Load Tap Changer (LTC) and Tap Position Monitoring

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Voltage Regulation & Power Quality Track
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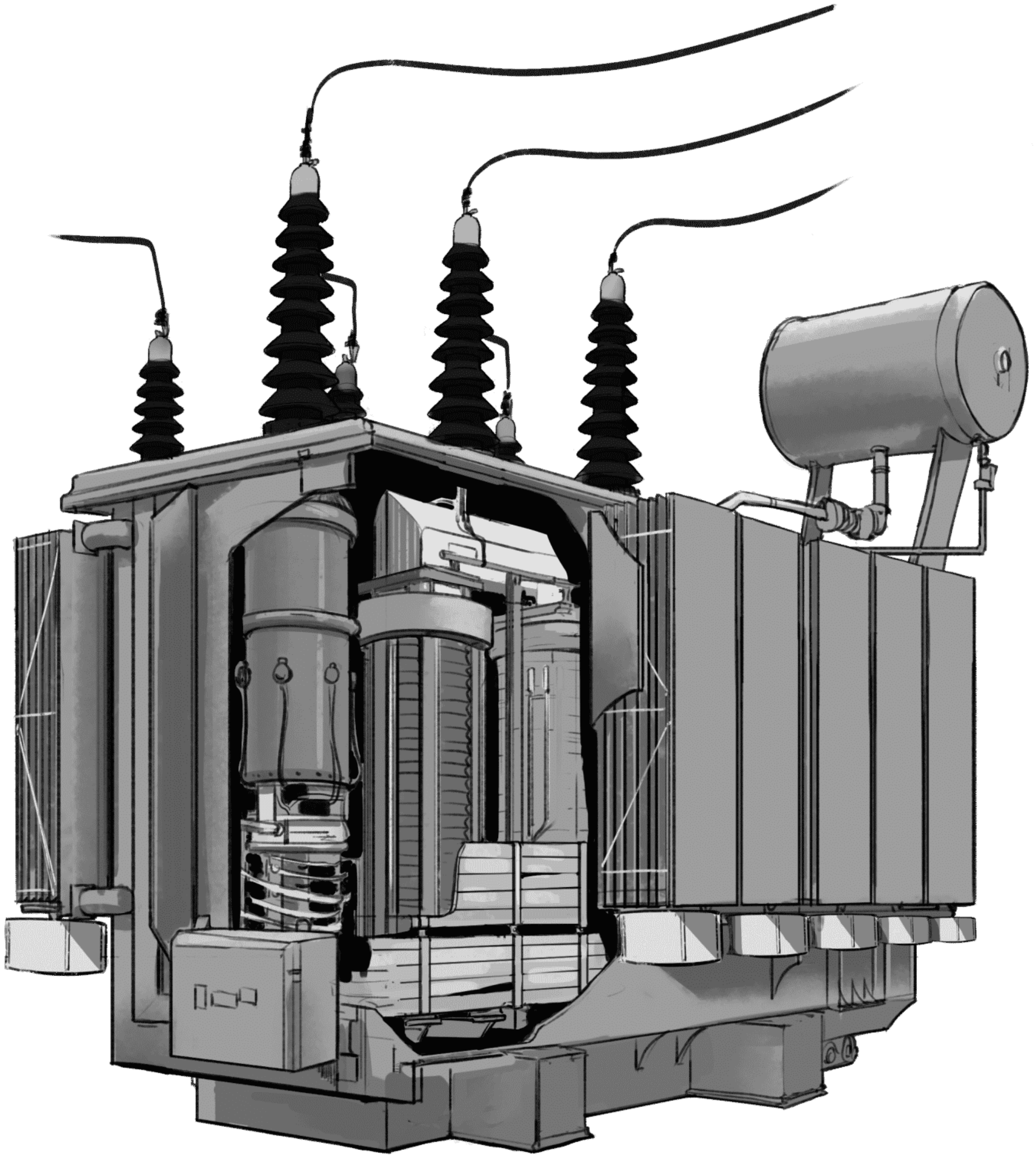
Load Tap Changer (LTC) and Tap Position Monitoring

Agenda

- Basics of an LTC
    - Different types of tap changer mechanisms
    - LTC for Single phase (auto transformer) vs 3-ph transformers
    - High side vs Low Side
- LTC Transformer vs Regulator Difference
- Tap Position Monitoring
    - Why you need tap position monitoring
    - Tap position sensors and how they connect to the LTC control
    - Tap position change current accumulation, number of operations per tap, monitoring & diagnostics, tap positions wear over time, LTC life.

AVR Control Regulation Basics

90 B Backup controls and supervisory devices



Program Introduction: Role & Importance of LTC Transformer & Tap Position Monitoring

Load Tap Changer (LTC) transformers are crucial for maintaining stable voltage in power grids by adjusting the transformer's output voltage as needed. LTC monitoring is vital because it provides insights into the transformer's operation, allowing for efficient and reliable voltage regulation. By monitoring tap position, utilities can identify potential issues, optimize performance, and prevent unexpected failures. In addition, tap position information may be required to run real-time power flow for volt var optimization algorithms implemented on ADMS.

Role of LTC Transformers:

Voltage Regulation:

LTCs adjust the turns ratio of a transformer (the ratio of primary to secondary windings) to regulate the output voltage, ensuring it stays within acceptable limits despite fluctuating load demands.

Maintaining Stability:

By providing stable voltage, LTCs contribute to the overall stability and reliability of the power grid.

Load Compensation:

LTCs enable transformers to adapt to varying load conditions, ensuring that the voltage delivered to customers remains consistent.

Normal Types & Uses

- **Isolation only** Does not change voltage. It does, however, provide isolation from the facilities electrical system, which eliminates much of the buildings electrical “noise” on the output.

- **Step down:** Changes a higher voltage to a lower voltage, such as 69Kv to 13.8 KV and provides isolation.

- **Step up:** Changes a lower voltage to a higher voltage and provides isolation.
- Note: In most cases the transformers (describe above) that provide isolation also incorporate a grounded “Faraday Shield”, between the primary and secondary windings, to reduce the transmittance of high frequency “noise”. Although shielding is generally included, it should be specified.

Program Introduction: Roll & Importance of LTC Transformer & Tap Position Monitoring

Importance of LTC Tap Position Monitoring:

•**Early Fault Detection:** Monitoring tap position can reveal irregularities, such as stuck or frequently operated taps, which can indicate developing problems within the LTC or the transformer itself.

•**Optimized Performance:** Analyzing tap position trends helps utilities understand the transformer's operating patterns, allowing for optimized voltage regulation and reduced power losses.

•**Preventive Maintenance:** By identifying potential issues early on, monitoring enables timely maintenance, preventing unexpected failures and costly downtime.

•**Reduced Operational Costs:** Efficient voltage regulation through LTC monitoring can lead to lower energy consumption and reduced overall power costs.

•**Improved Asset Management:** Real-time data from LTC monitors allows for better asset management, enabling proactive decision-making and optimized maintenance schedules.

•**Enhanced Grid Reliability:** By ensuring proper voltage regulation and preventing failures, LTC monitoring contributes to a more reliable and resilient power grid.

What is a tap changer?

- An electric switch with several switching positions
- Used to regulate the turns ratio (transmission ratio, winding ratio) of a transformer
- If the turns ratio (winding ratio) changes, the voltage ratio and thus the output voltage changes
- Tap changers are built with one, two or three phases
- On-load tap-changers enable voltage regulation and/or phase shifting by varying the transformer ratio under load without interruption

How do transformer and tap changer interact?

- Tap changers for power transformers are used to set the transformer ratio
- The change of the voltage at the transformer takes place by changing the transmission ratio, that means by changing the number of turns at one of the two windings
- With a tap changer, this can be realized with several taps on one winding
- In the automatic mode of the controllable transformer, the voltage is measured and as soon as the control bandwidth is exceeded or undershot over a definable time, a switching command is transmitted to the on-load tap-changer

APPLICATIONS OF TAP CHANGERS

Distribution Transformers
Tap changers in distribution transformers are vital for supplying electricity to homes, businesses, and industries. They ensure that voltage levels remain within acceptable limits, regardless of load fluctuations or grid disturbances.

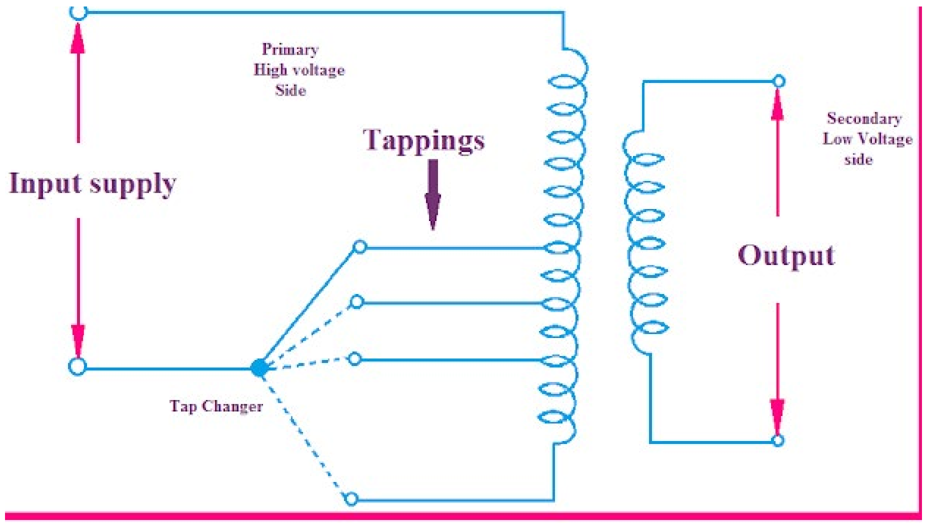
Substation Transformers
Power transformers in substations often use tap changers to regulate voltage levels in high-voltage transmission networks. This is crucial for efficient long-distance power transmission and grid synchronization.

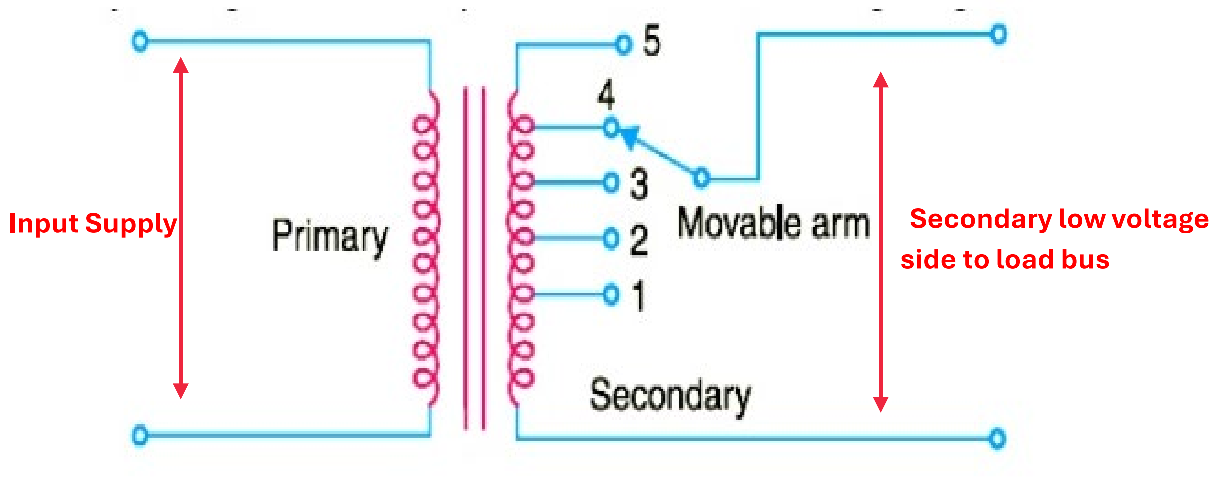
Renewable Energy Integration
With the growing integration of renewable energy sources like wind and solar, tap changers are essential for accommodating the variable power output from these sources. They help maintain grid stability when renewable generation fluctuates.

Industrial Applications
Industries with sensitive equipment rely on tap changers to provide consistent voltage levels, safeguarding their operations from voltage-related disruptions.

Basics of an LTC: Purpose

The purpose of a tap changer is to regulate the output voltage of a transformer. It does this by altering the number of turns in one winding and thereby changing the turns ratio of the transformer. Its internal mechanism allows for variable turn ratios to be selected in distinct steps. This is done by connecting to several access points, known as taps along either the primary or secondary windings.



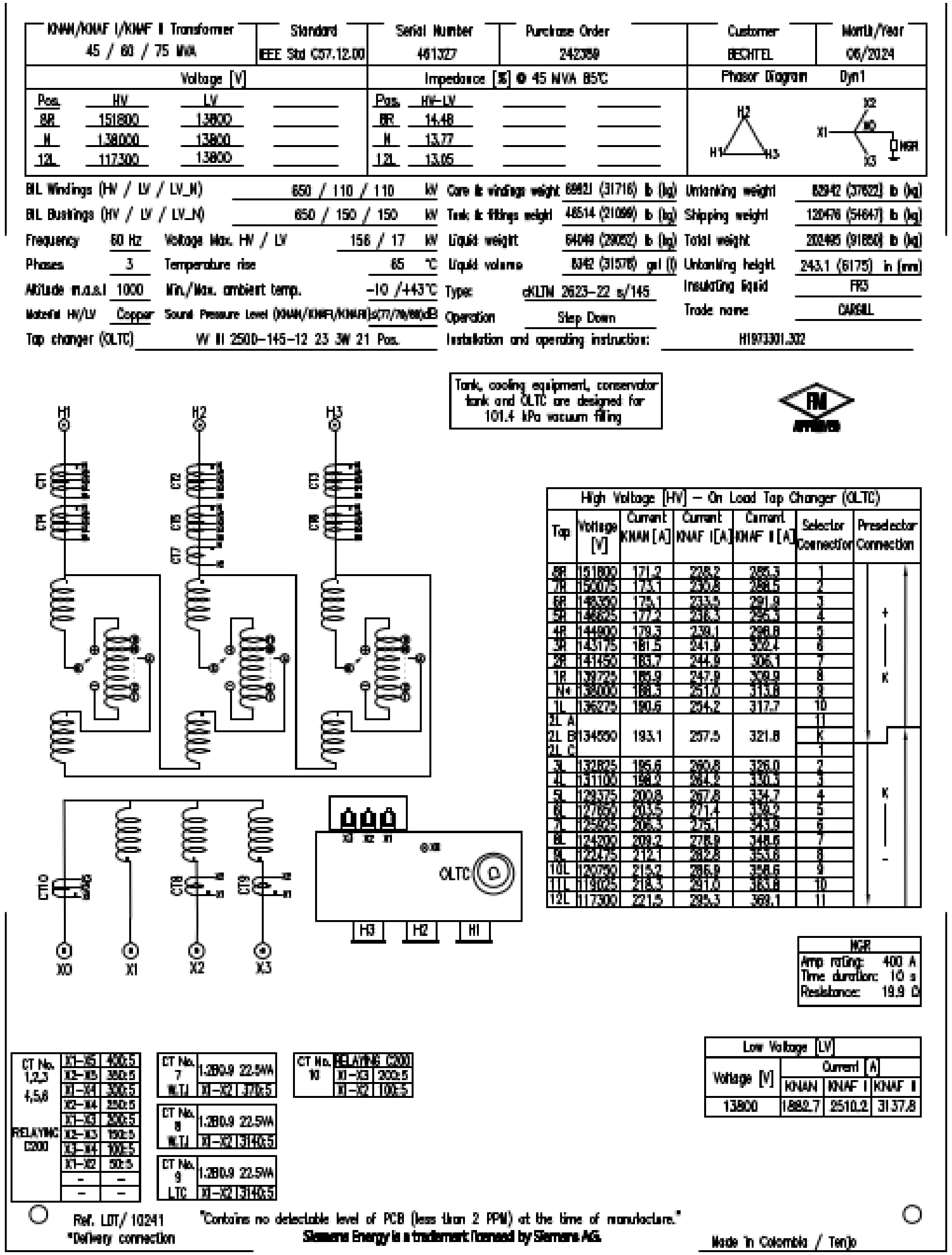


- Some LTC transformer typically have voltage taps located on the high-voltage winding. This is because adjusting the turns on the primary side (where the voltage is higher) requires fewer current-handling capabilities compared to the low-voltage side.

- The taps are spaced out in steps, commonly ±10% of the nominal voltage in increments of 1.25% or 2.5%.

Other benefits

- Reduced Current and Arcing:
- Smoother Voltage Regulation:
- Improved Transmission Line Voltage Regulation:
- Protection Against Circulating Currents:
- Accessibility:



LTC on the High-Voltage (HV) Side:

Advantages:

- Easier Wiring Access: The taps on the high voltage winding are typically connected to the outside winding for easier access.
- Lower Switching Current: The current on the high voltage side is lower, which can result in less stress and wear on the LTC's contacts during switching operations.

LTC Manufacturing and Applications Considerations:

- Higher Voltage Handling: The LTC and its components must be designed to withstand the higher voltage levels present on the high-voltage side.
- Increased Insulation Requirements: Greater insulation is needed to handle the high voltage environment.
- Higher Cost: Due to the need for more robust components and stricter insulation, high-voltage LTCs can be more expensive.

LTC on the Low-Voltage (LV) Side:

Considered Advantages:

- Lower Voltage Handling: The LTC is exposed to lower voltage levels, potentially reducing the insulation requirements and cost.
- Reduced Stress on Components: The lower voltage may mean less electrical stress on the tap changer's components.

Considerations on Manufacturer & Application

- Higher Switching Current: The current on the low voltage side is higher, which can lead to increased wear on the LTC's contacts and potentially require a more robust design to manage the switching current effectively.
- More Complex Wiring: The winding structure for low-voltage tap changers might be more complex to access and connect.

BASIC TYPES OF TAP CHANGERS

De-Energized Tap Changers (Off Load Tap Changer)

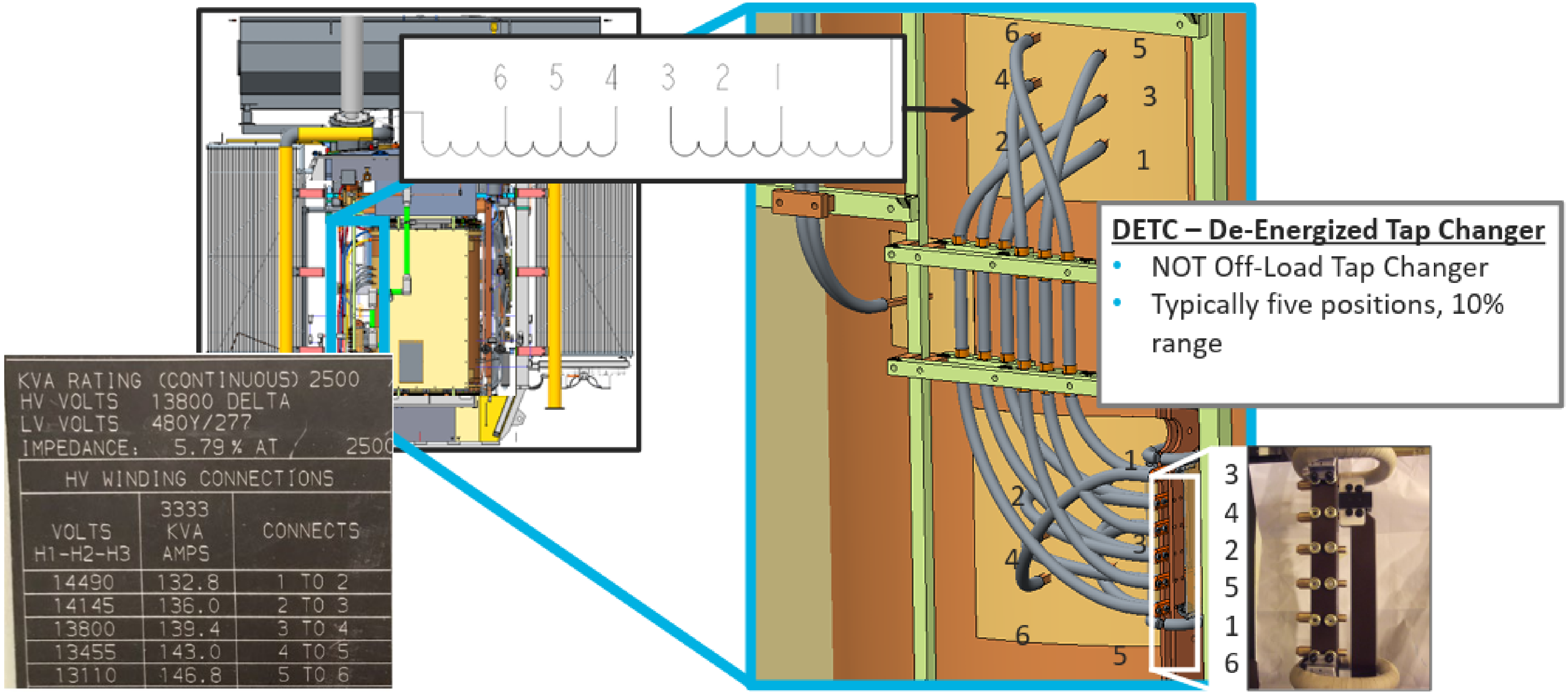
Unlike OLTCs, de-energized tap changers are designed to switch the transformer’s taps when it is de-energized or offline. They do not require complex switching mechanisms since they operate under no load conditions. (also know as a No-Load Tap Changers (NLTCs). It's required for the transformer to be de-energized before changing taps, making them ideal for applications requiring infrequent voltage modifications or programmed load interruptions, it does require planned outages for voltage adjustments.

