CHAPTER - I

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1.1 DIFFERENT TYPES OF FAULTS AND THEIR EFFECTS:

The power system elements generally consist of generators, transformers, transmission lines, cables, synchronous and induction motors and switchgear, each being subjected to some faults sooner or later. The fault or problem to an electrical system implies any abnormal condition which reduces the insulation strength between conductors of different phases or between the phase conductors and ground. Generally a fault produces excess current and reduces the system voltage which, if allowed to flow through the system for a long time, will damage the power system elements or influence on the system stability. Some of the most common form of disturbances, often encountered by the power system apparatus, are - Overloading, Short Circuit, Single phasing, Reversed phasing, Earth fault, Over current, Over and under Voltage etc. The most common form of disturbance in normal operation of electrical equipment is overloading, due to which flow of current exceeds rated value. Power system apparatus or equipment overloading leads to a rise in temperature with a consequent failure of the insulation and burning of the equipment/system. The most severe type of faults'
is the short circuit. The magnitude of the short circuit current depends upon the kind and character of the short circuit, the power capacity and circuit arrangement of the system, the method of connection and operation of the transformer neutrals, the distance of fault from the generating units, the rating of the main equipment and current limiting devices, the duration of the short circuit, the speed of action of the regulating and switching apparatus in the system and other factors. A short circuit may have the following effects on the system:

1) It can not only lead to damage of the equipment on the circuit element in which it develops but also spread to other parts of the system causing entire dislocation.

2) It causes a considerable drop in voltage and frequency at which stable parallel operation of the power unit is hampered.

3) It also causes motors to draw larger current, lead to switch off series of power consumers, increase the energy losses in all parts of the power system and loss of
industrial production. Over and under voltage, unbalance voltage exceeding a limit may deteriorate the system performance producing a current of higher level. Single phasing also produces distortion effect on the healthy part of the circuit. Certain systems require a rotation in a definite direction depending upon a proper phase sequence of voltage. Faulty connection of sequential voltages may create a tremendous destructive action on the system. Therefore, all of them require a device for protection.

1.2 **REASONS FOR THE USE OF PROTECTIVE DEVICES:**

The characteristic of high degree of interconnection and interdependence existing between the various elements of an electric system and its conditions of operation create a need for the use of protective devices and arrangements that will automatically and very quickly disconnect the faulty section from the system or initiate alarm of disturbance under abnormal operating conditions. These functions are performed by a system of protective relays, each constituting a relay protection scheme. The protective relay scheme may consist of one or several relays to operate, not only
instantaneously, but also with time delay. The same scheme may also employ relays of diverse type, construction etc.

1.3 RELAYING TECHNOLOGY:

During last few decades, hardware based relays or solid state relays (S.S.R) became extremely popular in every sphere of electrical engineering and those are extensively used in power supply industries. These static relays were developed mainly to replace their electromechanical counterparts (e.m.r) as they possess some special advantages.

Relaying technology has advanced dramatically during the last two decades. The main reason for such exponential advancement is the use of computer and microprocessor. Their uses range from the microprocessor employed in the relays themselves, for measurement or control, to testing by computer for development including power system simulation, production testing and even site testing.

Modern advanced relaying technology now depends much upon microprocessor as well as computer due to their extremely superior and versatile capabilities for handling intricate logics and generating proper control action with astounding speed along with reliability, flexibility
and many other unparallel qualities.

The correct application of protective relays require not only a knowledge of the relay design parameters but also a good understanding of the behaviour of the power system in which the relay is to be applied.

1.4 BASIC STRUCTURE OF PROTECTIVE RELAYING SCHEME:

All protective schemes basically consist of the three elements as shown in Fig. 1-1.

a) Measuring element:

This element at the relaying point is energised by one or more of the electrical quantities of the power system (vis. Voltage, current, frequency, etc.). The linking of the element with the power system is done by inductive coupling i.e. by current and voltage transformers in order to reduce the magnitude of the power system quantities and to isolate the relaying equipment from the power system.

b) Comparing element or comparator:

This compares the quantities fed to it from the
Fig 1-1 Basic Elements in a Conventional Protective Relaying Scheme.
measuring elements. Comparators may be single input, two input or multi-input in nature. In case of single-input comparator, the other input is generally a mechanical one e.g. tension or compression of a spring or some of mechanical torque. Comparison may be made generally on the basis of amplitude (Instantaneous, average or rms value comparison) or relative phase. The input quantities thus giving rise to basically two types of comparators, Viz, amplitude and phase comparators. Another type of comparator, known as hybrid comparator which is a combination of phase and amplitude comparator, is also realised in practice. After comparison is made in the comparator, whether in the from of a mechanical torque (Electromagnetic comparator) or in the form of a resultant electrical signal (Static comparator), it gives an output in one direction or other to actuate the control element.

c) Control element:

It is operated in one direction or other by the output of the comparator and it controls the tripping of circuit breaker (C.B.).
d) Trip element:

It is generally a trip coil associated with the tripping mechanism of C.B.

1.5 FUNDAMENTAL REQUIREMENTS OF PROTECTIVE RELAYING:

A good protective scheme should satisfy the following fundamental requirements.

1) Sensitivity in operation:

The abnormalities in a power system may be varied in nature. They may be very minute or extremely severe. The capability of the protective scheme to respond to the minutest abnormality is a desirable feature and this is known as the sensitivity.

