Benha University		Circuit Breakers and Substations - EP445
Faculty of Engineering (Shoubra)		Mid Term Exam, 11 Nov., 2013
Elec. Eng. Dept., 4 th Year (Power)		Time Allowed: 90 Minutes

Answer all questions in allowed time and use drawings if available

Question One (7.5 points)

Indicate if each of the following statements is **Correct** or **Not**. **If NOT, write the correct answer**. **If Correct, write down the Reason**.

a) Circuit breakers keep electrical circuits from being damaged by short circuits or overloads.
b) Minimum Oil Circuit Breaker utilize oil as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker.
c) Two schemes are used for tripping in circuit breakers; one of them is the relay with break type contact which not requires auxiliary D.C supply with its operation.
d) If the P.F is low then interrupting of such current is difficult.
e) Maintenance of Air Blast circuit breaker is comparatively easier than that of tank type oil circuit breaker and minimum oil circuit breaker.

Question Two (10 points)

Distinguish between each of the following:

a) Air Blast circuit breaker and Oil Circuit breakers, Merits – Demerits- Applications.
b) Live tank circuit breaker and dead tank circuit breaker.
c) Load break switches, isolators and circuit breakers.
d) Rated breaking current and rated making current of circuit breakers.
e) Circuit breakers used in extra high voltage transmission lines and that used in distribution system.

Question Three (12.5 points)

1. Transient recovery voltage is affected by various parameters of the system. Mention all of these various parameters and then discuss the effect of each of them on TRV and recovery voltage.

2. In a short circuit test on a 3 pole, 110kV circuit breaker, the power factor of the fault was 0.4, the recovery voltage was 0.95 times full line value. The breaking current was symmetrical. The frequency of oscillation of restriking voltage was 15000 cycle per second. The neutral is grounded and the fault involves earth. Neglect the first pole to clear factor and Estimate the following:

a) The resriking voltage across the C.B after 3 m sec.
b) The average rate of rise of restriking voltage.
c) The rate of rise of restriking voltage after 3 m sec.
d) If the power factor of the fault increased to 0.9 discuss what is its effect.

Best Regards

Prof. Dr Sayed A. Ward

Model Answer of Mid Term Exam, 11 Nov. 2013

1- Answer of Question No. 1

a) Circuit breakers keep electrical circuits from being damaged by short circuits or overloads.
(<u>Correct</u>, because Circuit breakers are a special type of switchgear that is able to interrupt fault currents during short circuit conditions and interrupt over currents during overload conditions**)**

b) Minimum Oil Circuit Breaker utilize oil as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker.
(**Not Correct**, Bulk Oil C.B utilizes oil as arc …….)

c) Two schemes are used for tripping in circuit breakers; one of them is the relay with break type contact which not requires auxiliary D.C supply with its operation.
(<u>Correct</u>, because the relay with break type contact uses the energy from the main supply source for its operation**)**

d) If the P.F is low then interrupting of such current is difficult.
(<u>Correct</u>, because for zero power factor currents, the peak voltage E_{max} is impressed on the circuit breaker contacts at the current zero instant. This instantaneous voltage gives more transient and provides high rate of rise of TRV, so interrupting of such current is difficult)

e) Maintenance of Air Blast circuit breaker is comparatively easier than that of tank type oil circuit breaker and minimum oil circuit breaker.
(<u>Correct</u>, because in ABCB, there is no oil, which needs regular testing and purification. Also the operating mechanism can be easily disassembled, checked and reassembled)

2- Answer of Question No. 2

a)

- **Air-blast circuit breakers** are used today from 11 to 1100 KV, for various applications. They offer several merits such as faster operations, suitability for repeated operation, auto-reclosure, simple, assembly, modest maintenance, etc.
  A compressor plant is necessary to maintain high air pressure in the receiver. Air-blast circuit breakers operate repeatedly.
  Air-blast circuit breakers are used for interconnected lines and important lines when rapid operation is desired.
  <u>Merits of Air Blast Circuit Breaker:</u>
  1. Can be used at high pressure.
  2. Reliable operation due to external source of extinguishing energy.
  3. Free from decomposition.
  4. Clean, non-inflammable.

