHV-AC Substations

Protective Functions	Busbar protection, Transformer protection, Transmission line protection.
Automatic functions	Synchronizing. Load switching, Sequential operations Tapchanging and voltage control. Load Shedding System restoration
Supervision and Monitoring	Data collection Data logging Fault annunciation Sequential event recording Measurements Disturbance recording Remote control
Interlevel communications.	Communication between two levels *e.g.* control centre and sub-station control room.
Manmachine Interface	Display, instructions etc.

Construction Principle. Most of the functions are performed by the substation CPMC system by means of Microprocessor or microcomputer in accordance with the stored Software (programme). The software in modularised to facilitate incorporation of new functions and to simplify future extension. Building block principle is used. The total CPMC system is tailor-made with required plug-in modules inserted on a standard racks. Combined protection Control and Monitoring System prove economical for complex protective tasks such as those for EHV-AC substations and HVDC substations.

Summary

In static relays the measurement is performed by static circuits. The static relays have following types :

(1) Analogue relays (2) Digital Relays. The static relays are assembled by using *Printed Circuit Boards (PCB)* or Integrated Circuits (IC's). Earlier relays were fixed wire relays having certain functional circuits.

The recent generation of static relays are 'Programmable Relays'. Programmable static relays are *'flexible'*. Programmable static relays include 'Microprocessors' or 'digital' computers in their circuits, Most recent advances include Combined Protection Monitoring Control Systems incorporating microprocessors or microcomputers.

With the developments in *digital techniques and microprocessors,* the static relays with microprocessors have become commercially acceptable. The static relays are preferred for almost all protective functions and the use of electromechanical relays is now rapidly reducing to very simple protective functions and auxiliary relays.

38-B

Introduction to Analogue and Digital Static Relays

Semi-conducting Material — Semi-conducting Devices — Diode — Transistor — Thyristor — Zener Diode — Thermistors — Logic Circuits — Digital Systems — Analogue Systems — Operational Amplifier and its Applications — Analogue/Digital Conversion — Auxiliary Voltage Supplies — Smoothing Circuits — Use of Zener — Timer Circuit — Transducers — Static Directional Units — Logic Circuits — Negative Sequence Circuit — Summary

Section 1. SOLID STATE DEVICES

38.19. SEMICONDUCTING MATERIALS

The common semiconducting materials are germanium and silicon. The resistivity of semiconductors lies between that of insulators and good conductors. The electrical resistivity of semiconductors decreases with temperature. Both germanium and silicon belong to the 4th group of periodic table, thereby they exhibit inertness. These materials have covalent bonds amongst their atoms.

If germanium or silicon crystals contain no impurities, the only current carries present are those produced by the thermal breakdown of the covalent bonds.

They are called intrinsic semiconductors. In general however the germanium crystals contain some trivalent (such as iridium) and some pentavalent (such as Arsenic) impurities of the materials. The formation of covalent bonds with a pentavalent impurity still leaves an excess electron in the outermost orbit of the atom thereby making the material behave as if it is an *n-type material.* It means that the excess electron or negative change is available for conduction. Silicon is used in semiconductor devices now.

In a similar way an addition of a trivalent impurity makes the material behave as if it is *P-type.* This is because there are only three electrons in the outermost orbit of the impurity atom which has to form a bond with the 4 electrons in the outermost orbit of the atom of the material, thereby giving a deficiency (hole) of an electron for stable covalent bond.

As a result pentavalent impurity in the semiconducting material makes it behave negatively (surplus electrons) and trivalent impurity makes the materials positively (surplus holes or unfilled electrons). For *n*-type materials, electrons are called major carriers holes being minor carriers. For *p*-type materials it is *vice-versa.* Semiconducting materials added with such impurities are called Extrinsic semiconductors.

P.N. Junction

When there is no external connection made to *p-n* junction there is tendency due to diffusion for the electron of the *n*-region to cross in the *p*-region and *vice-versa.* This creates a potential barrier across the junction as if an external source of e.m.f. is connected.

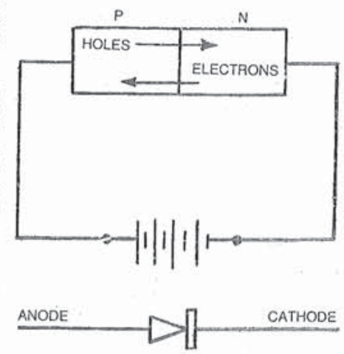


Fig. 38.2. Forward Bias of a *p-n* junction.

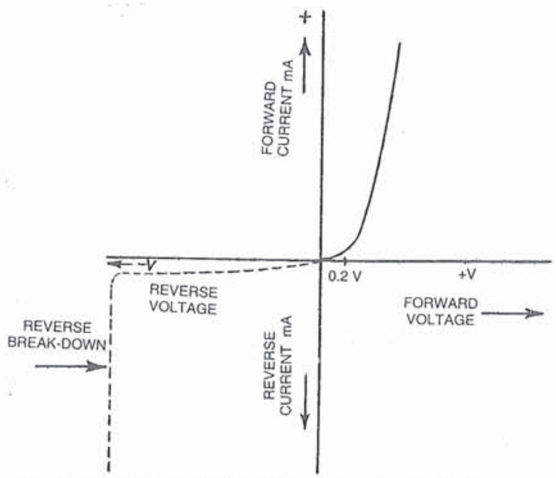


Fig. 38.3. Current voltage characteristic of *p-n* junction Diode.

The majority carriers are now able to cross the junction constituting considerable currents. The relation between current and voltage is shown in Fig. 38.3 *p-n* junction has rectifying characteristic.

When alternating voltage is applied to the *p-n* junction, large current flows for half cycles during which *P* is positive and *N* negative.

38.20. SOLID-STATE DEVICES : (BRIEF INTRODUCTION)

Several solid-state devices have been developed during the last thirty five years and several new are being developed. A brief introduction to solid-state devices is given here for the sake of familiarity.

38.20.1. Semiconductor Diode

A junction between *n*-type and *p*-type semiconducting materials is called *p-n* junction. Diode consists of a *p-n* junction and has two terminals. There are several types of diodes. The manufacturing methods include grown junction method, alloy junction method, diffused-junction method, combination method. Diodes are rated for peak inverse voltage (p.i.v.), *i.e.* maximum voltage between anode and cathode which the diode can withstand in reverse direction. While employing diode in a.c. circuits, the peak voltage of alternating voltage should not exceed peak inverse voltage of diode. Diode is used for rectification. Diode offers low resistance to current in forward direction and high resistance in reverse direction. The parameters of a diode include the p.i.v. maximum power dissipation, maximum voltage and current, operating temperature and storage temperature, capacitance, recovery time, maximum forward and reverse current, time of application of voltage surge, etc. Point contact diodes have high peak inverse voltage, high reverse resistance. They are used in high frequency and fast switching applications. Current limiting diodes allow constant current for a wide range of voltage across them. They are used in bias circuits, differential amplifiers, ramp and stair generators, over-current protection within the circuits, etc. Planer diodes are amongst the integrated circuits. They have high reliability, reduced capacitance stable performance, high switching speeds. Zener diodes have constant voltage across them for wide range of reverse current. They are used for voltage stabilization and voltage regulating circuits.

PN junction diodes can conduct only in one direction, *i.e.* in the direction of the arrow.

Semi-conductor Devices for Static Relays.

As regards, diodes and transistors, only silicon type are used today. Germanium is no more used due to poor quality such as high temperature dependance. Avalanche type diodes are used in circuits exposed to voltage transients. Avalanche diodes have better withstand against transient overvoltages compared to other types. Regulating diodes (Zener diodes, current regulating diodes) are used on static relays mainly to obtain stable reference voltage. In static relays circuits voltage stability tends to be the best at 5-6 volts with very low temperature coefficient and hence zener diodes with this zener voltage rating are widely used. Current regulating diodes are also called upon to protect the sensitive components from voltage and current transients. Uni-junction transistors are mainly used in time circuits as voltage level sensor organs where they have proved to be stable and have low temperature dependance. Thyristors are used in output stage in series with trip coil or tripping relay. A sudden rise in anode-cathode voltage can unduly trigger the thyristor. Hence triggering of transistor due to over-voltage transient should be prevented.

38.20.2. (B) Zener-Diodes (Voltage Regulating Diodes)

Zener diode is used for voltage stabilization.

Zener diodes have been developed in range of from a few volts to several hundred volts and for power-handling ability of over 100 Watts.

Some reverse biased junction diodes exhibit breakdown at a very low reverse voltage (about 5 volts) due to spontaneous pairs within the junction region from inner electron shells.

Zener diode can operate in reverse breakdown mode continuously without damage. Fig. 38.4 illustrates the characteristic of a zener diode. Under reverse breakdown condition, for a wide range of current the voltage across the zener diode remains constant. This property is used in voltage regulator circuits.

Zener diodes are silicon diodes, having low reverse voltage and reverse current being very small, at a certain reverse voltage however the current increases very rapidly and is limited by external impedance. The voltage across the zener diode remains fairly constant over a wide range of reverse currents. Hence, the voltage across the zener diode is held constant and the zener diode can be used for stabilizing the voltage. The reverse voltage at which the sudden-ly increase current occurs is called Zener voltage or breakdown voltage. No damage is done by operating zener diode in reverse current condition upto certain limit. Zener diodes are available with zener voltages from 3V to several hundred volts 50 volts being quite common.

The voltage of Zener diode changes with temperature. Zener diodes below zener voltage above about 5 V (called avalanche diodes) have positive temperature coefficient. Below this value the Zener diodes (called field effects diodes) have negative temperature coefficient. A combination of forward connected diodes and reverse connected zener diodes is used to overcome temperature effects.

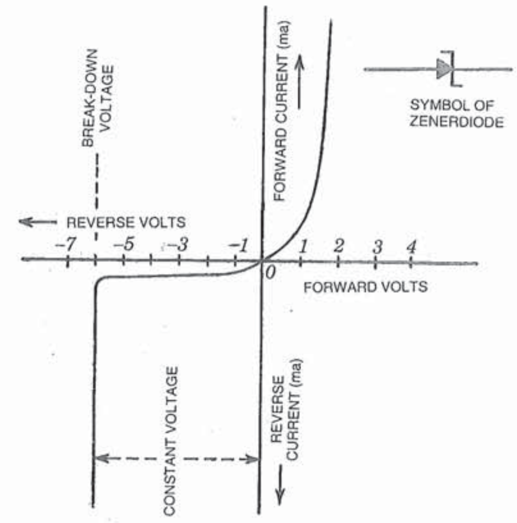


Fig. 38.4. Characteristic of Zener diode.

Zener diodes can be connected in suitable series circuit along with voltage grading parallel resistors for surge suppression.

38.20.2. (C) Junction Transistor (Bipolar Transistor)

Transistors are used in amplifiers, level detectors, switching circuits.

A junction transistor has two junctions and can be either *PNP* or *NPN* transistor as shown in Fig. 38.5. In *PNP* transistor a *N*-type layer is sandwiched between two *P*-type layers [Fig. 38.5 (*a*)].

