

# Module 10 : Differential Protection of Bus, Transformer and Generator

## Lecture 40 : Generator Protection

### Objectives

In this lecture, we will learn about protection of generator against various faults and abnormalities like:

- Internal Fault like LLG, phase and ground faults.
- Abnormal operations like overload, underfrequency, unbalanced generator, etc.
- Issue with numerical protection.

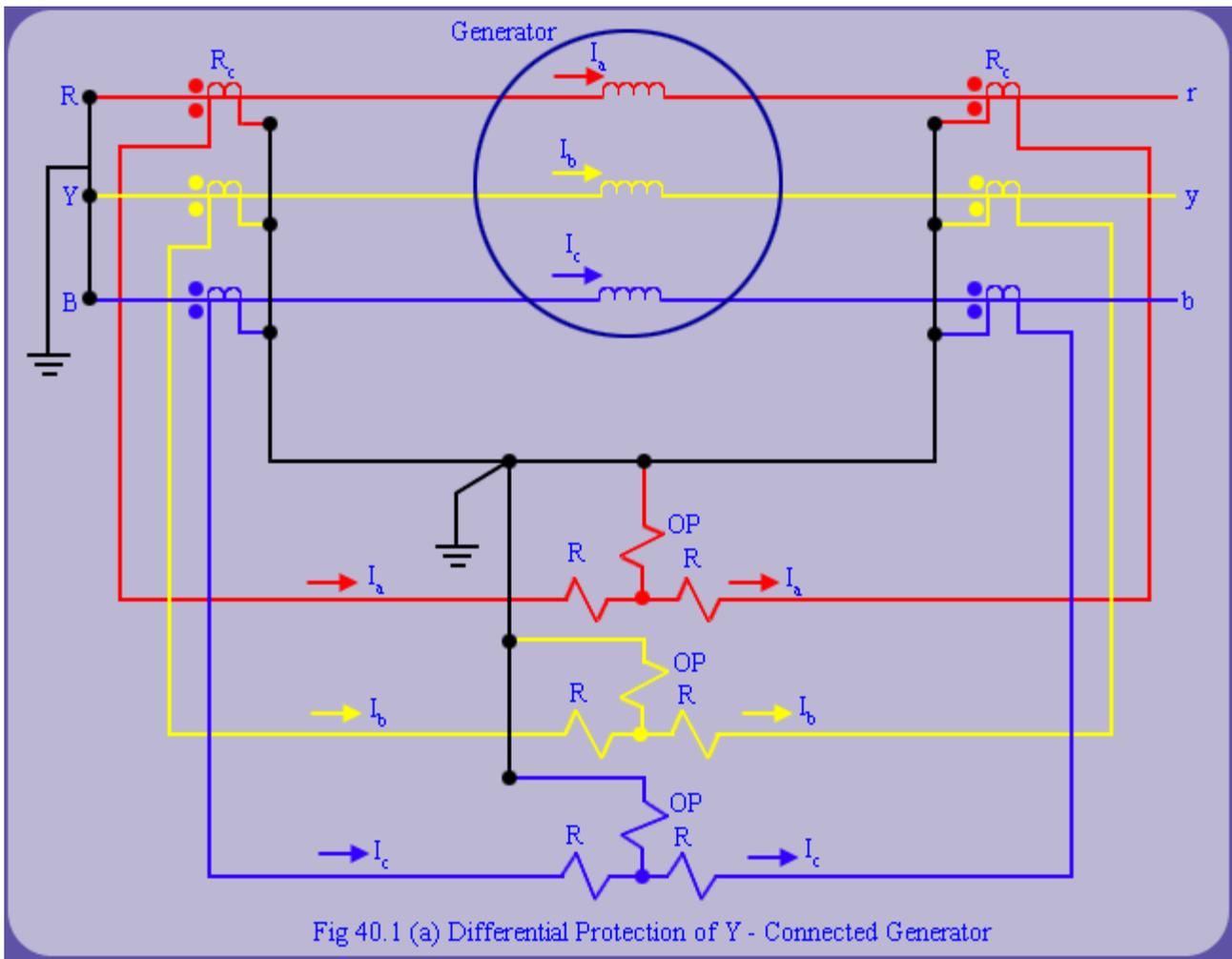
### Introduction

Generator protection and control are interdependent problems. A generator has to be protected not only from electrical faults (stator and rotor faults) and mechanical problems (e.g. Related to turbine, boilers etc), but it also has to be protected from adverse system interaction arising like generator going out of step with the rest of system, loss of field winding etc. Under certain situations like internal faults, the generator has to be quickly isolated (shut down), while problems like loss of field problem requires an 'alarm' to alert the operator. Following is a descriptive list of internal faults and abnormal operating conditions.

