MAINTENANCE OF DIESEL GENERATORS AND TRANSFORMERS

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities*****.**

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **MAINTENANCE OF DIESEL GENERATORS AND TRANSFORMERS** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

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1. Generators power rating: ISO-8528-1

STANDBY RATING

- Standby generators be operated roughly 200 hours per year. Extended utilization will be under strict supervision and maintenance.

PRIME POWER RATING

- Continuous use at variable load.
- Prime power generators be operated roughly 500 to 750 hours per year.
- This rating allows an overload capacity of 10 percent, but that additional capacity should not be used for more than one hour in every 12.
- *NOTE: All generators must be operated at 70% load mentioned at name plate unless otherwise advised by the manufacturer.*

1.2. Generator sizing

- ❖ As per International standards all generators must be operated at 70% load mentioned at name plate unless otherwise advised by the manufacturer.
- ❖ Sizing is made according to motors starting methods
  THUMB RULES
- ❖ Most generators are capable of delivering 250% of the rated current for 10 seconds, which is sufficient time for most induction motors to get up to the rated speed.

1.3 Sizing Generator If motor starter is D.O.L

- In D.O.L. the motor is started with the windings connected in DELTA so full voltage is applied directly to the motor terminals on start-up and during running.
- Starting current is 6 times its full load current.
- The generator set alternators' overload capacity is 2.5 times its rated output.
- So 2.5xKW of generator =6 x kWmotor/motor efficiency.
- KW of generator=2.67 times motor KW if efficiency of motor is 90 %.
- For a 100 KW motor the generator may be of 267 KW or 333 KVA if PF of generator is 0.8

1.4 Sizing Generator If motor starter is Star Delta

- In Star Delta starting the motor is started with the windings connected in Star so the starting voltage is reduced by √3.
- The starting torque is reduced to 1/3 of the D.O.L. value(1/3 of 6times of FLC)
- 2.5kW generator = 6/3 x motor kW/ 0.9

- kW generator = 2 x motor kW/ 2.5 x 0.9=0.9KW

- Almost equal to motor KW. But this is theoretical?

1.5 Standby Generator is to be operated at 70% of rated load

- Consider a 100 HP star delta motor having 90% PF & 93 % efficiency.
- Standby Generator is to be operated at 70% of rated load.
- If a generator is 100KVA
- To be operated at 70% load =70 KVA
- For 100KW motor the generator=100/0.7=1.42 times bigger generator.
- For a 100 KW motor.=142 KVA generator

1.6 Sizing Generator If motor starter is variable speed

- Variable Frequency Drives are considered non-linear loads, which are used to control the speed of induction motors, induce distortion in generator output voltage.
- Larger generators are required to prevent overheating due to the harmonic currents induced by the VFD and to lower system voltage distortion by lowering alternator reactance.
- For example, VFD loads on a generator must be less than approximately 50 percent of generator capacity to limit total harmonic distortion to less than 15 percent.
- For older six-pulse VFDs, a typical generator up-sizing factor would be 2X the running kW of the drive.
- If it is newer 12 pulse or pulse width modulated (PWM) type (or includes an input filter to limit current distortion to less than 10%), then you can reduce the sizing factor down to 1.4 X the running kW of the drive.

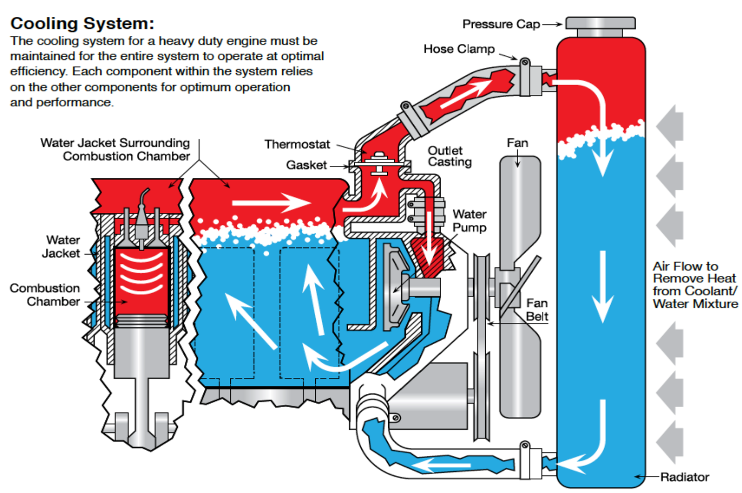
1.7 The Impact of Generator Set Under loading

