ENGINEERS INSTITUTE OF INDIA

India's Best Institute for SSC-JE/AE & PSU's

SSC-JE

STAFF SELECTION COMMISSION

ELECTRICAL ENGINEERING

STUDY MATERIAL

Power Systems: Generation, Transmission and Distribution

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CHAPTER-1

BASICS OF POWER SYSTEM

INTRODUCTION

A system of n vectors or quantities may be resolved, when n is prime, into n different symmetrical groups or systems, one of which consists of n equal vectors and the remaining (n -1) systems consist of n equi-spaced vectors which with the first mentioned group of equal vectors forms an equal number of symmetrical n-phase systems...”

3-PHASE SYSTEMS

Any three coplanar vectors V_a, V_b and V_c can be expressed in terms of three new vectors V_1, V_2 and V_3 with constant coefficients.

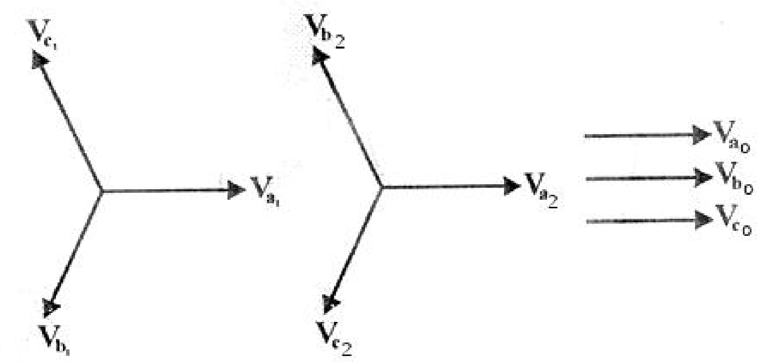
Each of the original vectors has been replaced by a set of three vectors making a total ofnine vectors. To simplify the calculations two conditions should be satisfied in selecting systems of components to replace 3- phase current and voltage vectors:

Fortescue's theorem, the three unbalanced vectors V_a, V_b and V_c can be replaced by a set of three balanced systems of vectors. Therefore, the solution is unique. **A** balanced system of three vectors is one in which the vectors are equal in magnitude and are equi-spaced.

1. Positive sequence component equal magnitude but displaced by 120° and same phase sequence as the original vectors.

2. Negative sequence component equal magnitude but displaced by 120° and the phase sequence opposite to the original vectors.

3. Zero sequence component equal magnitude and also are in phase with each other.



(A) (B) (C)

FigURE: (A) Positive sequence component; (b) Negative sequence component;

(c) Zero sequence component

FAULT CALCULATIONS

Classified as:

1. shunt faults (short circuits)
2. series faults (open conductor)

shunt type of faults involve power conductor or conductors-to-ground or short circuit between conductors. one or two phases opened is called series type of faults. shunt faults are characterized by increase in current and fall in voltage and frequency whereas series faults are characterized by increase in voltage and frequency and fall in current in the faulted phases. shunt type of faults are classified as

(i) line-to-ground fault (ii) line-to-line fault;

(i) double line-to-ground fault (iv) 3-phase fault

The first three unsymmetrical faults. the method of symmetrical components will be utilized to analyses the unbalancing in the system the 3-phase fault is a balanced fault.

The series faults are classified

(i) one open conductor (ii) two open conductors

Voltage of the neutral

The potential of the neutral when it is grounded through some impedance or is isolated, will not be at ground potential under unbalanced conditions such as unsymmetrical faults. the potential of the neutral is given as $v_n = - i_n z_n$, where z_n is the neutral grounding impedance and i_n the neutral current. here negative sign is used as the current flows from the ground to the neutral of the system and potential of the neutral is lower than the ground.

for a 3-phase system,

$$I_n = I_a + I_b + I_c = (I_{a1} + I_{a2} + I_{a0}) + (a^2 I_{a1} + a I_{a2} + I_{a0}) + (a I_{a1} + a^2 I_{a2} + I_{a0})$$

$$= I_{a1}(1 + a + a^2) + I_{a2}(1 + a + a^2) + 3I_{a0} = 3I_{a0}$$

$$V_a = -3I_{a0}Z_n$$

Question: A - 3ϕ T.L. supplies delta connected load line current in R-phase is 100A. Taking the current in R-phases is 100A. Taking the current in R-phase as reference find symmetry components of line current if phase-B is switched off. Assumed line current in Y-phase as $100\angle 180° A$