1. Internal Faults
  - a. Phase and /or ground faults in the stator and associated protection zone
  - b. Ground faults in the rotor (field winding)
2. Abnormal Operating Conditions
  - a. Overload.
  - b. Overvoltage.
  - c. Loss of field.
  - d. Unbalanced Operation e.g. single phasing.
  - e. Under and over frequency.
  - f. Motoring or loss of prime mover.
  - g. Subsynchronous oscillation.
  - h. Loss of synchronization (out of step).

### Multi – CT Differential Protection for Generators

Typical interconnections for differential protection of  $Y - \Delta$  connected generators is shown in fig 40.1(a). With a numerical relay, the circuitry as shown in fig 40.1 (a and b) is not to be hard wired. Instead, equivalent computations can be done in microprocessor. For differential protection, it is important to choose CTs from same manufacturer with identical turns ratio to minimize CT mismatch. To improve security, percentage differential protection is preferred. The accuracy of the differential protection for generators is expected to be better than that of differential protection for transformers, as issues like overfluxing, magnetizing inrush, no load current and different voltage rating of primary and secondary are non – existent.



Multi – CT Differential Protection for Generators (contd..)

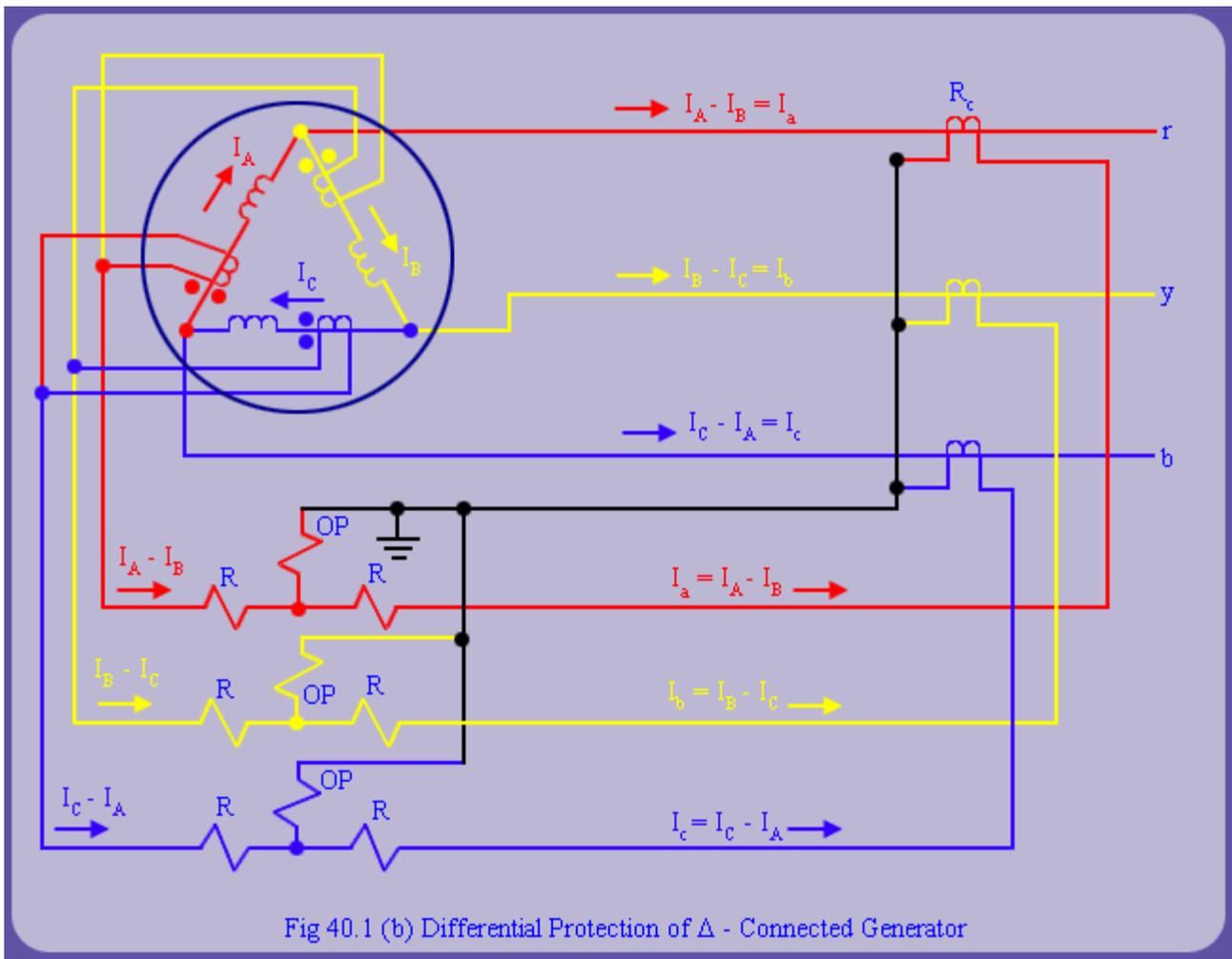


Fig 40.1 (b) Differential Protection of  $\Delta$  - Connected Generator

### Stator Ground Fault Protection

Most faults in a generator are a consequence of insulation failure. They may lead to turn – to – turn faults and ground faults. Hence ground fault protection is very essential for generators. Three types of grounding schemes are used in practice

1. Fault Protection with high impedance grounding.
2. Fault protection with low impedance grounding.
3. Hybrid grounding.

### High Impedance Grounding

It is used to limit the maximum fault current due to fault in winding near generator terminals to 1 – 10 A primary. This reduces iron burning in the generator and it helps in avoiding costly repairs. Fig 40.2 below shows a typical circuit connection.

High impedance grounding reduces sensitivity for both feeder ground protection and differential protection in the stators of the generators. Alternative to high impedance grounding is low impedance grounding.