- Operating diesel generator sets at loads less than 30 percent for extended periods can damage internal components and reduce engine life.
- Running at high idle with little or no load reduces the heat in the cylinder, allowing unburned fuel and oil deposits to leak through the exhaust slip joints.
- Result is exhaust manifold slobber, or wet stacking, which is the black oily liquid that can leak from the exhaust joints.
- Deposit build-up behind the piston rings or inside the cylinders, which can cause power loss, poor performance, accelerated wear and in extreme cases, cylinder liner polishing.

2. THE MOST COMMON CAUSES OF GENERATOR FAILURE

- POOR COOLING
- POOR LUBRICATION

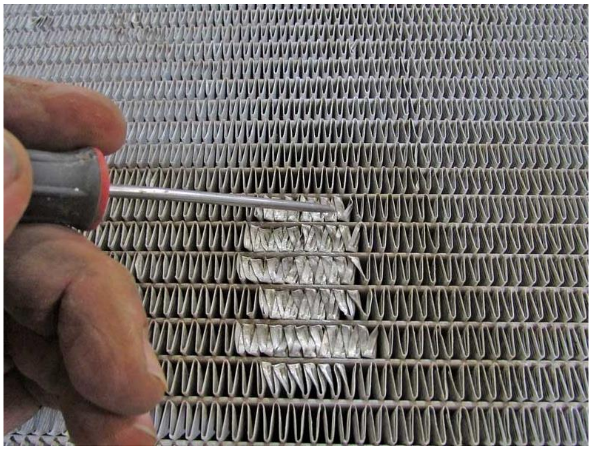
2.1 COOLING SYSTEM



2.2 WHAT CAUSES OVERHEATING

- A low coolant level
- Poor heat conductivity because of accumulated deposits in the water jackets.
- A defective thermostat that doesn't open
- Poor airflow through the radiator
- An inoperative electric cooling fan.
- A collapsed lower radiator hose.
- An eroded or loose water pump impeller, or even a defective radiator cap.

2.3 Engine Overheats When Loaded and Coolant is Known to be at the Proper Level



Efficient Radiator

- Combining closer tube spacing with a closer fin per inch count will give better heat transfer without increasing the thickness of the core
- A high efficiency core can have tubes on 7/16”, 3/8” or even 5/16” centers and fin counts increased to 12 to 14 FPI
- As an example; a 26” wide down flow style radiator with tubes on 9/16” centers has about 45 tubes from side to side. A high efficiency core of the same width has 57 tubes from side to side. This provides approximately 20% to 25% better cooling.

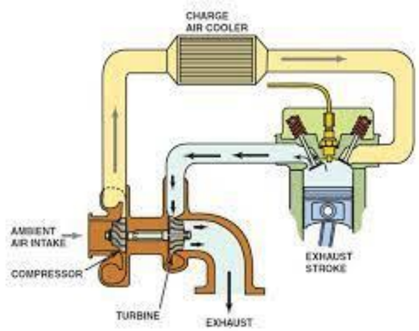
2.4 CONSEQUENCES OF ENGINE OVERHEATING

- Head gasket failure.
- Pistons swell inside their cylinders and can scuff or seize.
- Valve stems can swell and seize: broken rocker arms, bent pushrods, etc.
- Cylinder heads can crack (especially if someone dumps cold water into the radiator in an attempt to “cool off” the engine).