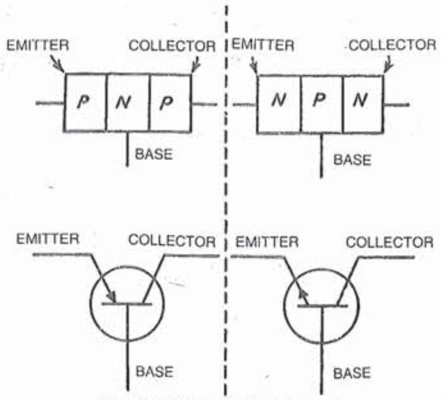


Fig. 38.5 *PNP* and *NPN* Transistors.

In NPN transistor a *p*-type layer is sandwiched, between two *N*-type layers [Fig. 38.5 (*b*)].

Fig. 38.6 (*a* and *b*) illustrates the circuit, symbol and Fig. 38.7 represents the characteristic of a FET. There are several other combinations of connections. When drain voltage is increased, the drain current increases. The slope of $l_N - V_{DC}V_{DC}$ depends upon V_{GS} (Gate to source voltage).

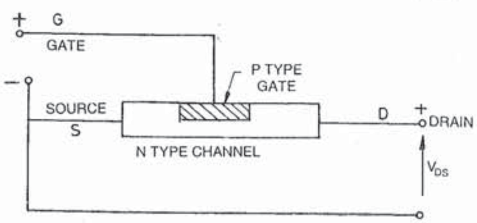


Fig. 38.6 (*a*) Structure of FET.

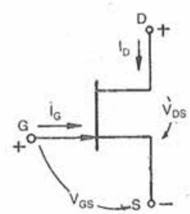


Fig. 38.6 Symbol of FET (Field Effect Transistor).

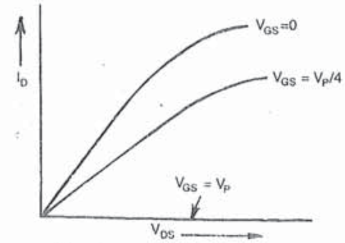


Fig. 38.7. Characteristics of FET.

38.20.3. PNPN Devices and Thyristor Tripping Circuit

PNPN devices consist of four regions arranged as shown in Fig. 38.8. We will briefly discuss about silicon-controlled rectifier Silicon-controlled rectifier has two stable states, one in which the resistance is very low (the conducting state) and the other in which the resistance is very high (non-conducting state). The device can be switched from non-conducting to conducting state very rapidly, and very little power is required to bring about this change. Thus PNPN device exhibits a property similar to that of thyratron but is far more efficient. The device is mainly used for switching and power control *e.g.* controlled rectifier. In thyristor (SCR) a brief signal (positive-charges or holes) into the base *P*-gate causes current to flow. The action is self-sustaining and even if the gate current is removed, the anode current continues to flow. In other words the thyristor is on. A reverse signal to the gate (negative) can make the thyristor off. Or if the circuit is interrupted by the auxiliary switch of the circuit breaker, the original non-conducting state is reached.

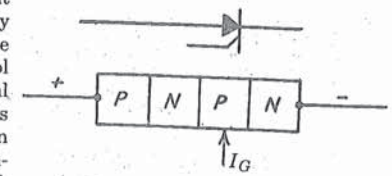


Fig. 38.8. Schematic diagram of *PNPN, P*-gate type.

Thyristor (Silicon Controlled Rectifier) is employed in the output stage of static relays as illustrated in Fig. 38.9. The measuring circuit of relay sends a pulse to gate of thyristor when threshold condition is reached. The thyristor triggers and the current from battery flows through trip coil of the circuit breaker. The circuit breaker opens and the auxiliary switch also open as it is interlocked with the circuit breaker and thereby the thyristor is turned off.

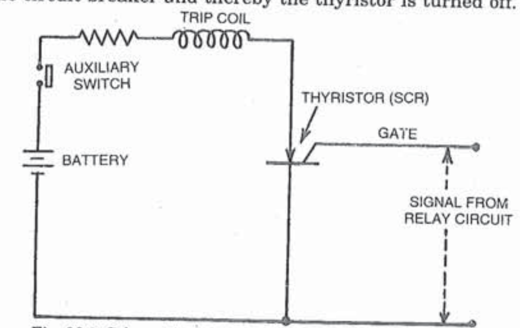


Fig. 38.9. Schematic diagram of thyristor tripping circuit.

There are several types of thyristors such as :

(1) Reverse blocking thyristor (2) Bidirectional thyristor (3) Turn off Thyristor (4) *P*-Gate Thyristor, etc. The following discussion pertains to *P*-gate thyristor only.

1. Application of positive voltage to gate with respect to cathode terminal.

2. Setting up a displacement current in *P*-type region, by means of a pulse-positive with respect to cathode, to the gate. The second method is used in the output stage of static relays.

Thyristor can be used in several applications such as controlled rectifiers, motor control circuits, temperature control devices a.c./d.c. switch circuits, inverters etc.

In typical thyristors, the range of rated forward current covers a few amperes to several hundred amperes. The thyristor can be triggered by a momentary pulse (4 μ sec) of a few milliamperes gate current. When used in a.c. circuits, the gate current pulse can be timed so as to fire the SCR at the desired angle with each positive half cycle, thereby producing phase control.

38.20.4. Power Switching Techniques with "Thyristors"

Conventional electromagnetic relays and contactors have numerous disadvantages, the moving parts wear out quickly when the rate of switching is high. There is also a danger of arcing across the contacts which demands flame proof enclosure if the contactor is to be installed in explosive atmosphere. Their efficiency can be adversely affected by dust and other air-born contaminants. 'Thyristors' have made possible solid state switching devices. These devices perform the operations performed by electro-mechanical units but with few of their disadvantages.

A.C. and D.C. Switching. A thyristor can be regarded as a conventional diode (rectifier) equipped with a third terminal through which a small pulse of current in injected to trigger it. Unlike the conventional rectifier the thyristor blocks both negative and positive voltages until the trigger signal is applied. Once triggered, the thyristor will pass current in one direction until the end of half a cycle when the current drops to zero. If a second pulse is applied at the next half cycle, the action is repeated. In other words, if the potential across the thyristor is suitable, the thyristor triggers when a pulse is applied to the gate and it continuous to conduct till the potential is suitable. Thyristors can be used for a.c. and d.c. switching application with high reliability. Fig. 38.10 gives diagram of a single phase thyristor switch.

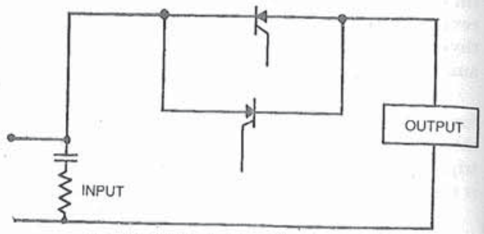


Fig. 38.10. Single phase thyristor switch.

The thyristor conducts for half the cycle when forward biased, provided positive pulse is applied to its gate. At natural current zero of the wave the thyristor automatically turns off. The period of conduction in half cycle can be controlled by controlling the phase of the pulse applied to gate. Two thyristors are necessary to get conduction for full-wave. In d.c. circuit, only a single thyristor of enough rating will be adequate instead of two thyristors shown for a.c. circuit in Fig. 38.10.

38.20.5. Triac

The output element of a static relay can be a *Triac.* Triac is a further development of SCR. Thyristor (SCR) conducts only in one direction (DC) when a positive pulse is applied to its gate; and conducts until the DC supply is interrupted. Triac is bi-directional device and passes current in either direction (A.C.) when triggered by either positive or negative gate signal. Once turned on, the triac conducts till the load current falls to zero. In D.C. circuit load current should be switched off by an auxiliary switch. In A.C. circuit load current reaches zero twice in a cycle.

With signal continuously present on the gate, the triac automatically turns on and off at the beginning and end of each half cycle. Thus the period of conduction is almost a complete cycle.

Since SCR and Triac cuts-off at current zero, there is no problem of switching over-voltages and radio-interference.

38.20.6. Thermistors

Thermistors are used for temperature measurement, temperature compensation circuits. The types include negative-temperature coefficient thermistor and positive temperature coefficient thermistor. The resistance of an n.t.c. thermistor decreases with the increase in temperature.

38.20.7. Resistors

Variable resistors are frequently used in static delays for continuously setting the operating values, time delays etc. Potentiometers are weakers links in relay circuits as regards reliability. Hence care should be taken in choosing the type of potentiometer for particular applications. Wire-wound type is most common. The reliability of this type is high upto a few kilo-ohms value. Carbon-potentiometers which are widely used in other electronic circuits are not suitable for static relays as regards precision and stability.

A new type of potentiometer called cemeto potentiometer is being widely used in static relays. It consists of a semiconducting material.

Carbon resistors are rarely used in static relays. Instead, metal-oxide resistors, metal film resistors and wire-wound resistors are used.

38.20.8. Capacitors

Capacitors are used in time circuits, integrating and differentiating circuits, filter circuits, smoothing circuits, protective-circuits of static relays. The selection depends on desired quality.

In time circuits, high stability and low leakage currents are desired. Plastic dielectric capacitors are, therefore, preferred.

Polycarbonate capacitors are generally used where high stability (better than 1%) is needed. Electrolytic capacitors are rarely used in static relays except in uncritical circuits such as smoothing circuits of feeding devices. Tantal electrolytic capacitors are better as regards stability than common electrolytic capacitors.

Capacitor Units

Separate plug-in modules of capacitor units are used in static protection systems. The standard units can be ordered and kept as spares. Capacitor units are available for

— Auxiliary relay pick-up and drop-out circuits

— For impulse lengthening or shortening

— For feeding trip coils upto 300 W, during interruption of auxiliary power. These units *capacitors* of following type :

(1) Aluminium-Electrolytic Capacitors (wet type)

— 16 V.220 μF to 63 V, 47 μF.

(2) Tantalum-Electrolytic capacitors :

— 6 V, 330 μF to 350 V, 47 μF.

38.21. PRINTED CIRCUIT BOARDS WITH DISCRETE COMPONENTS

The task of connecting the discrete (*i.e.* separate, individually identifiable), components was simplified by using Pre-printed Circuit Boards. Complete circuit is printed and etched on insulating board, and conducting material is filled into eached portion to provide electrical connection between the discrete components (resistors, capacitors, discrete components are inserted in the cavities provided in the board and terminals are soldered. The PCB's can be plugged into a frame in a modular form to get a compact and simple standard assembly. The first generation of static relays was with discrete components. The PBC circuits were much compact than the value circuits. The manufacturing process was also more economical and faster. However the reliability was not entirely satisfactory one to large number of discrete components.

The second generation of static relays was with integrated circuits (IC's). The static relays with IC's are most compact and have higher reliability.

38.22. STATIC RELAYS WITH INTEGRATED CIRCUITS

The hybrid IC's have resistance, capacitance, and *R-C* circuits formed by depositing conducting, semi-conducting and insulating materials on a passive or a neutral base such as glass or ceramic, by process of diffusion, printing/doping. These are not truly monolithic IC's, but a step towards IC's.

Truly monolithic IC has a basic electronic circuit (with its passive elements such as resistors capacitors and active elements such as diodes and transistors) in a single piece of silicon wafer (chip). The entire circuit is formed in a single manufacturing process.