### Low Impedance Grounding

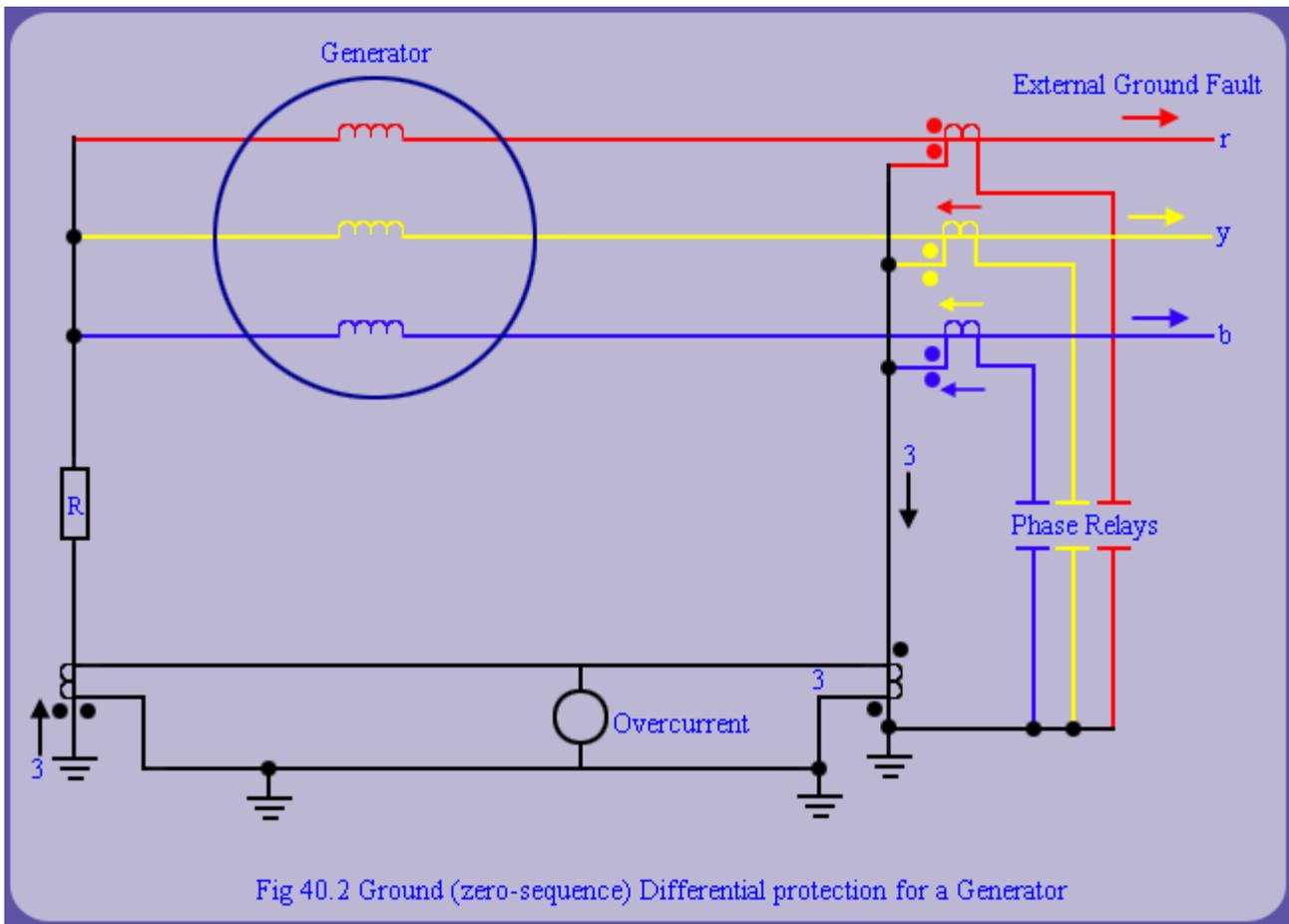


Fig 40.2 Ground (zero-sequence) Differential protection for a Generator

The advantage of low impedance grounding is improved sensitivity of the protection. However, if the fault is not cleared quickly, the damage to equipment can be much higher. It is possible to engineer ground (zero sequence) differential protection using a directional ground overcurrent relaying as shown in fig 40.2. The basic idea is to compare the sum of terminal  $I_a + I_b + I_c$  current with neutral current. If the two are identical, there is no internal ground fault. Conversely, a differential in the two quantities indicates an internal ground fault on the generator.

### Reduced or Loss of Excitation Protection

#### What is it?

Reduction or loss of excitation to the field winding is an abnormality rather than a fault. If the field winding is completely lost, then in principle, synchronous generator will try to mimic an induction generator. This mode of operation is possible provided that power system to which generator is connected is strong enough to provide necessary reactive power support. Recall that an induction generator has no field winding and hence it cannot generate reactive power. If adequate reactive power support is not available (a strong possibility!), then the generator will have to be shut down. It is likely that field winding will be accidentally shut off and usually loss of synchronism will require appreciable time to take effect. Hence, it is preferable to first raise an alarm for operator to restore field, failing which, generator has to be shut down.