5. Air is freely available everywhere.
6. Fresh medium is used every time. Hence the breaker can be repeatedly operated, if designed for such duty.
7. At high pressure the small contact travel is enough.
8. The same are serves purpose of moving the contact and arc extinction.
9. High speed of operation. The compressed air moves very fast and brings about the opening operation. The arcing time is also short. Hence total breaking time is short operation mechanism of air blast circuit breaker are pneumatic. The arcing time is almost exactly 0.01 second, i.e 1/2 cycle plus another 1/2 cycle for operation the contacts. Hence breaker speed of the order of 2 cycles can be achieved. This makes the circuit breaker suitable for important lines because high speed opening and auto-reclosure can improve system stability.
10. Rapid auto-reclosure The circuit breaker can be given rapid auto-reclosure feature. The manufacturer gives such a provision at additional cost. The ABCB is easy to reclose because the reclosure is by spring pressure against reduced air pressure.
11. Clean service. No need of maintenance as of oil
12. Unit type construction gives advantage in design, manufacturer and testing
13. Very high breaking capacities and service voltage can be obtained by connection more number of units in series. Hence for all extra high voltage and high breaking capacities of today air-blast circuit breakers are used, e.g. 420 KV, 63.5 KA, 2 cycles
14. Suitability for repeated operation, the fresh air is used every time. Hence the breaker can be used for repeated operation if designed for duty. This is not the case with oil circuit breaker.

<u>Demerits of Air Blast Circuit Breaker:</u>

1. Complex design of arc extinction chambers and operating mechanisms, problems for switching over voltages are reduced by reclosing resistors.
2. Auxiliary high pressure air system is necessary. The cost can be justified if there several breakers in the switching yard. For single breakers the cost of auxiliary compressed air system would be too high

- **Oil Circuit Breaker:** utilize dielectric oil (transformer oil) for arc extinction. In bulk oil circuit breakers, the contacts are separated inside steel filled with dielectric oil. In minimum oil circuit breakers, the contacts are separated in insulation housing (interrupter) filled with dielectric oil.

The oil in oil circuit breakers (OCBs) serves two purposes. It insulates between the phases and between the phases and the ground, and it provides the medium for the extinguishing of the arc. When electric arc is drawn under oil, the arc vaporizes the oil and creates a large bubble that surrounds the arc. The gas inside the bubble is around 80% hydrogen, which impairs ionization. The decomposition of oil into gas requires energy that comes from the heat generated by the arc. The oil surrounding the bubble conducts the heat away from the arc and thus also contributes to deionization of the arc.

Main disadvantage of the oil circuit breakers is the flammability of the oil, and the maintenance necessary to keep the oil in good condition) i.e. changing and purifying the oil).

Disadvantage of Oil Circuit Breakers

1. The decomposed products of dielectric oil are inflammable and explosive. If the oil circuit breaker is unable to break the fault current, the pressure in the tank may rise above safe limit and explosion may occur. This does not happen in SF6, ABCB, and vacuum C.B.
2. The oil absorbs moisture readily. The dielectric strength reduces by carbonizations which occur during arcing. The oil needs replacement after a certain breaker operations. It needs regular maintenance.
3. Oil is not a suitable medium for breakers which have to operate repeatedly. Breakers used for furnaces, railways, industrial loads etc., operate frequently. Oil circuit breakers are unsuitable because oil gets deteriorated.
4. The oil leakage, losses, replacement and purification is often troublesome. Hence oil circuit breakers involve more maintenance.

b)

- **Live Tank C.B**: in this circuit breaker, the switching unit is located in an insulator bushing which is live at line voltage (or some voltage above ground).
  Live Tank circuit breakers are cheaper than dead tank and require less space.
- **Dead Tank C.B**: in this circuit breaker, the switching unit is located within a metallic container which is kept at earth potential. As the incoming/outgoing conductors are taken through insulated bushings, it is possible to place current transformers on these. (With a Live Tank arrangement this is not possible and separate CTs are required).

c)

- **Load Break Switches**: manual switch used for disconnection under load condition for safety, isolation and maintenance.
- **Isolators**: manual switch used for disconnection under no-load condition for safety, isolation and maintenance.
- **Circuit-breakers**: automatic switch used for switching during normal or abnormal conditions.

d)