On-Load Tap Changers (OLTC)

On-load tap changers, also known as OLTCs, are designed to change the transformer’s tap settings while it is energized and under load. OLTCs use various mechanisms, such as diverter switches and selector switches, to alter the transformer’s winding connections. This allows for voltage adjustments to compensate for fluctuations in the power grid, ensuring a steady supply of electricity. OLTCs are commonly found in substation transformers, where voltage adjustments are frequently required to accommodate changing loads and voltage profiles.

DE-ENERGIZED TAP CHANGERS

De-Energized Tap Changers

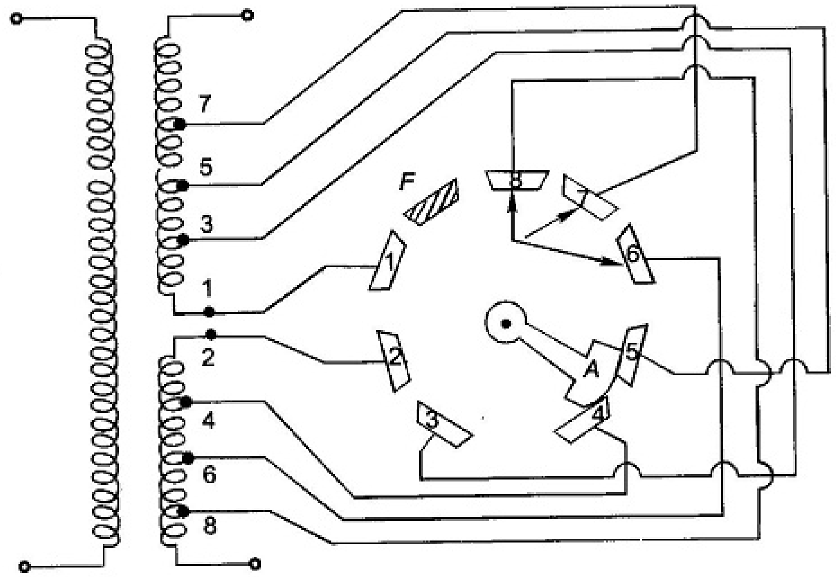


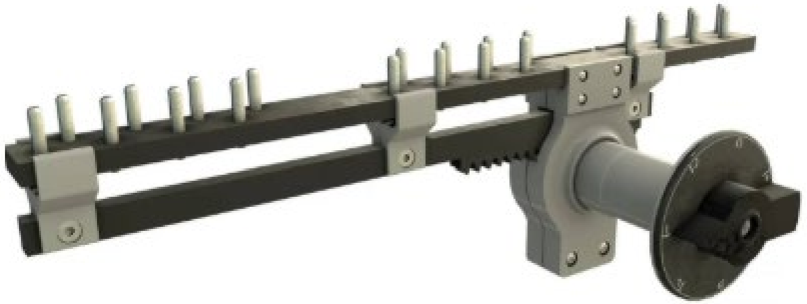
De-Energized Tap Changer Voltage Regulation

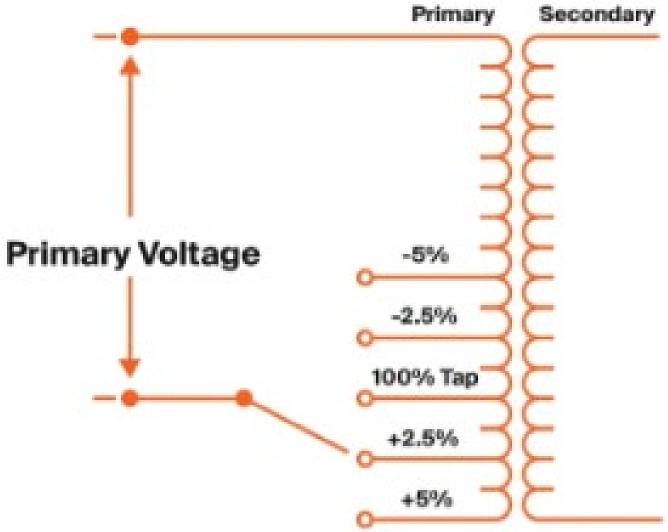
Unlike OLTCs, de-energized tap changers are designed to switch the transformer's taps when it is de-energized or offline. They do not require complex switching mechanisms since they operate under no load conditions.

- A tap changer is a device that adjusts the turns ratio of a transformer, which in turn changes the output voltage.
- De-energized tap changers (DETCs) are specifically designed to make these adjustments when the transformer is not energized.
- Unlike on-load tap changers (OLTCs), DETCs cannot interrupt current flow and must be operated when the transformer is disconnected from the electrical system.
- DETCs are typically used for adjusting voltage in response to seasonal changes or long-term voltage variations.

De-Energized Tap Changers (Off Load Tap Changer)







- Selector Rack-in pinion type design
- It has eight studs marked one to eight.
- The winding is tapped at eight points.
- The face plate carrying the suitable studs can be mounted at a convenient place on the transformer such as upper yoke or located near the tapped positions on the windings.
- The movable contact arm A may be rotated by handwheel mounted externally on the tank.

Transformer Tap Changing: Basic Principles DETC

Conventionally, normal rated winding is designated at 100% tap. There could be taps above 100% taps (called positive taps) or below 100% (called negative taps)

- To increase secondary voltage, turns ratio must be decreased.
- To decrease secondary voltage, turns ratio must be increased.

Tap is usually provided only on the primary HV winding and no adjustment of secondary winding is normally possible. This means to increase secondary voltage use fewer primary turns-decrease N1 and to decrease secondary voltage use more primary turns-increase N1.

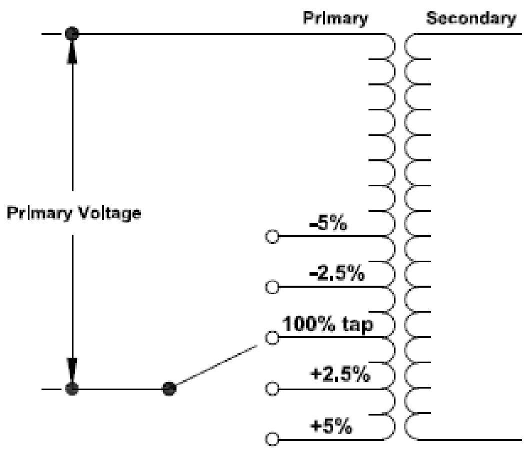


Figure 6: Transformer with four taps

$$Turns\ ratio = \frac{N1}{N2}$$

where N1 and N2 are number of turns on primary and secondary.

From transformer theory we know

$$\frac{V1}{V2} = \frac{N1}{N2}$$

where V1 and V2 are voltage on primary and secondary.

$$V2 = V1\frac{N2}{N1}\ or$$

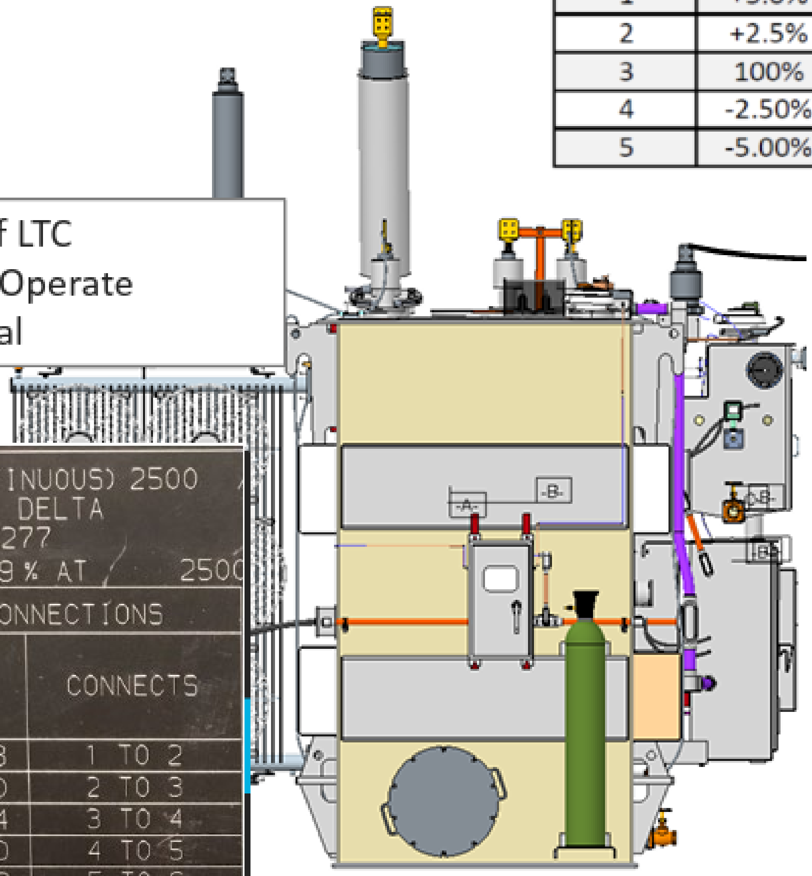
$$V2 = \frac{V1}{\left(\frac{N1}{N2}\right)} = \frac{V1}{Turns\ ratio}$$

If specified, the de-energized tap changer (DETC), the following four highvoltage rated kilovoltampere taps shall be provided: 2.5% and 5.0% above rated voltage, and 2.5% and 5% below rated voltage.

De-Energized Tap Changers

Tap	Tap %	HV connection voltage [V]	Turns ratio	Secondary voltage for normal primary voltage [V]
1	+5.0%	14,490	30.19	457
2	+2.5%	14,145	29.47	468
3	100%	13,800	28.75	480
4	-2.50%	13,455	28.03	492
5	-5.00%	13,110	27.31	505

Adjust Travel of LTC Mechanism to Operate Through Neutral



KVA RATING (CONTINUOUS) 2500
HV VOLTS 13800 DELTA
LV VOLTS 480Y/277
IMPEDANCE: 5.79 % AT 2500

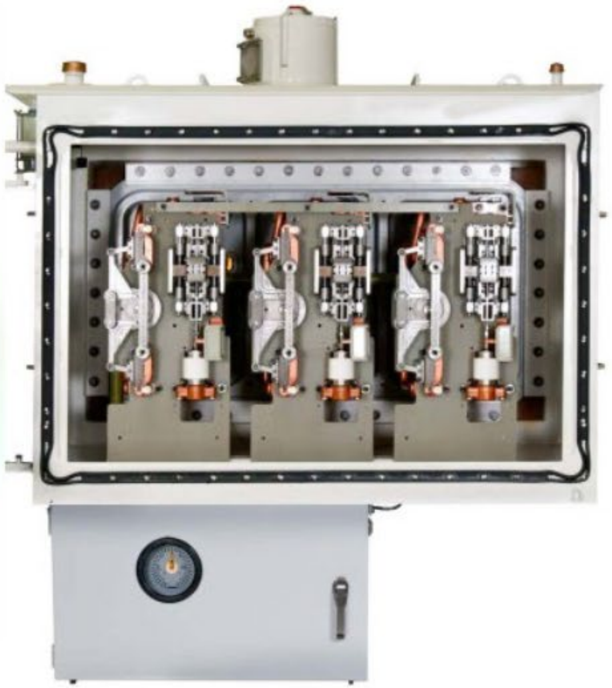
HV WINDING CONNECTIONS		
VOLTS H1-H2-H3	3333 KVA AMPS	CONNECTS
14490	132.8	1 TO 2
14145	136.0	2 TO 3
13800	139.4	3 TO 4
13455	143.0	4 TO 5
13110	146.8	5 TO 6

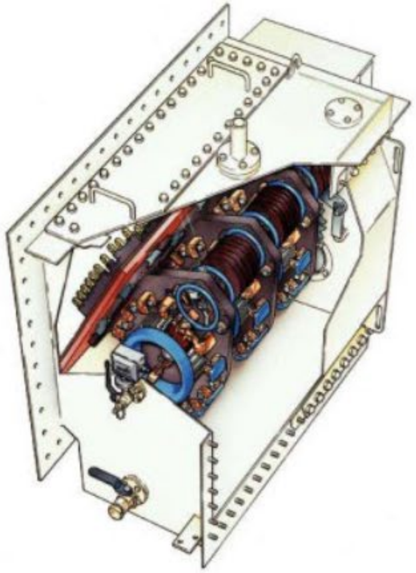
Basic Types of Load Tap Changer Mechanical Designs

In-tank
vacuum/resistance
Example: type VUCG
Application: HV winding

On-tank
vacuum/reactance
Example: type VRLTC
Application: LV winding

On-tank
resistance
Example: type UZ
Application: LV & HV winding





On-Load Tap Changers (OLTCs):

Basic Function: OLTCs are designed to regulate the output voltage of a transformer while it's actively supplying power.

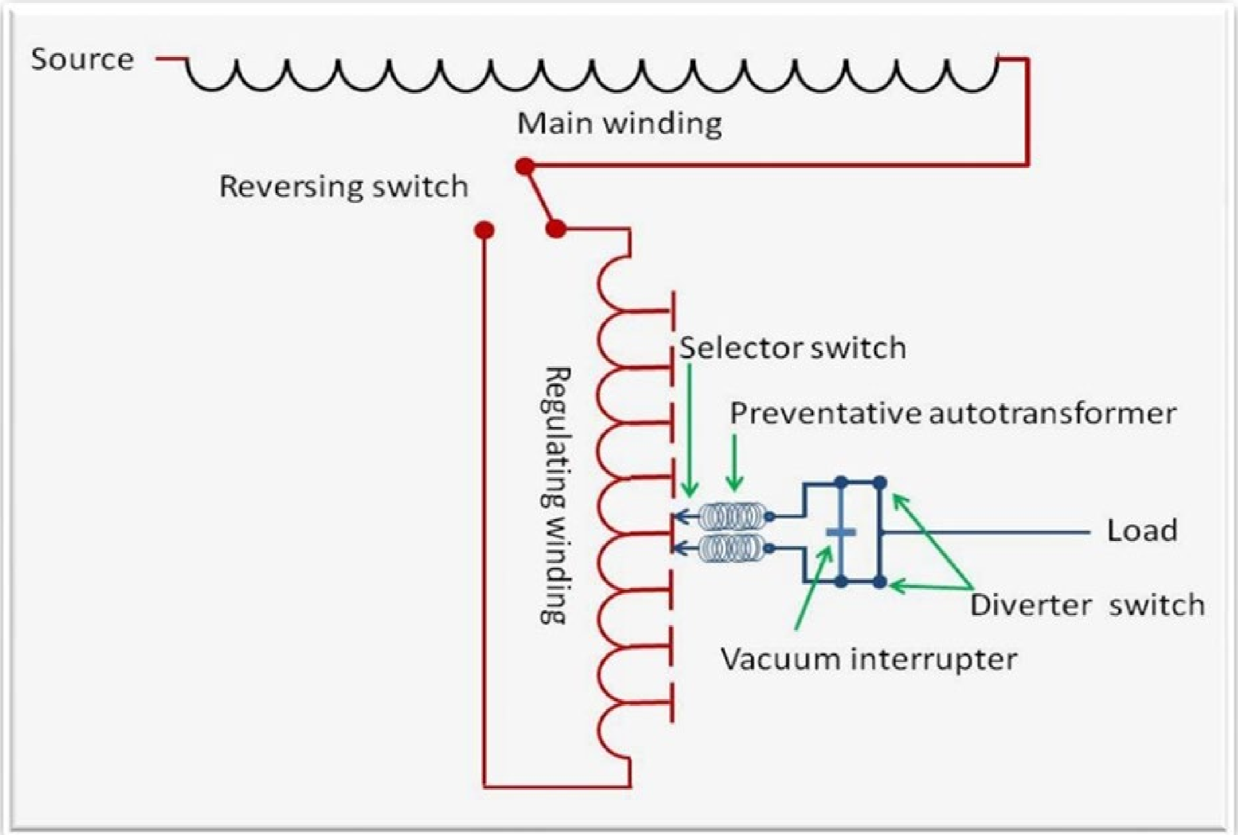
General Operation: They achieve this by switching between different tap positions on the transformer winding without interrupting the load current.

Primary Feature: The ability to change taps while under load is crucial for maintaining a stable voltage supply in systems with fluctuating demand.

Components: OLTCs typically include a selector switch to choose the active tap and a changeover switch (commonly called a reversing switch) to alter the polarity of the tapped winding.

Examples: They are often used in power distribution transformers to accommodate daily load variations.

Basic diagram of the key internal mechanical components of the OLTC load tap changer



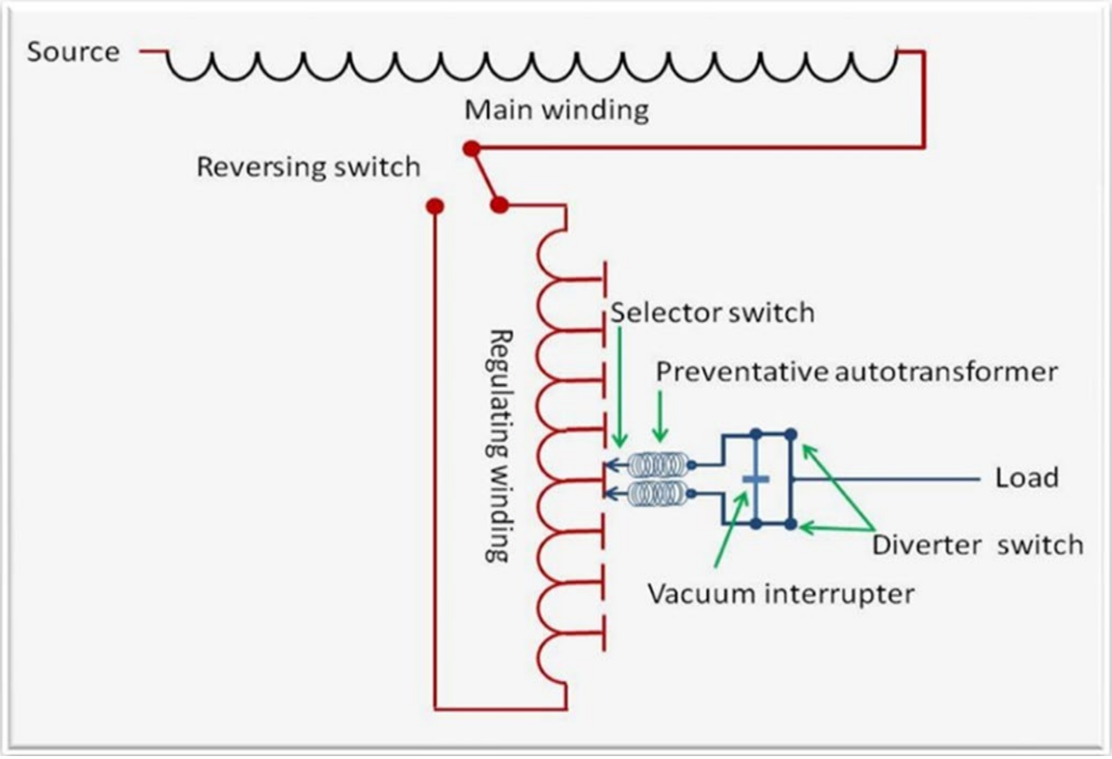
- The operating mechanism for the LTC is motor driven.
- Manual operation is used in the event of motor failure.
- The sequence of operation is mechanically linked, or interlocked, to ensure that all contacts always operate in their correct order.
- Any failure of the operating mechanism can result in severe damage to the transformer and tap changer.

The key components of the load tap changer include:

Selector Switches: These switches select the physical tap position on the transformer's regulating windings. They do not however, make or break the load current.