#### Consequences

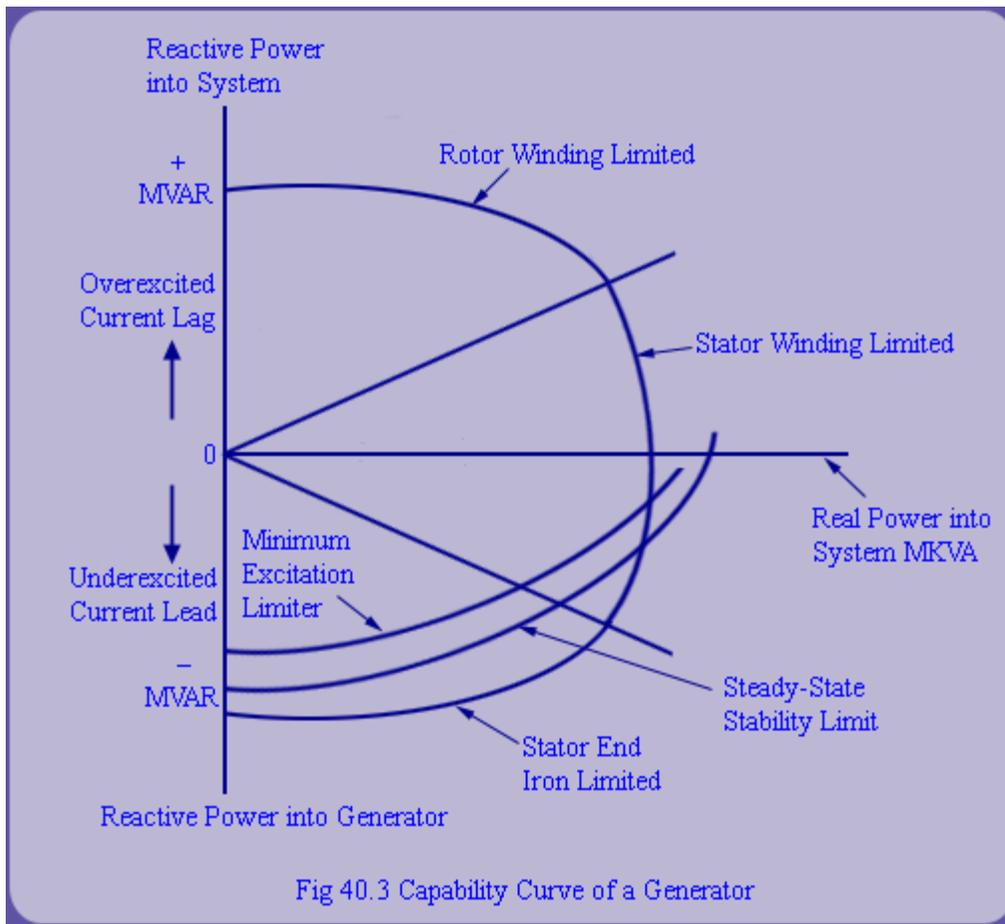


