❑ Desirable Attributes of Protection

- **Selectivity**

➢ **Like sensitivity, selectivity also implies an ability to discriminate.**

➢ **A relay should not confuse some peculiarities of an apparatus with a fault.**

➢ **For example, transformer when energized can draw up to 20 times rated current (inrush current) which can confuse, both overcurrent and transformer differential protection.**

○ **Typically, inrush currents are characterized by large second harmonic content.**

➢ **This discriminant is used to inhibit relay operation during inrush, there by, improving selectivity in transformer protection.**

❑ Desirable Attributes of Protection

- **Selectivity**

➢ **Also, a relay should be smart enough, not just to identify a fault but also be able to decide whether fault is in it's jurisdiction or not.**

✓ **For example, a relay for a feeder should be able to discriminate a fault on it's own feeder from faults on adjacent feeders.**

➢ **Recall that directional overcurrent relay was introduced to improve selectivity of overcurrent relay.**

➢ This jurisdiction of a relay is also called as **zone of protection .**

➢ Typically, protection zones are classified into primary and backup zones.

➢ **In detecting a fault and isolating the faulty element, the protective system must be very selective.**

❑ Desirable Attributes of Protection

- Selectivity

➢ **Ideally, the protective system should zero-in on the faulty element and only isolate it, thus causing a minimum disruption to the system.**

➢ **Selectivity is usually provided by**

(1)using time discrimination and

(2) applying differential protection principle.

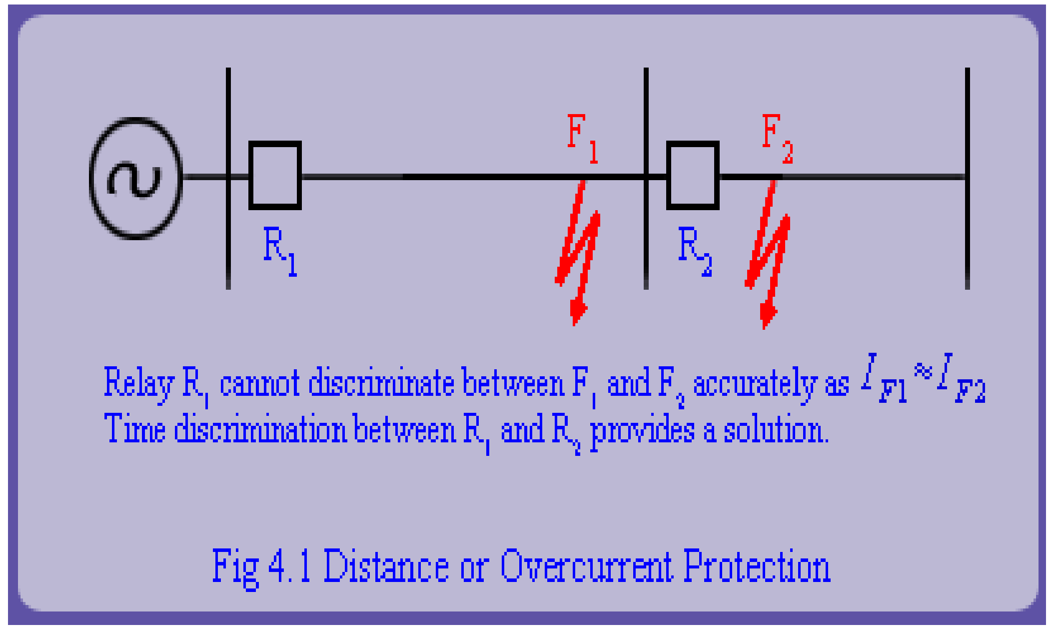


Fig 4.1 Distance or Overcurrent Protection

❖ **With overcurrent and distance relays, such boundaries are not properly demarcated (see fig 4.1).**

❑ Desirable Attributes of Protection

- **Selectivity**

➢ **However with a differential protection the CT location provides 'crisp' demarcation of zone of protection of CT (see fig 4.2).**