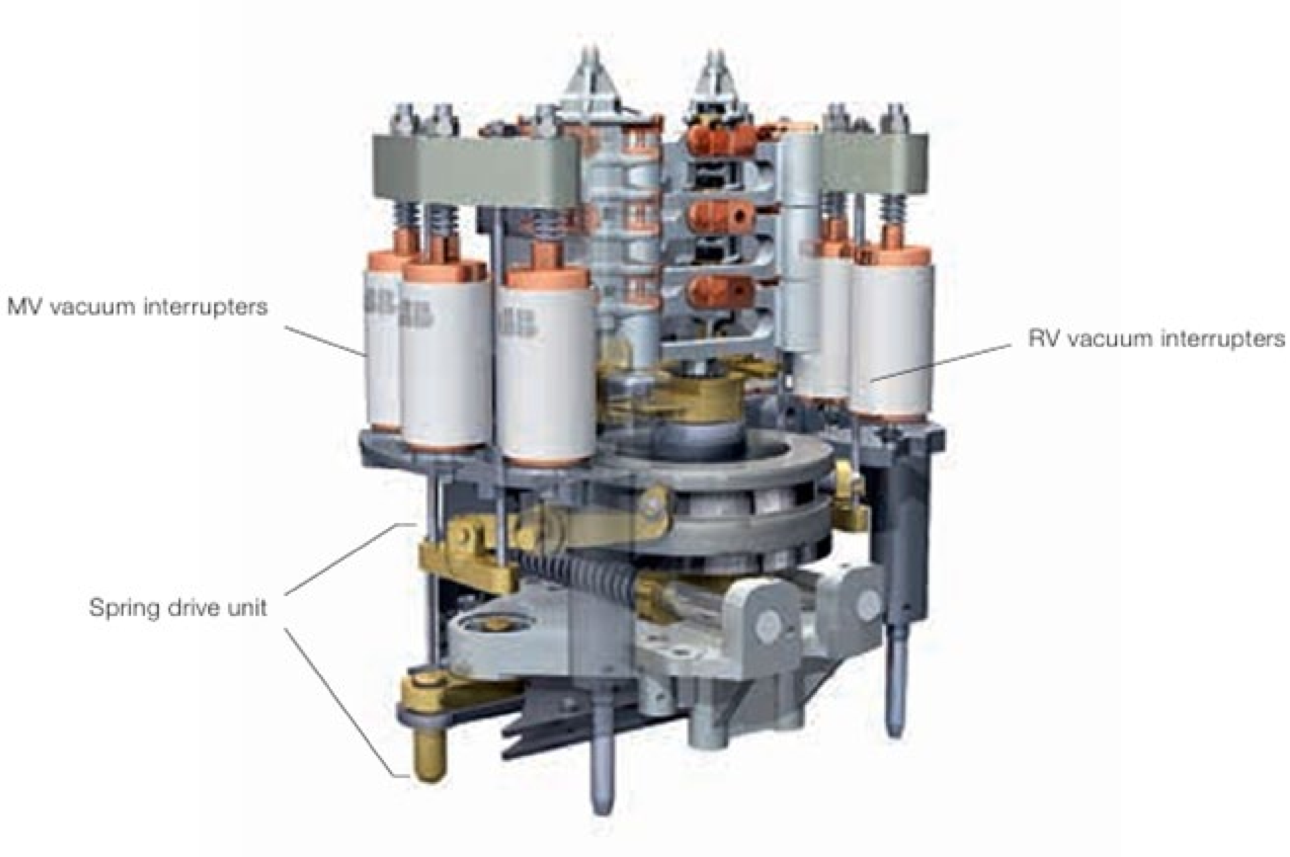
Preventative Autotransformers (PA): The preventive autotransformer serves as a current limiting device when the LTC is sitting on a bridging (odd number) tap position or passing through a bridging (odd number of tap position. Resistive or Reactive type

Vacuum Interrupter: This device acts as a circuit breaker that makes and breaks current during the tap changing sequence. With the arcing contacts contained in the vacuum bottle, there is no arc to contaminate the oil.



Using vacuum switch OLTCs

These types of tap changers confine the switching arc in vacuum bottles, which helps to mitigate oil degradation and contact wear.

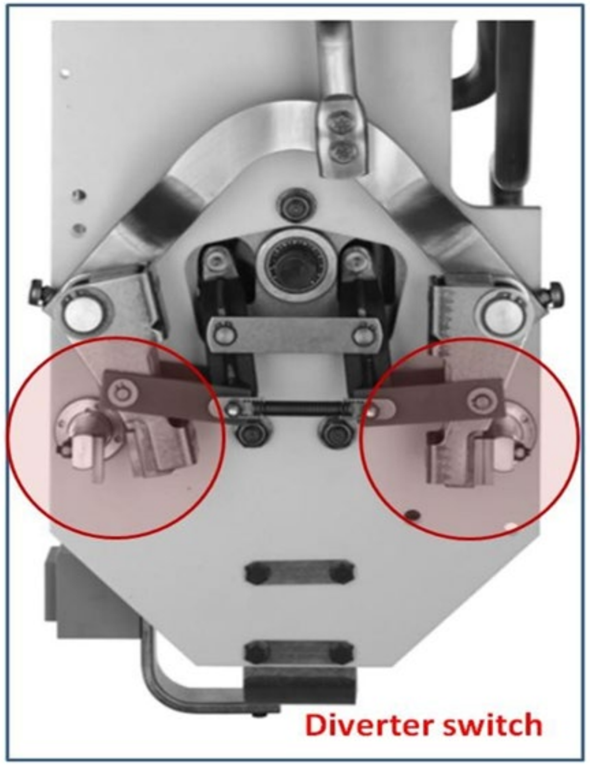


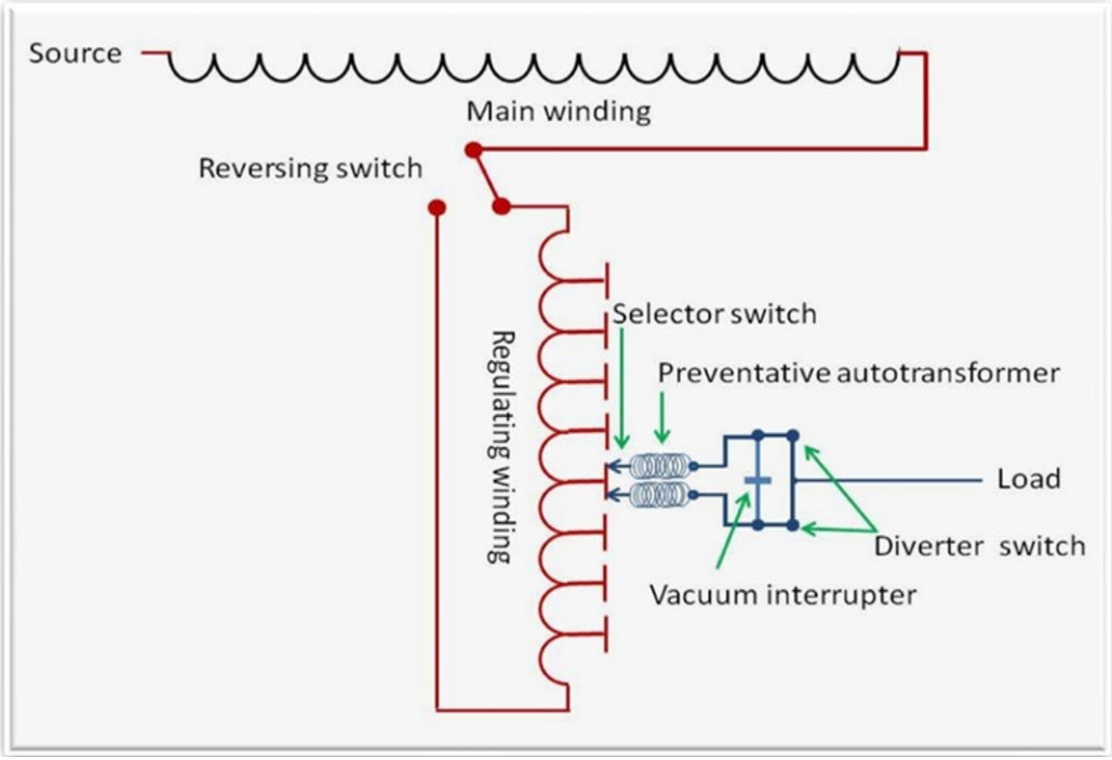
In a diverter switch type OLTC, only the diverter switch, where the switching power is handled, uses vacuum interrupters. The tap selector part is identical to that of a traditional tap changer.

This design philosophy allows the arcs during load commutations to occur in vacuum interrupters and not in the tap-changer oil. This greatly reduces the need for maintenance and creates the potential for using environmentally friendly insulating fluids.

The key components of the load tap changer continued:

Diverter Switch Also known as a bypass switch, this device operates during the tap changing sequence but, at no time makes or breaks load current, though it does make before break each connection. The illustration below highlights that the switch is comprised of 2 sets of contacts which are opened or closed by way of signals from the solid-state control.





The key components of the load tap changer continued:

Reversing Switch

- A standard 32 step LTC is comprised of 16 each 5/8% raise positions and 16 each 5/8% lower positions.
- The physical taps are located on a regulating winding within the main transformer tank which is connected in series with the main winding via a reversing switch.
- Voltage is increased or decreased by movable contacts which use a “stepping “ action to move from one connection to the next to add or subtract turns on the regulating winding.
- The raise or lower mode is dependent on the polarity on the connection through the switch. The eight approximate 1¼% taps on the regulating winding and center tapped preventative autotransformer provide for the individual 5/8% incremental voltage adjustments.
- The reversing switch enables the windings to double the number of tap positions without doubling the number of tap leads from the tap (regulating) windings

Other Load Tap Changer Operational Definitions

Neutral Position

- The neutral position is the position where the LTC is neither bucking nor boosting voltage and/or where the tap windings are not in the circuit.
- This is nominal position.
- The neutral position is the only position where the reversing switch is not carrying current.

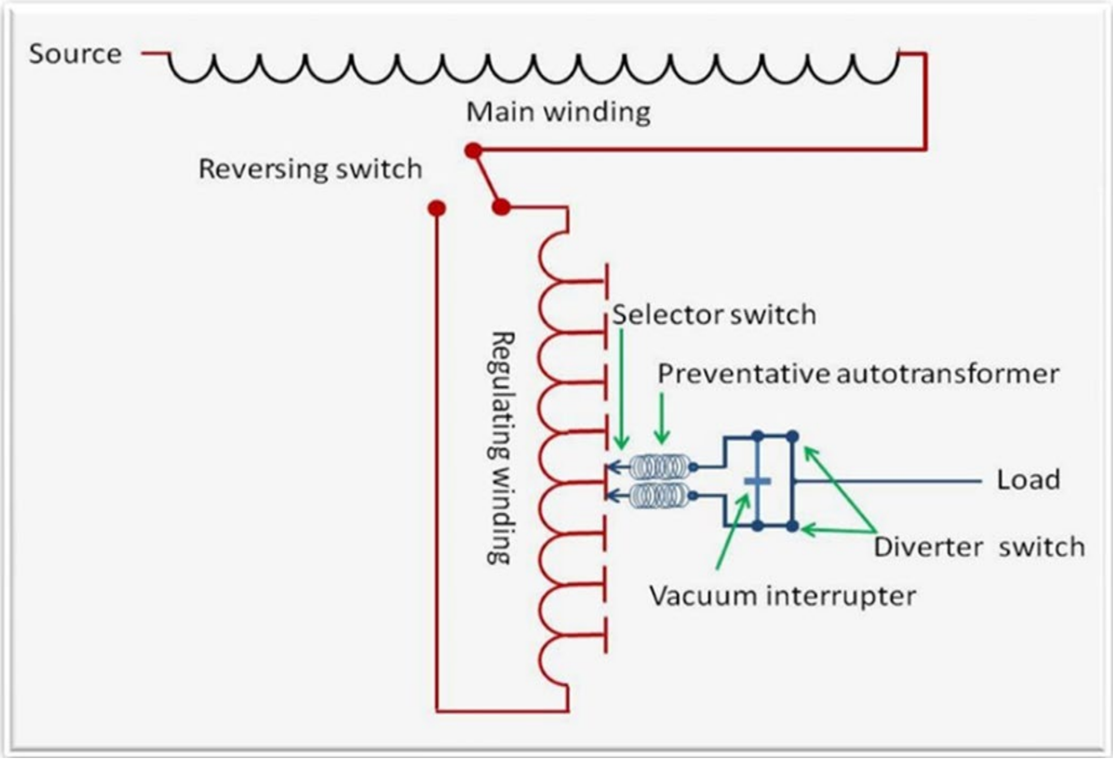
Full Cycle Position

- A Non-bridging position in an LTC. Both or all moveable contacts of the selector switch are on the same stationary contact and only one tap of the tapped winding.

Half Cycle Position

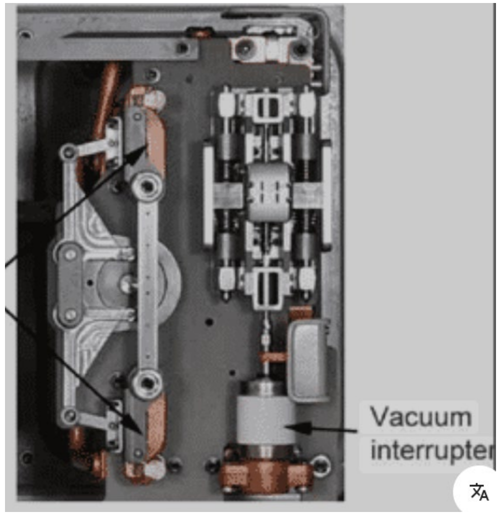
- A Bridging position in an LTC. The moveable contacts of the selector switch are on separate (different) stationary contacts and two points on the tapped winding.
- The turns ratio at the bridging tap position is the mean average of the two adjacent nonbridging tap positions, since the preventive autotransformer/reactor provides the center tap.

On Load Tap Changing Using a Reactor

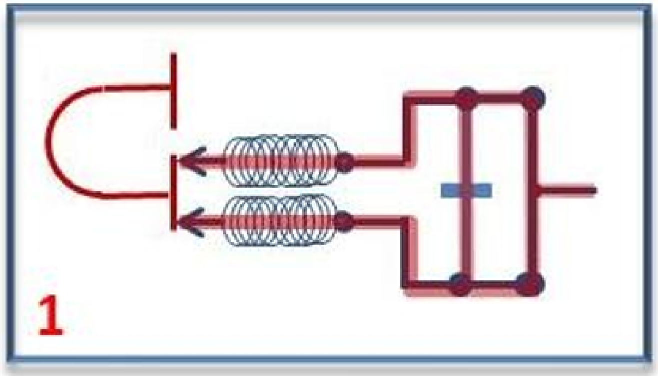


- The function of the reactor is to prevent the short circuit of the tap winding.
- During the normal operation, the short-circuiting switches S remains closed.
- The reactor prevents the flow of large values of current in any section of the primary winding when two tapping switches are closed simultaneously.

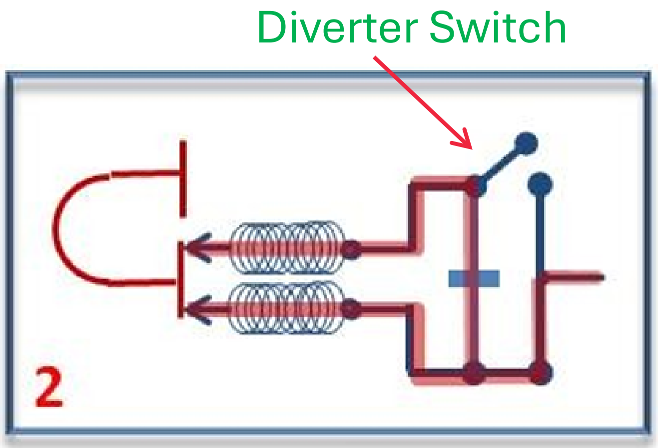
The sequence of events during a physical tap change:

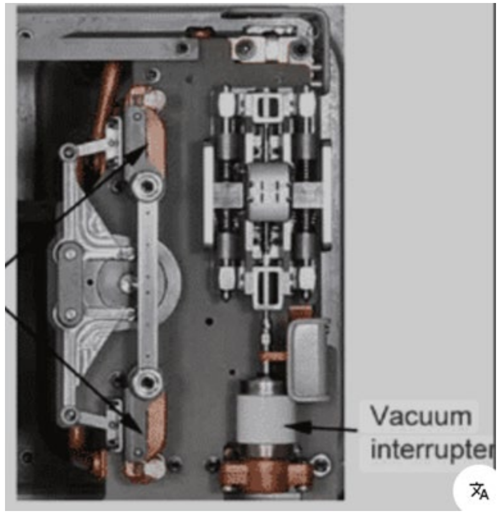


1. Both selector switch contacts located on common tap connection. Vacuum interrupter and diverter switch contacts are in closed position.

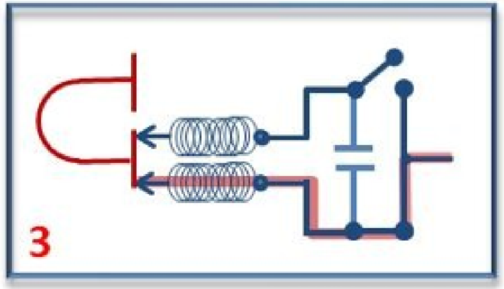


2. Selector switch contacts remain on common tap. Vacuum interrupter remains closed allowing upper diverter switch contacts to open without drawing an arc.

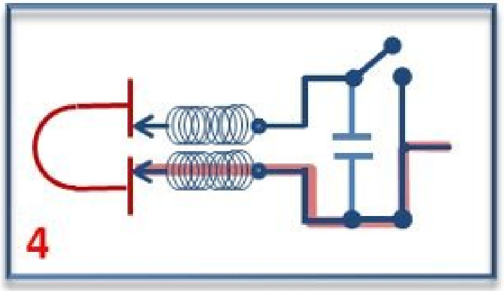




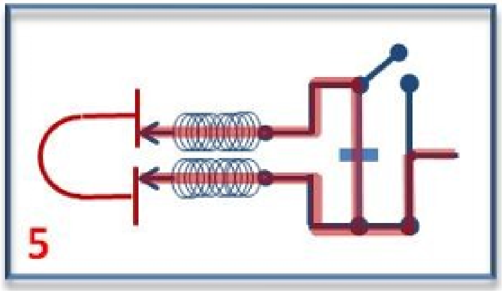
3. Vacuum interrupter opens. Current flow through upper selector switch has been cut.



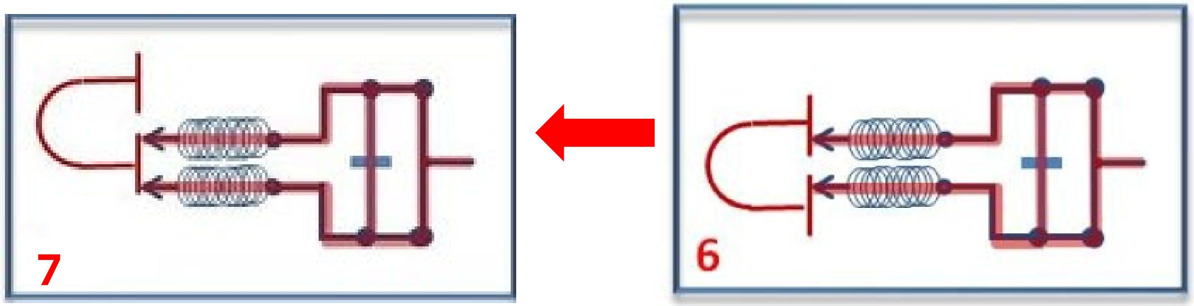
4. With no current flow in upper selector contact, switch is free to move one step up to bridge with next tap connection.



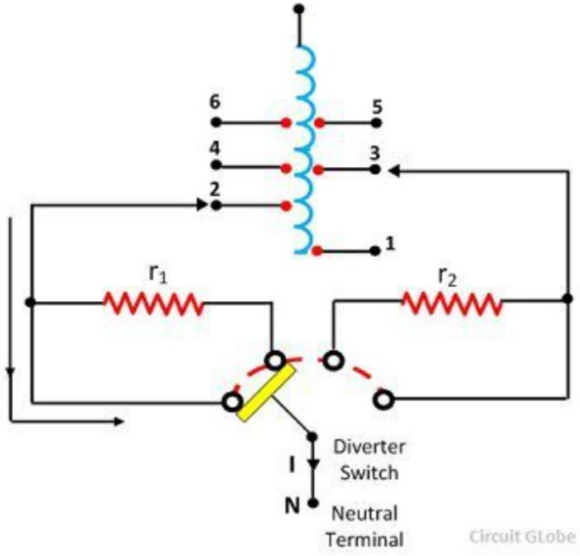
5. Vacuum interrupter closes to establish bridging tap connection.