2.5 How Does a Turbocharger Work?

- A turbocharger is made up of two main sections:
- the turbine and
- the compressor.
- Exhaust gas of engine is taken into the turbine wheel. The energy from the exhaust gas turns the turbine wheel, and the gas then exits the turbine housing through an exhaust outlet area .
- And the air entering a diesel engine is compressed by the compressor before the fuel is injected.
- This increase in air means that more fuel can be added for the same size naturally aspirated engine.
- This then generates increased mechanical power and overall efficiency improvement of the combustion process.

2.6 Charge Air Cooler

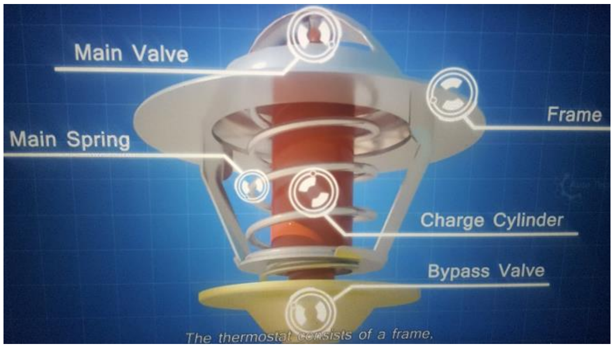


- For maximum power and efficiency, the air that enters an engine should be cool.
- Therefore the hot air passes through several small tubes in the core of the charge air cooler (intercooler) which cools the air while maintaining the pressure.
- A charge air cooler reduces the temperature from ~232C (from the turbo) to ~4 C above the ambient air temperature as it enters the intake manifold.

2.7 HOW A THERMOSTAT WORKS?

- When the engine is cold, the thermostats is normally closed; restricting flow to the radiator allowing the engine to "warm up"
- As the engine warms, the increase in heat forces the piston outward, opening the thermostat so coolant can start to circulate between the engine and radiator
- As heat increases, the thermostat continues to open until engine cooling requirements are satisfied

- If the temperature of the circulating coolant begins to drop, the wax element contracts; allowing spring tension to close the thermostat, which decreases coolant flow through the radiator



2.8 Radiator Cap

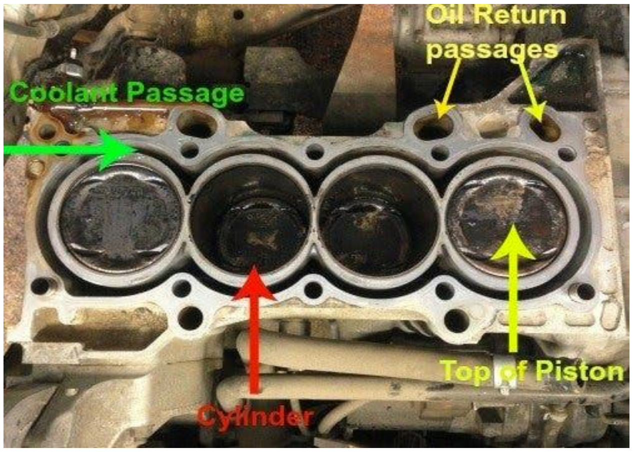
- The radiator cap is the gatekeeper of the cooling system. It maintains the proper amount of pressure.
- Pressurizing the cooling system is necessary to increase the boiling point of the coolant. This enables the liquid to hold more heat before evaporating.
- When your radiator cap does not seal properly, air could make its way inside of the cooling system.
- This will cause air pockets to get inside of the heater core, thermostat, and radiator hoses. As a result, the engine will start to overheat because it cannot sustain a temperature that is consistent.
- Each radiator cap is rated for a certain amount of pressure it can hold (13 PSI, etc. Different cooling systems call for different pressures.