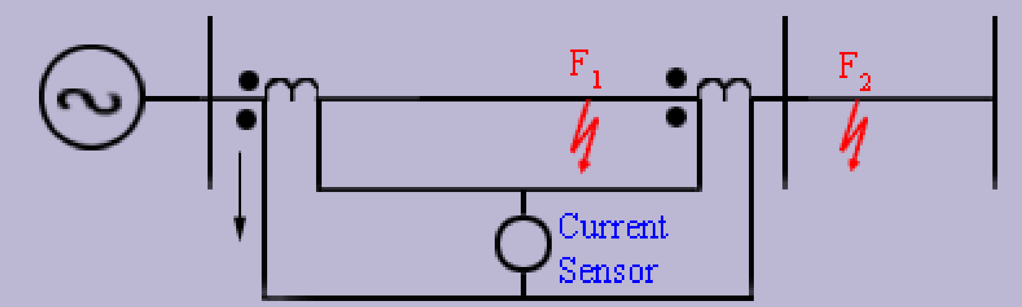


Fig 4.2 Differential Protection Scheme

➢ **The fault F1 is in the relay's zone of protection, but fault F2 is not in its jurisdiction.**

➢ **Because differential protection scheme do not require time discrimination to improve selectivity, they are essentially fast.**

➢ **These aspects will be discussed in more detail in the later lectures.**

Desirable Attributes of Protection

- **Reliability**

- **A relaying system has to be reliable.**
- **Reliability can be achieved by redundancy i.e. duplicating the relaying system.**
- **Obviously redundancy can be a costly proposition.**
- **Another way to improve reliability is to ask an existing relay say, protecting an apparatus A to backup protection of apparatus B.**
- **Both the approaches are used (simultaneously) in practice.**
- **However, it is important to realize that back-up protection must be provided for safe operation of relaying system.**

❑ Desirable Attributes of Protection

- **Reliability**

❑ **Redundancy in protection also depends upon the criticality of the power apparatus.**

❑ **For example, a 400 kV transmission line will have independent (duplicated) protection using same or a different philosophy;**

❑ **on the other hand, a distribution system will not have such local back-up.**

❑ **A quantitative measure for reliability is defined as follows:**

$$\%\,Reliability = \frac{Number\ of\ correct\ trips}{Number\ of\ desired\ trips + Number\ of\ incorrect\ trips} \times 100$$

❑ Desirable Attributes of Protection

✓ **The performance of an overcurrent relay was monitored over a period of one year. It was found that the relay operated 14 times, out of which 12 were correct trips. If the relay failed to issue trip decision on 3 occasions, compute dependability, security and reliability of the relay.**

Number of correct trips = 12
Number of desired trips = 12 + 3 = 15

$$\%\ Dependability = \frac{Number\ of\ correct\ trips}{Number\ of\ desired\ trips} \times 100 \qquad = \frac{12}{15} \times 100 = 80\%$$

$$\%\ Security = \frac{Number\ of\ correct\ trips}{Total\ number\ of\ trips} \times 100 \qquad = \frac{12}{14} \times 100 = 85.71\%$$

❑ Desirable Attributes of Protection

- ✓ **The performance of an overcurrent relay was monitored over a period of one year. It was found that the relay operated 14 times, out of which 12 were correct trips. If the relay failed to issue trip decision on 3 occasions, compute dependability, security and reliability of the relay.**

$$\%\,\text{Reliability} = \frac{\textit{Number of correct trips}}{\textit{Number of desired trips} + \textit{Number of incorrect trips}} \times 100$$