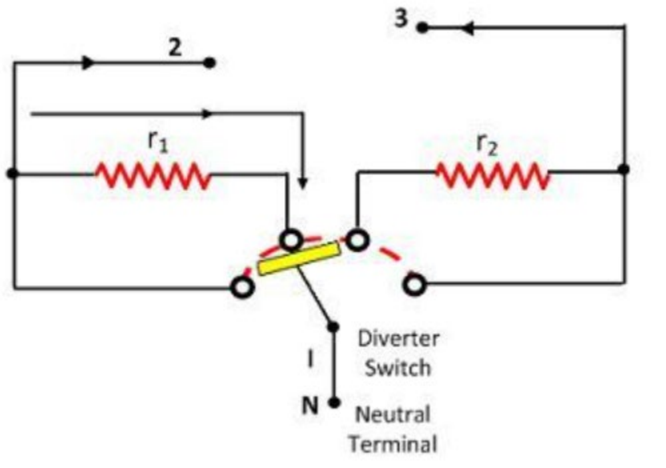


The voltage between the taps mentioned above is the step voltage, which normally lies between 0.8 % and 2.5 % of the rated voltage of the transformer.

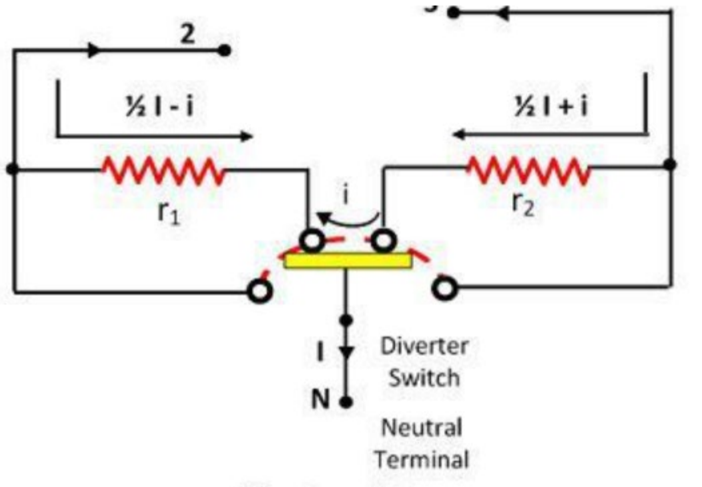


On-Load Tap Changing Transformer Using a Resistor

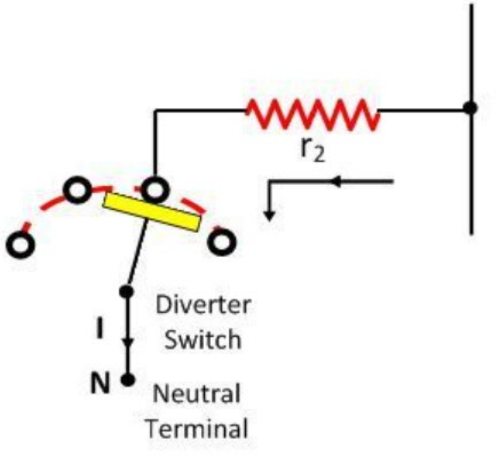




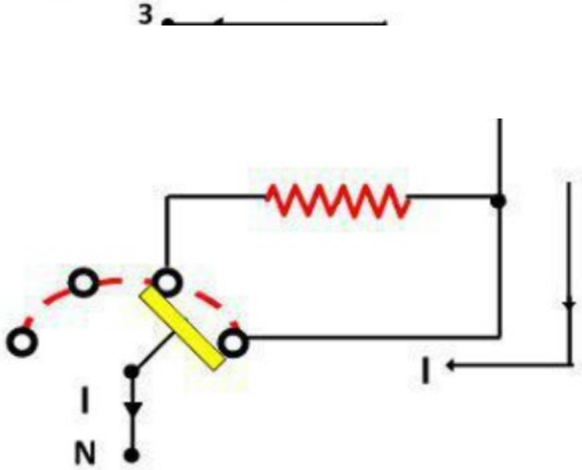
Tap 2 and r_1



Tap 2 and 3

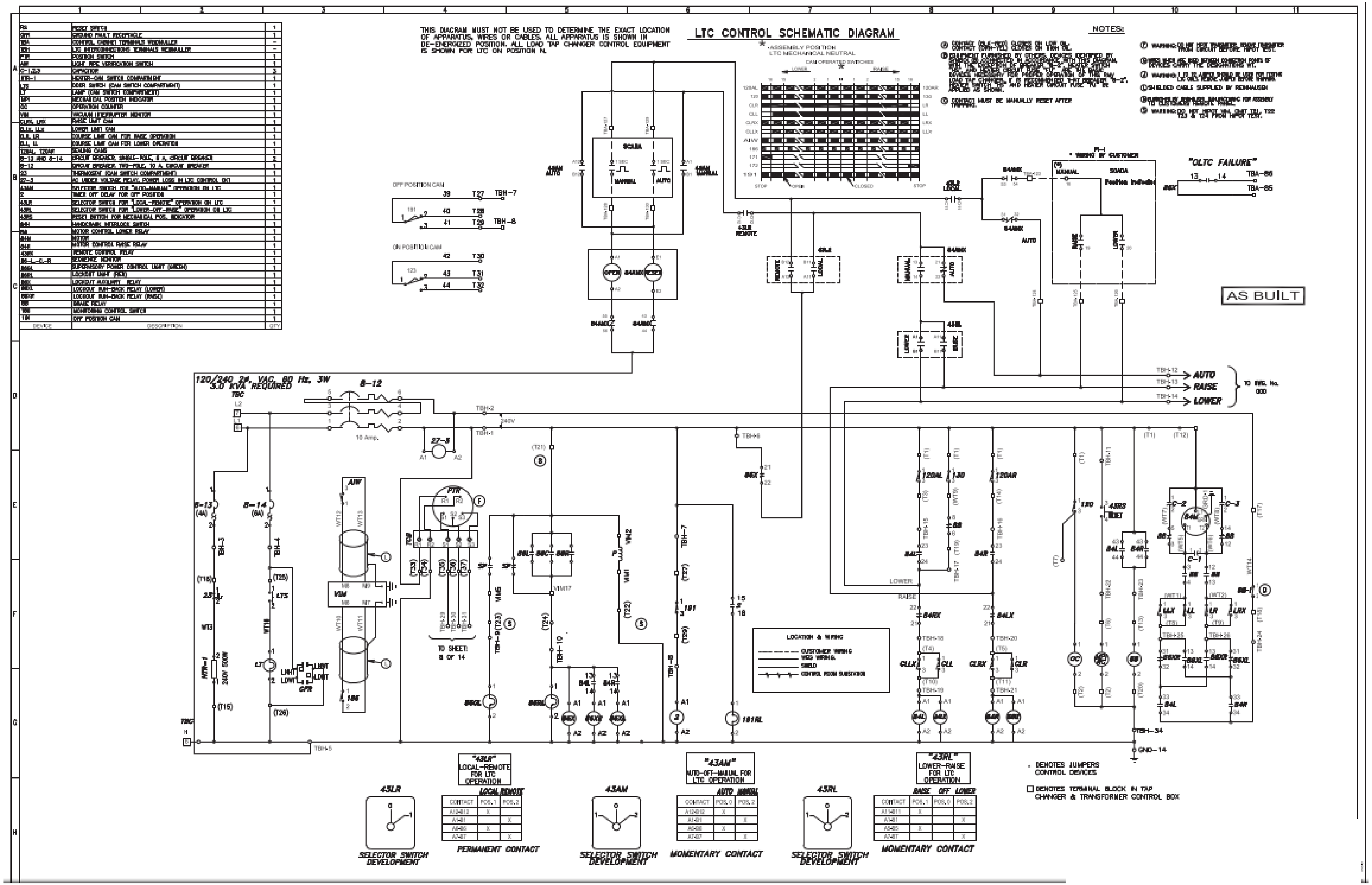


Tap 3 and r_2



Tap 3

Load Tap Changer Control Circuit Schematic



84R and 84L

Load Tap Changers (LTCs) and motor control, 84R and 84L refer to auxiliary relays that facilitate the "Raise" and "Lower" operations of the LTC motor supervised by limit switches.

- **84R (Raise Motor Auxiliary Relay):** This relay is associated with increasing the transformer's output voltage. When the control system determines a voltage increase is needed, it will energize the 84R relay. The 84R relay's contacts then activate the LTC motor, causing it to move to a higher tap position, thereby raising the output voltage.

- **84L (Lower Motor Auxiliary Relay**): Conversely, the 84L relay is involved in decreasing the output voltage. When a voltage reduction is necessary, the control energizes the 84L relay. This, in turn, activates the LTC motor to move to a lower tap position, reducing the transformer's output voltage.

Limit switches play a crucial role in regulating voltage by monitoring the position of the tap changer's mechanical components. They ensure that the LTC operates within its designated range, preventing over-travel and potential damage to the transformer.

LTC Motor Control Interlocking Contact Operations

Load Tap Changers (LTCs) are crucial components in transformers, adjusting the turns ratio to regulate voltage levels. Most LTCs utilize motor-driven mechanisms for operation, though manual operation is often available for emergencies. Interlocking contacts play a vital role in ensuring safe and correct operation of the LTC motor control circuit.

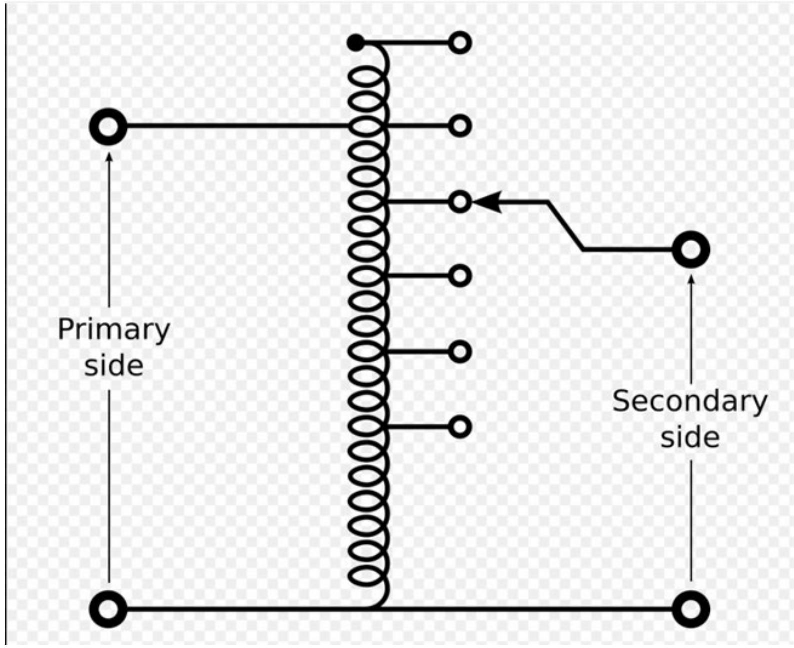
Ensuring safe tap changes

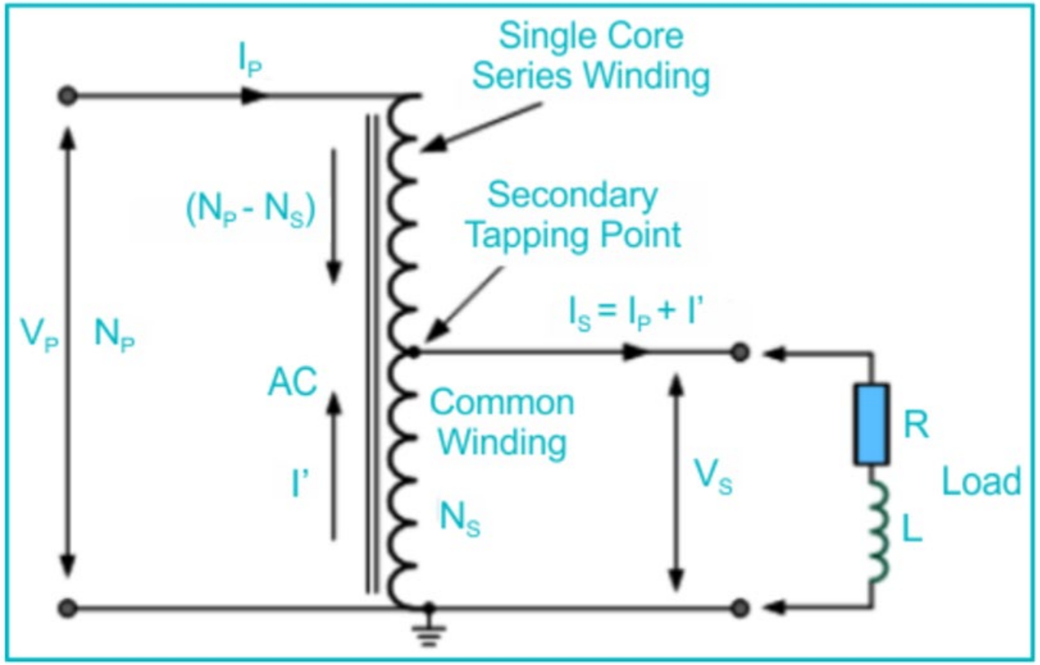
- **Sequential Operation**: Interlocking mechanisms ensure that the contacts operate in the correct sequence, preventing multiple taps from being engaged simultaneously or out of order.
- **Preventing Damage:** This sequential operation prevents damage to the transformer or tap changer that could occur from improper switching sequences.
- **Importance of interlocking:** Safety: Interlocking prevents hazardous situations, such as two motors running in opposite directions simultaneously or machines starting unexpectedly when a guard is open.

Auto Transformers vs Three Phase Transformers

Auto Transformer

An auto transformer or autotransformer is a type of electrical transformer that has a single winding that serves both as a primary winding as well as a secondary winding. An autotransformer is a transformer that has only one winding with taps brought out at different points along the winding. The concept of an autotransformer is unique in the sense that the primary and secondary windings are directly connected to each other internally, unlike a regular isolation transformer where the windings are kept completely isolated.





Auto Transformers vs Three Phase Transformers

Basic Features of Auto Transformer Construction:

Single Winding:

Autotransformers utilize a single coil of wire wound around a laminated core.

Tapped Terminals:

The winding has multiple terminals or taps along its length. These taps allow for different voltage ratios to be selected by connecting the load to different points on the winding.

Shared Winding:

A portion of the single winding acts as the primary winding, while another portion acts as the secondary winding. This means there is a shared section of the winding between the primary and secondary circuits.

No Isolation

Unlike traditional transformers, the primary and secondary sides of an autotransformer are not electrically isolated. This means there is a conductive path between the input and output circuits.

Core

Like other transformers, autotransformers use a laminated core (usually made of iron or steel) to concentrate the magnetic flux and improve efficiency.

Common Applications Involving Auto Transformers

Voltage Regulation:

- **Power Distribution:** Autotransformers are frequently used to step up or step-down voltages in power distribution systems, compensating for voltage drops and ensuring stable voltage levels for connected equipment.
- **Industrial Applications:** They can adapt machinery built for one voltage to operate on a different voltage supply, such as adapting 480V equipment to a 600V system.
- **Voltage Stabilizers:** They can act as automatic voltage regulators, providing a stable output voltage even with fluctuating input voltages.

Motor Starting: Autotransformers are commonly used in motor starters to reduce the inrush current during motor startup, protecting the motor and associated equipment.

Motor Speed Control: By adjusting the output voltage, autotransformers can control the speed of induction motors, which is useful in applications like fan speed control.

Voltage Conversion: Autotransformers facilitate the interconnection of systems operating at different voltage levels.

Advantages of Auto Transformer

- Some key advantages of auto transformers include:
- Lower cost due to single winding design and copper savings
- Reduced size and weight for the same power rating
- Higher efficiency as losses are minimized
- Ability to withstand short-circuit currents better
- Reliable with less maintenance requirements
- Variable voltage regulation by tap shifting
- Simpler construction than isolation transformers
- Improved capacity utilization for high-power applications

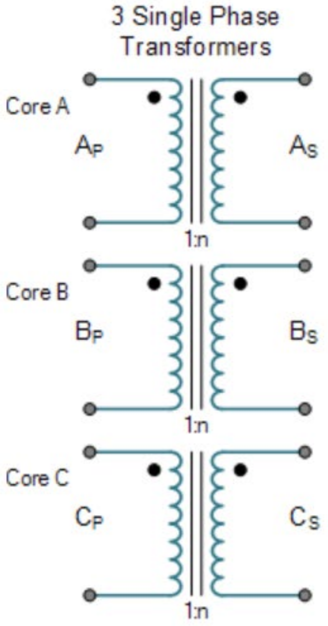
Disadvantages of Auto Transformer

- However, auto transformers also have certain disadvantages:
- No galvanic isolation between the input and output ports
- Higher short-circuit fault level for the system
- Difficulty in providing effective over-voltage protection
- Complex voltage regulation under load conditions
- Safety concerns due to the direct connection of live parts
- Unsuitable where isolation is critical or shock hazards exist
- Inrush current at switching can be considerable
- Subject to instability under certain fault conditions

Three Phase Transformers

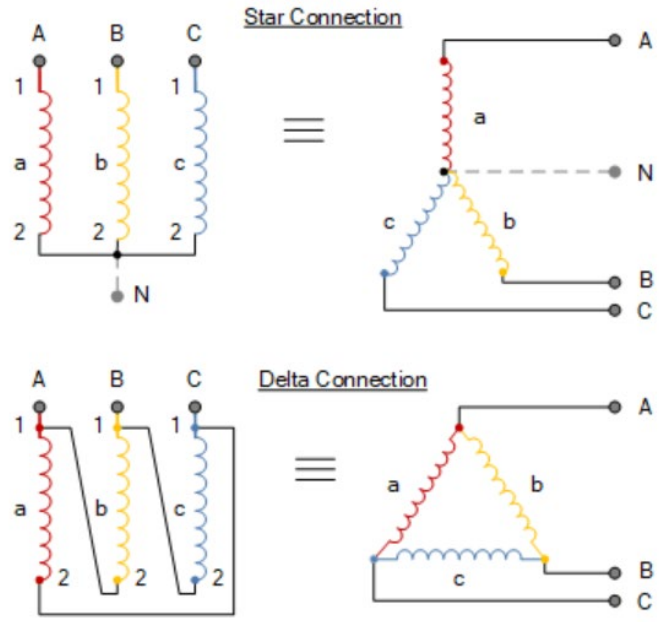
A three-phase (3-phase) electrical system is used to generate and transmit electric power over long distances for use by offices and industry. Three-phase voltages (and currents) are raised or lowered by means of three phase transformers, since a three-phase transformer can have its windings connected in various ways.

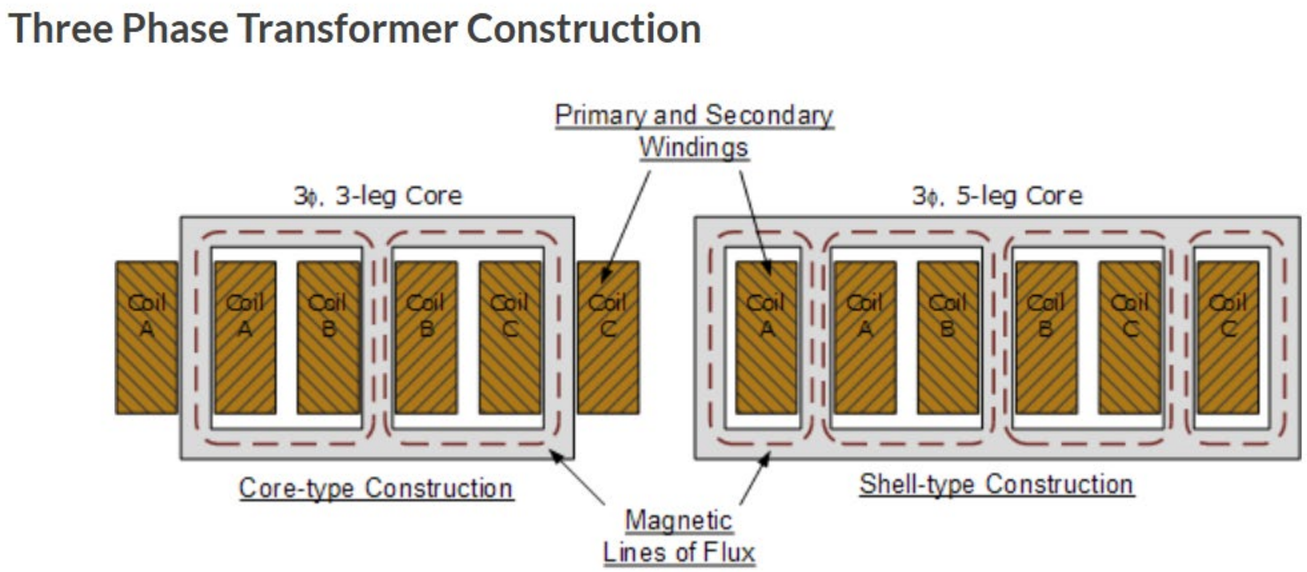
Three Phase Transformer Connections



Primary Configuration	Secondary Configuration
Delta (Mesh)	Delta (Mesh)
Delta (Mesh)	Star (Wye)
Star (Wye)	Delta (Mesh)
Star (Wye)	Star (Wye)
Interconnected Star	Delta (Mesh)
Interconnected Star	Star (Wye)

Transformer Star and Delta Configurations

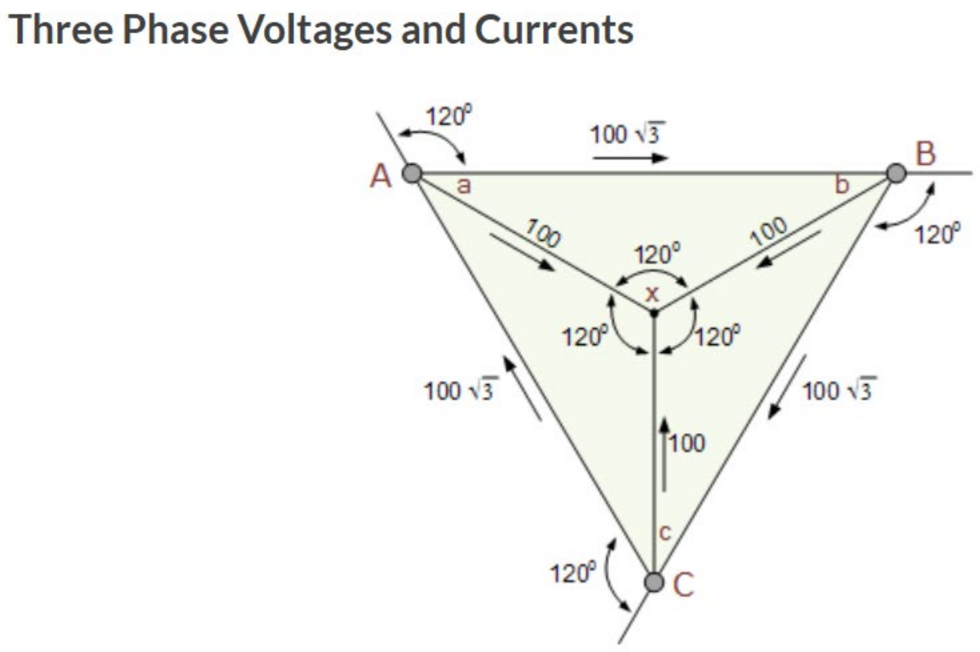




The three-limb core-type three-phase transformer is the most common method of three-phase transformer construction allowing the phases to be magnetically inter-linked. The magnetic flux flowing around each limb uses the other two limbs for its return path.