2) Reliability in operation:

It is not possible to foresee the occurrences of abnormalities in a power system. Any relaying scheme must continuously be on the alert over long intervals so that it can respond to abnormalities at any moment, when the occasion demands.
3) Quickness in operation:

Quick disconnection of faulty section on the occurrence of faults not only decreases the damages incurred but also helps in maintaining stability of the rotating machine. This also helps in maintaining the normal operation in the unfaulted section of a power system.

4) Selectivity in operation:

This is necessary to discriminate the abnormalities within the protective zones or outside it. The relaying scheme used for the protection of a certain zone should not respond when any abnormality occurs outside its zone of operation.

1.6 FEW BASIC OPERATIONS IN PROTECTION:

Normally four basic operations are needed for protection purpose:

a) To compare the magnitude of a particular quantity with a standard quantity (Level-detector).

b) To compare the magnitude of the particular quantity
with that of another quantity (Amplitude comparator)

c) To compare the phase difference between two alternating quantities (Phase Comparator).

d) To incorporate necessary time delay, so that the execution takes place after some desired delay.

1.7 FUNCTIONS & CLASSIFICATION OF PROTECTIVE DEVICES:

The importance of automatic protective systems has increased collaterally with the size and interconnection of electric-power system. Their functions are:

i) To isolate from the system a feeder, machine or other apparatus, quickly and with certainty, when a fault has developed therein;

ii) To remain in-operative, with equal certainty, on all parts of the system which are sound.

Automatic protective systems may be classified as follows:

1) Devices that operate when currents or voltages exceed or fall below predetermined limiting values, e.g., overload, minimum load, over-voltage and no-voltage relays.
2) Devices that operate when the current or power flows in the reverse direction to that which is normal, e.g., reverse current and reverse power relays.

3) Devices that operate when the current flows through abnormal paths, e.g., core-balance and leakage relays.

1.8 COMMON FEATURES BEHIND THE DEVELOPMENT OF DIFFERENT PROTECTIVE RELAYING SCHEMES:

Different types of relaying schemes do not differ at all so far as their fundamental principle of operation is concerned. All of them comprise the same basic elements (Viz. Measuring element, comparing element, Control element and trip element). They differ only in the utilisation of different power system quantities available at the relaying point.

The overall performance of a particular type of relaying scheme, will solely depend on the behaviour of the measuring and comparing elements. The measuring element (M.E.) will function to maintain its outputs provided the comparing element (C.E.) which is energised by these outputs does not demand any volt-ampere from the measuring
element. This volt-ampere (VA) requirement is the major burden of the relaying scheme. Hence constant endeavour is made to reduce the VA burden of the relaying scheme.

Starting from the earliest 'Induction disc unit' we see the gradual developments of 'Balanced beam Unit'; induction cup unit' and 'Moving coil unit' which are all electromagnetic units.

The electrical circuits used to energise the magnetic structure of these units constitute the 'Measuring element' and by electromagnetic action, the output from these elements are obtained in the form of mechanical torques which act on the movable element. These movable elements in the form of disc, armature, or cylinder constitute the comparator. Thus it is seen that all the basic elements of a relaying scheme are housed in the relay unit, and their separate entities can not be apparently recognised.

With the complexities of the power system it was felt that the fundamental requirements of the protective relays (viz. quickness of action, sensitivity, reliability and selectivity in operation) should be satisfied more stringently. This necessitated the reduction of relay offer. This gave rise to the
development of static relays having the following advantages: (1) simplicity in mechanical design, (2) lower VA burden (3) less maintenance and greater reliability, (4) a large scope of manipulating with the input electrical quantities to produce a variety of complex relaying characteristics, (5) very fast operation and long life, (6) quick reset action and absence of overshoot, (7) lower VA burden demanded by the measuring circuit making possible the miniaturisation of the relay module. In static relay, all the basic components of protective relaying will be seen to have their separate physical entities. The measuring elements give electrical outputs which are compared in their electrical state in the comparator. The comparator gives electrical output to operate a slave relay for the purpose of contact closure. The slave relay is the control element and since it is operated from another auxiliary source (Viz. battery), the VA burden demanded from the measuring elements is insignificant. Because all the inputs to the comparator are electrically compared, they are more flexible and very little power is demanded from the measuring elements inputs to change the electrical state of the comparing element which is absolutely not the case with the electromagnetic relays.

Currently, extensive work is going on in the application
of on-line digital and analog computers to power system protection, eliminating the necessity for separate protective relays as such. Previously digital protection philosophy was to use a large computer for the total protection of an integrated power system. With the development of low cost microcomputer/micro processor system the economics is changing at a fast rate and investigators are trying to develop dedicated digital protection schemes which closely imitate the existing relaying practices (Electromechanical and static analog). Each relaying function is served by a separate unit which requires a highly paralleled distributed processor network, in which each processor is strictly dedicated for a particular protective function.

1.9 E.M.R. VERSUS S.S.R. :

Traditionally the relay function is performed by a coil, which when supplied with a current, magnetically moves an arm to make or break physical contacts, as show in fig. 1-2 (a). Developments in solid state technology have now enabled this relay function to be performed with no moving parts, as shown in fig. 1-2 (b). As the majority of industrial power switching applications involve a.c. supplies and require isolation between the control and controlled circuits. Early devices that produced the
Fig. 12(a) Schematic layout of the Electro-mechanical relay (e.m.r.)