$$= \frac{12}{15+2} = 70.59\%$$

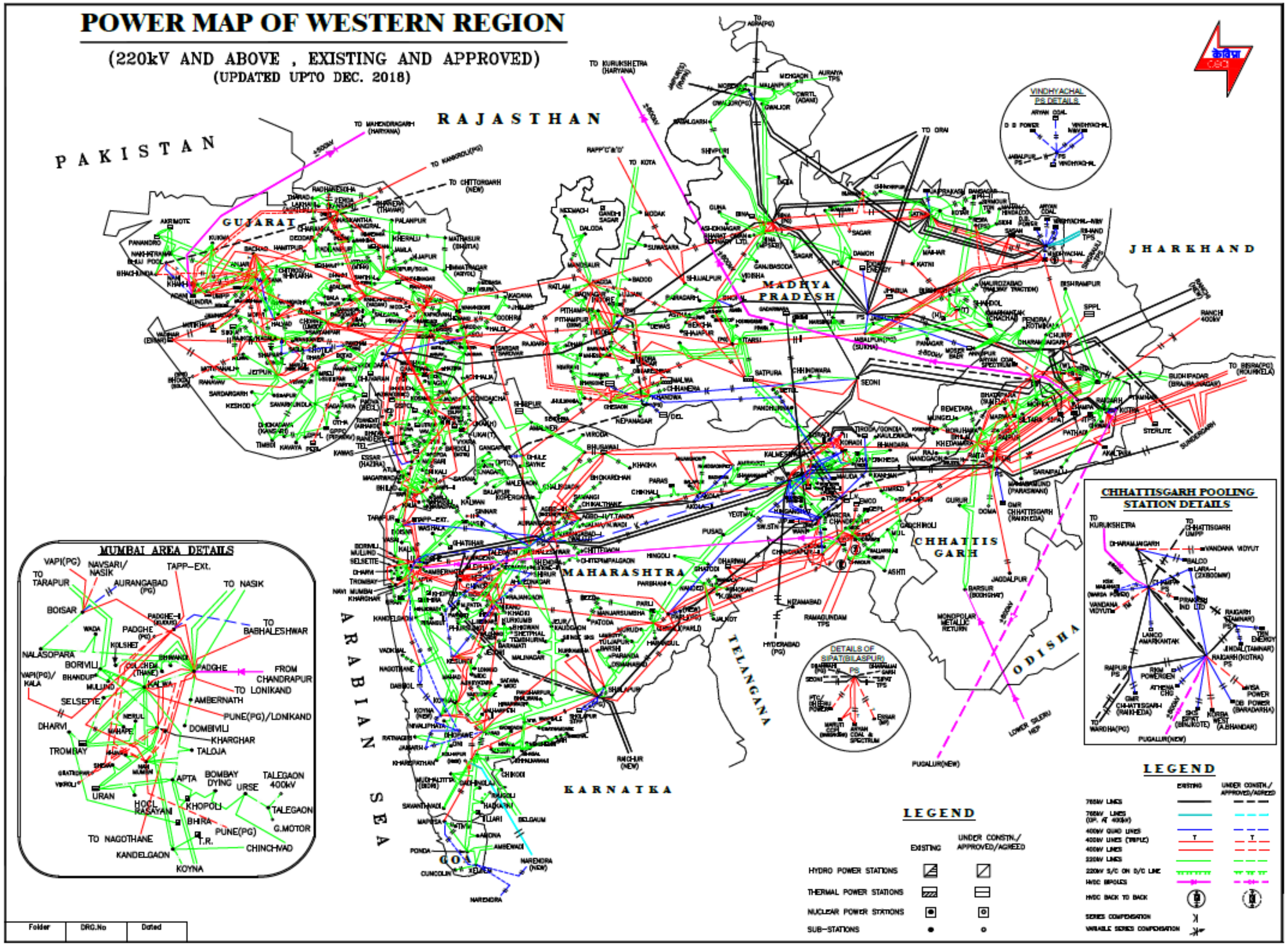
- ✓ **Note that even though dependability and security are individually above 80%, overall reliability much poor (only 70.55%).**

Fundamentals of Power System Protection

- **Overview of Electrical Energy Systems**
- Electrical energy systems consists of various equipments connected together.
- Typically, power is generated at lower voltages (a few kV) (3 phase ac voltage source) which is stepped up by a transformer and fed into a transmission grid.
- Thermal power should be generated at pit heads and hydro power at reservoirs.
- A transmission grid is a meshed network of high voltage lines and transformers.
- It can have multiple voltage levels like 400 kV, 220 kV, etc.
- The power is delivered to load centers which may be far off (even thousands of km's apart).

Fundamentals of Power System Protection

- **Overview of Electrical Energy Systems**



Fundamentals of Power System Protection

- **Overview of Electrical Energy Systems**

- A unique feature of electrical energy systems is its natural mode of synchronous operation.
- It implies that during steady state the electrical frequency is same all through the system irrespective of the geographical location.
- This closely knits the system together.
- We can perceive all generators acting in tandem like the ballet dancers in a dance.
- They may occupy different angular positions, but all machines rotate at the same electrical speed.
- This close knitting implies an embedded interaction of generators through the transmission network which is governed by the differential and algebraic equations of the apparatus and interconnects.
- This aspect is referred to as the system behavior. This system has to be protected from abnormalities which is the task of protection system.

Fundamentals of Power System Protection

- **Why do we need Protection?**

- ❑ Electrical power system operates at various voltage levels from 415 V to 400 kV or even more.
- ❑ Electrical apparatus used may be enclosed (e.g., motors) or placed in open (e.g., transmission lines).
- ❑ All such equipment undergo abnormalities in their life time due to various reasons.
- ❑ For example, a worn out bearing may cause overloading of a motor.
- ❑ A tree falling or touching an overhead line may cause a fault.
- ❑ A lightning strike (classified as an act of God!) can cause insulation failure.
- ❑ Pollution may result in degradation in performance of insulators which may lead to breakdown.
- ❑ Under frequency or over frequency of a generator may result in mechanical damage to it's turbine requiring tripping of an alternator.
- ❑ Even otherwise, low frequency operation will reduce the life of a turbine and hence it should be avoided.