2.9 Head Gasket failure

- Between the cylinder head and engine block.
- The head gasket seal pressures up to 2,700 psi and temperatures greater than 2,000 degrees F in turbocharged diesel engines.
- The head gasket also seals the pressurized coolant and oil flowing through it.
- 4. Since cylinder heads expand, the gaskets must resist the shearing forces associated with the uneven expansion rates.

- 5. Never reuse a head gasket.

Cylinder head gasket and cooling system failures

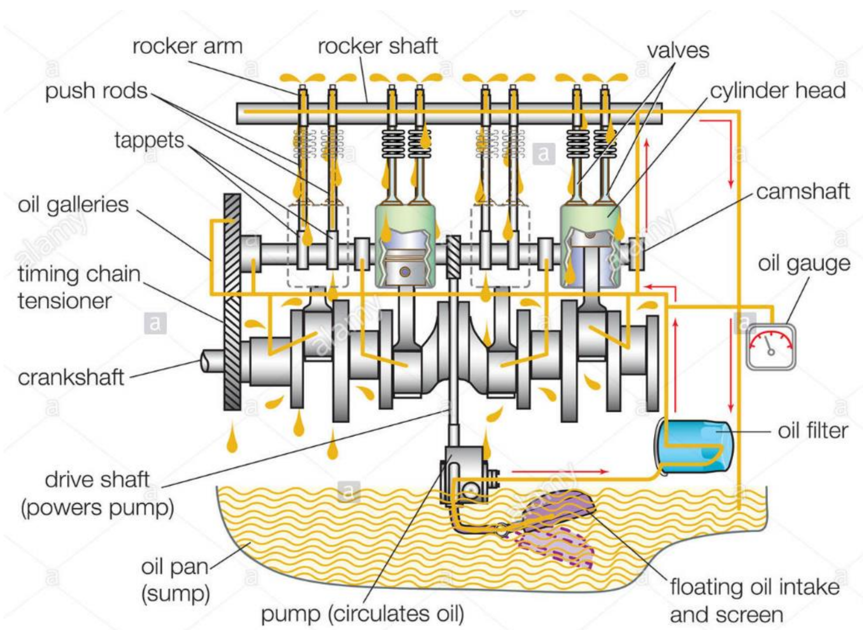


2.10 VISUAL SIGNS OF BLOWN HEAD GASKET

- Misfire on startup, if accompanied by a puff of white exhaust, could indicate a leak from the cooling system into the cylinder.

- Depending on the severity of the leak, you may see bubbles in the overflow tank, indicating that the cylinder is leaking into the cooling system.
- Discolored fluids are more subtle signs of a blown head gasket. This discoloration is a result of coolant mixing with motor oil in the engine. The result will be a lighter than normal, almost milk-chocolate-like color, since the engine oil is dark and coolant is light in color.
- Oil-contaminated coolant forms a mayonnaise-like film, which you might find on the radiator cap or in the overflow reservoir.

2.11 Engine Lubrication System Components



1. PRIMARY PURPOSE OF LUBRICATION

To keep a clean layer of lubricating oil film / luboil film between the contacting surfaces of the running parts / moving components in order to prevent friction, heat & metal-to-metal wear / abrasive wear.

2. SECONDARY PURPOSE OF LUBRICATION

2.1 COOLING

In passing through the engine, part of the heat is absorbed / picked up by the circulating oil. Therefore, it is made to pass through the cooler before being recirculated.

2.2 NEUTRALISATION OF ACID PRODUCTS OF COMBUSTION (sulphuric acid)

2.3 CLEANING

- **Washing away of wear detritus due to surface rubbing / friction. Therefore, the oil is filtered and centrifuged.**
- **Oil also cleanses hot moving parts from carbonaceous deposits.**

2.12 Dirty oil

- Failure to change the oil at proper intervals or to take proper care of the oil filter may cause the oil to be so dirty that it will promote clogging of the oil passages in the piston rings and pistons.
- This will increase the oil consumption.
- Dirty oil will also increase the rate of wear on bearings, cylinders, pistons, and piston rings.
- Note:*as a rule, dirt oil by nature is also consumed at a higher rate than cleaner oil.*