Fig. 12(b) Schematic layout of the Solid-State relay (SSR)
s.s.r. function were not truly solid state, in those cases they used REED relays as the isolation element and power thyristors or triacs as the output power switches; These types were generally known as hybrid s.s.r.

To eliminate moving parts completely the transformer coupled s.s.r. was developed. Here the control voltage being converted to pulses are fed to the transformer coupled to the main power control device. This method of construction has now largely been discontinued because of the technical advances made in the field of photocouplers which enabled such counters to be used in a solid state relay.

Photo-coupling achieves excellent voltage isolation and is unique in that it is an all d.c. link. The sensitivity makes it compatible with logic level signals and it provides unidirectional coupling except for the few picofarads of input-to output capacity. The block diagram for a photo-coupled s.s.r. is shown in Fig. 1-3.

The use of photo - coupling results in a system that is essentially free from noise transmitted from the power circuitry back into the signal level circuitry. It also means that the input characteristics are resistive and hence will not able to produce back e.m.f.s. as would be the case with REED coil input.
Fig.1-3. Photo coupled solid state relay.
The long term reliability of the s.s.r. exceeds that of electromechanical relays (e.m. r.s.) as there are no moving parts to wear out. A typical e.m.r. may have an expected life of $10^6$ operations and if operated every 5 seconds, it would achieve this number in about 2 months. With the need for equipment to have a useful life many years, the use of s.s.r. can offer distinct advantages in terms of cost savings, reliability and lack of servicing over the life of the equipment.

By using all solid state components as the power control elements, zero voltage and zero current switching can be readily provided. Voltage is applied to the load commencing at the zero crossing point, irrespective of when the control signal is applied to the s.s.r. Current to the load will be interrupted only at the next zero crossing, after the signal is removed. This method of switching gives a much more controlled ON/OFF characteristic than can be achieved by e.m.r's. With incandescent lamp loads, the voltage is applied sinusoidally, thus allowing the filament to heat up and increase its resistance before the supply voltage peak is reached and the amplitude of inrush currents is much reduced by this approach.

By using all solid state components as the power control
elements, zero voltage and zero current switching can be readily provided.

The signal sensitivity of s.s.r.'s enables them to be driven directly from logic level signals, and in many cases, the amplifiers necessary for e.m.r.'s. can be eliminated, making for overall system simplification and smaller printed circuit boards. The inherent power gain in an s.s.r. is typically a million, enabling the designer to concentrate more on the logic of a system than on the logic/power interface problems.

The absence of moving parts in s.s.r.'s implies that they are completely silent in operation and this is important in equipment using a lot of relays, particularly, if these operate frequently and are located in offices, studios, laboratories, hospitals etc.

With the advent of microprocessor systems which ultimately have to control power in the real world, there is a demand for types of s.s.r. which have been designed with this specific application area in mind. Some manufacturers have introduced s.s.r. packages that can be mounted on to p.c.b.s. and retain the ability to be easily connected to the controlled loads via screw terminal block type connections. This is quite a versatile package.
I/O switches: In microprocessor terminology this family of devices is called input/output switches, and of course the s.s.r. and its inverse function are included in this family. But in a much wider sense, they include devices capable of controlling d.c. loads and detecting d.c. signals from the loads, and from the interface between the logic processing board and the external power and load systems.

Solid state relays due to the energy requirements of the trigger circuitry and the leakage current of power semiconductor devices, have a finite off-state leakage current, typically a few milliamps, usually this leakage current generates only a small voltage across the load, but nevertheless the s.s.r. does not completely disconnect the supply. The s.s.r. should not be relied upon to give isolation of the load from the supply, this being performed by a conventional circuit breaker. The primary purpose of the s.s.r. is to actually control the load via the on/off function.

A characteristic of all power semiconductors, thyristors, and triacs is that they are sensitive to rapid changes of applied voltage and care must be taken to limit these rates of change to a value that can be withstood by the s.s.r. This is done by the use of resistor capacitor
networks, called snubbers. The s.s.r.'s which use an inverse pair of thyristors are less sensitive to rates of change of voltage than triacs. As triac is a single chip device, it conducts current in both directions, thus at the point of turn-off it is, if the load is inductive, required to immediately block voltage. It can only do this successfully if the rate of application is limited to a few tens of volts per microsecond. Thus to ensure reliable turn-off, a snubber is mandatory.

If the output power switch is built from a pair of inverse thyristors, the junction which must block voltage is not that, which has immediately ceases conducting current. It has had no current for half a supply cycle, and can thus withstand its full static rate of application of voltage, which will be several hundred volts per microsecond. However, in severe operating conditions, it may still be necessary to use a snubber to cope with the waveforms generated. Generally, snubbers should be optimised for the characteristics of the load, but some manufacturers do offer the option of built-in snubbers, and if these turn out to be insufficient, external components may be added.

A secondary, but important aspect of snubbers is that they do, in conjunction with the load, provide a filtering
effect against transients generated on the incoming ac lines.