- **Rated Short circuit breaking Current**: The rated short circuit breaking current of circuit breaker is the highest r.m.s value of short circuit current which the circuit breaker is capable of breaking under specified conditions of transient recovery voltage and power frequency voltage.
  The breaking current refers to the highest r.m.s value of short circuit current at the instant of the contact separation. It is expressed in KA (r.m.s).
  The rated breaking capacity of circuit breaker is expressed in terms of MVA given as follows: $MVA = \sqrt{3} \times KV \times KA$
  Where MVA = Breaking capacity of C.B, kV = Rated voltage, kA = Rated breaking current
- **Rated Short circuit making Current:** The circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop.
  In such cases the circuit breaker should be able to close without hesitation as contact touch. Also the circuit breaker should be able to withstand the high mechanical forces during such a closure.

The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current (Imax) Which the circuit breaker is capable of making at its rated voltage.
These capabilities are proved by carrying out making current test.

e)

- The rapid fault clearing of **extra high voltage transmission lines** improves the power system stability. Hence, faster relying and fast circuit breaker are preferred for extra high voltage transmission lines, where the circuit breaker time being in order of 2.5 cycles.
- For **distribution system**, such a fast clearing is not necessary. Discrimination is obtained by "graded time lag. Hence, slower circuit breaker, 3 to 5 cycles, are used.

Total breaking time varies between 80-120 ms for circuit breaker up to 12KV and 40-80 ms for circuit breaker above 36KV. It is less than 60 ms for 145KV, less than 50 ms for a 420 kV circuit breaker.

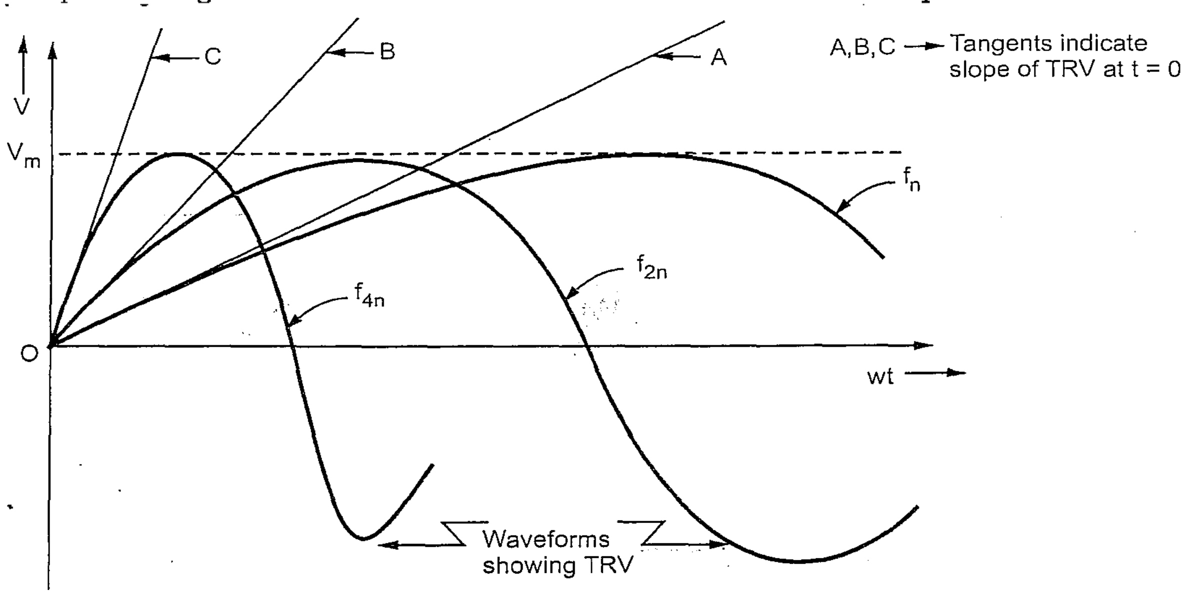
3- Answer of Question No. 3

1. Transient recovery voltage is affected by various parameters of the system such as:

- Inductance and capacitance in the system
- Fault current level of the system at point of study of TRV.
- Bushing capacitance of circuit breakers, voltage transformers etc.
- Number of transmission lines terminating at a bus and their characteristics impedance.
- Internal factors of the circuit breaker like the first pole to clear a fault etc.
- System grounding.