Fundamentals of Power System Protection

- **Why do we need Protection?**

- ❑ It is necessary to avoid these abnormal operating regions for safety of the equipment.
- ❑ Even more important is safety of the human personnel which may be endangered due to exposure to live parts under fault or abnormal operating conditions.
- ❑ Small current of the order of 50 mA is sufficient to be fatal!
- ❑ Whenever human security is sacrificed or there exists possibility of equipment damage, it is necessary to isolate and de-energize the equipment.
- ❑ Designing electrical equipment from safety perspective is also a crucial design issue which will not be addressed here.
- ❑ To conclude, every electrical equipment has to be monitored to protect it and provide human safety under abnormal operating conditions.
- ❑ This job is assigned to electrical protection systems.
- ❑ It encompasses apparatus protection and system protection.

Fundamentals of Power System Protection

- **Types of Protection**

❑ **Protection systems can be classified into apparatus protection and system protection.**

✓ **Apparatus Protection**

❑ **Apparatus protection deals with detection of a fault in the apparatus and consequent protection.**

❑ **Apparatus protection can be further classified into following:**

➢ **Transmission Line Protection and feeder protection**

➢ **Transformer Protection**

➢ **Generator Protection**

➢ **Motor Protection**

➢ **Busbar Protection**

Fundamentals of Power System Protection

- **System Protection**

✓ System protection deals with detection of proximity of system to unstable operating region and consequent control actions to restore stable operating point and/or prevent damage to equipments.

✓ Loss of system stability can lead to partial or complete system blackouts.

✓ Under-frequency relays, out of-step protection, islanding systems, rate of change of frequency relays, reverse power flow relays, voltage surge relays etc. are used for system protection.

✓ Wide Area Measurement (WAM) systems are also being deployed for system protection.

✓ Control actions associated with system protection may be classified into preventive or emergency control actions.

Fundamentals of Power System Protection

- **Analogy with Functioning of a Human being**

- A human being is a complex system that performs through various apparatus like legs, hands, eyes, ears, heart, bones, blood vessels etc.
- The heart is analogous to an electrical generator and stomach to the boiler.
- The eating process provides raw material to generate calories.
- The power generated is pumped by heart through a complex network of blood vessels.
- The primary transmission is through arteries and veins.
- Furthermore, distribution is through fine capillaries.
- The system operator is the brain which works on inputs of eyes, ears, skin etc.
- Diagnosing abnormality in any of these organs and taking remedial measures can be thought of as job of "apparatus protection".
- However, does this cover the complete gambit of anomalies?
- Are fever, infection etc., a specific apparatus problem?
- Why does it cause overall deterioration in functioning of the human being?

Fundamentals of Power System Protection

- **Analogy with Functioning of a Human being**

- **The answer lies in the fact that the system which encompasses body has also abstraction like the mind.**
- **Overall health is not just an aggregation of apparatus.**
- **It is something much more complex.**
- **It involves complex process and associated dynamics (biological, chemical, mechanical etc.) and control.**
- **Thus, protecting a system is not just apparatus protection but something much more.**
- **Since we cannot define this "much more" clearly, it is complex and challenging.**
- **Monitoring of system behavior, taking corrective measures to maintain synchronous operation and protecting the power system apparatus from harmful operating states is referred as system protection.**

Fundamentals of Power System Protection

- **What is a Relay?**

➢ **Formally, a relay is a logical element which processes the Inputs mostly voltages and Currents from the system/ apparatus and issues a trip decision if a fault within the relay's jurisdiction is detected.**