A small disadvantage of a snubber is that the off-state leakage current is increased, but the amount of voltage generated across the load due to this current through it is of minimal consequence. For example a 240v 10A load would represent an impedance of 24 thus a 10mA leakage current would only develop 240mV across the load when the s.s.r. was off.

Most manufacturers have concentrated on producing s.s.r.'s that can be controlled from d.c. logic level signals, and are thus compatible with I.C. drive capabilities. There are, however, some applications where the s.s.r. is used to replace an e.m.r. that was controlled from a contact such as a thermostat fed with a.c. supply level voltages. There are manufacturers who have recognised this requirement and also offer models that can accept these high level a.c. signals, thus easing the substitution of the e.m.r. by s.s.r., and avoiding the necessity to provide the auxiliary d.c. power supply needed if a d.c. control s.s.r. is used.

Before ruling out the use of s.s.r.'s on the grounds of cost, it is important to appreciate the operational
advantages offered by the use of s.s.r's and consider such factors as reliability, lack of maintenance, signal sensitivity, and zero voltage switching.

A major disadvantage in the use of s.s.r's is that, in the on-state they generate heat due to their voltage drop, which is typically 1.0V; this is some twenty times greater than the drop for a mechanical contact. This means that for applications above a few amps, the s.s.r. will need an external heatsink to dissipate this heat.

A single-pole e.m.r. may easily be converted to a two-pole or change-over configuration, without much added expense, because they are operated from the same magnetic system that represents most of the component cost. With an s.s.r. the major cost is the output power switching device, thus to make a two-pole type would nearly double the cost, and there would be little advantage over using two single pole s.s.r's. Even to make a change-over contact version of an s.s.r. presents a problem. The possible uses of s.s.r's are varied; however they are usually appropriate when used as the interface between a low power control system and an a.c. line voltage power load. The control signal can be derived from a mechanical switch power load. The control signal can be derived from a mechanical switch for manual operation,
or from an electronic switch such as a transistor, thyristor, or integrated circuit. If more than one s.s.r. is to be operated from a single control source, it is possible to connect the control terminals in series or parallel depending on the signal available.

If the available voltage is higher than that s.s.r. can accept, an external series resistor can be added. As the input to s.s.r's is resistive in nature, it is not necessary to provide the freewheel diode required when operating an electromechanical relay from a d.c. source, and most manufacturers fit a diode across the internal polarity sensitive component to protect the device against inadvertent incorrect connection of the control signal.

The areas of use of s.s.r's are expanding rapidly, as more designers realise the advantages offered by the complete package function and packages optimised for particular power ratings are developed to provide more cost-effective solutions to the switching problems. Mostly they will find applications in new designs, not just as replacements for e.m.r's in existing circuitry.

There will still, of course, be a high demand for e.m.r. types and if they can cope with the demands made upon
them, they will continue to be the best answer to the switching problem. But nevertheless, s.s.r's have become accepted as important functional components, not just a passing peculiarity, and deserve due and proper examination when considering an overall power control system.

1.10 PROTECTION OF POWER APPARATUS AND SYSTEMS: THE DIGITAL APPROACH:

The concept of digital protection has attracted much attention from the protection engineers. Growing interests are being shown in the use of digital principles for critical protection function by research workers, practising engineers and power supply authorities. While the relative economics for computer relaying scheme versus conventional solid state or electro-mechanical relay equivalent are not entirely clear and are also changing, there are definite technical and performance advantages which computers can bring to the relaying art.

The application of computers to Power System Protection can be divided into two main classes: Viz. (1) Analog techniques, (2) Digital techniques. So far as protection is concerned, a computer may be identified to
perform mainly two types of functions (i) simulation of the various types of equipment used for protective purpose in order to study their steady state and transient behaviour and (ii) to perform the functions of a complete protective system and thereby eliminating the necessity of any static or electromagnetic protective relays.

Analog computer has found its application in the field of simulation of various protective gear equipment in order to study their transient behaviour. On the other hand, digital computer being a much more powerful tool is used mainly for two purposes (i) off-line studies and (ii) on-line implementation of the various functions of the protective system.

The off line studies include (a) development of relay co-ordination programmes and subsequent settings of different relays associated with such programs, (b) study of different protective gear equipment under various conditions with the help of accurate mathematical models, (c) development of different digital testing methods to prove the performance characteristic of the protective relays that are being developed. The on-line implementation of the protective functions by digital computer, essentially means the development of accurate
mathematical models and their subsequent step by step solutions and implementation by different numerical methods.

1.11 ADVANTAGES OF DIGITAL RELAYING :

a) Flexibility:

some general purpose hardware can be used to perform a variety of protection function with the change of stored program only. Drastic addition and/or alteration of the protection logic hardly requires any hardware replacement.

b) Adaptive capability:

The behaviour of the processor can be made to change automatically depending upon the external circumstances which changes with time. The basis of this change can be either local information available to the processor or the change may be initiated by an external source of intelligence, such as data link or the central computer system.

c) Detailed logical & mathematical Capabilities:

While the conventional relay designer is somewhat
somewhat constrained by the characteristic and limitations of the electromagnetic or solid state sensing circuit, the programmer in digital relaying scheme is free to provide almost any characteristic within the limits of his understanding. Specific protection problems can be broken into fine details and each handled separately. In addition, measurement problems can be stated as mathematical equations and directly implemented.

d) Self-checking ability:

Conventional relays are idle for essentially their entire lives, faults are present for a total of perhaps only a few seconds out of 20 to 30 years of service. Periodic maintenance and testing are therefore essential to ensure its ability to do the job correctly. A digital processor, on the otherhand, by its very nature, is a dynamic device and most hardware failures are immediately flagged by a processor stop. Beyond this, specific programs can be carried out during non-fault periods which tests the processing hardware, the integrity of the programe memory and the calibration of the analog to digital interface etc. Even though a micro-processor may not be more
reliable than a conventional relay system, in the hardware designer's sense, it may prove more reliable and more secure to the relay engineer's sense because it can alert the user to a mal-function before a false trip or failure to trip occurs.

e) Low burden on transducer:

Unlike conventional electromagnetic relays, microprocessor based relays impose a very small burden on the c.t.s. and v.t.s. This is a great advantage, since saturation can be avoided by use of airgap c.t. which have a limited output.

f) Data interface access:

A general purpose digital computer can always be equipped with input/output ports through which data and control commands can be exchanged. The sequence of software events that occurs in the processor in response to a fault can be stored in the memory and subsequently recorded in black and white to provide with a detailed information on the specifics of the faults and the software action. In turn, data can be introduced into the processor
g) Memory action:

Since the prefault voltage samples are within the computer memory, voltage collapse due to short-circuit at relaying point does not introduce any difficulty when the voltages are used in input quantities.

h) Standardisation:

With conventional static or electromagnetic relays, any special requirement of the consumer has to be met by the change in the design of the relay itself which may be a very costly and time consuming affair. But the component sub-units in a microprocessor based protection system are constructed with a standard hardware feature and any special feature can be met with modification of the program only. This standardisation provides a considerable simplification in production, testing and maintenance.

i) Possible economic benefits:

While cost of conventional relays are steadily
in analog form through different types of transducers (such as v.t., c.t. etc.). So in order to make the analog quantities suitable for inputs to the digital computer, large number of Analog-Digital converters should be used.

c) A general purpose computer is completely programmable and can perform almost an unlimited variety of numerical calculations in the engineering, scientific and business areas, whereas a special purpose computer is designed for a single type of applications and frequently has most of its program prewired.

d) In order to solve any problem (like the substation switching or the protection of transmission lines and substation equipment), the mathematical modelling of the problem will have to be formulated first and the process of solving will have to be devised and stored in the memory locations of the computer in the form of different sets of programs.

To store the programs in the computer, various programming languages have been developed, amongst which fortran IV and cobol programming languages are increasingly used for engineering purposes in the general purpose computers whereas the
rising, those of digital processors suitable for apparatus protection are slowly decreasing. This trend is likely to continue. Even now the processor will all its peripherals for transmission line protection is priced in the same neighbourhood of conventional relays. The above discussions indicate some of the benefits which may be gained by applying the relatively new micro-computer technology to power system protection. Considerable studies are however, required for solving hardware and software (Program) features and to derive optimum configurations for protection schemes employing this device.

1.12 DIFFERENT PROCESSES INVOLVED IN DIGITAL PROTECTION

Without going into the detail organisation of a computer, the following general comments may be made.

a) A computer communicates with the outside world through its input/output peripheral devices called interfaces.

b) A computer can accept only digital data inputs whereas most of the power system quantities (Such as voltages, currents, frequency etc.) are obtained
mini-computers and/or micro-processors available at present are programmable in machine language and this allows a highly efficient dedicated macro language to be developed for the description of fault detection algorithm.

e) In an ON line digital computer used for the purpose of protection, the input quantities are continuously being monitored and are being fed to the computer through A/D converters. These input data are stored in the memory locations. On receipt of the command signals from the pre-stored programs located in the memory. Various mathematical operations are performed sequentially on the input data in the Arithmetic & Logic Unit (ALU) of the computer. The processed outputs are then compared with the set of programmed standard inputs in order to detect any abnormal fault conditions. Signals are then given to the different output devices in order to actuate the various isolators, circuit breakers etc. for the successful disconnection of the fault element.

In case, the previous sets of input data after processing do not detect any abnormal conditions, fresh sets of data are being processed and the same cycle is being repeated again.
With the development of low cost micro-computer system and micro-processor, the economics are changing at a fast rate and the attention of the investigators have been focussed on developing dedicated digital relay system which closely imitates the existing relaying practice. Each relaying function is served by a separate unit which requires a highly paralleled, distributed processor network in which each processor is strictly dedicated to a particular protection function.

1.13 THE MICROPROCESSOR : AN EFFECTIVE TOOL IN MODERN PROTECTIVE SYSTEMS

Historical Development:

The microprocessor is the culmination of the developments which have been taking place in semiconductor technology since the first production of transistors were produced in the early 1950's. Then in rapid succession came IC's (integrated circuits) in early 1960s, MSI's (Medium scale integrated circuits), LSI's (Large scale integrated circuits) and VLSI's (very large scale integrated circuits). LSI technology has since given birth to the microprocessor. A microprocessor is a device that forms the central part of a computer.
The first microprocessor was announced in 1971 by Intel Corporation. It was a 4-bit microprocessor (Intel 4004). As technology developed, Intel introduced improved version of 4004 and 4040 4-bit microprocessors. Since then, many other 4-bit microprocessors have been announced, Rockwell International's PPS4 and Toshiba's T 3472 being two examples.