A single silicon wafer of about 25mm diameter can accommodate about ten to hundred IC's made simultaneously, the number depending upon the complexity and size of individual circuits.

The individual IC's are then separated. To give an idea, a complete IC comprising about 12 transistors and associated resistors can be accommodated on a 1.3 mm^2. The IC package containing this circuit and terminals will be about 1.5 mm^2.

Such a circuit is known as Integrated Circuit (IC). Integrated Circuits for common functions are manufactured on large scale as per international standards (IEC 147, 141). Standard IC's are commercially available (Ref. Table 38.3). Integrated Circuits can be broadly divided in two categories.

— Analogue — Digital

Analogue IC's operate on continuous signals and linear range. They are used mainly in operational amplifiers, oscillators, regulators etc. (Ref. Table 38.3). They find application in carrier current protection, and various static relay functional circuits. Digital IC's are principally used as switching units which perform on/off function. These IC's do not require precise components like Analogue IC's. Hence Digital IC's are easier and cheaper to manufacture and are preferred in wide range of applications such as binary logic circuits, switching gates, etc. (Ref. Table 38.3).

Table 38.3. Integrated Circuits

Digital	*Analogue (Linear)*
Inverters	Operational amplifiers
Flip-flops	Peramplifiers
Monostable circuits	A.F. amplifiers
Pulse generators	Z.P. amplifiers
Emitter-coupled circuits	Power amplifiers
Schmitt triggers etc.	Voltage regulators
NAND, NOR, AND, OR Gates	Wideband amplifiers
Transistor-transistor circuits	Level detectors etc.

The digital systems are based on pulse and pulse chain inputs. They are used in logic circuits. Logic circuits are being increasingly used in protective relaying.

Monolithic techniques are used to make ICs (Integrated Circuits). A monolithic circuits is contained within a single crystal. The advantages of integrated circuits compared with discrete circuits* (*circuits where various separate components are connected to form the circuit) include :

(*a*) Higher total reliability as number of soldered points is reduced.

(*b*) Smaller dimensions. (*c*) Generally, lower price.

(*d*) High stability due to uniform temperature in the monolithic circuit.

(*e*) Design is simplified.

38.22.1. Reed Relays

(*i*) **Application.** Reed relays are not static devices. They are used in industrial control Circuits and Switching Circuits. Reed relays are sometimes used in between conventional input device and solid state logic circuits. Reed relays are used in low voltage, low current circuits.

Conventional electromagnetic relays are used in majority of application. However, reed relays are used in logic circuits and where the contacts need the following :

— Sealed construction to overcome problems of dust, humidity, corrosive fumes.

— Faster switching, repeat accuracy.

— Large number of switching cycles.

(*ii*) **Construction.** (Ref. Fig. 38.11) The reed relays consists of a set of pairs contacts on two long flat strips (Reeds) of ferromagnetic material. The other end of reeds are fused into glass tube which is hermetically sealed and filled with inert gas like nitrogen. Contact tips are plated with silver or gold for lowering contact resistance.

The tube is surrounded by a coil. When current flows through the coil, the magnetic field causes magnetisation of the reeds. The contact ends get opposite polarity. Thereby the contact get closed. On removal of the magnetic field the reeds reach the original open state.

In Reed Relay with normally closed contacts, a permanent biasing magnet is placed near the tube. The reads remain closed due to magnetic field of the magnet. When the coil is energised, it gives a magnetic field opposite to that of the permanent-biasing magnet. Thereby the total field is zero and reeds open. When the current in field coil is stopped, the reeds come in closed position due to the field of the permanent magnet.

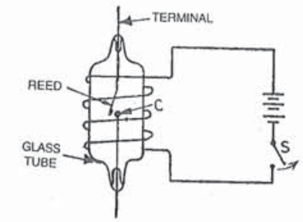
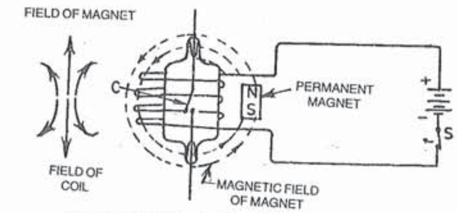


Fig. 38.11 (*a*) Reed relays operated by magnetic coil.
Coil energised — relay closes Coil de-energised — relay opens.



Logic
When
S closed = *C* open
S opened = *C* closed

Fig. 38.11 (*b*) Reed relay with permanent magnet and magnetic coil.

(*iii*) **Typical Characteristic of a Reed Relay**

Continuous Current rating (main contacts)	:	0.1 A to a few amperes
Operating time	:	1 ms.
Switching capacity (main contracts)	:	Upto 50 W (recently)
Number of operations	:	10^6
Number of contact-pairs	:	Upto 6

38.23. STATIC DIRECTIONAL UNITS

(*i*) **Hall Generator.** Hall generator consists of a semi-conductor flat crystals usually N-type Germanium, placed in magnetic field created by voltage coils (Fig. 38.12). Current is passed through the crystal, from one edge to the other. A d.c.e.m.f. '*E*' appears the mid-points of the other edges of the crystal (Ref. Fig. 38.12).

The d.c.e.m.f.'*E*' depends upon the phase angle between the flux produced by voltage coil and the current. This property is used to obtain the measurement of phase angle between *V* and *I* for directional relays (Ref. Fig. 38.12).

(*ii*) **Magneto-resistors.** These devices have been recently developed. Their resistance depends upon the surrounding magnetic field. This property is utilized in them in using directional units.

— High repetition rate due to rapid response of the elements.

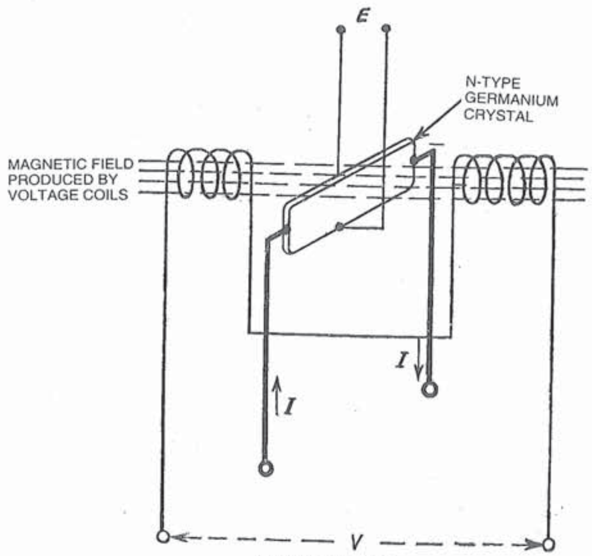
— Unaffected by shock and vibration.

— Require no maintenance of adjustment, space saving.

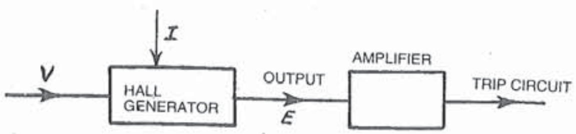
— Can be used in dusty, humid or corrosive atmosphere.

— Enables sequential control circuits to be arranged which memorize their information, even in the case where the power supply is cut-off.

— Complete eliminating of race condition due to non-simultaneity in the operation of closing, opening and inversion of the different contacts of a relay.



(a) Hall generator.



(b) Directional relays unit employing Hall generator.
Fig. 38.12. Hall generator for Directional Protection.

Section II. DIGITAL CIRCUITS AND THEIR APPLICATIONS IN PROTECTIVE RELAYING

38.24. LOGIC CIRCUITS*

Complex protective relays can be achieved by means of logic approach. A switching circuit may be though on in terms of the schematic Fig. 38.13.

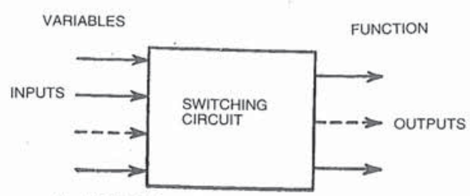


Fig. 38.13. Schematic diagram of a logic circuit.

* Ref. Sec. 44.14, Table 44.2 for symbols.

Each input and output line must be in one of the two possible states at any given time. For instance a line may be 'on or off', *i.e.* 'conducting, or 'non-conducting'. The output of a logic circuit is a function of its input. We will not bother about why the circuits behave that way, but only see how they operate.

Switching circuits are made up of interconnection of basic 'logic blocks'. Five common functions are performed by logic blocks used in static relays and computers, these are

AND OR NOT NAND MEMORY. Logic units can be used in all fields of "on and off" control. They are particularly suitable for the following applications : (Ref. Sec. 44.14)

— Installations requiring fairly complicated sequences of operation; the use of static logic elements is particularly interesting in complex problems or in those which involve a large number of variables, *e.g.*, Auto-reclosing schemes.

The term *logic variable* is used for a quantity which expressing these states, can only two distinct values, conventionally designated 0 or 1. This quantity can occur in the form of a voltage of the terminals of a circuit, a current in the coil of a relay or electrovalve, illumination of a photo-electric cell, opening or closing of a relay contact or a limit switch stop etc.

These functions will be explained here with the diagram-symbol and the truth-table of each.

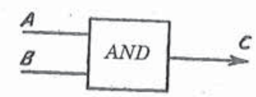
38.25. AND FUNCTION (Ref. Table 44.2 *a*)

The function is equal to 1 when all the variables are equal to 1.

The function is 0 when one or more varial is 0. Here '1' and '0' denote the two states such as conducting, non-conducting or positive and negative.

Logic Truth Table

A	*B*	*C* = *A and B*
0	0	0
0	1	0
1	0	0
1	1	1



$C = A$ and D
Fig. 38.14.

AND function is represented by the symbol $\wedge$ *e.g.*, $x \wedge y$ means x and y. [Symbols $\wedge, +\cap$ are used for *AND functions*]. Consider two statements A and B.

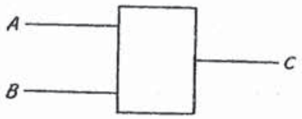
The entire statement can now be written as 'A and B' or '$A \wedge B$' where

If A is true 1.
If A is false 0.
If B is true 1.
If B is false 0.

Truth Table AND function

A	*B*	$A \wedge B$
1	1	1
1	0	0
0	0	0
0	1	0

AND Circuit. The output C is positive + if all the inputs are positive. Output is negative if one or more in inputs are negative.



Voltage Truth Table

A	B	$C = A \wedge B$
–	–	–
–	+	–
+	–	–
+	+	+

Fig. 38.15

Fig. 38.16 illustrates a logic AND gate achieved by Diodes. It is called Diode Logic. This gate can be achieved either by a discrete component circuit or by integrated circuit (IC).

AND Circuit

Truth Table (Ref. Fig. 33.16)

A	B	C
–	–	–
–	+	–
+	–	–
+	+	+

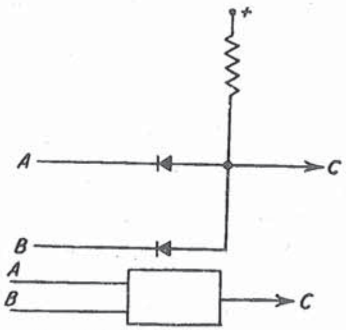


Fig. 38.16. AND circuit using diodes.

The input terminals have one of the two states called.