Effect of natural Frequency on TRV

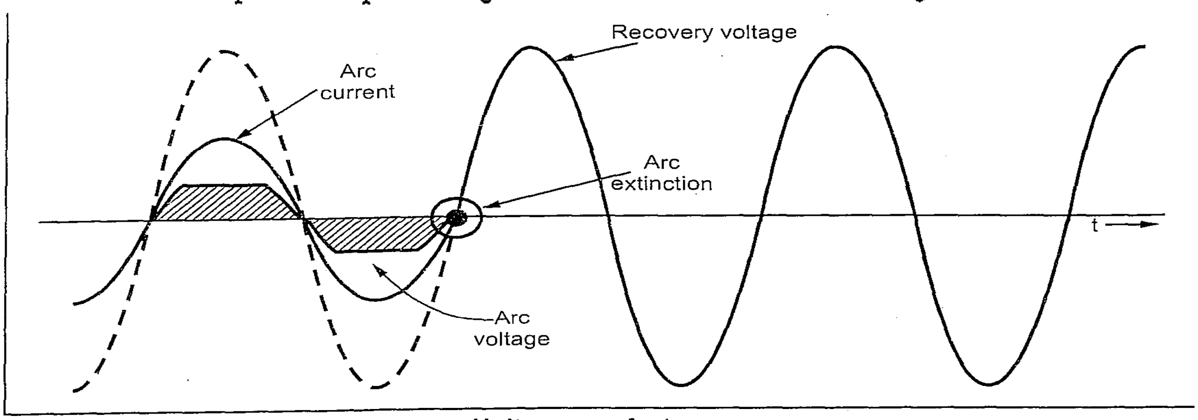
With increase in the natural frequency the rate of rise of TRV at current zero increases. This is shown in the Fig. The rate of rise of transient recovery voltage is represented by slopes of tangents to the three waveforms drawn at different frequencies.



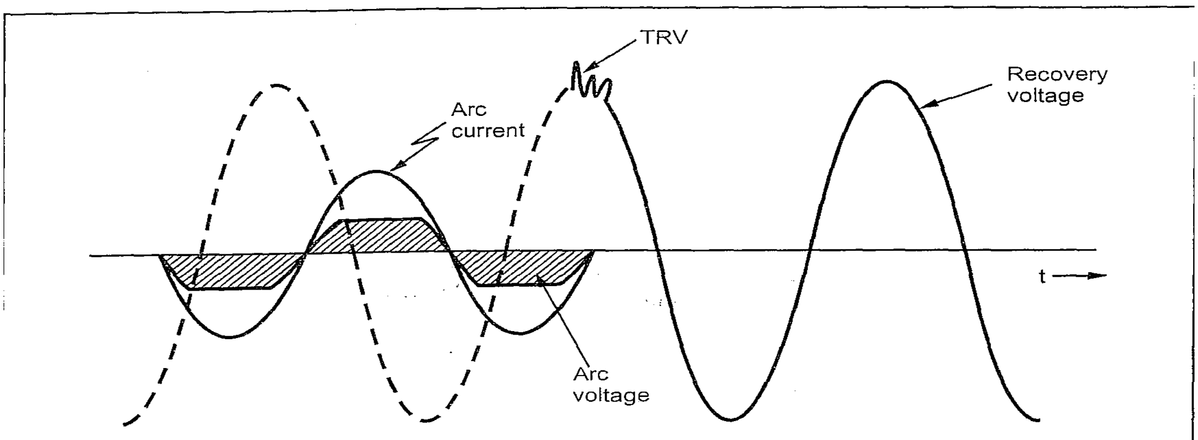
Rate of rise of TRV causes voltage stress on the contact gap which will continue the arc. If the frequency is increased then relatively small time is available for building of dielectric strength of contact gap. Hence increase in frequency causes greater stresses. The rate of rise of TRV is related with the breaking capacity of a circuit breaker. Thus it also means rate of rise of TRV is dependent on natural frequency of TRV. As frequency increases the breaking capacity reduces.

Effect of P.F on TRV

At the instant of final current zero the voltage appearing across the C.B. contacts is affected by the p.f. of the current. At current zero the arc is extinguished. After this power frequency voltage appears across the circuit breaker. The instantaneous value of the voltage at current zero depends on phase angle between the current and voltage.