First general purpose 8-bit microprocessor 8008 was introduced by Intel USA in 1973. It was implemented in P-Channel MOS technology and had an instruction execution time of 20 micro second. As technology developed, Intel introduced an 8-bit processor 8008A with an instruction execution time 2 μs. The processor employed N-channel MOS technology and was software compatible with 8008. With the objective of improving the performance of microcomputers further, the 8085A was introduced by Intel in 1977. There are two versions of this processor --- the 3MHz 8085A and the 5MHz 8085A - 2. The 3MHz version has an instruction execution time of 1.3 us and the 5 MHz Version of 0.8 usec. Today there is a variety of 8-bit processors, some examples being Motorola's M 6800, National Semiconductors SC/MP, Zilog Corporations Z-80, Fair Child's F8.

Thus with the development of technology, the instruction
execution time for a processor which had 20 \mu s. in the year 1973, came down to 1.3 \mu s by the end of 1977. During the same period, the number of components required for building an average microcomputer system was reduced from 60 to 3.

The 8-bit microprocessor was followed by microprocessors operating on 12 and 16 bit data words, respectively. Intersil's IM 6100 and Toshiba's T 3190 are examples of 12-bit processors. Examples of 16-bit processors are Fair Child's 9440, Data General's MN 601 and Texas Instrument's TMS 9900. Intel's 8086, Motorola's M 68000 and Zilog's 8000 are some of the most powerful, 16-bit microprocessors available today. The evolution of microprocessors from 1971 till today has been characterised by improvement in architecture and the instruction set alongwith the execution time. Today even 32-bit processors are available some examples being Intel-80386, Zilog Z-80000, Motorola 68020, MC 68030, National Semi Conductor NS 32032, NS 32332 etc.

1.14 **A MICROPROCESSOR CHIP ORGANISATION**

A microprocessor is essentially a large scale integrated central processing unit (CPU) chip of initially 4 and later 8/16/32 bits in multipin packages together with a suitable supporting system to convert them into a usual
micro-computer. The CPU unit may be described as the heart of any micro-computer and its main function is to operate on input data by means of instructions to generate a set of output.

Although the internal construction of CPU chip differs from manufacturer to manufacturer but essentially it consists of:

1) ALU:--- Arithmetic & Logic Unit: Performing all the arithmetic operations and the necessary boolean logic operation on the functional input data. Some of the elementary operations that are carried out are addition, clear, complement, logical AND, logical OR, exclusive OR, Shift left, shift right, increment and check if zero and also compare instructions etc.

2) Accumulator: Accumulator and other registers which may be used to store data words, memory addresses, counters etc. following an input and prior to an output operation. The main arithmetic operations of ALU are carried out in the Accumulator which has also the data shift facilities.

3) Multiplexers: Due to package pin limitations in a
microprocessor chip, a given pin set may be employed for multiple purposes e.g. data input, data output or use of common lines for memory and peripheral data. The different multiplexers inside the chips (and possibly externally) control the pin employment after getting necessary instructions from the control unit.

4) Control Unit: All the command instructions (Written in micro-program) to C.P.U. are decoder in the control unit. These decoded signals together with the clock pulses provide the correct sequential operation signals to the A.L.U., the registers and multiplexers. Fig. 1-4 shows a typical C.P.U. chip organisation.

1.15 THE MICRO-COMPUTER SYSTEM:

All C.P.U. chips require a supporting structure to convert them into a useable micro-computer. The memory and communications with external devices are the two main features of the system external to the C.P.U. unit as shown in Fig. 1-5.

Memory Units:

R.A.M: A memory unit is a collection of storage registers together with associated circuits needed to transfer information in and out of the registers. The
Fig. 1-4. A typical CPU chip organisation
Fig. 1-5. A typical micro-computer organisation
Random Access Memory represent the semi-conductor equivalent of the conventional core store. Here the registers may be thought of as being separated in space and any register location can be accessed at random without reference to others. The contents of the registers may be read or rewritten. Here the read process is non-destructive and store cycle time is of the order 300-400 nano secs. The capacity per chip of simple cost effective R.A.M's increases almost bi-monthly and 4K bit units organised in various word/bit structure are available now. Both data and programmes are stored in the different registers of R.A.M. memory. Unlike the core memory, the contents of semiconductor R.A.M. memory are automatically destroyed when there is a power failure and this should be taken into consideration while designing a fool proof system.

The partial solution to this problem is the use of the Read only Memory (R.O.M.)

R.O.M.: By an appropriate address system, the Read only Memory locations may be accessed in any sequence. However the contents of the locations are preset, each location presenting a fixed work pattern which is set by Memory program during the manufacturing process. In this form, very large R.O.M's are available (8K Bits) but the device is very inflexible. To remove the
inflexibility, programmable R.O.M's are used these days where we get a blank memory and the desired bit pattern are programmed by electrical means from the external source. Two main types of programing by electrical means are available viz. The fusible link and M.O.S. capacitor type. The latter although slower in operation, is preferred because the register may be erased when desired, a feature essential for the development purpose.

This P.R.O.M. provides a non volatile storage and usually holds the micro-instructions required to control the C.P.U. chips. The total system program may be R.O.M. stored if power fail protection is required.