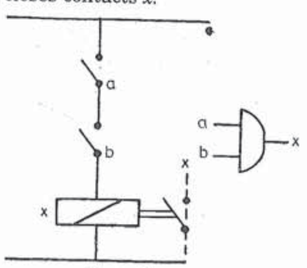
high	low
+	–
1	0

The output also has two states.

Consider the logic of the Fig. 38.16. When both V_A AND V_b are high (+, 1) the two diodes are reverse biased. Hence the current does not flow through resistor and the output C is at high (+ or 1).

Hence when V_A AND V_B are +, the output V_c is +. This is AND function drops to low (–, 0)

Fig. 38.17 illustrates AND gate employing contact a, b and contactor X. When a AND b are closed, contactor X closes contacts x.



a	b	x
0	0	0
1	0	0
0	1	0
1	1	1

$Fx = a \cdot b$

Fig. 38.17. AND gate with conventional contacts a, b and contact X.

38.26. OR FUNCTION (Ref.Table 44.2 b)

Consider the two statements A and B.

A = Mohan is an Engineer True = 1, False = 0
B = Mohan is a Doctor True = 1, False = 0
C = Mohan is an Engineer or a Doctor
A or B is written in $A \vee B, A \cup B$

Logic Truth Table

A	B	$C = A$ *or* B
0	0	0
0	1	1
1	0	1
1	1	1

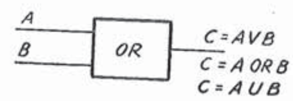
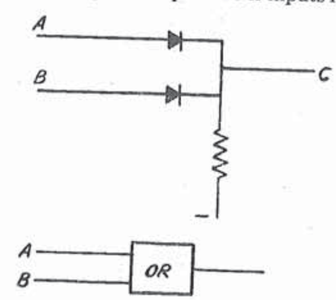


Fig. 38.18.

The function equals 1 if one or more variables equal 1. Conversely the function is zero if all the variables are zero.

Or Circuit with Diode

In Fig. 38.19 the output C is positive if inputs A OR B is positive. Otherwise C is negative.

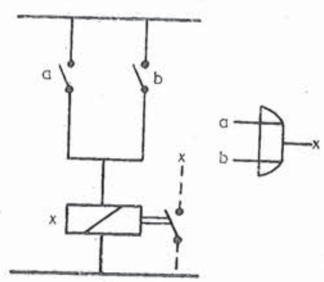


Truth Table

A	B	$C = A$ *OR* B
–	–	–
–	+	+
+	–	+
+	+	+

Fig. 38.19.

The OR operation is performed by contacts in parallel in conventional relay systems. Relay X in Fig. 38.20 picks up and produces and output signal at its normally open contact X when of the contacts a OR b is closed.



a	b	x
0	0	0
1	0	1
0	1	1
1	1	1

$Fx = a + b$

Fig. 38.20 OR circuit with conventional contacts a, b and contactor X.

38.27. NOT FUNCTION (Ref. Table 44.2 *c*)

This function is negative *e.g., Mohan is not a child.* NOT function is signifies negation

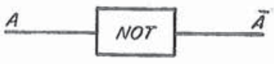


Fig. 38.21

A	$C = \bar{A}$
0	1
1	0

NOT function

Statement A = Mohan is a child.

$\bar{A}$ means not A.

The function is equal to 1 when single variable is zero. The function equals zero when single variable is to 1. Hence

NOT function signifies that the incoming signal and output signal are inversed. In Fig. 33.22, when contact A of conventional relay is closed, contact C of contactor C' is opened. When A is open, C is closed. In other words $C = A$, *i.e.* C = NOT A.

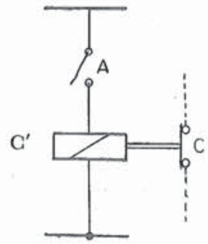


Fig. 38.22. NOT Function with convention relay contact A and contactor contact C.

38.28. COMBINED FUNCTIONS (Table 44.2 *j, k*) .

About 75% logic operations can be achieved by logic gates AND, NOT, OR. These are used on combinations :

NAND = NOT AND NOR = NOR OR

'NAND' Function. NOT AND is shrinked to NAND. Its Boolean Symbol is |. For example $A \mid B$ or $\overline{AB}$ or $\bar{A} + \bar{B}$.

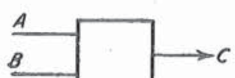


Fig. 38.23

Truth Table

A	B	C
–	–	+
–	+	+
+	–	+
+	+	–

A	B	$C = \overline{AB} = \bar{A} + \bar{B}$
0	0	1
0	1	1
1	0	1
1	1	0

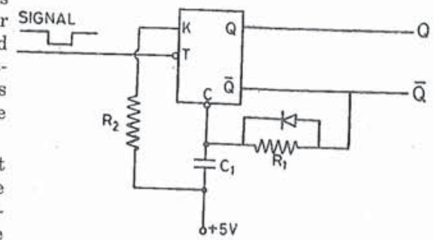
'NOR' Function. NOR is a combination of NOT OR. Boolean symbol is ↓ *e.g.* $A \downarrow B$.

A	B	$B = \downarrow B$
0	0	1
1	0	0
0	1	0
1	1	1

A	B	$B = A \downarrow B$
–	–	+
+	+	–
–	+	–
+	+	–

38.29. MEMORY FUNCTION (STORAGE FUNCTION)

The memory unit retains the binary signal for a definite or indefinite period of time. In conventional relays, a self-holding contactor retains its contacts in closed position retains the memory for a short duration of time and a magnetically latched contractor for an indefinite time. These are monostable or single short functions. Storage functions have two states : 'set and cleared'. These states are either of definite time or indefinite time.



(*a*) Monostable Circuit.

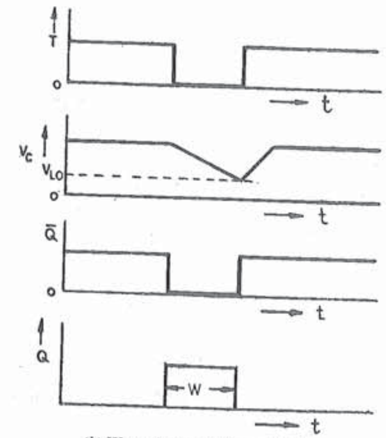
(*i*) **Monostables.** These have a single input pulse. The 'monostable multivibrator' or 'single shot' (because it gives a single pulse). In conventional relays, the definite time storage with a single pulse is achieved by RC element. A single can be delayed by a RC network or a time-delay relay. If a pulse is applied to the input of such a time an output pulse having a limited period T is produced. The period of T is determined by the RC element. The output signal can be delayed by combining the timer with other basic functions. Fig. 38.24 (*a*) illustrates a typical circuit which generates a pulse in response to a trigger pulse. The width W of the output pulse is adjustable. This circuit can be called as monostable or monostable multi-vibrator.

In Fig. 38.24, the output Q of the flip-flop is connected to clear C through resistor R_1.

Because of this connection this circuit has only one stable state $q = 1$ and $Q = 0$.

If Q does becomes zero, the voltage V_c decays towards zero until V_{10} stage is reached [Fig. 38.24 (*b*)]. At this instant, the flip-flop clears and $\bar{Q}$ goes back to 1 and Q goes to zero.

Thus the state with $Q = 1$ and $\bar{Q} = 0$ is unstable and persists for a pulse with W which depends upon R_1C_2 time constant.



(*b*) Wave forms of Monostable.
Fig. 38.24. Monostable.

In static relay circuits, monostables are used for a variety of timing application such as production of pulses of specified width, production of delayed waveforms etc. For example, the trigger T given to a triggering circuit (Ref. Fig. 38.24) could be used to produce a pulse of width W required in a particular application.

(*ii*) **Flip-flop Bi-Stables.** Two NAND gates can be connected back-to-back in such a way that the output of one element is connected to the other element and *vice verse.*

In set-reset flip-flop (*S-R* flip flop). (Ref. Fig. 38.25) If both S and R are held at 1, the Q and $\bar{Q}$ continue their respective earlier state. If S is kept 1 and R is set to 0, Q will be forced to zero and Q will be forced to 1. If R is returned to 1, without changing S from 1, the output state remains indefinitely $Q = 1$ and $\bar{Q} = 0$.

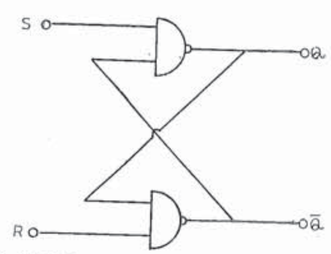


Fig. 38.25. Set reset flip-flop using NAND gates.

Similarly if R is kept 1 while S is set zero output is forced to 0 while $\overline{Q}$ becomes 1. If S is returned to 1 and $Q = 0$. $\overline{Q} = 1$ persists. Thus by applying the correct pattern 1 - 0 to S-R inputs the desired state can be achieved at Q. *The circuit retains that state until an appropriate input is changed.*

In other words, the flip-flop circuit retains the binary signal and has a memory.

38.30. FAMILIES OF LOGIC CIRCUITS

The logic functions can be achieved by applying the following elements. Accordingly, the family or logic circuit is named.

— *Diode-Transistor Logic DTL*

incorporates diodes and transistors to achieve the logic function

— *Transistor-Transistor Logic (TTL)*

incorporate Transistors.

— *MOS Transistor Logic :*

Employ metal oxide-semiconductor (MOS) Logic employes MOS transistor and diodes instead of bipolar (junction) semiconductors.

(*i*) **DLT Logic (Diode Transistor).** Fig. 38.26 illustrates a basic NAND gate circuit. Transistor NPN conducts when base has positive polarity with respect to emitter when both inputs V_a and V_b are (+) high, the current flows through the circuit $+ V D_1, D_2$ into base of transistor causing its saturation. The transistor conducts and voltage of terminal V_x is then close to ground potential. Thus the gate acts according to following logical function :

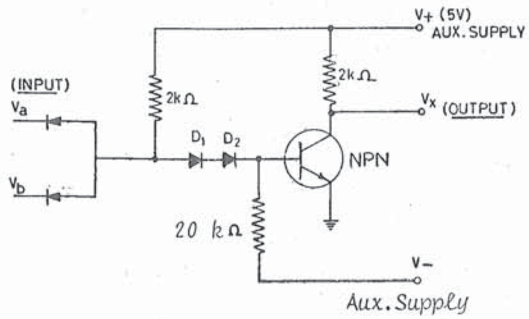


Fig. 38.26. NAND gate with DTL.

V_a	V_b	V_x
0	0	1
0	1	1
1	0	1
1	1	0

Where $V_x = 1$ represents high potential or V_x and $V_x = 0$ represents ground potential of the V_x. This is a NAND logic function. Diode D_1 and D_2 do not conduct till the voltage V_1 does not exceed 1.4 (0.7 + 0.7). This prevents wrong operation of the gate due to spurious signals. The propagation delay time of a typical DTL gate is 30 nenoseconds. It is moderately slow, but quite adequate for protective relaying applications. DTL logic gates family includes AND, OR, NAND, NOR gates. These can be in form of Discrete Component Circuits or Integrated Circuits. Thereby DTL family provides a vast scope to the designer of Logic circuit to design any logic sequence. Unused input are either connected to ground or to 5 V (+).