2.13 Oil grading

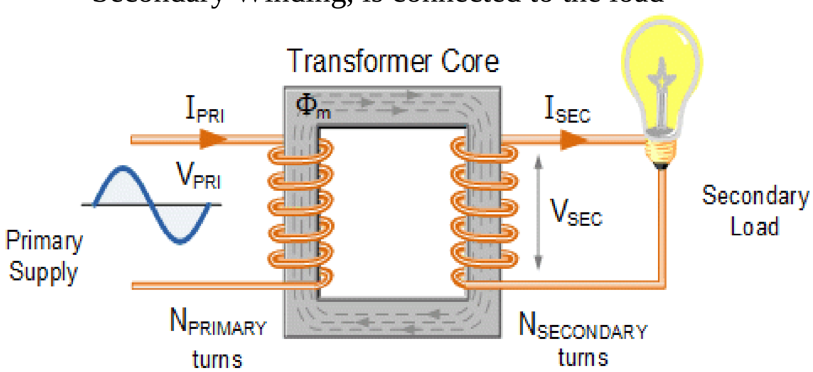
- The number preceding the "W" rates the oil's flow at 0 degrees Fahrenheit (-17.8 degrees Celsius). The "W" stands for winter, not weight as many people think. The lower the number here, the less it thickens in the cold. So 5W-30 viscosity engine oil thickens less in the cold than a 10W-30, but more than a 0W-30.
- The second number after the "W" indicates the oil's viscosity measured at 100 degrees Celsius. This number represents the oil's resistance to thinning at high temperatures. For example, 10W-30 oil will thin out at higher temperatures faster than 10W-40 will.

2.14 Generators fuel consumption

Manufacturer	Duty	Capacity(KVA)	100% Load	75% Load	50% Load
CAT	Standby	200	43.8	34.2	22.3
Perkins	Standby	200	41	31	20
CAT	Standby	500	98.6	74.4	50.9
Perkins	Standby	500	99	73	51
CAT	Standby	1000	224.1	168	115.1
CUMMINS	Standby	1000	196	145	101
	Prime	906	219	163	107

3.What is a transformer

- An apparatus for reducing or increasing the voltage of an alternating current.
- Accordingly it is called:
- step up or
- step down transformer.
- Two separate coils of wire are wound on a common iron core.
- Number of turns in each of the two coils decide the voltage.
- Secondary Winding, is connected to the load



3.1 Step Down Transformer

- Voltage at the secondary of the transformer can be calculated using the following equation.
- $V_P/V_S = N_P/N_S$
- V_P – is the Primary Voltage, V_S – is the Secondary Voltage
- N_P – is the Number of Primary Windings, N_S is the Number of Secondary Windings.
- Suppose N_P primary turns = 550
- N_S is secondary winding turns = 20
- V_P = 11000V, V_S =?
- Using the above equation, $V_S = (V_P * N_S)/N_P$ = 11000*20/550 = 400V.
- Ratio of primary/secondary=27.5
- Now consider Primary turns as 50 and secondary turns as 100
- Vs will become=11000*100/50=22000=22KV

3.2 Full load current calculation on HT & LT side of transformer

- KVA of transformer=voltage × current ×√3/ 1000
- Current=KVA×1000/voltage×1.732
- Consider a 400 KVA transformer
- HT side current=400 x 1000 /11000 x1.732 =20.99 SAY 21A
- LT side=I= 400 x 1000 /400 x1.732=577 A
- For 200 KVA transformer
- HT side(11KV side) I=200 x 1000/11000 x1.732=10.5 A
- LT side (Load side)I= 200 x 1000/400 x1.732 = 288.7 A