Communication with external devices:

This involves data and control signal transmission and reception which are carried out by many M.S.I. and L.S.I. chips. Some of them are multiple data latches, Parity generators, interrupt controllers etc. More complex devices which provide a complete serial data communication interface are frequently used to connect the micro-computer to its peripheral, large sources, other micro-computers or large computer systems.

With the advent of microprocessor and the facilities available now-a-days for using the same, microprocessor
based protective relays are becoming popular. There are number of reasons why microprocessors are becoming popular. The most important reason is that they provide software as a good substitute for hardware logic, they are programmable and flexible. The inherent flexibility of a microprocessor based design makes introduction of changes quicker and cheaper. This provides greater functional capability at a reasonable cost and removes technical observations. The design of a complicated system using microprocessor reduces the number of components thereby increasing the reliability of the final product. In case of failure, servicing can be made easily by introducing self-diagnostic features.

With the development of large scale integrated technology, sophisticated and fast microprocessors are emerging tremendously in application to the problems of different protective schemes in the field of modern electrical technology. With the growing complexity of modern power networks fast, accurate and reliable protective schemes are becoming extremely necessary. Microporcessor based protective schemes can easily fulfil these requirements at a competitive price. These schemes offer attractive compactness and flexibility. They reduce the number and the types of relaying unit. A small dedicated microprocessor has the ability to protect
a number of power system elements/apparatus (Viz. alternator, transformer, transmission line, etc.) from all undesirable conditions and faults by suitable time multiplexing. This will definitely bring down the cost of the protective scheme by a large margin. Basically, a protective relay may be regarded as a "Processor" having a comparing element or device to compare any quantity (X) with a standard quantity or a quantity (X) with another quantity (Y) and so on. A microprocessor can perform all such functions in almost no time if suitable interfacing arrangements are provided to link-up the processor with the power system. With the facilities available now-a-days for using microprocessor in various processes, it is worth reviewing the application of such unit in the field of protection of power system and apparatus.

To delineate clearly the basic schemes of a conventional protective relaying system and a microprocessor based one, Figs. 1-6 may be referred. In a microprocessor based system, interfacing arrangements are necessary firstly to communicate the real world information to the microprocessor in a suitable language, understandable by it and secondly to translate the result of the microprocessor into a
Basic Elements in a Conventional Protective Relaying Scheme.

Fig. 1-6. Basic Scheme in Micro-processor Based Relaying.
Fig. 1-1(a). Conventional Trip Circuit
Microprocessor Based Trip Circuit.
Fig. 1-7. A typical µP based basic scheme with an input-output interfacing arrangement.
suitable format, so that it is acceptable to the real world. Real world in this context means the power system.

One such basic arrangement is shown in fig. 1 - 7. While discussing protection schemes, it will be assumed that current voltage or other signals are available from suitable measuring or sensing elements. It will be further assumed that necessary interfacing arrangement exist so that these signals are converted to digital signals which are acceptable to that particular micro-processor unit.

1.16 - 1. THE BASIC PHILOSOPHY OF PROTECTION : USING MICROPROCESSOR :

One such basic arrangement is shown in fig. 1-8.

An analog input subsystem accepts the three phase a.c. quantities from the power system transducers, such as conventional c.t's and v.t.s. The input quantities are sampled simultaneously or sequentially at uniform time intervals between 4 to 32 samples per a.c. cycles, converted to digital form and then transferred to the digital processor. The processor validates, stores and organises the data and then takes decisions based on the
Fig. 1-8. Basic protection scheme
values of samples. The prime purpose is to produce a breaker tripping command when a fault occurs on the protected line. Other secondary control and data outputs may also be provided. Stored in the processor memory is an elaborate program which implement the 'on' line protection sensing and logic. At the core of the relaying program is an algorithm or equations which operates on the incoming raw data samples to provide meaningful indications of fault presence and location.

The first two units (1 and 2) of Fig. 1-8, may be combined together to form what is known as "Measurement sub-unit". The last three units (3, 4 and 5), combined together is known as the "Evaluation sub-unit".

1.16-2. MEASUREMENT SUB-UNIT

Its primary function is data acquisition, isolation, data validation, conversion to digital form and storage. Fig.1-9 shows the main blocks of the measurement sub-unit. Three phase analog current and voltage from the power system transducers e.g. c.t.s., and c.v.t.'s together with machine, circuit breaker or isolator status in digital system as the protection system is highly susceptible to catastrophic failure if subjected to even a very small overvoltage. A measure of protection against induced voltages on signal lines must be
Fig. 1-9. A typical measurement sub unit.
considered as an essential requirement, which may be particularly true during close-up fault conduction. Ideally interface should be protected even if transducer suffers direct flash-over from the H.V. network.

**Isolation by optical method.**

Several methods are available for isolation, amongst them optical isolation seems promising. In its typical form shown in fig. 1-10 there is a light emitting diode and a photo detector arrangement. The transparent medium may be a thin film as in the integrated device, giving an input/output isolation of approximately 1500 volts. A transparent light pipe several metres in length giving almost any isolation required may be used. Multicore light pipe cables are also available and this type of signal transmission is highly attractive without any inductive or capacitive coupling. This type of signal transmission suffers from inherent non-linearity however.