(*ii*) **TTL Logic (Transistor-Transistor Logic).** Transistor-Transistor Logic Circuit family is exclusively of Integrated Circuits (IC's) and is not possible with discrete components. A basic TTL

gate circuit is shown in Fig. 38.27. The circuit contains a Multi-emitter input transistor (which is possible only in Integrated Circuit and not in discrete component), in which the collector currents is the sum of two emitter currents. The multi-emitter input transistor has behaviour similar to single emitter transistor.

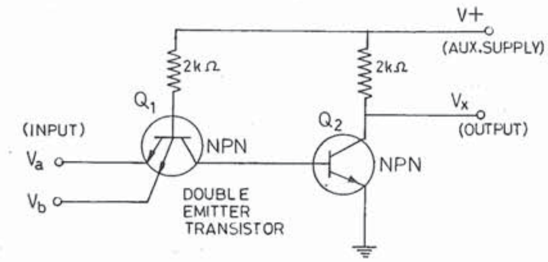


Fig. 38.27. NAND gate with TTL (Transistor-Transistor Logic).

When either of V_a and V_b is low (corresponding to 0) the transistor Q_1 will have a positive current i_1. This will drive the transistor Q_2 into cut-off state and input V_x will rise to + 5 V (corresponding to state).

When both V_a and V_b are raised to 5 volts (*i.e.* 1 state) then the base collector part of Q_1 gets forward biased and base-emitter part of Q_2 gets reserve biased. This results in reversed operation of input transistor Q_1. The current i_1 is reversed and becomes negative. Output transistor Q_2 is driven into saturation. (It conducts from collector to emitter much larger current and collector to emitter impedance drops down to a low value). Thereby output V_x drops to earth potential (state 0).

The truth table of this gate corresponds to NAND operation.

Truth Table of Gate in Fig 38.27:

V_a	V_b	V_x
1	1	0
0	1	1
1	0	1
0	0	1

When V_a and V_b is high, V_x is low

V_a and V_b is not V_x

This is NAND function.

(*iii*) **Metal Oxide Semiconductor Logic (MOS).** In this family of logic circuits, enhancement mode MOS transistors are used instead of junction transistors. (Ref. Section 38.9 *b*)

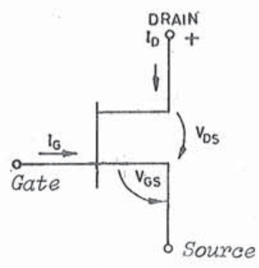
MOS transistors can be used as ON-OFF switches. Low current part of MOS transistor characteristics can be used as resistance. Thus it is possible to fabricate all resistor, switches and transistors with MOS family.

MOS logic is slower than other logic families (TTL/DTL).

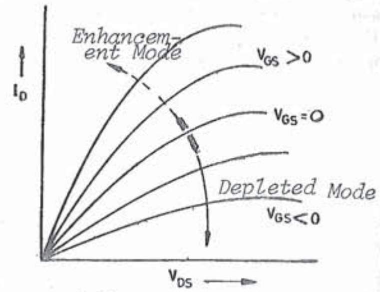
However MOS logic has several advantages such as :

— it requires less power.

— it needs only a fraction of area required by other logic gates. This leads to large scale integration IC's. (LSI-IC's). In MOS-LSI integrated circuits a single chip may contain thousands of transistors.



(a) Symbol of MOS.



(b) Characteristic of MOS

Fig. 38.28. Metal. Oxide Semiconductor (MOS).

Pocket calculators with MOS-LSI circuit can perform computation, logic and control functions.

COS/MOS logic gates (complementary symmetry MOS Logic) have both p-type and n-type channels. COM/MOS logic gates are available in NAND, NOR and many complex functions. Unused inputs are connected to positive or negative supply illustrate symbol and characteristic or a COM/MOS inverter.

MOS logic is used in recent digital circuits for static relays.

38.31. APPLICATIONS OF LOGIC CIRCUITS IN PROTECTIVE RELAYING

Logic functions AND, NOT, OR MEMORY INVERT, NAND, NOR etc., can be conveniently used for the following :

— in measuring circuit of relay, in comparators.
— in auxiliary systems for interlocking and control functions (To replace auxiliary and all or nothing relays)
— for starting and control of power consuming devices.
— for control of power plant and generating systems.
— in conjunction with digital computers for remote on-line monitoring of back-up protections of system components.

Some of these applications have been covered in section IV.

Consider auto-reclosure of a circuit-breaker. The sequence is as follows : (Ref. Sec. 44.14, Fig. 44.11).

If fault has continued, open the circuit breaker. If fault has not continued, let it remain closed. So, the circuit breaker has two alternatives. (To REMAIN CLOSED) OR (TO OPEN)

The static auto-reclosure system suitable for auto-reclosure scheme can incorporate an OR gate, alongwith other components.

In static comparators, the two inputs to be compared can be fed into an NAND gate. The output of the AND gate can be given to other circuit components. (Ref. Ch. 39)

In complex protection schemes, various logic gates are used.

Section III. OPERATIONAL AMPLIFIERS AND ANALOGUE CIRCUITS

38.32. DEFINITION AND APPLICATION

The term 'operational amplifier' is used widely to denote a circuit containing a high gain d.c. amplifier with a feedback from output to input. The operational amplifier circuit comprises tran-

sistors, registors and capacitors connected in suitably form and satisfies the following basic conditions :

— very large Thevenin's Equivalent Input impedance (Ref. Sec. 19.13) and resistance.
— very small Thevenin's Equivalent Output impedance and resistance.
— Operates linearly over its working range as high gain voltage amplifier.

Operational amplifier is an Analogue circuit which operates on continuous input and in linear range.

A basic operational amplifier is represented by a triangle having two input terminal and one output terminal. (D.C. supply is not indicated in the symbol).

The basic operational amplifier (the triangle) circuit is available in readily built modules (either discrete or IC's). Such modules can be connected with appropriate feedback circuit to achieve mathematical function such as :

— addition, subtraction,
— integration,
— differentiation,
— combination of the above.

Operational Amplifiers are widely used in analogue circuits to instrumentation, control on protective relaying. While studying application of Operational Amplifiers it is not essential to be familiar with the internal circuit of the same (triangle). But the function of the operational amplifier (triangle) with respect to the external terminals must be clearly understood for understanding the application.

38.33. SYMBOL OF OPERATIONAL AMPLIFIER

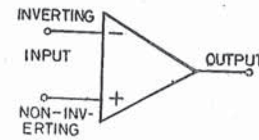


Fig. 38.29. Symbol of an Operational amplifier.

Fig. 38.29 gives the symbol of an operational amplifiers. Most operational amplifiers have several terminals in addition to those shown in the basic symbol. The addition terminals are for connection to external circuit to achieve near-ideal behaviour. Operational amplifier has two input terminals. The negative terminal is called 'Inverting Input'. The positive terminal is called 'Output Terminal'. Supply terminals (usually not shown in block diagrams) get d.c. supply from batteries or regulated power supply. Usually only one output terminal is indicated, the other terminal of load being earth (ground).

38.34. CHARACTERISTICS OF IDEAL OPERATIONAL AMPLIFIER

An ideal operational amplifier has infinite input resistance, a zero output resistance and voltage characteristic illustrated in Fig. 38.33. Infinite input resistance results in zero input current. The zero output resistance means, the voltage drop in output stage is zero. The circuit model for ideal operational amplifier can be represented by Fig. 38.30 (a).

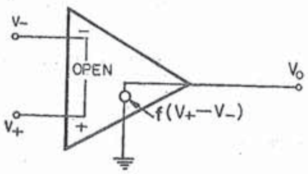
In linear range,

$$V_o = A\,(V_+ - V_-)$$

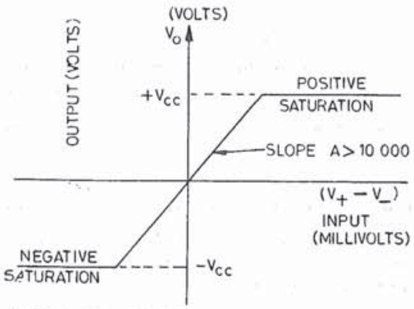
where A = voltage gain usually 10,000
V_+ = inverting input
V_- = non-inverting input.

From Fig. 38.30 (b) it can be seen that in ideal operational amplifier a very small input voltage brings a saturation. This draw-back is overcome by negative feedback.

*Ref. Fig. 38.52 (a), when $V_A + V_B \neq 0$
Negative sequence current output of the filter, $I_2 \neq 0$.



(a) Circuit Representing ideal Operational Amplifier.

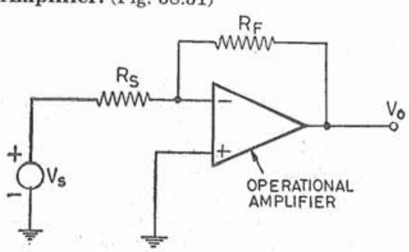


(b) Typical Transfer Characteristic of an Operational Amplifier. (Output saturates at supply voltage. Linear range input voltage is very small).

Fig. 38.30

38.35. SOME APPLICATIONS OF OPERATIONAL AMPLIFIERS

(i) **Inverting Amplifier.** (Fig. 38.31)



$V_0 = -\frac{R_F}{R_s} V_s$

$V_0 = V_s$ for $\frac{R_F}{R_s} = 1$

Fig. 38.31. Use of Operational Amplifier as an inverter.

The output is fed back to negative input through a resistance R_F.

$$V_0 = \frac{R_F}{R_s} V_s$$

The effect of negative feedback is

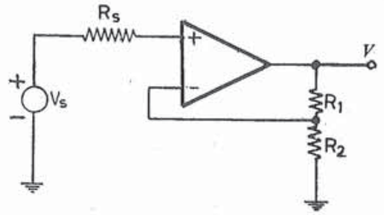
— to reduce gain and make it independent of open circuit gain A.

— to permit relatively large input voltage V_s without saturation.

— to produce an inverting closed loop gain R_F/R_S.

(ii) **Non-Inverting Amplifier.** (Fig. 38.32)

Feedback is applied to negative terminal through R_1. Input is supplied to positive terminal through R_s.



$V_0 = \frac{R_1 + R_2}{R_2} V_s$

Fig. 38.32. Non-inverting Amplifier.

If R_2 is infinite, V_0 tends to zero. If R_2 is zero, V_0 tends to infinity.

(iii) **Follower.** (Fig. 38.33)

Output terminal is connected to input negative. Input is connected positive through R_s.

The output voltage 'follows' input.

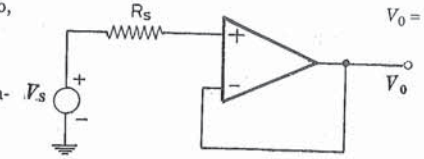


Fig. 38.33. Follower.

$V_0 = V_s$

(iv) **Analogue Addition.** (Fig. 38.34)

The waveforms V_1 and V_2 are added by means of addition circuit.