Solution: Given system is delta connected. Load current

Flowing in R-phase = $I_R = 100\angle 0^0$

Flowing in Y-phase = $I_Y = 100\angle 180^o$

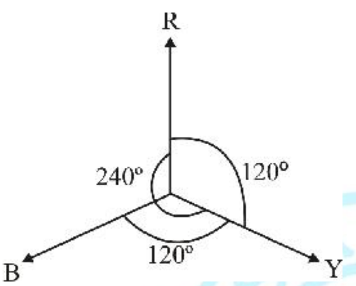
Flowing in R-phase = $I_B = 0$

We know

$$\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & K & K^2 \\ 1 & K^2 & K \end{bmatrix}\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

$$I_{R_1} = \frac{1}{3}\left[I_R + K I_Y + K^2 I_B\right] = \frac{1}{3}\left[100 + 100\angle 180 \times 1\angle 120°\right] = 57.74\angle 330°$$

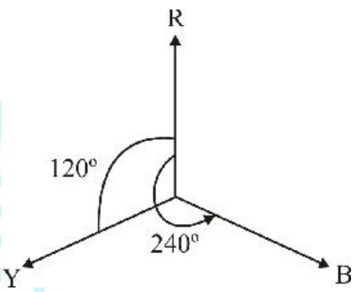
Since R_1, Y_1, B_1 is displaced by $1\angle 120$ as for default R.Y.B. phase



$$I_{Y_1} = I_{R_1}\angle 240 = K^2 I_{R_1} = 57.73\angle 210°$$

$$I_{B_1} = I_{R_1} 1\angle 120 = K I_{R_1} = 57.73\angle 90°$$

As the negative phase sequence is opposite to the original signal



$$\left.\begin{aligned} I_{Y_2} &= K I_{R_2} = 57.73\angle 150^{\circ} A \\ I_{B_2} &= K^2 I_{B_2} = 57.73\angle 270° A \end{aligned}\right\}$$

Severity of faults:

Three-phase (3L) faults	5%
Double line-to-grounded (LLG) faults	10%
Double line (LL) faults	15%
Single line-to-ground (LG) faults	70%

Calculation of 3-phase Short-Circuit Currents

The impedance of the alternator grows from the instant of short circuit to the steady state condition. Which impedance should be considered for evaluating the short-circuit currents, depends upon whether sub transient, transient or steady state short circuit current is required.

The p.u. impedance of equipment = $\frac{IZ}{V}$.

Where Z is the impedance of the equipment in ohms and I and V are the rated current and voltage respectively.

Now $I_{SC} = V/Z$

$$Z_{p.u.} = \frac{IZ}{V} = \frac{I}{I_{SC}} = \frac{IV}{I_{SC}V}$$

If VI is the base or full load volt-amperes and VISC the short-circuit volt-amperes, then

$$Z_{p.u.} = \frac{Base\ or\ full\ load\ volt - amperes}{Short - circuit\ volt - amperes}$$

$$S.C.MVA = \frac{Base\ or\ full\ load\ MVA}{Z_{p.u.}}$$

Selection of Circuit Breakers

Two of the circuit breaker ratings which require the computation of SC current are:

rated momentary current and rated symmetrical interrupting current. Symmetrical SC current is obtained by using sub transient reactance for synchronous machines.

Momentary current (rms) is then calculated by multiplying the symmetrical momentary current by a factor of 1.8 to account for the presence of DC off-set current.

The current that a circuit breaker can interrupt is inversely proportional to the operating voltage over a certain range, i.e.,

Amperes at operating voltage = $Amperes\ at\ rated\ voltage \times \frac{rated\ voltage}{operating\ voltage}$

Rated interrupting MVA (three-phase) capacity

$$= \sqrt{3}\,|V(line)|_{rated} \times |I(line)|_{rated\ interrupting\ current}$$

V (line) is in kV and I(line) is in kA

Three-phase SC MVA to be interrupted, where

SC (MVA) (3-phase) = $\sqrt{3}$ × pre fault line voltage in kV

×**SC CURRENT IN KA.**

If voltage and current are in per unit values on a three-phase basis

$$SC\ MVA(3-phase) = |V|_{perfault} \times |I|_{SC} \times (MVA)_{Base}$$

Rated MVA interrupting capacity of a circuit breaker is to be more than (or equal to) the SC MVA required to be interrupted.

A three-phase fault though rare is generally the one which gives the highest SC MVA and a circuit breaker must be capable of interrupting it.