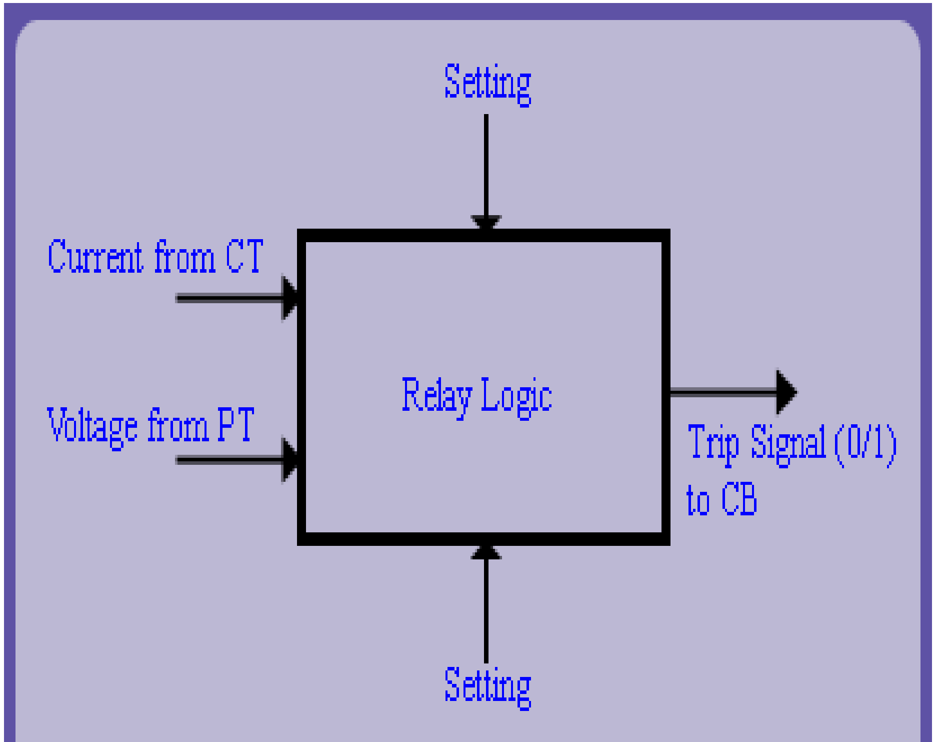


Fig 1.2 Conceptual Diagram of Relay

➢ A conceptual diagram of relay is shown in fig 1.2.

Fundamentals of Power System Protection

- **What is a Relay?**

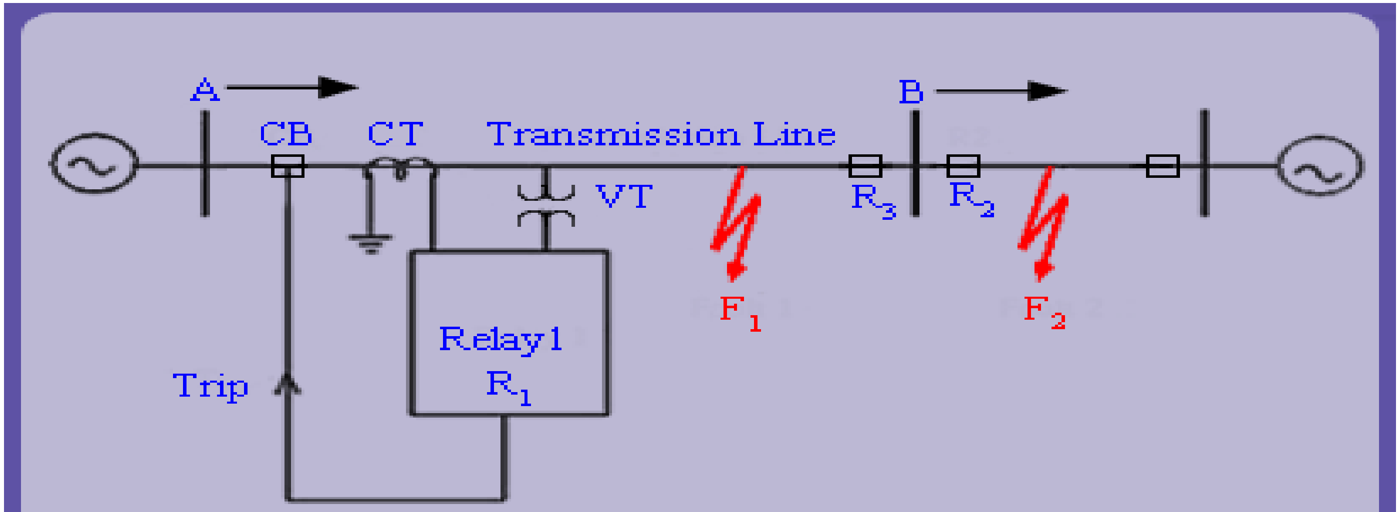


Fig 1.3 Typical Relaying System

- **To monitor the health of the apparatus, relay senses current through a current transformer (CT)**
- **Voltage through a voltage transformer (VT).**
- **VT is also known as Potential Transformer (PT).**

Fundamentals of Power System Protection

- **What is a Relay?**
  - **The relay element analyzes these inputs and decides whether (a) there is a abnormality or a fault and**