If R_F, R_1, R_2 equal

$$V_0 = -(V_1 + V_2)$$

$$V_0 = \left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2\right)$$

If R_F, R_1, R_2 equal, $V_0 = -(V_1 + V_2)$

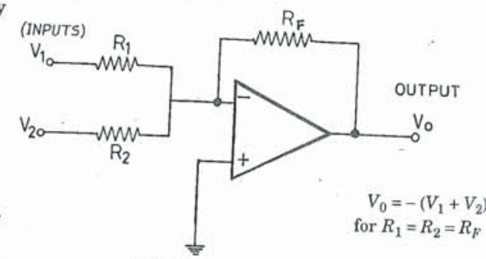


Fig. 38.34 Analogue Addition.

(v) **Analogue Subtraction.** (Fig. 38.35)

The waveform V_1 and V_2 can be subtracted by a suitable circuit of operational amplifier.

$$V_0 = \left(\frac{R_1 + R_3}{R_1}\right)\left(\frac{R_4}{R_2 + R_4}\right) V_2 - \left(\frac{R_2}{R_1}\right) V_1$$

If R_1, R_2, R_3, R_4 are equal,

$$V_0 = V_2 - V_1.$$

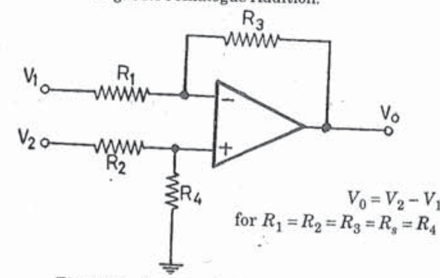
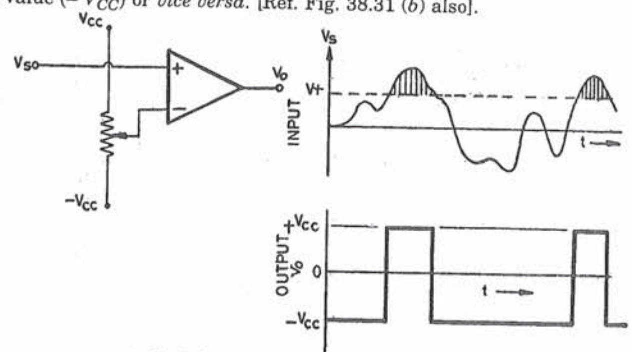


Fig. 38.35. Analogue Substration.

(vi) **Analogue Zero Detector.** Operational amplifier can be used as zero detector by a simple circuit illustrated in Fig. 38.36 (a) when V_s touches zero, output V_0 swings from positive saturation ($+V_{CC}$) value to negative saturation value ($-V_{CC}$) or *vice versa*. [Ref. Fig. 38.31 (b) also].

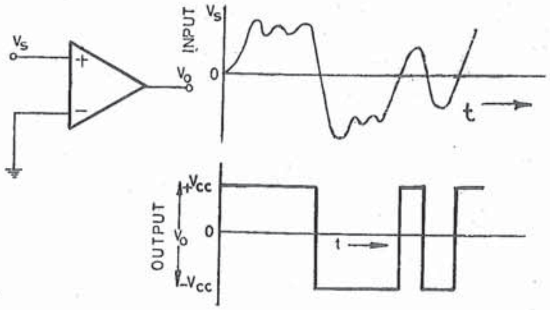


(a) Symbol (b) Characteristic

Fig. 38.36. Analogue zero detector.

38.35.1. Analogue Level Detector or Comparator (Fig. 38.37)

An analogue comparator can be arranged to compare the instantaneous value with preset threshold value.



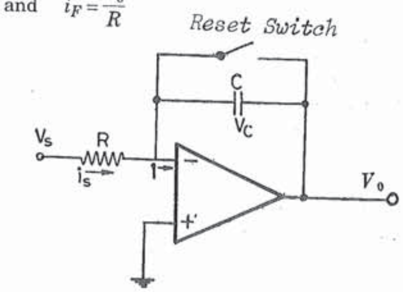
(*a*) Symbol (*b*) Characteristic
Fig. 38.37. Analogue level detector.

If V_s is more than threshold value V_t, the output of comparator is positive $(+V_{cc})$. The output V_0 swings from $+V_{cc}$ when the V_s crosses V_1 and becomes less than V_t. (Ref. Sec. 39.11).

(*vii*) **Analogue Integrated by Operational Amplifier.** An operational amplifier along with a resistor and capacitor can be arranged to integrate input voltage with respect to time (Fig. 38.38).

where i is the current flowing in capacitor. As flows through capacitor only ($i = 0$ due to infinite input impedance),

$$i_s = \frac{V_s}{R} \quad \text{and} \quad i_F = \frac{V_s}{R}$$



$$V_0 = \frac{-1}{RC}\int_0^t V_s\,dt$$

Fig. 38.38. Analogue integrator.

$Q = CV$

The charge on the capacitor C is given by $\int_{-\infty}^{t} i\,dt$

Total charge on capacitor

$$Q = \int_{-\infty}^{t} \frac{V_s}{R}\,dt$$

but

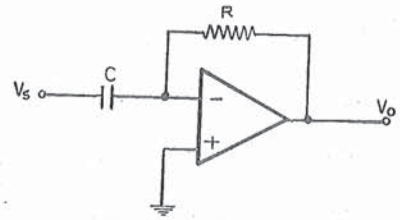
$$Q = -CV_0$$

Hence

$$CV_0 = \int_{-\infty}^{t} \frac{V_s}{R}\,dt$$

$$V_0 = -\frac{1}{RC}\int_{-\infty}^{t} V_s\,dt.$$

This is an integration of waveform. A switch is added to permit discharge of the capacitor resetting the output to zero.



$$V_0 = -\frac{1}{RC}\int_0^t V_s\,dt$$

Fig. 38.39. Analogue differentiator.

(*iii*) **Analogue Differentiation by Operational Amplifier.** Input current it does not flow in input terminal. The input current is given by

$$C\,\frac{dV_s}{dt}.$$

The circuit is an inverting amplifier (Sec. 38.15.4) with a differential function added in input. Hence

$$V_0 = -RC\,\frac{dV_s}{dt}$$

This is a differentiation of input voltage.

38.35.2. Analogue/Digital Conversion

(*i*) **Signals processing systems.** The static relay circuits incorporate signal processing systems. A signal processing system is an interconnection of components and devices that can accept an input signal or a group of input signals and act in such a way so as to extract or improve the quality of the information and deliver the output information in the proper form at proper time.

Fig. 38.40 illustrates the basic blocks in Signal Processing System. The continuous signals (derived from secondaries of CT's or PT's, transducers etc.) are called analogue signals as they are similar or comparable to original entity. They are fed to the analogue signal processing block.

The digital signals received from digital computer, from digital protective relay circuit etc. are fed into the Digital Signal Processing block.

The analogue processing block and digital processing block are interconnected through A/D and D/A conversion block. (A/D = Analogue to digital and D/A = Digital to analogue).

Consider a protective relaying system comprising analogue input derived from secondaries of CT's, PT's or tranducers like thermocouple, pressure transducers. "Transducer" is a device which converts physical variables (either electrical or mechanical) to any equivalent voltage or current signal. Some transducers require same form of electrical supply for excitation.

In analogue system the signals (waveforms) are processed continuously. Output of Analogue Processing Block can be in many forms. It can be in analogue form such as measuring instrument, recorders, analogue black and with or coloured display on control boards, *comparators/level detectors of protective relays.*

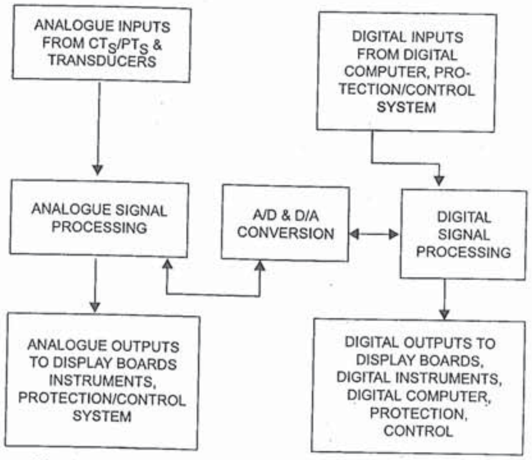


Fig. 38.40. Interaction between analogue and digital systems in power system protection and control.

Alternatively the analogue signals can be converted into representative digital signals and then fed to the digital computer, digital display devices, digital process control devices or *Digital Protective Relaying Circuits.*

In protective relaying systems, the input variables are compared in a 'comparator' the output of comparator is given to 'level detector' the output of level detector is given to 'Amplifiers' and finally, the output of amplifier is given to output (Tripping) stage.

The protective relay system may be purely analogue system as in conventional electromagnetic relays and many simple protection systems. However, in complex protective systems having several input variables and functional requirements, it becomes necessary to use digital systems and digital computers. In such cases the input analogue signals are converted into representative digital signals.

The representative digital signals are supplied to digital measuring instruments, digital display boards, digital control units, digital circuits of protective systems.

(*ii*) **Analogue to Digital Conversion.** There are many methods of analogue to digital conversion. The concept of a simple scheme is illustrated in Fig. 38.41.

The input signals is given to + of operational amplifier. The output of the operational amplifier is connected to a up/down counter.

This type of counter counts up when the control line is high and counts down when control line is low. The up and down counter receives continuous pulses from a clock when the counter undergoes a change of one up or down count, the comparator (Ref. Ch. 39) output reverses in sign and the output of the A/D converter becomes stable.

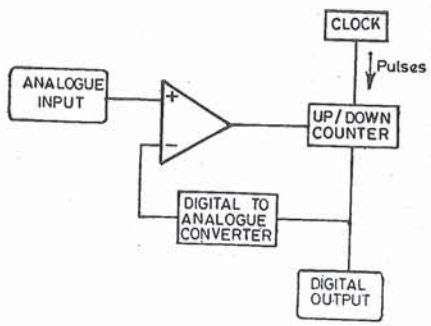


Fig. 38.41. An analogue to digital converter.

38.35.3. Digital to Analogue Conversion

The output of D/A convertor gives analogue signal proportional to the digital input.

38.35.4. Digital Multiplexers

The primary function of combination logic is to produce an output which is combination function of input, variables. If the system has 'n' inputs, there will 2^n combination of inputs and each combination will assign a specific value to the output. This type of operation is performed by digital multiplexer.

Digital multiplexer is a multi-input, single output combination of logic circuit. In digital multiplexer, the logic signal from input is directed towards output as per the *signal routing.*

The signal routing action of the multiplexer is controlled by the external logic signals applied to the selection control inputs which can be considered as the input variables for the device.

In practice the inputs are 2^n numbers where n is limited to 2, 8 to 16. Multiplexers provide general signal routing and its function is controllable externally.

Multiplexers are widely used as general purpose combination logic devices. A 2^n to 1 multiplexer can be used to implement any logic function with n input variables using suitable direct mapping.

The truth table of a 4 input-output Multiplexer is given below :

Channel	*Input Variables*			*Sum at output*
	Selection control		C_1	
	x_1	x_2		
0	0	0	0	1
1	0	1	0	1
2	1	0	0	1
1	1	0	1	0
3	1	1	0	0
	1	1	1	1

A multiplexer's signal routing capability is an important feature in digital protection and control systems. The multiplexer's signal routing is used in microprocessor-based and digital computer based protection and control systems to route the date from data bus structure to relevant functional circuits *via* the communication bus. Multiplexers are commonly used in microprocessors and digital computers to connect and route on common data highway or bus system and to apply *time division multiplexing* different classes of information along these bus systems.