3.3 Thumb Rule for approximate current calculation

Current on HT side is roughly 0.05 times of KVA of transformer

Current on LT side is roughly 1.44 times of KVA of transformer

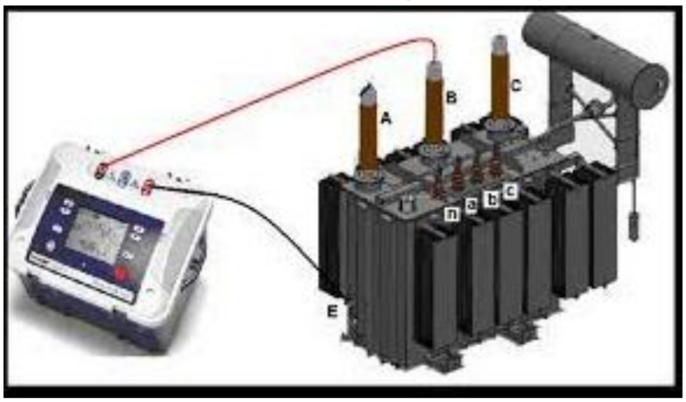
3.4 Electrical Power in a Transformer

- In an ideal transformer, the power available in the secondary winding will be the same as the power in the primary winding but practically it is not so.
- A transformer does not require any moving parts to transfer energy. However, transformers do suffer from other types of losses called "copper losses" and "iron losses"
- Copper losses, also known as I^2R loss is the electrical power which is lost in heat as a result of circulating the currents around the transformers copper windings.
- Efficiency= Secondary KVA/Primary KVA
- If transformer has 95% efficiency it means that 5% power is lost in copper and iron losses during conversion due to heating up. Secondary KVA=Primary KVA*0.95

4 Transformer tests

4.1 Insulation Resistance Test of Transformer

- It is also known as megger test of transformer.
- Disconnect all line and neutral terminals of the transformer.
- Measure the insulation resistance between the LV and HV windings.
- between the HV bushing stud and earth terminal of the transformer (body of the transformer).
- between the LV winding and the earth.
- All the readings taken above should be tending to infinity for a healthy transformer.



4.2 Transformer Ratio Test

- The performance of a transformer largely depends upon perfection of specific turns or voltage ratio of transformer.
- The procedure of the transformer ratio test is simple. We just apply three phase 400 V supply to HV winding, with keeping LV winding open.

- We measure the induced voltages at HV and LV terminals of the transformer to find out actual voltage ratio of the transformer.
- We repeat the test for all tap position separately.

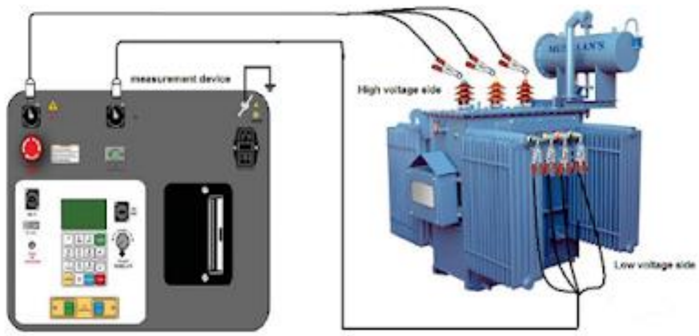
4.3 Induced voltage/high voltage test

- This is to test the quality of the turn-to-turn insulation.
- A 3- phase voltage supply that is twice of the rated voltage of secondary winding in magnitude and frequency is applied to the secondary winding of the transformer for 60 seconds and the primary winding is kept open-circuited.
- The test is started with a voltage lower than 1/3 of the full rated voltage and it has to be quickly increased up to the desired value.
- Practically you will induce 22KV on HT side for one minute.
- The test would be successful if no failure of insulation occurs.