    (b) if yes, whether it is within jurisdiction of the relay.
  - **The jurisdiction of relay R1 is restricted to bus B where the transmission line terminates.**
  - **If the fault is in it's jurisdiction, relay sends a tripping signal to circuit breaker(CB) which opens the circuit.**
  - **A real life analogy of the jurisdiction of the relay can be thought by considering transmission lines as highways on which traffic (current/power) flows.**
  - **If there is an obstruction to the regular flow due to fault F1 or F2, the traffic police (relay R1) can sense both F1 and F2 obstructions because of resulting abnormality in traffic (power flow).**
  - **If the obstruction is on road AB, it is in the jurisdiction of traffic police at R1; else if it is at F2, it is in the jurisdiction of R2.**
  - **R1 should act for fault F2, if and only if, R2 fails to act.**
  - **We say that relay R1 backs up relay R2.**

Evolution of Relays

- Electromechanical Relays
- Solid State Relays
- Numerical Relays

Electromechanical Relays

- When the principle of electromechanical energy conversion is used for decision making, the relay is referred as an electromechanical relay.
- These relays represent the first generation of relays.
- Let us consider a simple example of an over current relay, which issues a trip signal if current in the apparatus is above a reference value.
- By proper geometrical placement of current carrying conductor in the magnetic field, Lorentz force $F=Bil\ sin\theta$ is produced in the operating coil.
- This force is used to create the operating torque.
- If constant 'B' is used (for example by a permanent magnet), then the instantaneous torque produced is proportional to instantaneous value of the current.

Evolution of Relays

- **Electromechanical Relays**

- Since the instantaneous current is sinusoidal, the instantaneous torque is also sinusoidal which has a zero average value.
- Thus, no net deflection of operating coil is perceived.
- On the other hand, if the B is also made proportional to the instantaneous value of the current, then the instantaneous torque will be proportional to square of the instantaneous current (non-negative quantity).
- The average torque will be proportional to square of the rms current.
- Movement of the relay contact caused by the operating torque may be restrained by a spring in the overcurrent relay.

Evolution of Relays

- **Electromechanical Relays**

- **If the spring has a spring constant 'k', then the deflection is proportional to the operating torque (in this case proportional to I_{rms}^2)**

- **When the deflection exceeds a preset value, the relay contacts closes and a trip decision is issued.**

- **Electromechanical relays are known for their ruggedness and immunity to Electromagnetic Interference (EMI).**