The three magnetic flux within the core generated by the line voltages differ in time-phase by 120 degrees (120^{o}). Thus, the flux in the core remains nearly sinusoidal, inducing and producing a sinusoidal secondary supply voltage.

A three-phase transformer has three windings each on the primary and secondary sides. Each of these can be operated as part of a star or delta circuit. For reasons of economy, electrical energy is transmitted via three-phase systems instead of single-phase systems. The three-phase systems used for this purpose contain three equal variables, each comprising a single-phase alternating voltage displaced by 120° with respect to the others.



What Are The Common Uses Of Three-Phase Transformers?

Power Distribution

- Because the voltage coming out of the transmission lines is often too high to be directly used by residential and commercial properties, a three- phase transformer is typically required to bring it down to a more manageable level.

Industrial Applications

- These are all businesses that demand large amounts of electricity:
- Steel/Mining
- Oil and Gas/Chemical/Automotive
- They facilitate the reliable transmission of electricity for diverse processes such as refining, distillation, mixing, pumping, and heating, ensuring smooth and uninterrupted operation of the plants.

Power Generation

- Moreover, in hydroelectric, thermal, nuclear, wind, and solar power plants, three-phase transformers play a critical role in voltage upscaling for electricity generated. These include turbines, boilers, reactors, turbines, or solar panels, before transmitting it to the power grid. Without these transformers, the electricity would not be able to transmit over long distances to consumers at the appropriate voltage levels.

Renewable Energy

- Similarly, in solar and wind power plants, 3 phase transformers are mainly used to step up the voltage of the electricity generated by the solar panels before transmitting it to the power grid.

What Are The Advantages Of Three-Phase Transformer

- **Balanced Loading**: This means that the load on each of the three phases is relatively equal, which helps to maximize the efficiency of the transformer.
- **Improved reliability**: A three-phase transformer is less likely to experience voltage drops or power outages due to its balanced loading and lower current requirements.
- This means that it can provide a more reliable source of power, which is particularly important in industrial and commercial applications where downtime can be costly.
- **Increased Stability In Voltage**: A three- phase transformer has a more constant output voltage due to the balanced load on the three phases.
- This is because the power is highly distributed over three phases instead of one, which reduces the current flowing through the transformer.

What Are The Disadvantages Of Three-Phase Transformers?

- **Increased Initial Investment**: Three-phase transformers incur higher costs. This is because they require more complex construction and manufacturing techniques.
- This is because they require more copper, iron, and other materials to build, as well as more complex manufacturing processes.
- **Size and weight:** 3 phase transformer is larger and heavier than single-phase transformers, which makes them more difficult to install and transport.
- This can be a disadvantage in situations where space and weight are highly limited, such as in residential or small commercial buildings.
- **Maintenance:** 3 phase step up transformer require regular maintenance to ensure that they are functioning properly.
- This can be time-consuming and expensive, especially in large power systems where many transformers are in use.

What Are The Disadvantages Of Three-Phase Transformers?

- **Faults and failures**: In some cases, three phase pole mounted transformers can be prone to faults and failures, which can cause power outages and other problems.
- These faults and failures can be mainly caused by a variety of factors, including overheating, insulation breakdown, and mechanical stress.
- **Complexity:** Three-phase distribution transformers are more complex than single-phase transformers, which can make them more difficult to understand and troubleshoot.
- This complexity can also make it more difficult to find replacement parts or skilled technicians to perform repair

What are the advantages of three-phase over single phase?

1. **Power generation**: 50% higher than single-phase power supply3 phase pad mounted transformer

2. **Transmission:** 25% less steel than single-phase transmission

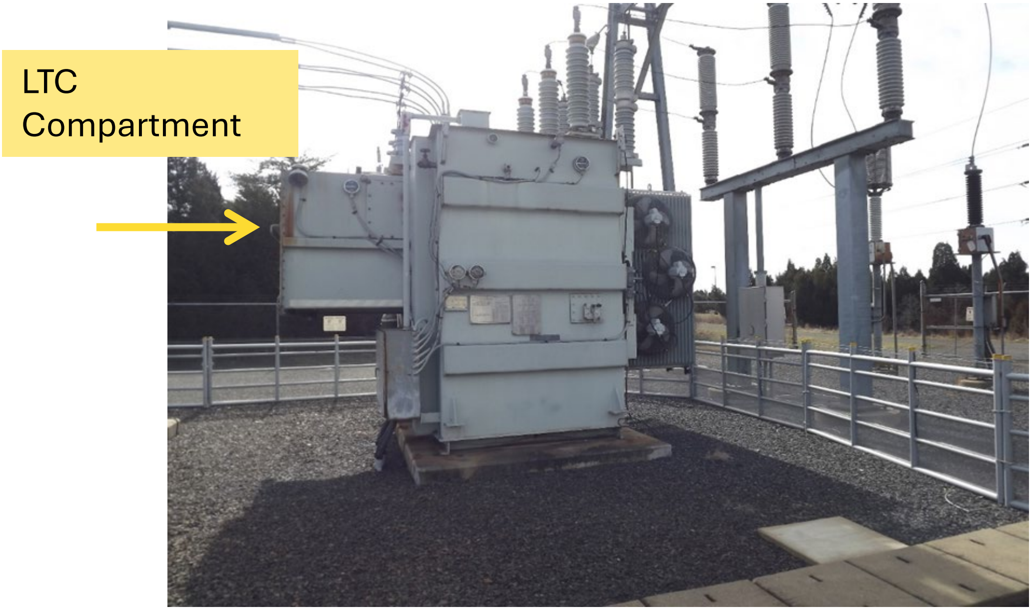
3. **Power distribution**: three-phase transformer is more economical and easier to access the load than single-phase transformer

4. **Power transmission equipment**: it has the advantages of simple structure, low cost, reliable operation, and convenient maintenance.

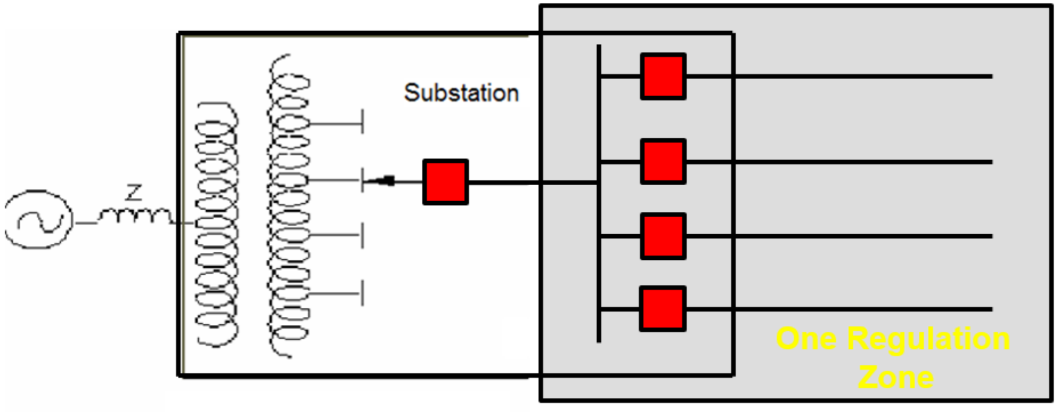
5. **According to Power Transformer Market**, 3-phase transformers have a simpler design with fewer moving parts, which reduces the chance of failure.

LTC Transformers vs Single Phase Regulators Differences - LTC Transformers

Load Tap Changers



Substation with LTC



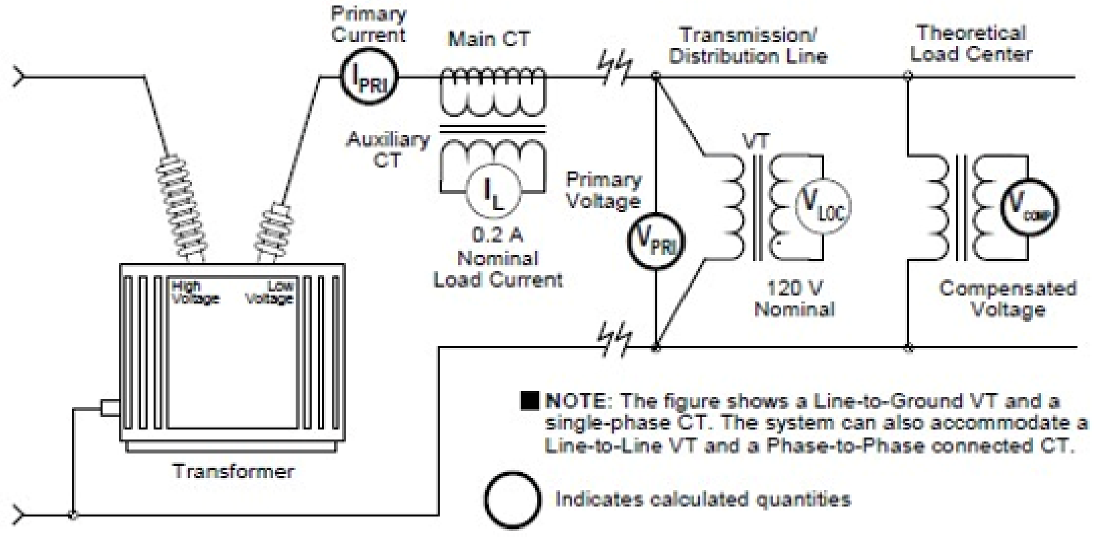


Figure 2-34 Secondary Quantity Metering and Primary Quantity Calculations for Transformer Applications

LTC Transformers vs Single Phase Regulators Differences - LTC Transformers

LTC Transformers: Advantages

Continuous Voltage Regulation:
LTC transformers can adjust the voltage output while under load, ensuring a stable voltage supply without interruption.

Dynamic Load Handling:
They are well-suited for systems where loads fluctuate significantly, maintaining a consistent voltage level.

Reliability:
By preventing voltage dips and surges, LTC transformers contribute to overall system reliability and prevent damage to connected equipment.

Suitable for Large Power Systems:
They are commonly used in substations and transmission systems to regulate voltage for large industrial or commercial loads.

Potential for Higher Maintenance Costs:
LTC mechanisms can require more complex maintenance due to their more intricate design.

LTC Transformers vs Single Phase Regulators Differences - LTC Transformers

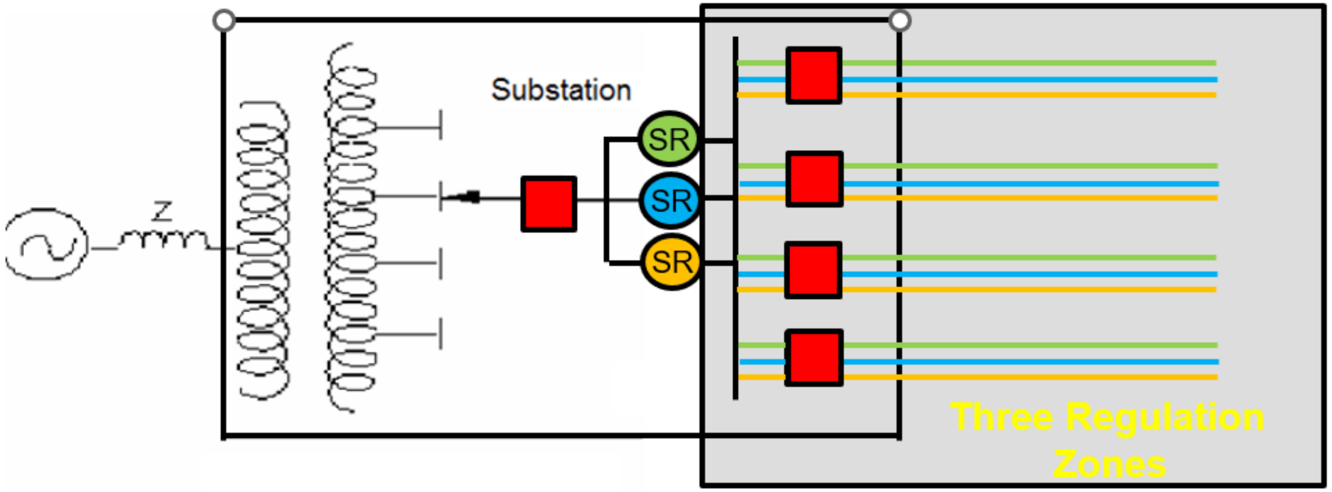
LTC Transformers: Disadvantages

- **Higher initial cost:** LTC transformers, especially those for substation applications, can be substantially more expensive initially, with costs potentially exceeding $300,000.
- **More complex design**: LTCs are mechanically complicated and often require more complex maintenance procedures.
- **Requires periodic maintenance**: Due to the moving parts and the nature of switching under load, LTCs require regular inspection, testing, and refurbishing. Neglecting maintenance can lead to voltage instability, equipment damage, and safety hazards.
- **Higher maintenance costs**: LTC repair costs can be significant, with estimates of $25,000 per repair.
- **Prone to failure:** LTCs are more susceptible to wear and tear due to their moving parts, making them a common point of failure for transformers.
- **Can disrupt the power supply during maintenance:** While OLTCs operate under load, repairs still require taking the transformer out of service.

LTC Transformer vs Regulator Difference - Single Phase Regulators

Bus Regulation

Substation with Bus Regulators

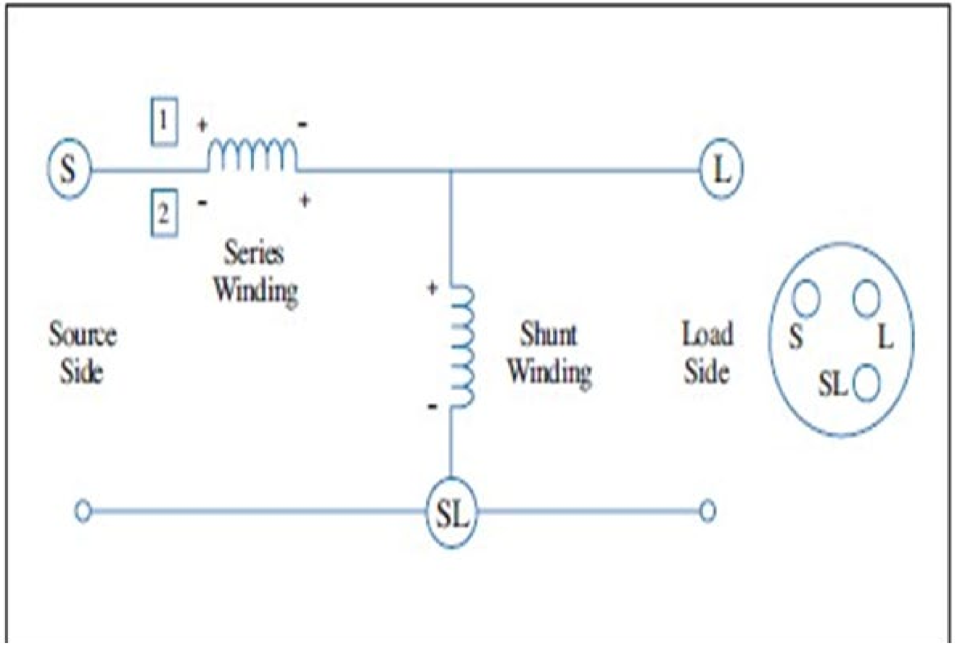


LTC Transformer vs Regulator Difference - Single Phase Regulators

How it works :

A single-phase regulator is represented by the autotransformer.

When referring to a regulator, the low-voltage winding is called the “series winding” and the high-voltage winding the “shunt winding.” By reversing the polarity of the series winding, the autotransformer can boost (increase) or buck (decrease) the output voltage with respect to the input voltage. Polarity reversing is achieved via a reversing switch. An on-load tap-changer connects a variable number of turns of the series winding into the circuit, there by allowing small increments of voltage change.



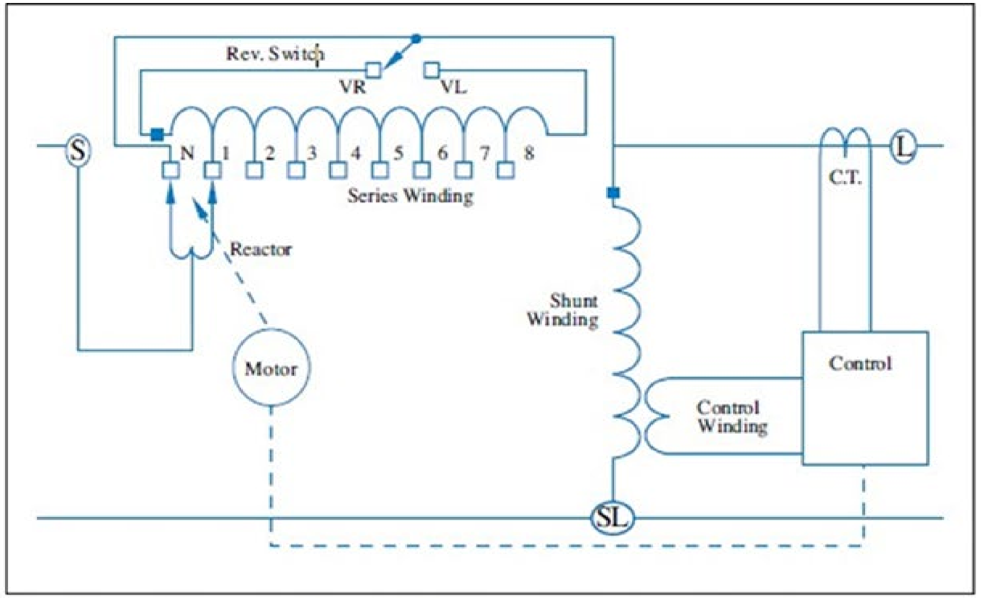
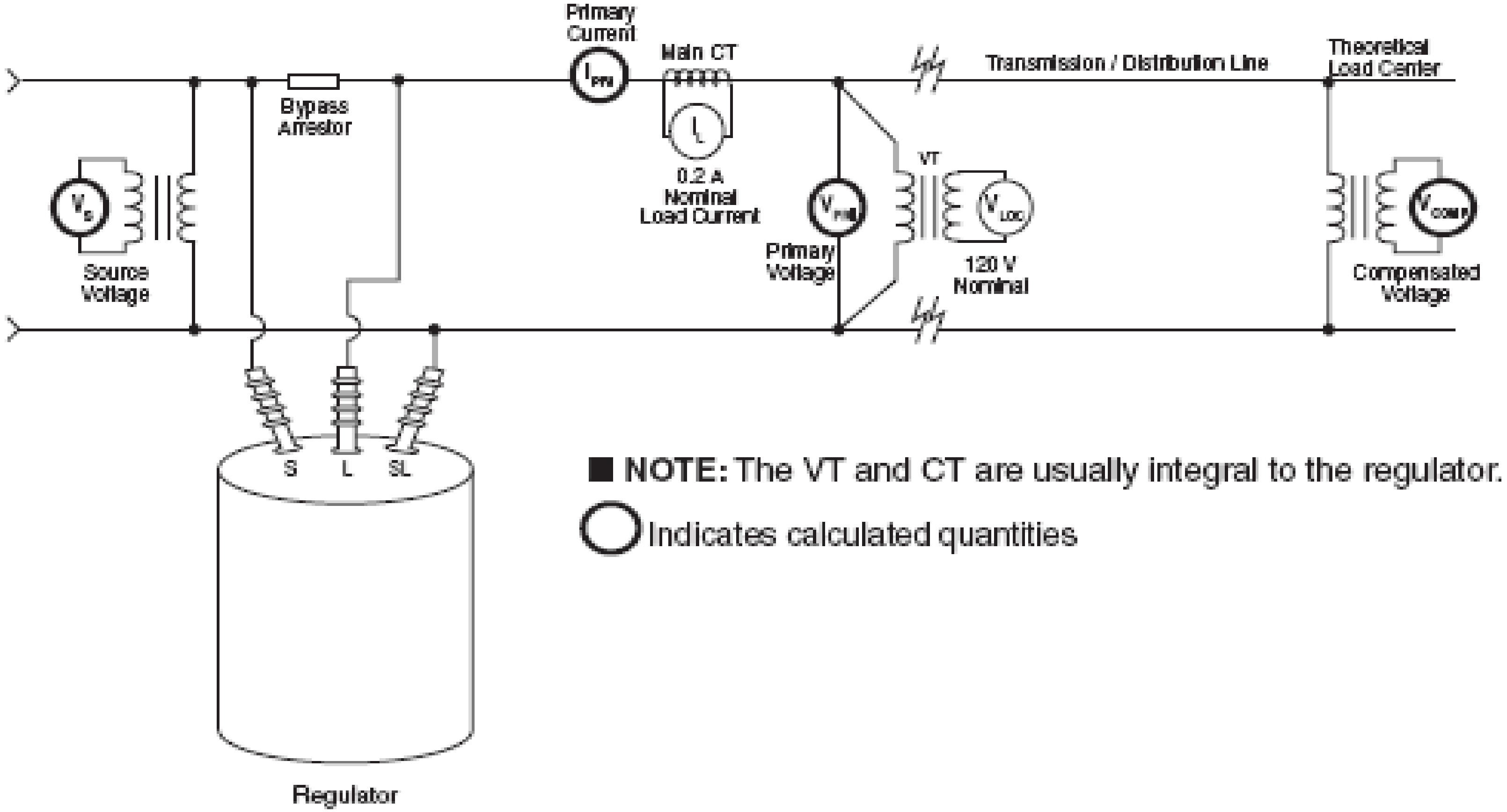


Figure 6: Schematic of a single-phase, 32-step voltage regulator.