Unity power factor



Zero power factor

If we consider zero power factor currents, the peak voltage E_{max} is impressed on the circuit breaker contacts at the current zero instant. This instantaneous voltage gives more transient and provides high rate of rise of TRV. Hence if the p.f. is low then interrupting of such current is difficult.

Effect of Reactance Drop on Recovery Voltage

Before fault is taking place let us consider that the voltage appearing across circuit breaker is V_1. As the fault current increases, the voltage drop in reactance also increases. After fault clearing the voltage appearing say V_2 is slightly less than V_1. The system takes some time to regain the original value.

Effect of Armature Reaction on Recovery Voltage

The short circuit currents are at lagging power factor. These lagging p.f. currents have a demagnetizing armature reaction in alternators. Thus the induced e.m.f. of alternators decreases. To regain the original value this e.m.f. takes some time. Thus the power frequency component of recovery voltage is less than the normal value of system voltage.

2.

$\because E_{rms\,(L-L)} = 110$ kV $\longrightarrow$ Peak value of voltage $E_{M\,(L-L)} = 110\sqrt{2} = 155.6$ kV

$\therefore$ Peak value of voltage (Line To ground) $E_{M\,(Ph)} = \frac{155.6}{\sqrt{3}} = 89.8$ kV

$\because P.F = \cos\varphi = 0.4 \longrightarrow \varphi = \cos^{-1} 0.4 \Rightarrow K_1 = \sin[\cos^{-1} 0.4] = 0.9165$

$\because$ The Recovery voltage was 0.95 Times full line value $\Rightarrow K_2 = 0.95$

$\because$ The neutral is grounded & The fault involves earth $\Rightarrow K_3 = 1$

- Active Recovery voltage $V_{ar} = K_1 K_2 K_3 E_m$

$\therefore V_{ar} = 0.9165 * 0.95 * 1 * 89.8 \Rightarrow V_{ar} = 78.2$ kV

$\because F_n = 15000$ Hz , $F_n = \frac{1}{2\pi\sqrt{LC}} \Rightarrow \sqrt{LC} = \frac{1}{2\pi F_n} = \frac{1}{2\pi * 15000}$

$\therefore \sqrt{LC} = 1.06 * 10^{-5}$

a) restriking voltage $(e) = V_{ar}\left[1-\cos\left(\frac{t}{\sqrt{LC}}\right)\right]$, $t = 3*10^{-3}\,s$

$\therefore e = 78.2\left[1-\cos\left(\frac{3*10^{-3}}{1.06*10^{-5}}\right)\right] = 60.58\ kv$

$\therefore$ Restriking Voltage across C.B after 3ms is $e = 60.58\ kv$

b) Peak restriking Voltage $\rightarrow e_m = 2\,V_{ar} = 2*78.2 = 156.4\ kv$

Time To reach Peak RV $\longrightarrow T_{m1} = \pi\sqrt{LC} = \pi*1.06*10^{-5} = 33.33\ \mu s$

$$RRRV_{avg} = \frac{e_m}{T_{m1}} = \frac{156.4}{33.33} = 4.697\ kv/\mu s$$

$\therefore$ Average Rate of Rise of Restriking Voltage is $RRRV_{avg} = 4.697\ kv/\mu s$

c) Rate of Rise of Restriking voltage $RRRV = \frac{V_{ar}}{\sqrt{LC}}\sin\frac{t}{\sqrt{LC}}$, $t = 3\ ms$

$$RRRV = \frac{78.2}{1.06*10^{-5}}\sin\frac{3*10^{-3}}{1.06*10^{-5}} = -7.187\ kv/\mu s$$

$\therefore$ RRRV after 3ms is $\rightarrow RRRV = -7.187\ kv/\mu s$

d) if $P.F = 0.9 \longrightarrow K_1 = \sin\left[\cos^{-1}0.9\right] = 0.4359$

$\therefore V_{ar\,(new)} = 0.4359 * 0.95 * 1 * 89.8 = 37.2\ kv$

$\therefore$ if The P.F Increased To 0.9 $\longrightarrow$ Factor K decreased To 0.4359 and so active Recovery voltage decreased To 37.2 kv and so Both of Restriking voltage and Rate of Rise of Restriking Voltage will be decreased Also.