- **Evolution of Relays**

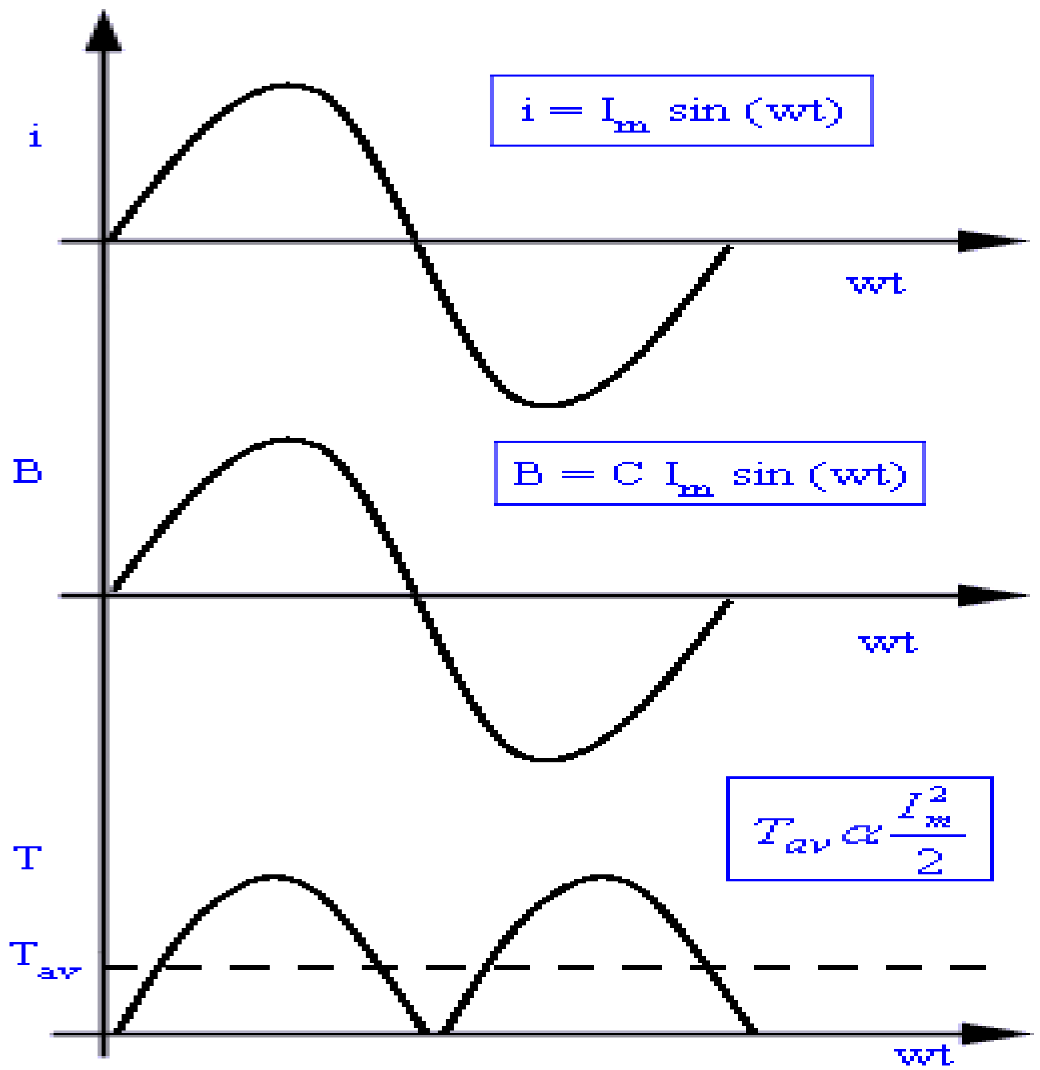


Fig. 1.4 Torque and Current Relationship in Attracted Armature Relay

Evolution of Relays

Solid State Relays

- With the advent of transistors, operational amplifiers etc, solid state relays were developed.
- They realize the functionality through various operations like comparators etc.
- They provide more flexibility and have less power consumption than their electromechanical counterpart.
- A major advantage with the solid state relays is their ability to provide self checking facility i.e. the relays can monitor their own health and raise a flag or alarm if its own component fails.
- Some of the advantages of solid state relays are low burden, improved dynamic performance characteristics, high seismic withstand capacity and reduced panel space.

Evolution of Relays

❑ Solid State Relays

- Relay burden refers to the amount of volt amperes (VA) consumed by the relay.
- Higher is this value, more is the corresponding loading on the current and voltage sensors i.e. current transformers (CT) and voltage transformers (VT) which energizes these relays.
- Higher loading of the sensors lead to deterioration in their performance.
- A performance of CT or VT is gauged by the quality of the replication of the corresponding primary waveform signal.
- Higher burden leads to problem of CT saturation and inaccuracies in measurements.
- Thus it is desirable to keep CT/VT burdens as low as possible.
- These relays have been now superseded by the microprocessor based relays or numerical relays.