- Local voltage is the measured sense voltage
- Source Voltage is the calculated source voltage on the regulator
- Compensated Voltage is the calculated voltage seen at load center after applying LDC



Bus Regulation – Single Phase

Single Phase Bus Regulators Advantages

Cost-effectiveness (initial and maintenance): Regulators are generally less expensive to manufacture and maintain than LTC transformers. Maintenance costs for a regulator change-out and repair are estimated to be $10,000.

Easier maintenance and repairs: The single-phase regulator option allows for maintenance on individual phases without taking the entire system offline. They are simpler in design, which translates to lower maintenance requirements. Troubleshooting and repairing single-phase systems is easier, reducing downtime and operational costs.

Standardization: Both the regulator and the non-LTC transformer are typically of a more standard design, leading to quicker order lead times, lower-cost spare parts, and easier installation and maintenance.

Compact size and lighter weight: Single-phase voltage regulators are usually smaller and lighter, making them easier to install and move. This is beneficial in applications where space is limited.

Simplified design and installation: The design is less complex, allowing for easier integration into existing infrastructure.

Protection of equipment: These regulators help protect appliances like computers and TVs by providing a constant output supply.

Can be bypassed: If one regulator fails, the feeder can still be operated by bypassing the regulator in many instances.

Bus Regulation – Single Phase

Single Phase Bus Regulators- Disadvantages

•**Higher initial cost for the regulator:** While simpler overall, the individual voltage regulators themselves can be more expensive than an LTC system.

•**Lower power output:** Compared to three-phase systems, single-phase regulators are less efficient for high-power industrial machinery and systems.

•**More susceptible to power fluctuations:** Single-phase systems may be more vulnerable to power fluctuations than three-phase systems.

•**Limited capacity:** Best suited for lower-power applications like household appliances and small office equipment.

•**Higher electricity bills (operational cost):** Voltage regulators use power to operate, which can slightly increase electricity consumption.

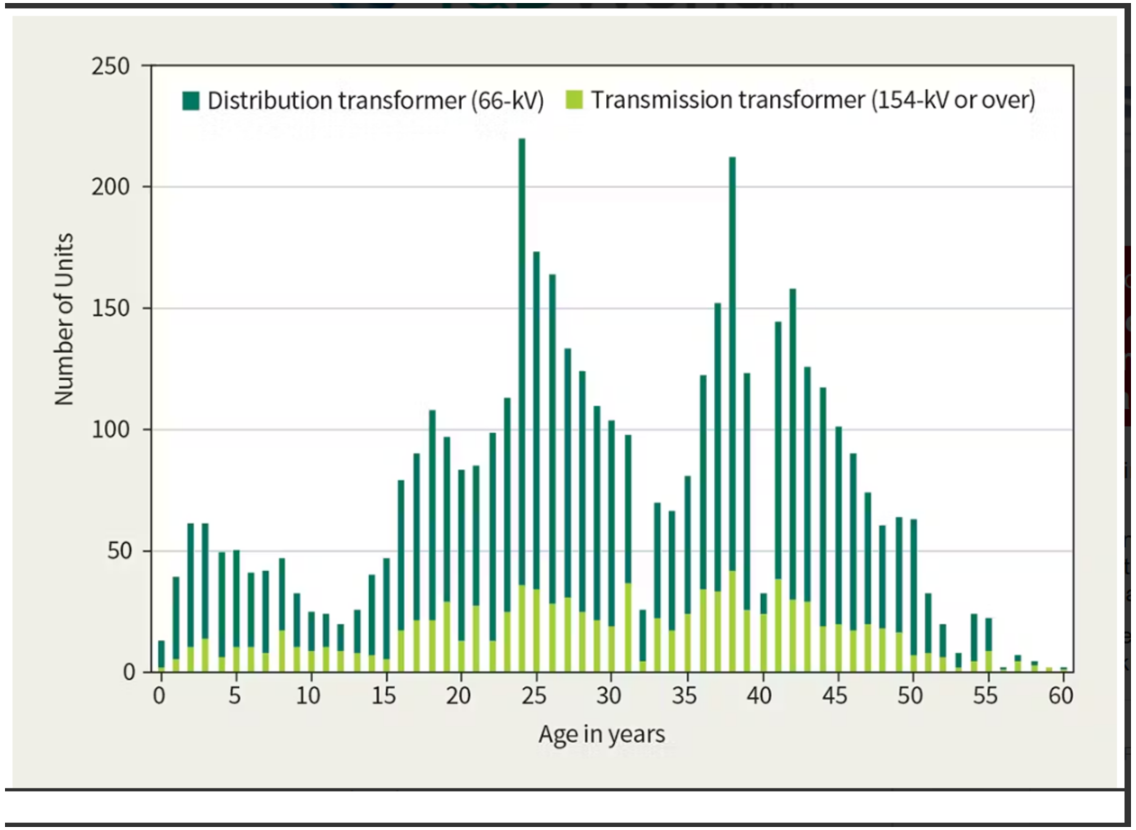
- They sit in the bus differential zone so a failure can cause a fault that may be harder to detect
- A failure of one phase can create voltage imbalances
- Requires three controllers (although some newer controllers can support all three phases with one controller which can protect against the voltage imbalance issue)
- Limited to small transformers (typically 15 MVA and below)

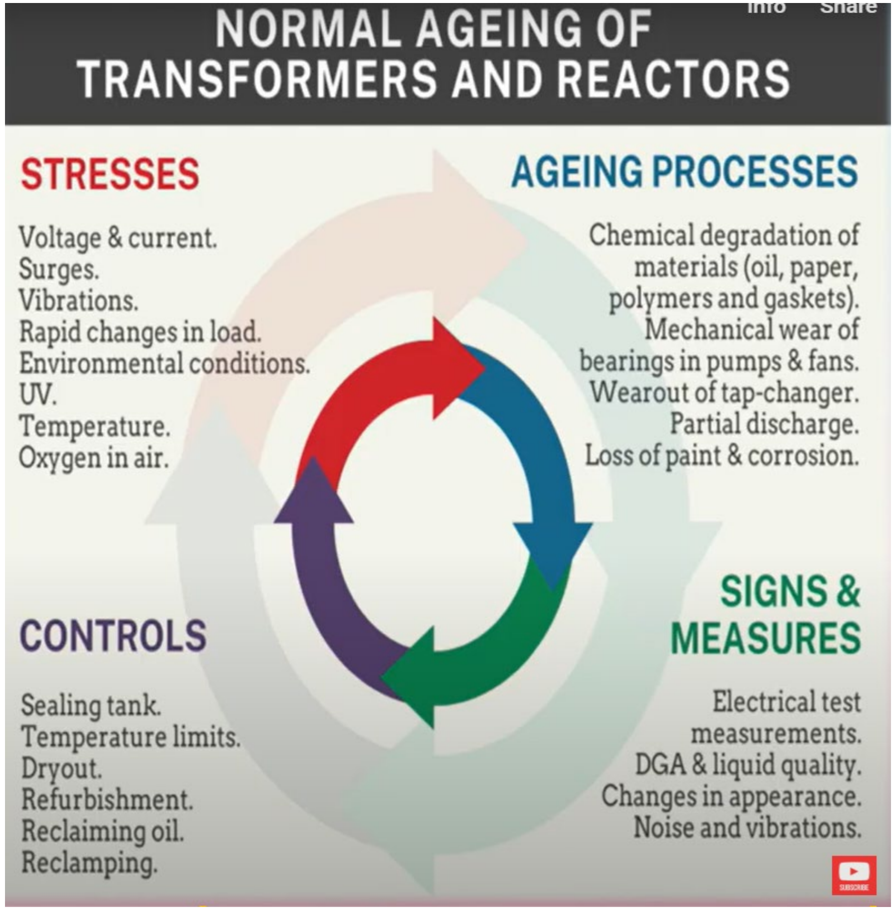
What are the main parts of a three-phase transformer

1. Three-limb core
2. LV Winding
3. HV Winding
4. Tapped Winding
5. Tap Leads
6. LV Bushings
7. HV Bushings
8. Clamping Frame
9. On-Load Tap Changer
10. Motor Drive
11. Tank
12. Conservator
13. Radiators

Life Expectancy of Transformers

- After a transformer is installed and makes it though the burn-in period, some researchers put the expected life of power transformers in the range of 25 to 40 years.
- Electrical experts describes the normal life expectancy of transformers as about 20 to 30 years and acknowledges that a transformer might last for more than 50 years.





Factors Affecting Transformer Reliability:

Age:

While transformers can last for decades, their reliability can decrease with age due to insulation degradation and other factors.

Operational Stress:

Overloading, overheating, and exposure to voltage surges or transients can accelerate aging and increase failure risk.

Environmental Conditions:

Exposure to moisture, pollution, and extreme temperatures can impact insulation and lead to failures.

Maintenance Practices:

Proper maintenance, including oil testing, bushing maintenance, and timely repairs, is essential for maximizing lifespan and reliability.

Design and Manufacturing:

The quality of materials, manufacturing processes, and design choices all play a significant role in a transformer's inherent reliability.

Bushings:

Bushings, which connect the transformer to external circuits, are a common point of failure, particularly in high voltage applications.

Signs of an Aging Transformer

- **Unusual sounds:** A well-functioning transformer will produce a consistent, low-humming sound. Irregular buzzing, crackling or popping noises typically indicate loose connections or failing insulation.
- **Increased operating temperatures:** Excessive heat rapidly breaks down the insulation and can lead to electrical shorts. If your transformer is operating hotter than normal, it could indicate deterioration internally.
- **Visible deformations:** Rust, corrosion, bulging components and other deformations can indicate environmental damage or internal pressure buildup. Even minor external damage can mean there's heavy damage on the inside.
- **Discoloration on windings or insulation:** Look for tracking on windings, carbonization or color changes on insulation materials during inspections. These signs often indicate overheating or loose connections.
- **Performance changes:** Voltage fluctuations or frequent breaker trips usually occur when transformers reach the end of their service life. These signs may start out small before growing into persistent problems and failing.
- **Inadequate resistance:** Insufficient measurements during dielectric absorption tests suggest insulation degradation that requires immediate attention.

What are the failure modes of on-load tap changers?

Mechanical Failures:

Worn or damaged contacts: Repeated switching operations lead to contact erosion and arcing, especially in oil-immersed LTCs.

Damaged or misaligned components: This can include issues with the drive mechanism, linkages, or other moving parts.

Bearing and spring failures: Wear and tear on these components can disrupt the proper operation of the LTC.

Lubrication issues: Improper lubrication can accelerate wear and increase friction.

Vibration damage: External vibrations from nearby equipment can loosen connections and cause mechanical failures.

What are the failure modes of on-load tap changers?

Electrical Failures:

•**Arcing:** The arcing process during tap changes can degrade the oil and contacts, leading to increased resistance and eventual failure.

•**Overheating:** High currents or poor connections can cause localized overheating, damaging insulation and other components.

•**Insulation breakdown:** Degradation of insulation due to age, moisture, or electrical stress can lead to shorts or other electrical faults.

Thermal Failures:

•**Overheating:** Similar to electrical failures, overheating due to various factors can damage components and reduce lifespan.

•**Oil deterioration:** The insulating oil in the LTC can degrade due to heat, arcing, and contamination, affecting its dielectric strength and cooling properties.

•**Coking:** Arcing can cause carbon deposits (coke) to form on contacts, increasing resistance and potentially leading to further arcing and overheating.

Transformer Control: Understanding the Tap Position Indicator

- Transformer tap position indicators serve the crucial purpose of displaying the current tap position of a transformer's on-load tap changer (OLTC), which is essential for voltage regulation and monitoring.

- These indicators provide real-time information on tap positions, enabling operators to optimize transformer performance, improve efficiency, and ensure reliable operation under varying load conditions.

5 Primary Principals of Use:

1. Voltage Regulation: OLTC's change the voltage ratio of a transformer by altering the number of turns in the winding, which is necessary to maintain a stable output voltage despite changes in load or input voltage

2. Monitoring and Control: Tap position indicators allow operators to see the current tap setting, which is vital for monitoring the transformer's operation and making informed decisions about voltage regulation

3. Remote Monitoring: Many tap position indicators can transmit their readings to a remote location, such as a control center, allowing for centralized monitoring and control of multiple transformers.

4. Preventing Disruptions: By providing accurate and timely information, tap position indicators help prevent power disruptions and maintain system efficiency.

5. Ensuring Reliability: These indicators enhance the reliability of transformer operation by enabling operators to maintain voltage levels within specified ranges and respond to changes in load conditions.

Tap Position Benefits: Summary

- Tap position indicators provide operators with accurate and real-time information about the position of tap changers, enabling precise control and optimization of transformer operation.

- By allowing operators to monitor and adjust tap positions remotely, tap position indicators contribute to the efficient management of transformer voltage levels, ensuring better performance under varying load conditions.

- Monitoring tap positions helps identify abnormal operation or potential issues with tap changers, allowing for maintenance and intervention to prevent equipment failure.

- Real-time monitoring of tap positions enhances the reliability of transformer operation by ensuring that voltage levels are maintained within specified ranges, minimizing the risk of overvoltage or undervoltage conditions. Tap position indicators integrated into RTCC panels play a vital role in enhancing the control, monitoring, and maintenance of transformers. By providing real-time information about tap positions, these indicators enable operators to optimize transformer performance, improve efficiency, and ensure reliable operation under varying load conditions.

Tap Position and Power Factor

- Tap position refers to the specific setting on a transformer's tap changer, which adjusts the turns ratio and, consequently, the output voltage. Power factor, on the other hand, indicates how effectively electrical power is being used in a circuit

- Adjusting the tap position can indirectly impact the power factor by influencing the voltage and current levels, while a power factor controller can be used to maintain a desired power factor by adjusting reactive power compensation.

- **Relationship to tap position:** Adjusting the tap position on a transformer can affect the voltage and current levels, which can indirectly influence the power factor. For example, optimizing the tap position for a given load can help reduce reactive power and improve overall efficiency.

- **Why it's important:** A low power factor can lead to increased current draw, higher energy costs, and potential overloading of electrical equipment.

- **How to improve it:** Power factor can be improved by adding capacitors (or other reactive power compensation devices) to the circuit to counteract the inductive effects of loads.

What will using a different transformer tap do to the power factor?

- When the transformer tap adjustment makes the output voltage higher, the power factor of the load may decrease. This is because the current of the load may increase, resulting in an increase in reactive power, while the increase in active power is relatively small.

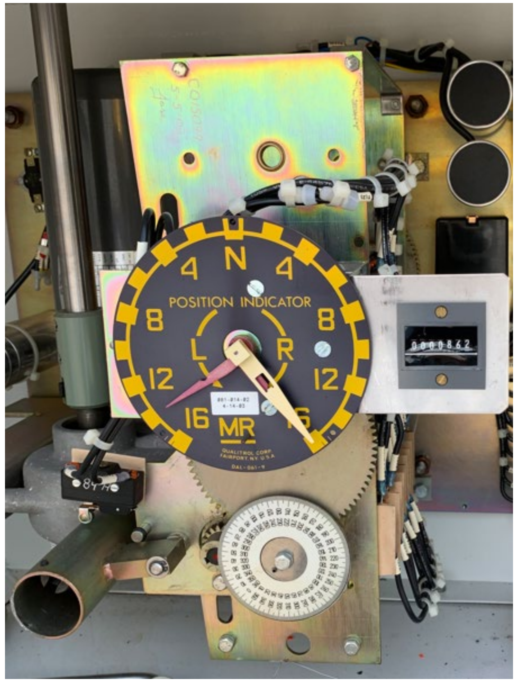
- However, when the transformer tap adjustment makes the output voltage lower, the power factor of the load may increase. This is because the current to the load may be reduced, resulting in a reduction in reactive power and a relatively small reduction in active power.

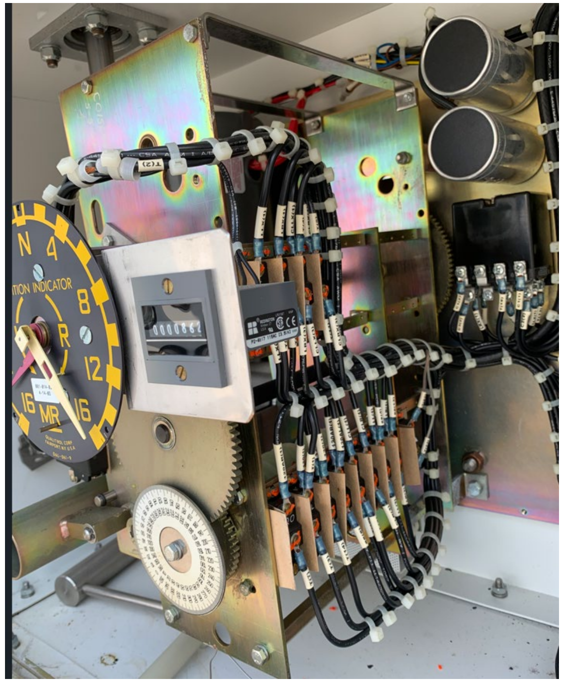
- Improvement in power factor helps to increase the efficiency of the grid as more electrical energy is converted into useful working energy rather than being lost as reactive power.