38.35.5. Encoders and Decoders.

Combination of circuits are usually necessary to produce more than one output from the given set of inputs variables.

An *encoder* generates n outputs from 2^n inputs.

A decoder generates 2^n outputs for 'n' inputs.

Decoders are used extensively in programmable static relay circuits and computers to enable addressing a specific device or element in the system.

For example a microprocessor (Central Processing Unit) will communicate with a particular device or element *via* bus structure with the help of address decoder.

38.35.6. Programmable System

A digital system processes signals or data according to 'program'. The various functions include data collection, data transfer, data storage, data processing by *arithmatic* means, given output etc. These functions are performed internally in the digital system. These functions are performed by appropriate configurations of combinational and sequential logic circuits including memory elements. In programmable systems, the configuration of the general purpose logic is flexible. The hardware is controlled by a programme or sequence of instruction codes which defines the sequence of operations of processing functions. The instruction codes are sorted in the memory part of the system. The function of programmable system can be changed by changing the programme.

38.35.7. Microprocessor [Refer Ch. 43-B]

The advances in digital electronics and computing systems have resulted in development of complete Central Pocessing Unit (CPU) of a computer on a single Integrated Circuit (IC) called a chip. Such a CPU is called a microprocessor or processor and is designated as μp. Microprocessor is an advanced programmable logic device. In static protection systems special microprocessor are incorporated to perform specific functions.

38.35.8. Microprocessor Module [Ref. Ch. 43-B]

The heart of a microprocessor-based protective relay is a microprocessor. For example in a Programmable Distance Relay for protection of transmission line, a 16 bit microprocessor operating at 10 MHz is used.

The microprocessor has a separately replaceable programme memory in the form of chips. The subsystems also include read and write memory for working storage and nonvolatile RAM for storing settings and targets when the relay is de-energized. Included on the processor is the Analog to Digital Conversion system and multiplexer. AC input quantities (4 currents and three voltages) are analogue multiplexed to single sample/hold circuit. The sample/hold subsystem output is fed to an A/D subsystem which yields 15 bits dynamic range. Each ac input is sampled 8 times per cycle (1/50 sec).

The single Microprocessor based protective relay described above can perform several on-line functions including :

— Overcurrent supervision
— Power swing blocks
— Time delay
— Loss of potential supervision
— Fault type identification
— Distance protection, etc.

The digital programmable relays have several analogue, digital components and microprocessor. Ref. Ch. 43-B for Microprocessor based Protection.

38.35.9. Hybrid of Analogue and Digital Systems

The static relay systems receive analogue signals from CTs, VTs and other tranducers. Also from remote terminals (*e.g.* from other substation) digital signals are received. Hence, the inputs are digital and analogue. The functions within the relay include analogue multiplexing, analogue comparison etc. as well as digital logic, digital processing etc. Hence the protective system are 'hybrid' systems of analogue and digital.

The Analogue/Digital hybrid Systems can perform the functions by four different techniques.

1. Continuous space, continuous time.
2. Discrete space, continuous time.
3. Continuous space, discrete time.
4. Discrete space, discrete time.

Technique 1 is not suitable for analogue, digital and hybrid computation.

Techniques 2 and 3 require digital and analogue hybrid system. The digital subsystem handles discrete variables and analogue subsystem handles the continuous variables.

Technique 4 works purely on discrete space and discrete time. Therefore it requires a digital computer within the protective system. (Sec. 46.15. Fig. 46.7).

Section IV. ELECTRONIC CIRCUITS COMMONLY USED IN STATIC RELAYS

38.36. AUXILIARY VOLTAGE SUPPLY FOR STATIC RELAYS

The static relays require auxiliary d.c. supply; which is generally obtained from station battery system. The station battery system is also used for other purposes such as tripping, control etc.

Most static relays require various auxiliary d.c. voltage between 24 V and 240 d.c. The voltage stabilizers are used in the circuit of relays. The disadvantages of using station battery system for auxiliary d.c. voltage supply to static relays are the following :

— Voltage transients are introduced by opening of inductive circuits connected to the same battery supply (trip circuit for example). The voltage surges can damage the static relays. Hence special precautions are taken to design the static relays to absorb such transients (Ref. Ch. 43)

— The battery voltage is generally high, *e.g.* 250 V, this causes higher power loss in volt-ratio boxes used in static relays to get the reduced voltage.

To avoid these difficulties, the d.c. to d.c. converter is used. The station battery voltage is converted to a.c., then transformed and then rectified.

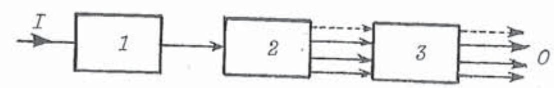


Fig. 38.42. Block-diagram of auxiliary d.c. voltage supply scheme.

1 — Input, d.c. voltage from station battery (d.c.)
1 — Inverted ; d.c. to a.c.
2 — Step-down transformer with required secondary voltages.
3 — Rectifiers, voltage regulators and smoothing circuits.
O — Output voltage for static relays (d.c.).

Fig. 38.42 illustrates the principle.

The d.c./a.c. converters are self-contained units. The voltages are converted generally from 220 V d.c. to about 50 V d.c. The converters are of enough ratings to supply the requirements of several relays.

In some cases, nickel-cadmium battery supplies are used for supplying static relays. These batteries are tricle changed from rectified a.c. source obtained from main potential transformers.

In some static relays, normal a.c. voltage is stepped down in the built-in auxiliary transformers in the relays, the rectified, established and smoothed.

38.37. FULL-WAVE RECTIFIER

Fig. 38.43 illustrates the circuit of a full-wave bridge rectifier having four diodes (1, 2, 3, 4) and input auxiliary transformer (5). When A is positive with respect to B, current flows through diodes 1 and 4. When B is positive with respect to A current flows through 2 and 3. In both cases, C is positive with respect to D and full wave rectification is achieved. The output contains ripple. To overcome this problem, smoothing circuit is necessary in the output.

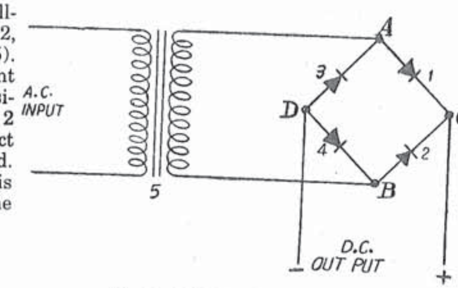


Fig. 38.43. Full-wave bridge rectifier.

38.38. SMOOTHING CIRCUITS

Smoothing circuit comprises reservoir capacitors, resistors, inductors. These are connected in output side of the rectifier. The process of charging the capacitors exponentially smooths the output waveform. The resistance determines the time-constant RC.

The voltage across the capacitor does not change instantaneously as capacitor requires finite time to get charged or discharged. Hence the voltage spikes or ripples get smoothened due to capacitor.

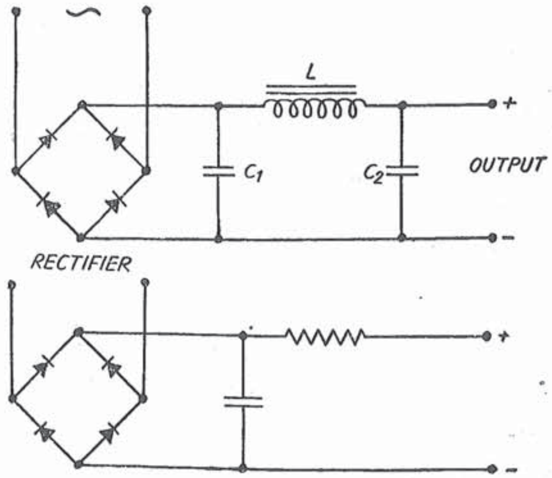


Fig. 38.44. Smoothing circuits in rectifier output side.

38.39. VOLTAGE STABILIZATION (REGULATION) BY ZENER DIODES

Zener diode is used for voltage stabilization. Fig. 38.45, illustrates the method of stabilizing the output voltage of a rectifier bridge by means of zener diode, zener diode is connected for reverse current flow. An improved stabilization is obtained by cascade connection of zener diodes.

The voltage across the zener diode remains constant over a wide range of current.

The bias of the input circuit (base-emitter) should be held constant. Zener **diodes** can be used for this purpose.

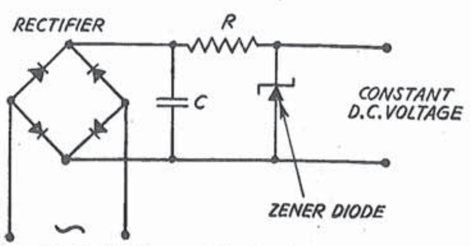


Fig. 38.45. Voltage stabilization by Zener diodes.

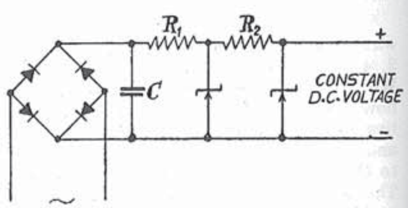


Fig. 38.46. Use of two zener diodes.

38.40. TIME-DELAY CIRCUITS

Time delay circuits are necessary in electronic circuits of static protection. These employ suitable combination of resistance and capacitance. The principle is as follows :

$$Q = CV$$

$$V = Q/C \text{(Ref. sec 3.2)}$$

$$= \frac{1}{C}\int i dt = \frac{1}{RC}\int V dt.$$

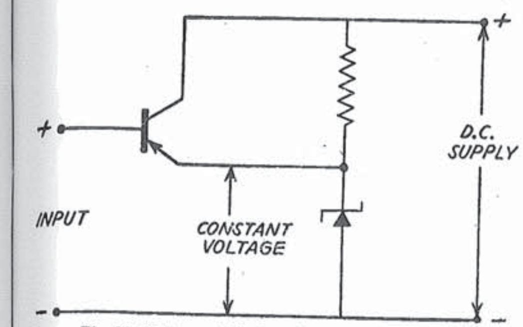


Fig. 38.47. Zener diode for voltage stabilization of input circuit.

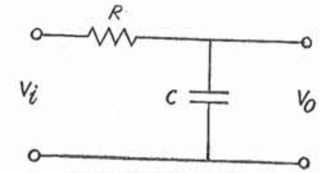


Fig. 38.48. Time circuit.

where T = Charging time of capacitor (From V_0 to V_i)

V_0 = Initial voltage across C

V_i = Final voltage across C, input voltage.

Consider Fig. 38.48. The capacitor is charged by the voltage V_i

The time is given by $T = RC \log_e \frac{V_i}{V_i - V_0}$

Delay Circuit

To achieve a very short delay of the order of a few micro-seconds delay line is used in Fig. 38.49.

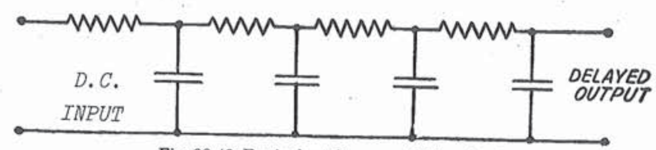


Fig. 38.49. Equivalent diagram of delay circuit.