A three-phase (3L) fault being the most severe must be used to calculate the rupturing capacity of circuit breakers.

Methods for Power Factor Improvement

The following devices and equipment are used for Power Factor Improvement.

1. Static Capacitor
2. Synchronous Condenser
3. Phase Advancer

1. Static Capacitor

We know that most of the industries and power system loads are inductive that take lagging current which decrease the system power factor . For Power factor improvement purpose, Static capacitors are connected in parallel with those devices which work on low power factor.

These static capacitors provide leading current which neutralize (totally or approximately) the lagging inductive component of load current (i.e. leading component neutralize or eliminate the lagging component of load current) thus power factor of the load circuit is improved.

These capacitors are installed in Vicinity of large inductive load e.g Induction motors and transformers etc, and improve the load circuit power factor to improve the system or devices efficiency.

Suppose, here is a single phase inductive load which is taking lagging current (I) and the load power factor is cosθ as shown in fig-1.

In fig-2, a Capacitor (C) has been connected in parallel with load. Now a current (Ic) is flowing through Capacitor which lead 90° from the supply voltage (Note that Capacitor provides leading Current i.e., In a pure capacitive circuit, Current leading 90° from the supply Voltage, in other words, Voltage are 90° lagging from Current). The load current is (I). The Vectors combination of (I) and (Ic) is (I') which is lagging from voltage at θ2 as shown in fig 3.

It can be seen from fig 3 that angle of θ2 < θ1 i.e. angle of θ2 is less than from angle of θ2. Therefore Cosθ2 is less than from Cosθ1 (Cosθ2> Cosθ1). Hence the load power factor is improved by capacitor.

Also note that after the power factor improvement, the circuit current would be less than from the low power factor circuit current. Also, before and after the power factor improvement, the active component of current would be same in that circuit because capacitor eliminates only the re-active component of current. Also, the Active power (in Watts) would be same after and before power factor improvement.

Advantages:

- Capacitor bank offers several advantages over other methods of power factor improvement.
- Losses are low in static capacitors
- There is no moving part, therefore need low maintenance
- It can work in normal conditions (i.e. ordinary atmospheric conditions)
- Do not require a foundation for installation
- They are lightweight so it is can be easy to installed

Disadvantages:

- The age of static capacitor bank is less (8 – 10 years)
- With changing load, we have to ON or OFF the capacitor bank, which causes switching surges on the system
- If the rated voltage increases, then it causes damage it
- Once the capacitors spoiled, then repairing is costly

2. Synchronous Condenser

When a Synchronous motor operates at No-Load and over-exited then it's called a synchronous Condenser. Whenever a Synchronous motor is over-exited then it provides leading current and works like a capacitor.

When a synchronous condenser is connected across supply voltage (in parallel) then it draws leading current and partially eliminates the re-active component and this way, power factor is improved. Generally, synchronous condenser is used to improve the power factor in large industries.

Advantages:

- Long life (almost 25 years)
- High Reliability
- Step-less adjustment of power factor.
- No generation of harmonics of maintenance
- The faults can be removed easily
- It's not affected by harmonics.
- Require Low maintenance (only periodic bearing greasing is necessary)

Disadvantages:

- It is expensive (maintenance cost is also high) and therefore mostly used by large power users.
- An auxiliary device has to be used for this operation because synchronous motor has no self starting torque
- It produces noise

3. **Phase Advancer**

Phase advancer is a simple AC exciter which is connected on the main shaft of the motor and operates with the motor's rotor circuit for power factor improvement. Phase advancer is used to improve the power factor of induction motor in industries.

As the stator windings of induction motor takes lagging current 90° out of phase with Voltage, therefore the power factor of induction motor is low. If the exciting ampere-turns are excited by external AC source, then there would be no effect of exciting current on stator windings. Therefore the power factor of induction motor will be improved. This process is done by Phase advancer.

Advantages:

- Lagging kVAR (Reactive component of Power or reactive power) drawn by the motor is sufficiently reduced because the exciting ampere turns are supplied at slip frequency (fs).
- The phase advancer can be easily used where the use of synchronous motors is Unacceptable

Disadvantage:

- Using Phase advancer is not economical for motors below 200 H.P. (about 150kW)
- Power Factor Improvement in single phase and three phase star & delta connections

Power factor improvement in three phase system by connecting a capacitor bank in

(1). Delta connection

(2). Star Connection)