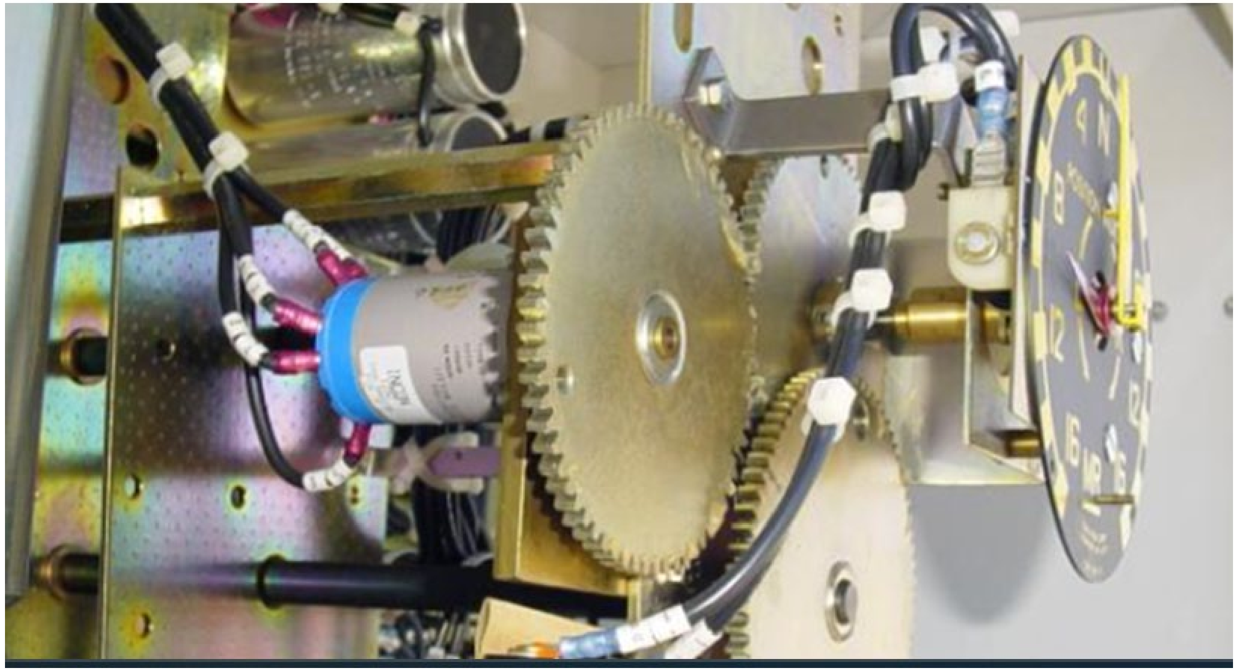
- Therefore, when using a transformer, the appropriate tap position should be selected according to the characteristics and requirements of the load in order to optimize the power factor and improve the efficiency of the grid and the use of electrical energy.

Transformer Control: Understanding the Tap Position Indicator

Working Principle: - Tap position indicators operate by detecting the physical position of tap changers and converting this information into a readable format. - The indicators are typically equipped with sensors or switches that detect the movement of tap changer components, such as selector switches or motorized mechanisms. - When the tap changer changes position, the sensors or switches trigger the tap position indicator to update its display accordingly.







LTC Tap Position – Why it is important

Many utilities are implementing VVO/CVR systems with their DMS, and they may require the tap position

Distributed generations is causing more operations on equipment and the utility needs to monitor the wear it may be adding to the LTCs

The variables are
The number of neutrals
The number of taps on each side of the neutral(s)

The Low tap, the Neutral tap(s) and the High tap

LTC Tap Position – How is it Sensed?

There are two categories of implementations

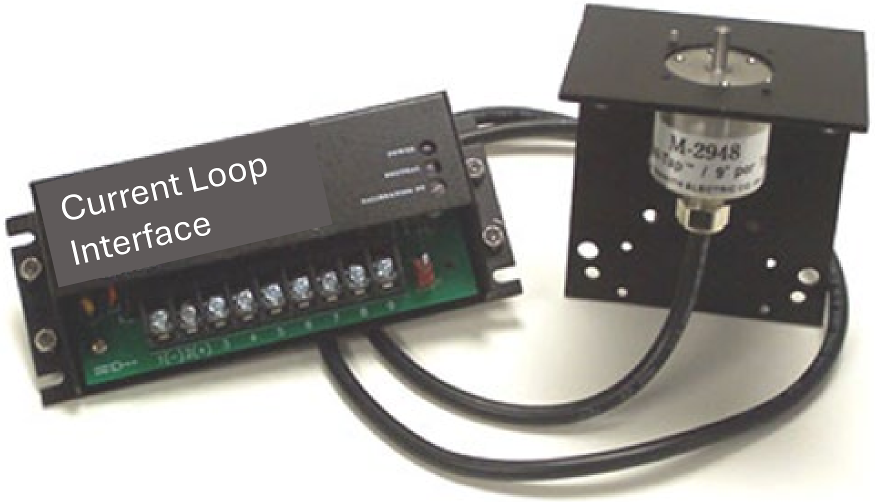
Sensor Method

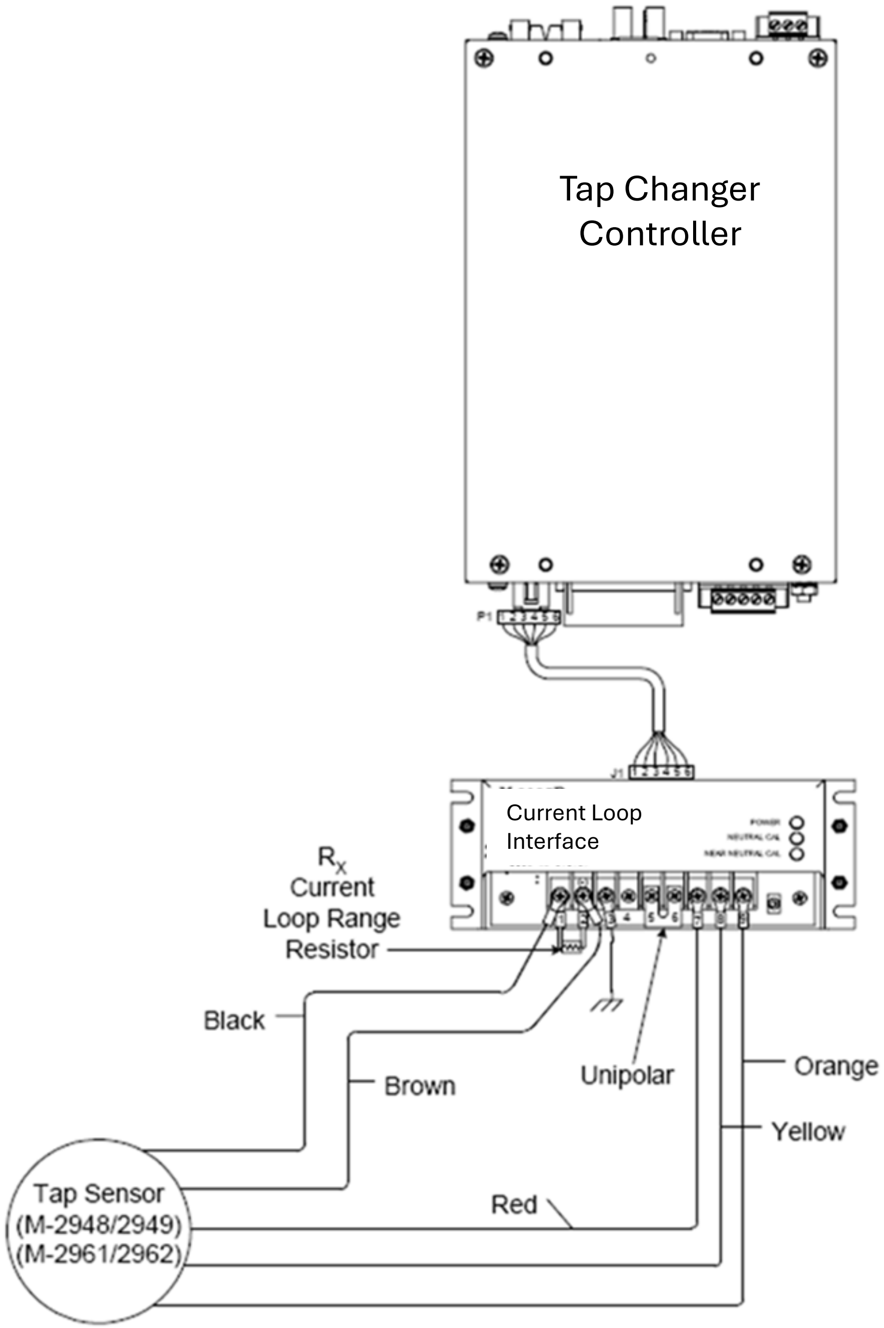
- A sensor is mounted to the LTC shaft or gear
- As the LTC taps, the shaft/gear rotates, and this causes the sensor to change its output
- The sensor is wired into another device to generate low voltage signal for the tap changer control to read and associate it with the corresponding tap positions

Contact Method

- Auxiliary contacts are wired into inputs to the tap changer control
- Inputs required are:
  - Contact at 1 raise and 1 lower
  - Contact in the Neutral position

Tap Position Sensing and Monitoring

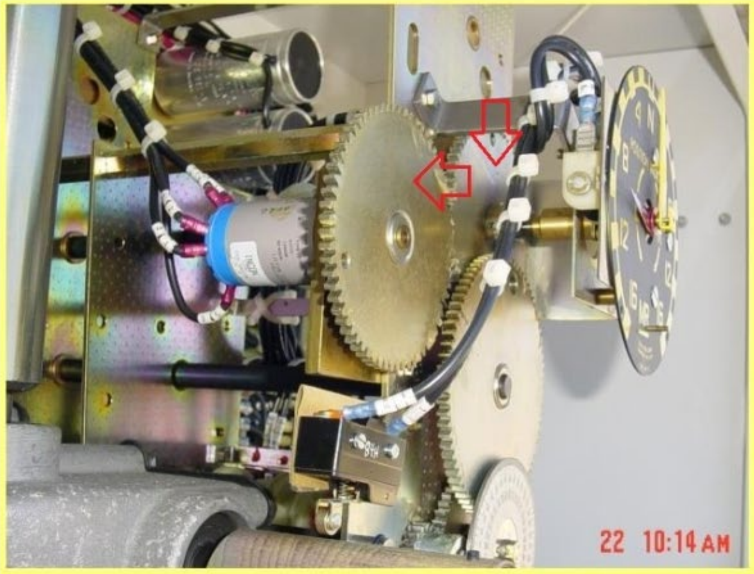


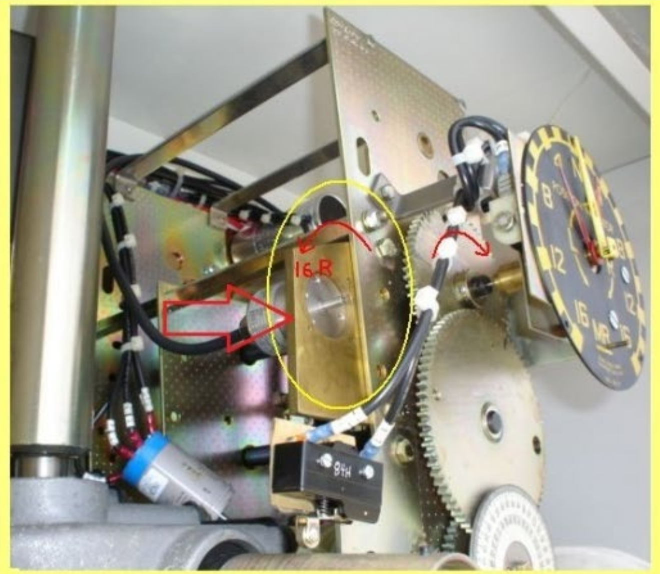


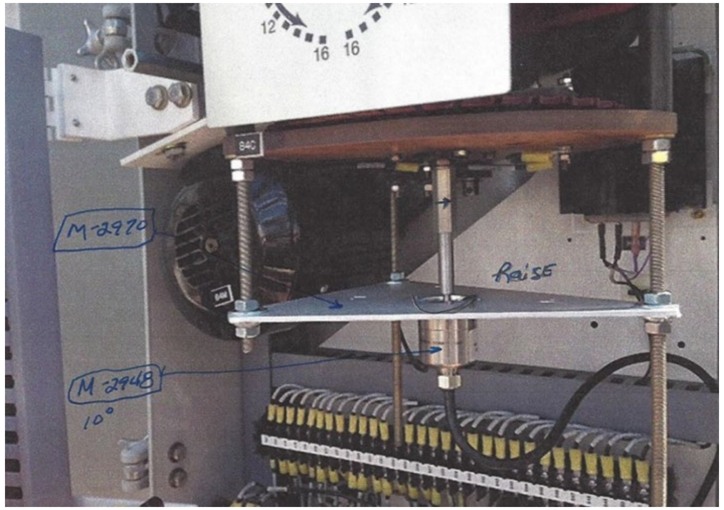
Example Beckwith Electric Devices:

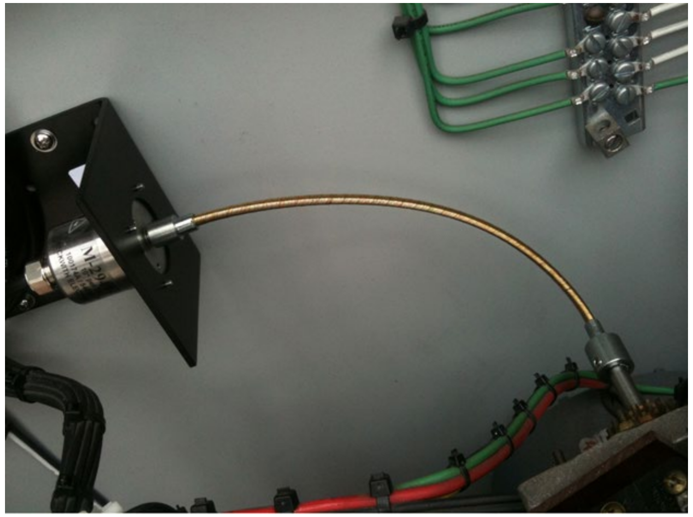
- M-2025D Current Loop Interface
- M-29XX Tap Position Sensors
- M-2001D Tap Changer Control

Installation Example of a Tap Position Sensor









Determining Direction

- Both the INCON 1250B Programmable Monitor and the Beckwith Sensors require knowing the rotation of the gear or shaft driving the sensor

- Perform a raise and determine if the gear/shaft rotates clockwise (positive rotation) or counter-clockwise (negative rotation

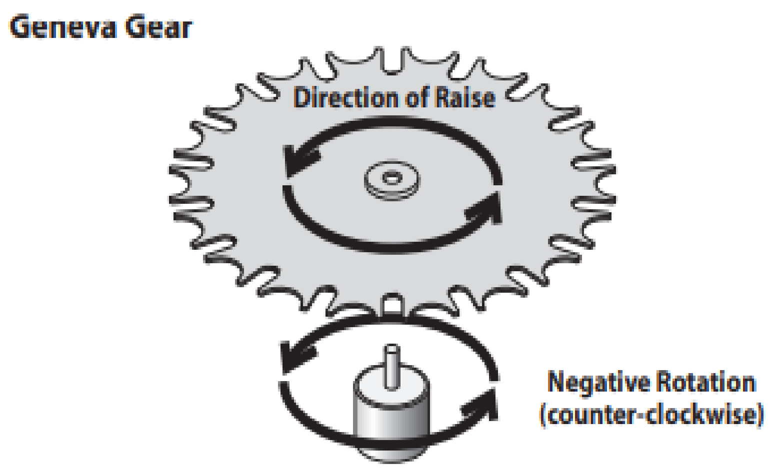
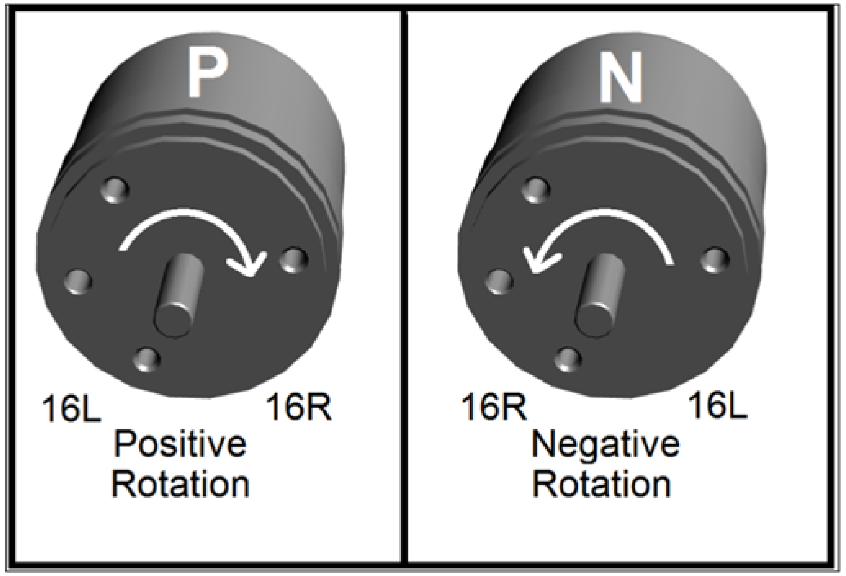


Figure 5 Tap Position Sensor Rotation Direction Example

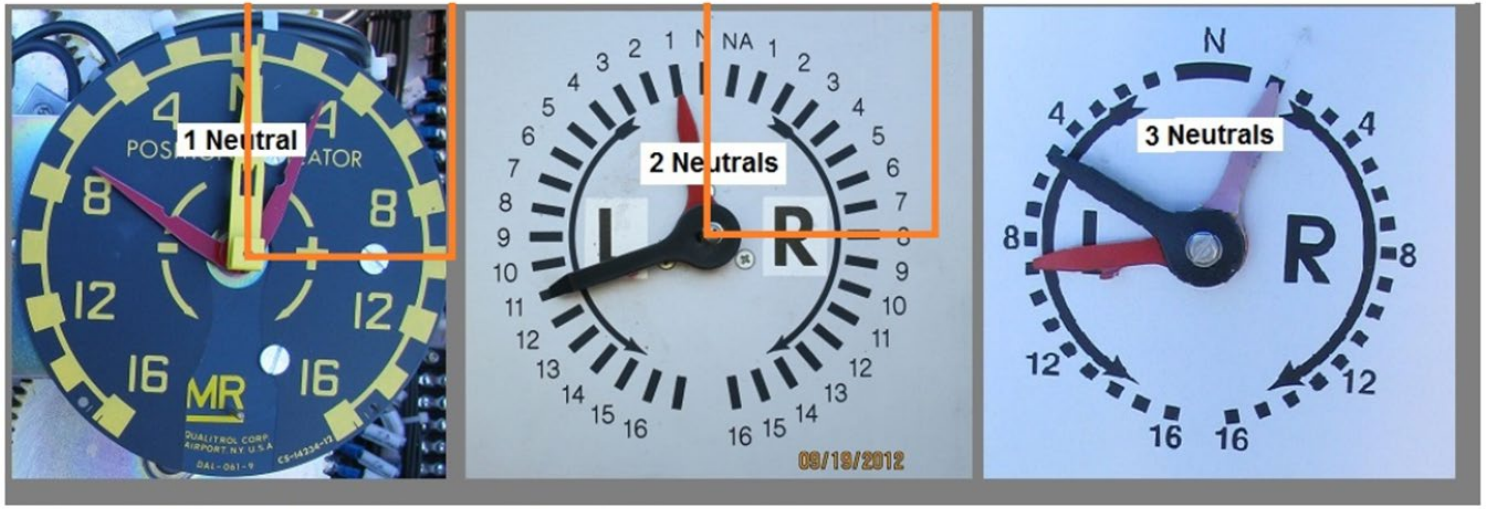


Determining Direction

Both the INCON 1292 and the BECO sensors require knowing the degrees of rotation per tap of the gear or shaft driving the sensor

The two options or 9 or 10 degrees

Looking at the Dial Indicator will provide the answer



10 Taps in 90 deg.= 9 Deg/Tap

9 Taps in 90 deg.= 10 Deg/Tap

Common Tap Position Device Installation Single Line

Courtesy of INCON

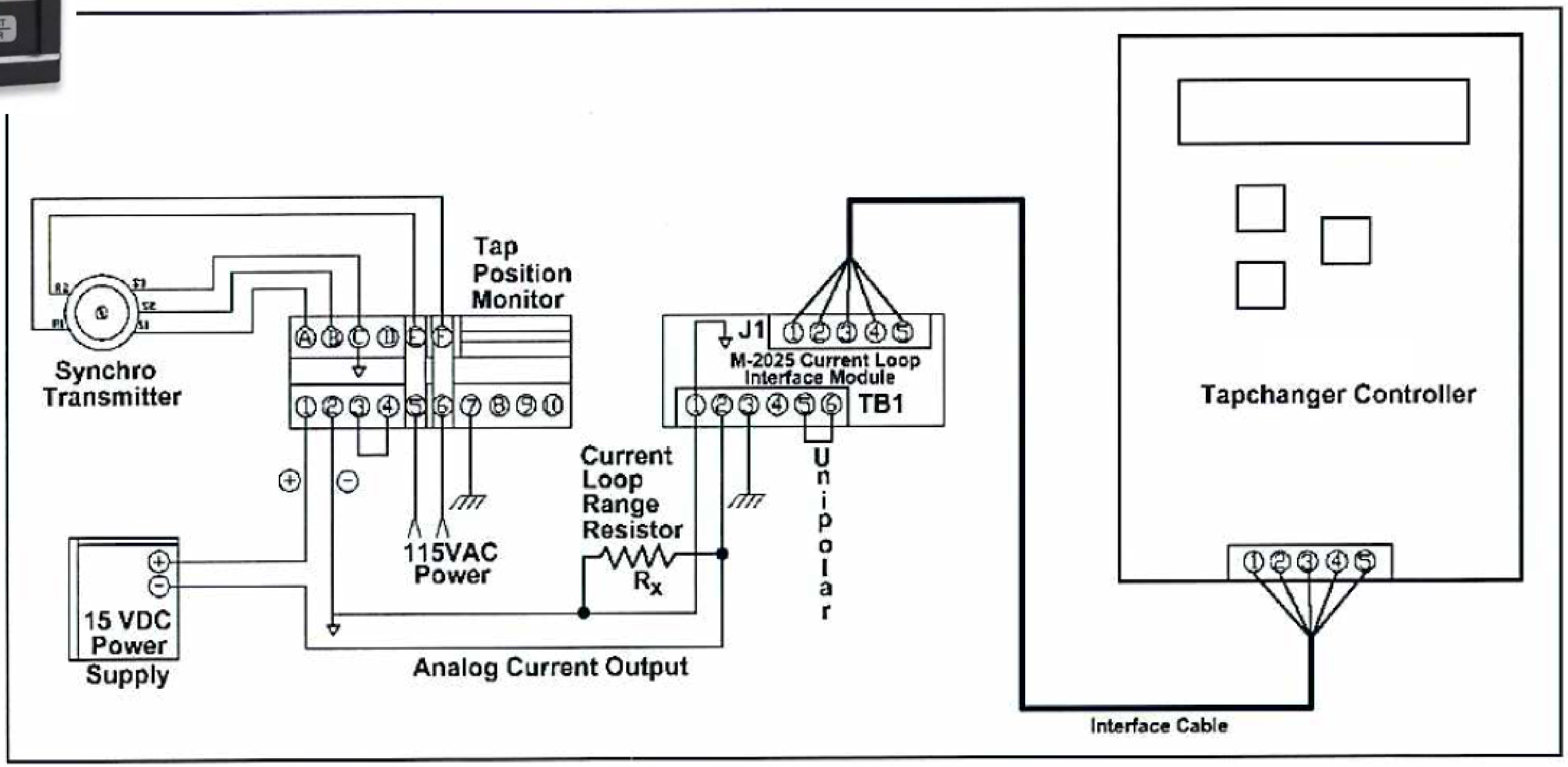


Figure 2 Wiring for model 1250B-4

Current accumulation during transformer tap change refers to the accumulation of current on the tap changer contacts during the tap-changing process, particularly in on-load tap changers (OLTCs).