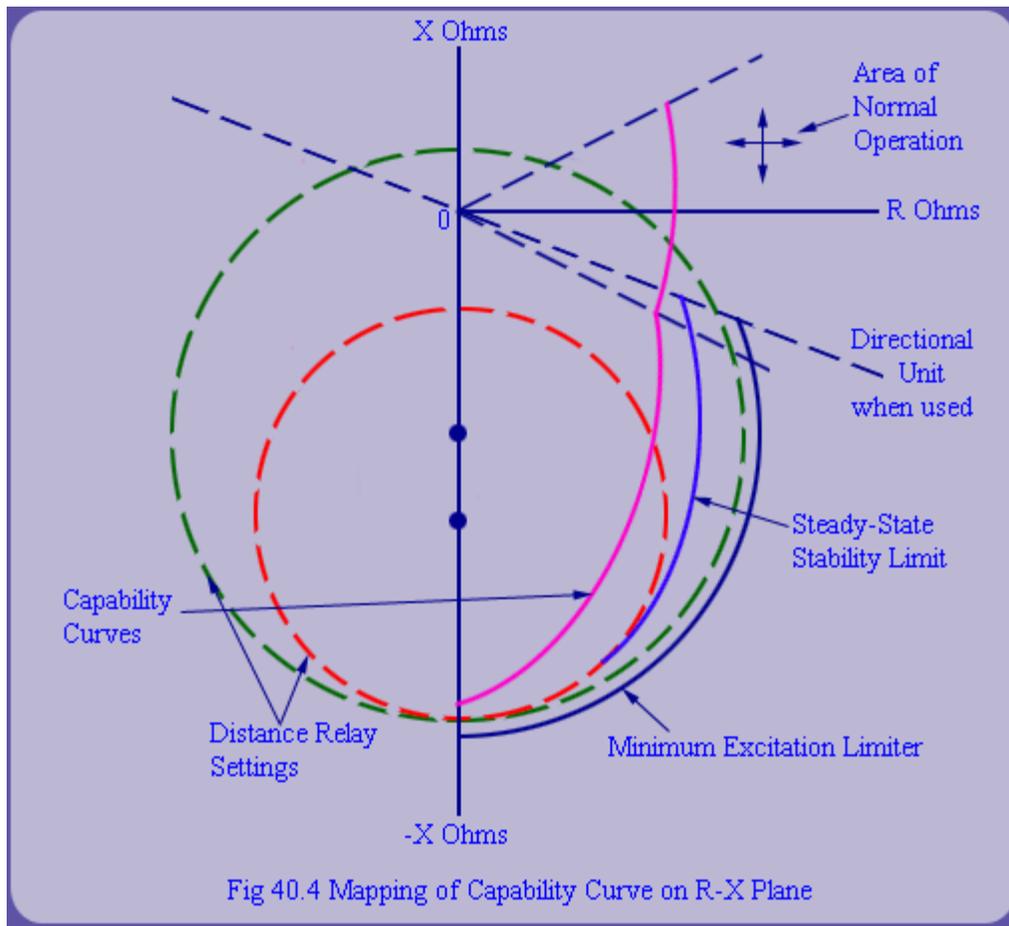
Fig 40.3 Capability Curve of a Generator