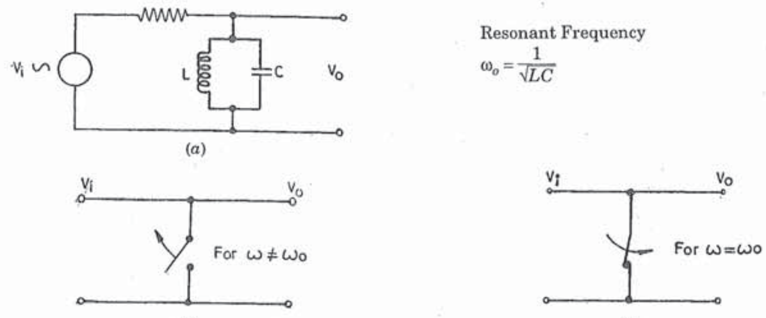
Time Delay Relay. For achieving intentional time delay in protection system, time delay relays are used. Time lags of 0.1 sec to several seconds can be adjusted in these (Details in Ch. 40).

38.41. FREQUENCY FILTERS

Filters are used for 'blocking' or attenuating certain frequencies and passing other frequencies.

Resonant circuits (turned circuits) are for passing of blocking the frequencies.

Parallel Resonant LC Circuit. (Fig. 38.50). The circuit having L and C in parallel with supply has a Resonant Frequency ω_0 at $\frac{1}{\sqrt{LC}}$. At resonant frequency, the impedance of parallel LC combination approaches **zero.** Thereby the voltage V_2 across output is reduced to zero. By judicious selection of L and C, the circuit can alternate/block frequencies from appearing across output (V_0).



Resonant Frequency

$\omega_o = \frac{1}{\sqrt{LC}}$

Fig. 38.50. Parallel LC circuit blocks resonant frequency w_o and passes other frequencies.

Series Resonant Circuit (Fig. 38.51). It has series, R, L, C. At resonant frequency $\omega_0 = \frac{1}{\sqrt{LC}}$, the impedance of LC resonant circuit becomes zero. The resonant frequency is passed through the circuit. For other frequencies, the circuit offers higher impedance.

Band Pass Filter [Fig. 38.51 (*a*) and (*b*)]. A simple *RLC* filters discussed above are called passive filters.

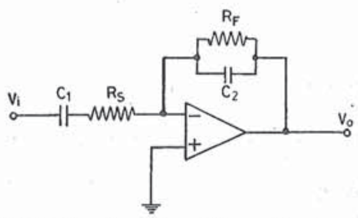
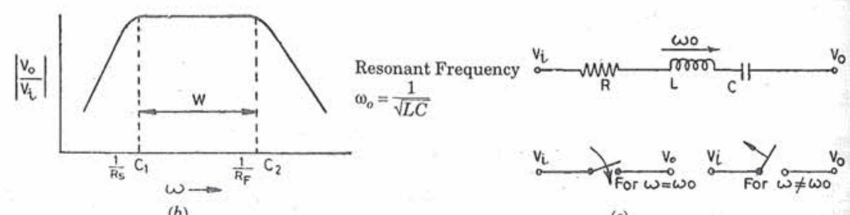


Fig. 38.51 (*a*). Band pass filter with operational amplifier, and its frequency response.

An active filter such as band pass filter contains active element like operational amplifier and attenuates frequencies beyond its two limits and passes the frequencies within its band limits without attenuation [Ref. Fig. 38.51 (*b*)]



Resonant Frequency

$\omega_o = \frac{1}{\sqrt{LC}}$

Fig. 38.51. Series resonant circuit passes frequency ω_0 and block other frequencies.

38.42. SYMMETRICAL COMPONENT FILTERS

The three phase vectors of an unbalanced system can be derived by vector sum of three sets of component balanced vector called positive sequence, negative sequence and zero sequence components (Ref. Ch. 21).

Symmetrical component filters are necessary to drive the symmetrical component (from output of CT's or VT's) for feeding into the comparator/level detector of static relay. For example in unbalance current protection, the negative phase sequence components is filtered and supplied to overcurrent relay (Ref. Sec. 31.7).

(*i*) **Negative Sequence Current Filter.** Negative sequence current filter is quite complex. Its design is complicated and expensive as it incorporates a trans-reactor (also called transactor). This is a special multi-winding CT having gapped core.

The secondary leads of main CT's are connected to the various primary terminal of trans-reactor (Transactor or Intermediate CT) is a required manner. The filtered output depends upon phase sequence of input connections. (If two of the input connections are interchanged, the negative sequence filter becomes positive sequence filter).

A simplified diagram of negative sequence filter is illustrated in Fig. 38.52 (*a*).

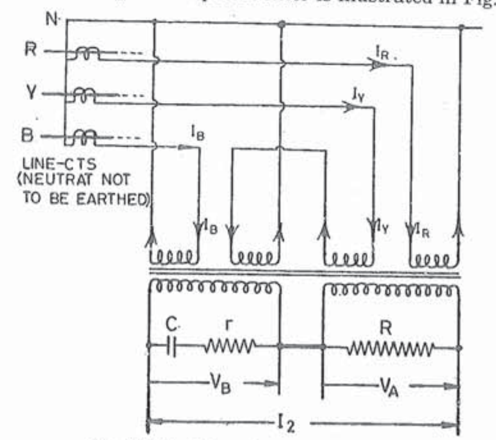


Fig. 38.52 (*a*). Negative sequence current filter.
– Circuit Diagram (Ref. Fig. 33.19, Sec. 33.11).

Fig. 38.52 (*b*) shows vector diagram for negative sequence condition (*YRB*) and Fig. 38.52 (*c*) give vector diagram for condition when only positive sequence condition (*RYB*) prevails.

The flux produced in the gapped-core of the transreactor due current $\bar{I}_R$ and $\bar{I}_Y$ is proportional to $\bar{I}_R - \bar{I}_B$ and $\bar{I}_B - \bar{I}_Y$. The resultant voltages depend upon the phase relations between V_A and V_B.

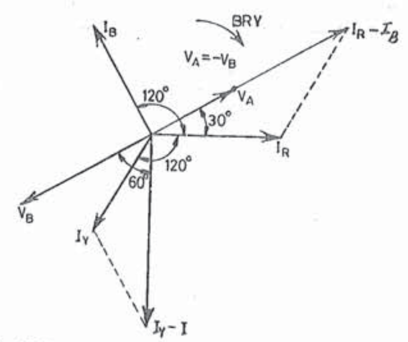


Fig. 38.52 (*b*). Vector diagram for positive sequence condition of I_R, I_Y, I_B. V_B is equal and opposite to V_A.

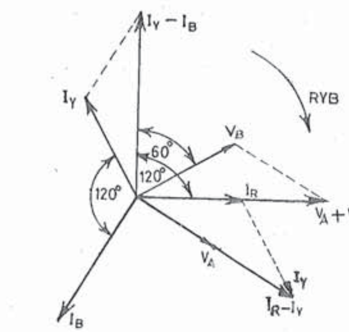


Fig. 38.52 (*c*). Vector diagram for negative phase sequence condition of I_Y, I_R, I_B, $V_A + V_B \neq 0$.

* Ref. Fig. 38.52 (*a*), when $V_A + V_B \neq 0$,
Negative sequence current output of the filter, $I_2 \neq 0$.

(*ii*) **Negative Sequence Voltage Filter.** Negative sequence voltage filter is connected to the secondary side of VT's. It passes Negative Sequence Component (V_2) the circuit voltage and rejects positive sequence and zero sequence components. The relay connected to the output side of negative sequence voltage filter respond to V_2 only.

For simplicity, the three input terminals of negative sequence filter are connected to line side having no zero sequence component (Star connection without earthing)

There are many possible methods of connecting r, L, C to get the filtered negative sequence output.

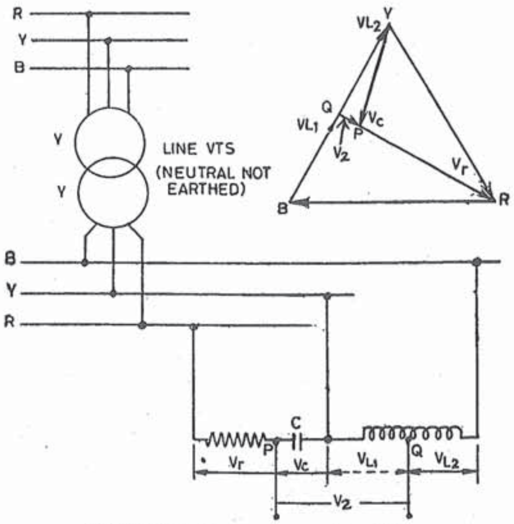


Fig. 38.53. Negative sequence voltage filter.

Consider Fig. 38.52 (*a*). For negative sequence condition of supply voltage (phase sequence YRB or when supply voltage contains negative sequence component) negative sequence voltage V_2 appears across *P*, *V*. When negative sequence component in line voltage is zero, the voltage V_2 is zero.

The same circuit can be used as a positive sequence filter by interchanging supply terminals.

39

Comparators and Level Detectors

Static Relay — Functional Circuits — Comparators — Amplitude Comparators — Rectifier Bridge Comparators — Phase Comparators — Pulse and Squared Input — Direct and Integrating Type Comparators — Integrating Amplitude Comparator — Hybrid Comparator Level Detectors — NPN Transistors — PNP Transistors — Operational Amplifier — Schmitt Trigger .

39.1. STATIC RELAY FUNCTIONAL CIRCUITS

The static relay unit comprises several functional circuits such as :

— input circuit with main CT's, Auxiliary CT's
— rectifiers smoothing circuits, filters
— level detector
— timer circuit
— filter circuit
— directional unit
— comparator
— amplifiers
— setting device
— starting relay
— output stage, etc.

The required functional circuits or units are connected in the final assembly.

Input stage

The input is derived from CT/PT. The output of CT/PT is connected to the auxiliary CT/PT. The input stage of a static relay comprise the following :

— CT's and or PT's.
— Auxiliary CT's or PT's.
— Summation units.
— Filter.

Rectifier and Smoothing Circuit

In single actuating quantity relays, the quantities are rectified in a single rectifier bridge. The output of the rectifier is smoothened to remove the ripple. The output is given to the level detector. Single actuating quantity relays include overcurrent relay, under voltage relay etc.

In double actuating quantity rectifier relay there are generally two rectifier bridges. The output of these bridges is compared. The output of the comparator is given to the measuring unit (level detector) after smoothing.

Comparator

Comparators receive the rectified inputs. After comparison the comparator output is given to the measuring unit.

There are several types of comparators such as amplitude comparator, phase comparator, hybrid comparators.

These are either direct (instantaneous) or integrating type.

Level Detector or Measuring Unit

This unit comprises a multi-stage feedback amplifier. The feedback ensure that for values of unit above a certain level, the output power increases in a step. Hence for input below threshold value, the level detector has no output. For input above threshold value, the output is obtained.

The measuring unit comprises logic circuits, amplifiers and level detector circuit. The logic elements determine the conditions of various input quantities for which output is obtained.