Evolution of Relays

❑ Numerical Relays

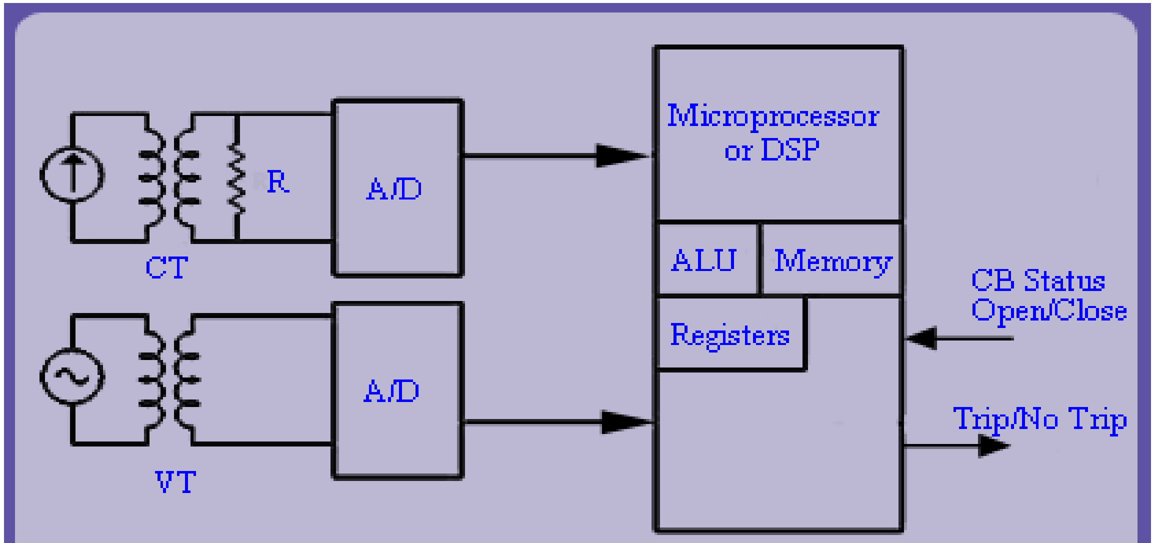


Fig 1.5 Block Diagram of Numerical Relay

- The block diagram of a numerical relay is shown in fig 1.5
- It involves analog to digital (A/D) conversion of analog voltage and currents obtained from secondary of CTs and VTs.
- These current and voltage samples are fed to the microprocessor or Digital Signal Processors (DSPs) where the protection algorithms or programs process the signals and decide whether a fault exists in the apparatus under consideration or not.
- In case, a fault is diagnosed, a trip decision is issued.
- Numerical relays provide maximum flexibility in defining relaying logic.

Evolution of Relays

❑ Numerical Relays

- The hardware comprising of numerical relay can be made scalable i.e., the maximum number of v and I input signals can be scaled up easily.
- A generic hardware board can be developed to provide multiple functionality.
- Changing the relaying functionality is achieved by simply changing the relaying program or software.
- Also, various relaying functionalities can be multiplexed in a single relay.
- It has all the advantages of solid state relays like self checking etc.
- Enabled with communication facility, it can be treated as an Intelligent Electronic Device (IED) which can perform both control and protection functionality.
- Also, a relay which can communicate can be made adaptive i.e. it can adjust to changing apparatus or system conditions.
- For example, a differential protection scheme can adapt to transformer tap changes.
- An overcurrent relay can adapt to different loading conditions.
- Numerical relays are both "the present and the future".

❑ Desirable Attributes of Protection

- Dependability.
- Security.
- Sensitivity.
- Selectivity.
- Reliability.
- Necessity of speed in relaying.
- Speed vs. accuracy conflict.

✓ A protection system is characterized by following two important parameters:

- Dependability
- Security

❑ Desirable Attributes of Protection

- **Dependability**

- ❖ A relay is said to be dependable if it trips only when it is expected to trip.
- ❖ This happens either when the fault is in it's primary jurisdiction or when it is called upon to provide the back-up protection.
- ❖ However, false tripping of relays or tripping for faults that is either not within it's jurisdiction, or within it's purview, compromises system operation.
- ❖ Power system may get unnecessarily stressed or else there can be loss of service.
- ❖ Dependability is the degree of certainty that the relay will operate correctly:

$$\%\ Dependability = \frac{Number\ of\ correct\ trips}{Number\ of\ desired\ trips} \times 100$$

- ❖ Dependability can be improved by increasing the sensitivity of the relaying system.

❑ Desirable Attributes of Protection

- **Sensitivity**

- For simplicity, consider the case of overcurrent protection.
- The protective system must have ability to detect the smallest possible fault current.
- The smaller the current that it can detect, the more sensitive it is.
- One way to improve sensitivity is to determine characteristic signature of a fault.
- It is unique to the fault type and it does not occur in the normal operation.
- For example, earth faults involve zero sequence current.
- This provide a very sensitive method to detect earth faults.
- Once, this signature is seen, abnormality is rightly classified and hence appropriate action is initialized.

Fundamentals of Power System Protection

❑ Desirable Attributes of Protection

- **Security**
  - On the other hand, security is a property used to characterize false tripping on the relays.
  - A relay is said to be secure if it does not trip when it is not expected to trip.
  - It is the degree of certainty that the relay will not operate incorrectly:

$$\% \, Security = \frac{Number \, of \, correct \, trips}{Total \, number \, of \, trips} \times 100$$

  - False trips do not just create nuisance.
  - They can even compromise system security. For example, tripping of a tie-line in a two area system can result in load-generation imbalance in each area which can be dangerous.
  - Even when multiple paths for power flow are available, under peak load conditions, overloads or congestion in the system may result.
  - Dependability and security are contrasting requirements.
  - Typically, a relay engineer biases his setting towards dependability.
  - This may cause some nuisance tripping, which can in the worst case, trigger partial or complete blackout!
  - Security of the relaying system can be improved by improving selectivity of the relaying system.