Prima-facie, consequence of reduced excitation may not appear to be dramatic, but it can lead to end-region over-heating in turbo-alternators. Hence, this abnormality has to be detected and an alarm has to be raised for the operator. The ultimate measure would be to shut down the generator. Fig 40.3 shows the reactive power capability curve of a generator. It can be seen that in the lagging power factor-operating region, limits are determined either by rotor field heating limit or by stator armature heating limit.

### Reduced or Loss of Excitation Protection (contd..)

#### Consequences (contd..)

Turbo-alternators may not have adequate reactive power absorption capability. Hence, they are seldom operated with leading power factor. Typically leading power factor operation of generators results when the field excitation is reduced. Hence, limitations on the reactive power absorption capability set a lower limit on the reduction on field excitation system (see dotted line in fig 40.4).



### Reduced or Loss of Excitation Protection (contd..)

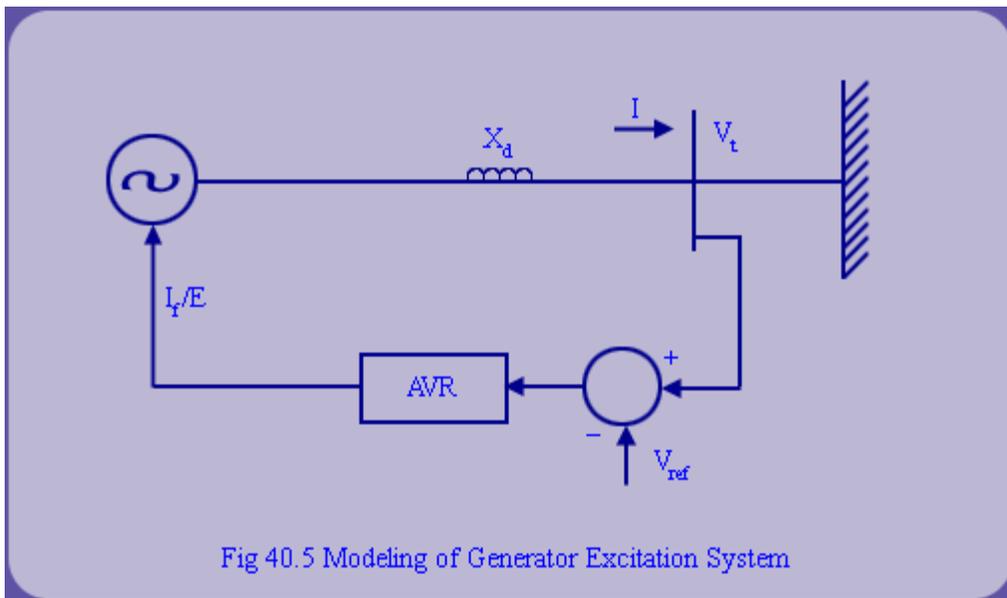
#### Consequences (contd..)

How?

Protection system for synchronous-generators should detect reduced or loss of excitation condition, raise an alarm and if the abnormality persists, trip the generator. This can be achieved by use of distance relays that are installed at generator terminals. Directionally, they look into the generator. For this purpose, we need to interpret capability curve on the R-X plane. If the complex power generated is given by  $P + jQ$  then the apparent impedance seen by the distance relay installed on the generator terminals is given by

$$Z_{app} = \frac{|V|^2}{P - jQ} = \frac{|V|^2}{P^2 + Q^2} (P + jQ) \quad (1)$$

For simplicity, we have referred impedance has been referred to the primary side. Fig 40.5 shows the capability curve transferred to R-X plane using eqn. (1).



To protect the generator two distance relays and directional units are used. To protect generator against complete loss of field, inner circle is used. The relay operates when the impedance vector moves into this circle. Operating time of about 0.2 to 0.3 seconds are used with a complete shut down of the generator. The diameter of this circle is of the order of  $X_d$ , with the upper part of the circle 50-75% of  $X_d'$  below the origin.

The larger circle is used to detect reduced or partial loss of excitation system. Directional blinder may be used to limit pickup on normal operating condition.