4.4 OIL BREAK DOWN TEST

- Collect the 300-400 ml oil sample of transformer oil.
- Keep the oil pot in open air for 5 Minutes so that air bubble if any gets out. Now put the oil sample in the machine.
- Increase the KV at the rate of 2 KV/Sec and observe the oil sample through a glass window.
- Note down the KV at which sparking is observed in the oil.
- The voltage at which sparking observed is the breakdown voltage of oil.
- Repeat the step for the same sample for six times and note down the breakdown KV in each case.
- Take the average of BDV values. If oil BDV value is above 30 KV, transformer oil is good.

4.5 Transformer Winding Resistance Test



- The main purpose of this test is to check for gross differences between windings and for opens in the connections.
- Transformer winding resistance measurements are obtained by passing a known DC current through the winding under test and measuring the voltage drop across each terminal.
- Winding resistance in transformers will change due to shorted turns, loose connections, or deteriorating contacts in tap changers.
- Regardless of the configuration, the resistance measurements are normally made phase-to-phase and the readings are compared with each other to determine if they are acceptable.
- Depending on the size of the transformer winding under test, resistance readings will be expressed as ohms, milliohms, or microhms.

4.6 Why Do Transformers Fail?

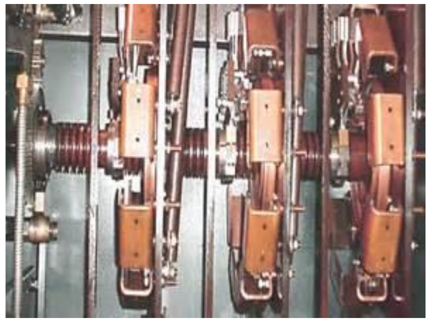
1.External Short Circuit

- The short – circuit: The level of fault current is always high enough.
- When a short-circuit occurs, the voltage at fault point is reduced to zero and current of abnormally high magnitude flows through the network to the point of fault.
- The copper loss of the fault feeding transformer is abruptly increased. This increasing copper loss causes internal heating in the transformer.
- Large fault current also produces severe mechanical stresses in the transformer

4.7 Causes of external short circuit

- Insulation failure of electric motors.
- Overheating of loose cable connections.
- Overheating due to overloading of circuit (more load on transformer than its capacity).
- Loose fittings of panel parts or substandard panel component.
- Malfunction of mechanical switching mechanism
- High resistance contacts
- Overheating

- Breaker Failure



4.8 .Overloading

- The loading of transformer is decided by permissible temperature rise of windings and oil.
- Permissible oil temperature is 65 °C and hot spot temperature of the winding is 80 °C at rated load.
- The output which can be obtained from a transformer without causing undue deterioration of the insulation may be either more or less than the name plate rating depending upon the operating conditions, such as ambient temperature, initial loading, cooling provision, life expectancy, etc.
- The rated output of a power transformer is mentioned on its name plate with reference to specified temperature rise under specified test conditions.

4.9 High voltage surge

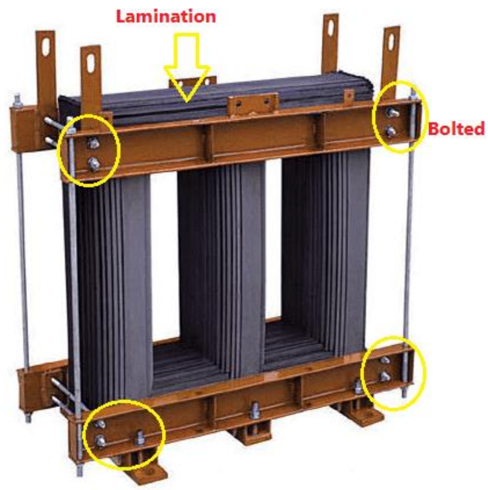
- Transient Surge Voltage
- High voltage and high frequency surge may arise in the power system due to any of the following causes,

1. Atmospheric Lightening Impulse.
2. Arcing ground if neutral point is not connected to ground.
3. Switching operation of different electrical equipment.

- Whatever may be the causes of surge voltage, it is a traveling wave form and also having high frequency.