**Signal ranging amplifier.**

The analog signals obtained from transducers are being isolated, but they are subjected to a very wide range of fluctuations starting from a very small percentage of load to about 20 to 25 times full load under fault
Fig. 1-10. Optical isolation

Fig. 1-11. Amplifier range switching scheme
condition. Since the analog section of the interface have a limited signal operating range (say \(10\,\text{V}\)), it is essential that the incoming data be prevented either the signal/noise ratio from becoming unacceptably large with small signals, or at the other end of the range saturation with very large signals. The problem is tackled by the case of multi-amplifier range switching scheme as shown in fig. 1-11. The function of the control unit is best described by the flow diagram of fig. 1-12.

**Multiplexers with hold circuit**

Even a single corner of the power system presents a large number of analog data and if instantaneous value of each of these quantities are to be collected simultaneously, some means must be provided for storage after the sampling time until each has been digitised and presented to the D.A.P. This requirement could be obviated if multiple Analogue to Digital (A/D) converter used. (I.e. 1 converter per source or if serveral very high speed A/D converters are multiplexed between sources). Such a solution would be unrealistic economically. Such a problem is solved by the use of multiplexers and a special sample hold circuit. The block diagram of fig.1-13 explains the fundamental principles of the sample-hold circuit where the buffered input signal is
Fig.1-12. Function of control unit

Fig.1-13. Fundamental principle of sample hold
connected to the storage capacitor for the duration of the sampling pulse by the closure of the analog switch. The capacitor thus charges to the input voltage and when the switch opens, the charge remaining on the capacitor provides the hold output, the high input impedance buffer amplifier preventing discharge. The salient features are (i) hold time, (ii) accuracy, (iii) range, (iv) droop and (v) acquisition time. In many ways these are confliction requirements e.g. a long hold time with low droop implies a very high input impedance output buffer amplifier and a large capacitor. If the capacitor is large, its charging time-constant will be large and thus to obtain a reasonable accuracy, a long acquisition time is required.

**Analogue/digital converter**

The selection of A/D converter is very important. For a given input voltage, the resolution of the converter is set by its output word length. Considering a 10 bit converter used in the 2's complement mode for an input range of +10V, we have 1 sign bit and 9 bits for the resolution of 10V. The least significant bit (LSB) of the data thus represents overall accuracy of 0.25% which is considered acceptable for most applications. In general, larger the word length, greater is the accuracy;
the penalty to be paid is an increase in the comparison
time from, say 20 microsecs for 10 bits to 30 microsecs
for 12 bits. For many uses, an 8 bit converter is
sufficiently accurate in which one bit is used for sign
bit and 7 bits for the data.

The synchronised Clock

The rate at which the system data are to be sampled
should be constant and a fixed relationship with the
power system frequency. A synchronised clock is
therefore in-built within the system which generates
pulse train output of constant repetition rate and which
is capable of being synchronised with the fundamental
frequency of the power system.

Data Acquisition processor (DAP)

The different blocks of the measurement sub-unit so far
considered are all under the control of the data
acquisition processor (A mini-computer). This work can be
carried out by the MOS devices with cycle time of about
10 microsecs. Typical memory is 10K words of core
storage, the word length varying between 4 to 16 bit as
required. Its main function is to collect the data from
the power system and to feed them after processing to the
evaluation sub-unit, usually by direct memory access which is very fast.

Diagnostic software is also run on a periodic basis. If the DAP has a surplus capacity to the overhead of simple data acquisition, this may be gainfully employed in preprocessing and data validation tasks.

1.16 - 2 EVALUATION SUB-UNIT

For each block of data supplied by the measurement sub-unit, the evaluation processor must solve that particular fault detection algorithm to which it is dedicated fig. 1-14. In this respect the protection algorithm may include digital filtering, if required, together with fault detection calculation and output switching commands.

This processor must be able to perform logical and arithmetical operation within the available time.

1.17 PROTECTION ALGORITHMS

Current and voltage transformers are used to monitor the power system for the purpose of measurement, control and protection. Measurement and control equipment are
Fig. 1-14. Dedicated protection relay
usually slow action, so that power system transients do not affect them but the protection equipment should act very fast and before the transients die down. The transients might be caused by (i) sudden energisation or deenergisation of the circuit, (ii) incidence or clearance of fault and (iii) lightning or switching surges.

These undesirable, but irrestable transients can take the form of (i) an exponentially decaying d.c. offset, (ii) distortion in wave form, (iii) high or low frequency oscillation. But we are interested in the steady state component of currents and voltages which are buried in the transient signals.

Several protection algorithms have been proposed with an aim of deriving the information regarding the steady state component of current and voltage in magnitude and phase by studying the sampled waveform even during the transient condition. Since power system fault produces transients which might be very complex in nature and varies with type, instant of occurrences and location of fault, it is not possible to specify the exact nature of the transient that might occur in practice. As a result one algorithm is better for a particular type of fault whereas some other algorithm might prove better for another fault.
1.18. CONCLUSION

In view of the scenario related to the field of protection of power system and associated apparatus, it is thought to be worth while to undertake the task of investigating some improved protection schemes concerning over and under voltage, over current, earth fault, overheating, single phasing, reversed phasing and phase faults etc. employing microprocessors. These schemes have been presented in the chapters to follow.

1.19 REFERENCES;

Books : 1-13, 14-16, 21-26, 35-41