### Protection against unbalanced operation

Quite often, a generator is connected to grid using a  $\Delta/Y$  transformer. The  $\Delta$  - winding on the generator side, traps the zero sequence current from flowing through the phase winding. However, positive and negative sequence currents will find their way into stator winding. Positive sequence currents cannot discriminate between balanced and unbalanced operating conditions. On the other hand, negative sequence currents clearly indicate the abnormality. Hence, it can be used as an effective discriminant for unbalanced system operation. Negative sequence currents create an mmf wave in opposite direction to the direction of rotation of rotor. Hence, it sweep across the rotor induces second harmonic currents in rotor, which can cause severe over heating and ultimately, the melting of the wedges in the air gap.

ANSI standards have established that the limits can be expressed as  $\int i_2^2 dt = k$  where  $i_2$  is the negative sequence current flowing. The machine designer establishes constant k. It can be in the range of 5 – 50. An inverse-time overcurrent relay excited by negative sequence current can be used for this protection.

### Generator Motoring: why and how?

If the mechanical input to the prime mover is removed while the generator is in service, then rotors mmf wave will tend to drive the rotor, just like an induction motor. This is dangerous to both steam and hydro turbine. In steam turbines, it may lead to overheating while in hydro turbine it would cause cavitation of the turbine blades. The motoring of generator can be detected by reverse power flow relays having sensitivity of 0.5% of rated power output with time delay of approximate 2 seconds.

### Over Voltage Protection

#### How?

On its face value, over voltage protection should be more or less straightforward. First, one should raise an alarm if the over voltage is above 110% of rated value. There would a subsequent trip if it persists for 1 min or more. Very large over voltages of the order of 120% of rated value or above, will lead to trip within approximately 6 seconds.

#### Why?

Terminal voltage of a generator is controlled by an automatic voltage regulator (AVR). If the load current (I) on the generator reduces, the AVR would automatically reduce the field current so as to reduce open circuit emf E to maintain constant terminal voltage V. However, loss of a VT fuse, incorrect operation or setting of AVR etc can lead to over voltage which is detrimental to the generator. Steady state over voltage will lead to saturation of iron, both for generator and the unit transformer connected to it. This will lead to large magnetizing currents, unacceptable flux patterns, over-heating, which can damage the power apparatus. Hence, generators have to be protected against overvoltage.

### V/f Protection

During start-up or shut down, the speed of the generator will deviate significantly from the nominal

speed. As per the emf equation ( $E = 4.44f \phi_m N$ ), overfluxing of the core is not simply a consequence of over voltages with respect to nominal voltage. Rather overfluxing occurs when V/f ratio exceeds its nominal value. Hence, over voltage protection is implemented after normalizing the terminal voltage by the frequency of the generator.

## Out-of-Step Protection

With modern generators having large  $X_d$  and EHV transmission having low reactance, it is likely that the electrical center, a consequence of out-of step condition would be within the generator step-up transformer unit. To detect this condition, distance relay looking into the generator (or into the transformer-generator unit) should be installed. Even a distance relay used for loss-of-field protection will pick-up on such power swing. If the swing moves out of the relay characteristic, before the timer runs down, then, no trip action will be initiated. However, if the swing persists for sufficient time, the loss-of-excitation distance relay will operate on power swing.

### A Note on Numerical Protection

At this point of time, there are no new principles to be introduced from the numerical relaying perspective. The differential protection scheme can be implemented by either using sample comparison (time domain approach) or by using phasor comparison (frequency domain approach). Time domain approach can be faster, than phasor comparison approach. The DFT approach with 1-cycle window will require one cycle to latch on to the phasor. Usually, the time constant associated with DC offset currents for generator faults will be large. Hence, decaying dc offset can be approximated by dc signal, which implies the full cycle DFT will be able to reject it. However, with half-cycle estimation, mimic impedance should be used.

Sample comparison approach is immune to dc-offset problem but building reliability with such an approach requires a polling scheme. In other words, reliability is obtained at the cost of time by ascertaining that successive samples return the trip decision. One can even implement a hybrid approach where in one switches from time domain to frequency domain approach. The decision to switch will depend upon the speed of rotation.

## Recap

In this lecture we have learnt about the following:

- Internal Fault like LLG, phase and ground faults.
- Abnormal operations like overload, underfrequency, unbalanced generator, etc.
- Issue with numerical protection