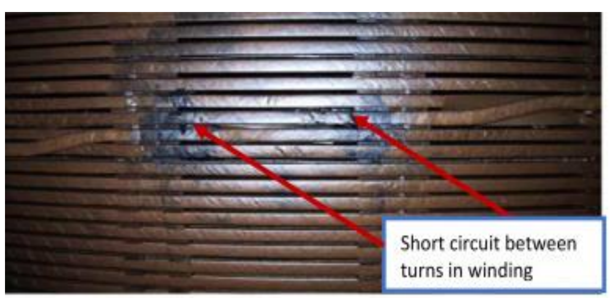
- This wave travels in the electrical power system network, upon reaching in the transformer, it causes breakdown of the insulation between turns adjacent to line terminal, which may create short circuit between turns.

4.10 System Over Voltage



- There may be always a chance of system over voltage due to sudden disconnection of large load.
- increased voltage causes proportionate increase in the working flux that is diverted from the transformer core to other steel structural parts like core bolts.
- Under such condition, the bolt may be rapidly heated up and destroys their own insulation as well as winding insulation.

4.11 Internal Faults in Power Transformer



- The principle faults which occur inside a transformer are categorized as,
- Insulation breakdown between winding and earth.
- Insulation breakdown in between different phases.
- Insulation breakdown in between adjacent turns i.e. inter – turn fault
- Transformer core fault

4.12 Inter Turn Faults

- Inter Turns Fault in Power Transformer
- Very large number of power transformer failure arises from fault between turns.
- Transformers connected with electrical extra high voltage transmission system, is very likely to be subjected to high magnitude, and high frequency impulse voltage due to lightening surge on the transmission line.
- The voltage stresses between winding turns become so large, it can not sustain the stress and causing insulation failure between inter – turns in some points.
- Inter turn fault may also be occurred due to mechanical forces between turns originated by external short circuit.

4.13 Core Fault in Power Transformer

- Core faults due to its insulation breakdown can permit sufficient eddy-current to flow to cause overheating, which may reach a magnitude sufficient to damage the winding

4.14 Windings insulation material

- Faults may also occur in the windings insulation material, *as a consequence of:*
- Insulation deterioration from:
  - Moisture
  - Overheating
  - Vibration
  - Voltage surges
  - Mechanical Stress from through-faults

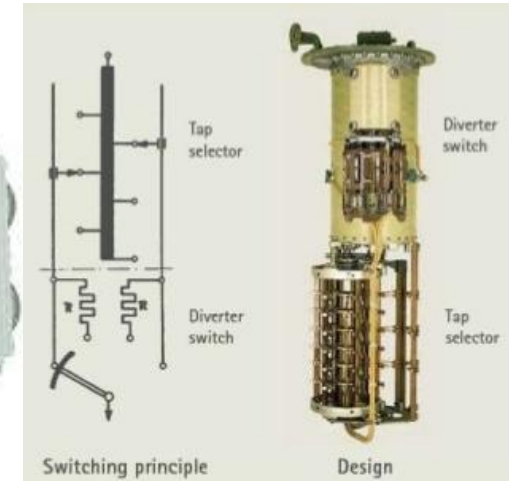
4.15 Internal moisture. Oil contamination

- Air is expelled (breathed out) when transformer is loaded causing the oil temperature to increase and expand. As the volume of the oil is increased, the air above the oil level in conservator will come out.
- During light load conditions oil cools down and contracts in volume so air is breathed in from the atmosphere.
- A silica gel breather is the most commonly used way of filtering air from moisture.
- Slica gel is blue when dry & pink color when fully absorbs moisture

4.16 Tap changer & Bushings

- Malfunction of mechanical switching mechanism
- High resistance contacts
- Overheating
- Bushings
- General aging
- Contamination
- Cracking



4.17 On which part of transformer the most failures occur?

Parts	**Position as per the most faults**
Winding failures	1st
Tap changer failures	2nd
Bushing failures	3rd
Core failures	4rth

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