Here's a breakdown of the process and associated effects:

•During a tap change, the OLTC switches the winding connection from one tap to another to adjust the transformer's turns ratio and regulate the output voltage.

•Transition resistors are utilized to maintain circuit continuity during this process and limit circulating currents.

•As the tap changer transitions, current flows through the transition resistor as it briefly bridges the previous and next tap contacts.

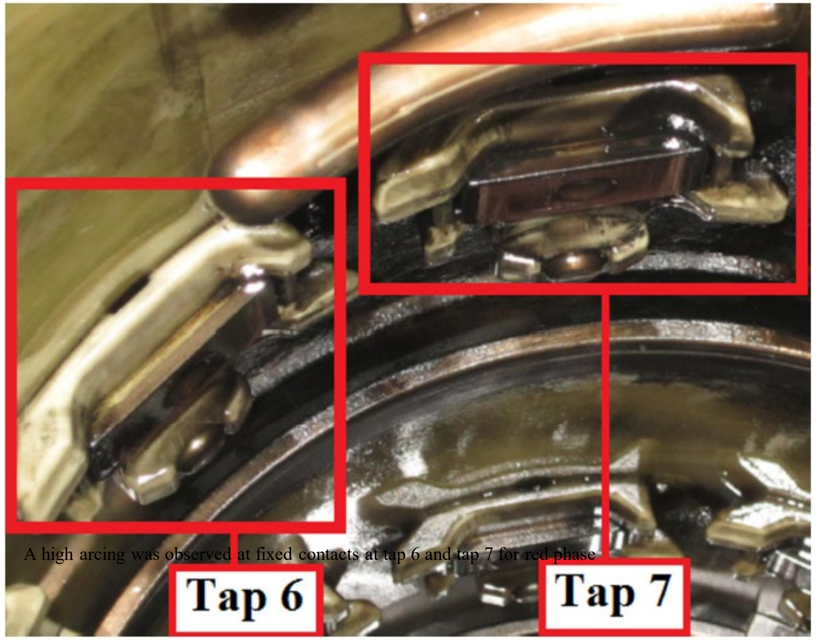
•This flow of current through the resistor causes ohmic heating.

•While these resistors are designed to handle the temporary current, excessive or prolonged accumulation of current can lead to:

- Overheating of the tap changer contacts and surrounding oil.
- Pitting and coking of the contacts due to arcing.
- Reduced contact lifespan and potential failure.

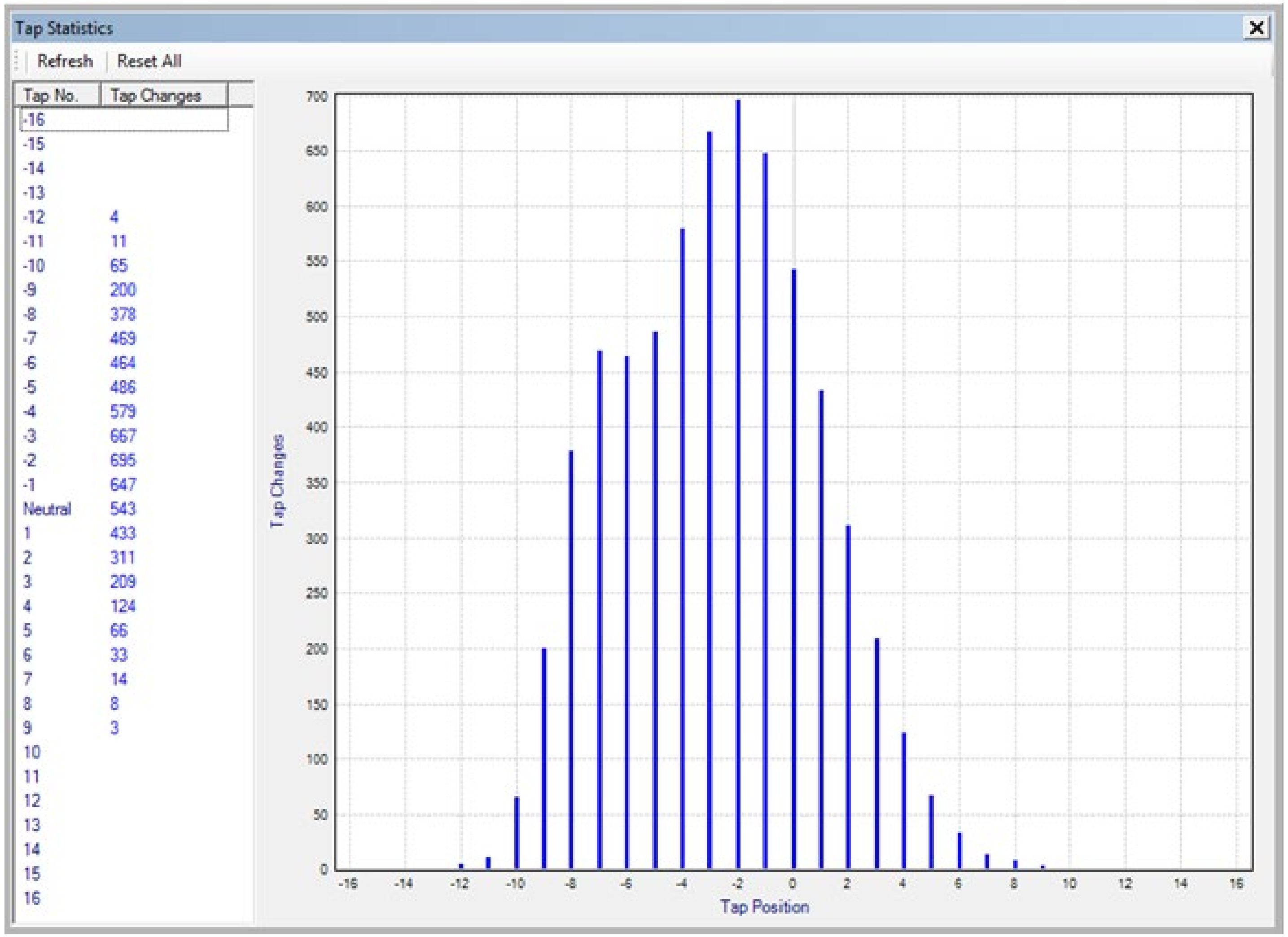
Consequences of tap position wear:

- **Poor voltage regulation**: Worn contacts can lead to increased resistance and inefficient voltage regulation.
- **Increased risk of arcing:** As contacts wear, the gap between them can become inconsistent, increasing the risk of larger or sustained arcs during tap changes.
- **Potential for mechanical failure**: Excessive contact wear or mechanical component degradation can lead to complete LTC failure, which can then result in damage to the transformer itself.



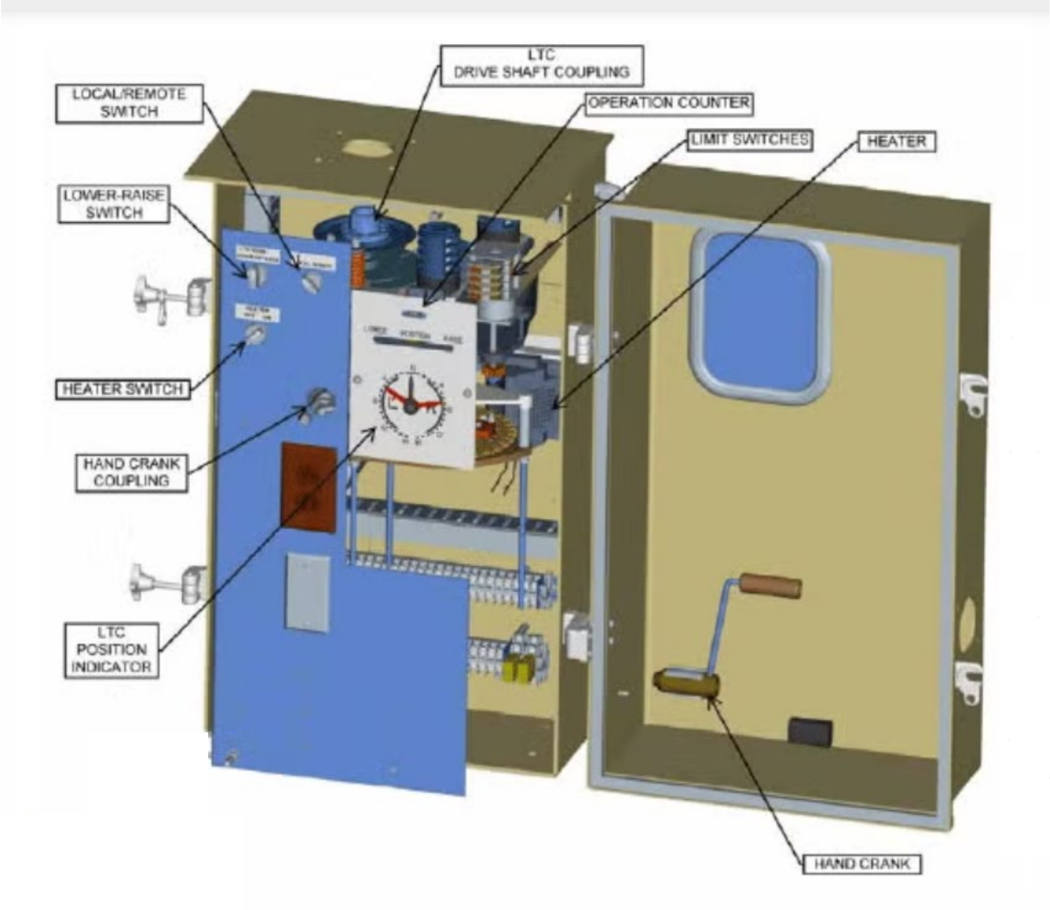
Predictive Maintenance : Tap Position Tracking

- Records the number of times each tap has been crossed.
- Operations Counter may look like the regulator or LTC is seeing normal wear but if it is constantly changing between the same taps, those taps can wear out sooner.

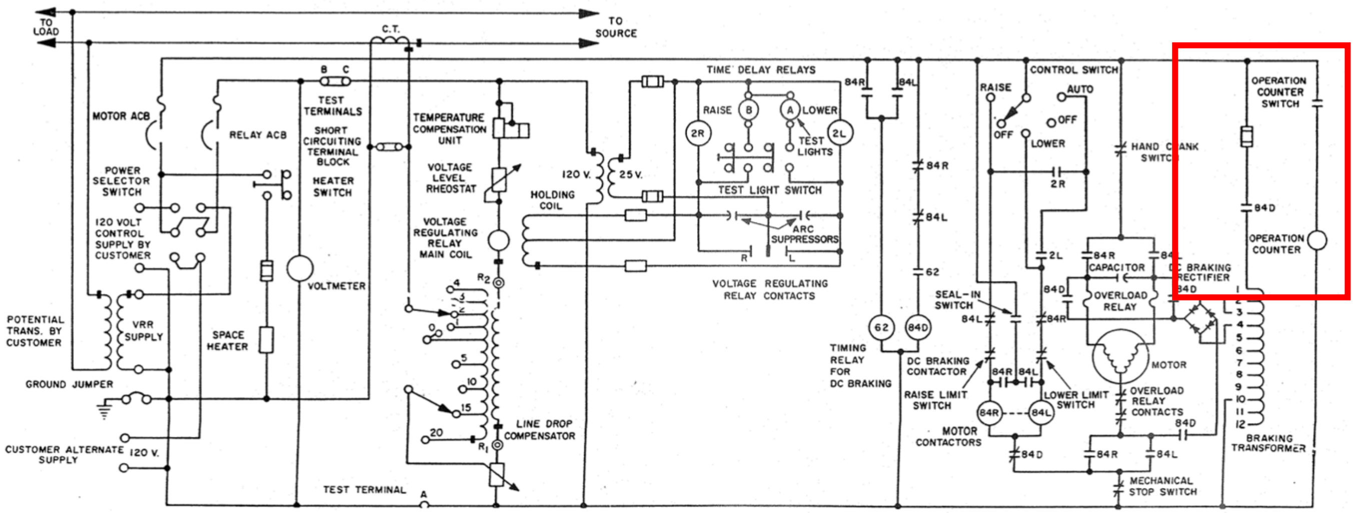


Operation Counter

In an LTC (Load Tap Changer) tap mechanism, the operation counter is typically located within the motor-drive compartment or control cabinet of the LTC. The counter records the number of tap-change operations, which is crucial for scheduling maintenance and overhauls.



The counter serves to record every tap-change operation, which helps determine maintenance schedules and assess the wear and tear on the LTC's components, particularly the contacts



Load tap changers (LTCs) are designed to handle many operations, but the exact number can vary depending on several factors. (Operations Counter)

General Expectations:

- **Average Daily Operations:** Most transformer LTCs in network applications average around 20 switches per day.

- **Maintenance Schedule:** Typically, LTC maintenance is recommended every 7 years or every 80,000–100,000 operations, whichever comes first. This suggests that a tap changer is designed to handle at least this number of operations before needing maintenance, although contact replacement may be necessary at least once during the lifetime of a transformer.

- **Estimated Contact Life:** Electrical transformers typically have a rating plate specifying the estimated contact life at rated loads.

Factors Affecting Life and Number of Operations:

- **Load and Operations Frequency:** The frequency of tap changes directly impacts the wear and tear on the tap changer.
- **Maintenance:** Routine inspection, cleaning, contact replacement, and oil analysis are crucial for maintaining the health and longevity of an LTC. Proper maintenance helps prevent issues like carbon buildup, contact wear, and gasket deterioration.
- **Operating Conditions**: Harsh environments or high humidity can lead to corrosion and damage the tank and other components.
- **Oil Quality**: Degradation and carbonization of oil within the LTC can lead to problems like tracking and arcing, potentially causing permanent damage. Frequent tap changes can accelerate oil degradation.
- **Mechanical Integrity:** Proper alignment and lubrication of mechanical parts are essential. Failure to do so can lead to premature wear and failure.
- **Design and Materials**: High-quality components and proper design contribute to the tap changer's lifespan.

Monitoring and testing methods are used to assess the condition of tap changers and detect potential issues related to current accumulation and contact degradation:

Dynamic Resistance Measurement (DRM) is a common offline testing method that injects a DC current through the tap changer as it moves through its positions. By analyzing the current waveform during tap changes, problems such as slow transition times, contact issues, and transition resistor degradation can be identified.

Oil analysis, including dissolved gas analysis (DGA), can help detect signs of overheating and arcing within the tap changer compartment.

Monitoring tap position and load can help identify excessive wear situations related to frequent tap changes and high interrupted currents.

Motor current profile monitoring can reveal issues with the tap changer's drive mechanism and the energy consumed during operation.

Regular maintenance and testing of tap changers are crucial to ensure their reliable operation and prevent transformer failure

In transformer load tap changers (LTCs), tap position wear over time is a significant concern due to the mechanical and electrical stress placed on the contacts during tap changes

Here's a breakdown of factors contributing to tap position wear:

- **Arcing during tap changes**: When the tap changer switches between positions under load, an arc is created between the contacts. This arcing causes erosion and pitting of the contact surfaces over time.
- **Contact degradation:** Different contacts within an OLTC experience varying levels of wear. For example, arcing switch contacts designed to interrupt load current will wear faster than tap selector or changeover selector contacts that don't switch significant currents. The formation of surface films on contacts, which reduces conductivity, also contributes to degradation.
- **Mechanical stress:** The mechanical components of the LTC, like the drive mechanism and contacts, are subject to wear due to repeated operation. Problems like contact misalignment, lubrication issues, or worn components can accelerate mechanical wear.
- **Oil degradation**: The oil in the tap changer compartment can degrade due to arcing moisture, oxidation, and the formation of particles and film from contact wear.

Consequences of Exceeding Limits or Ignoring Maintenance:

- **Reduced Life:** Neglecting maintenance or operating the tap changer outside of its specified limits can drastically reduce its lifespan.

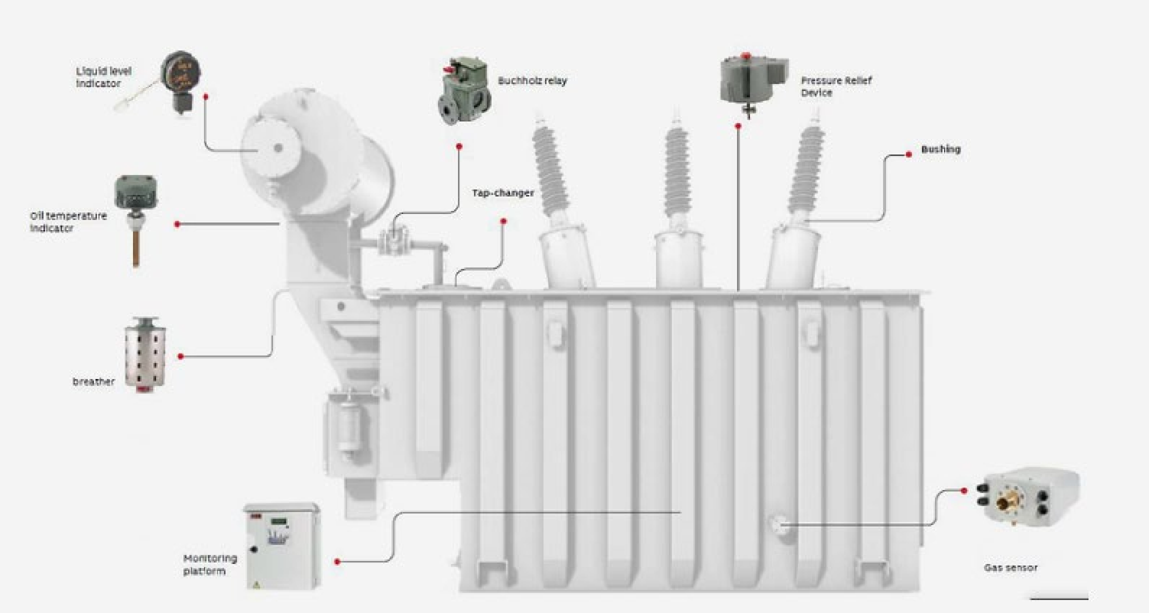
- **Potential for Failure**: Tap changers are a leading cause of transformer failures, often due to issues like contact wear, misalignment, or problems with the insulating oil.

- **Costly Repairs and Downtime:** A failed LTC can take the entire transformer out of service, resulting in significant costs and power interruptions.

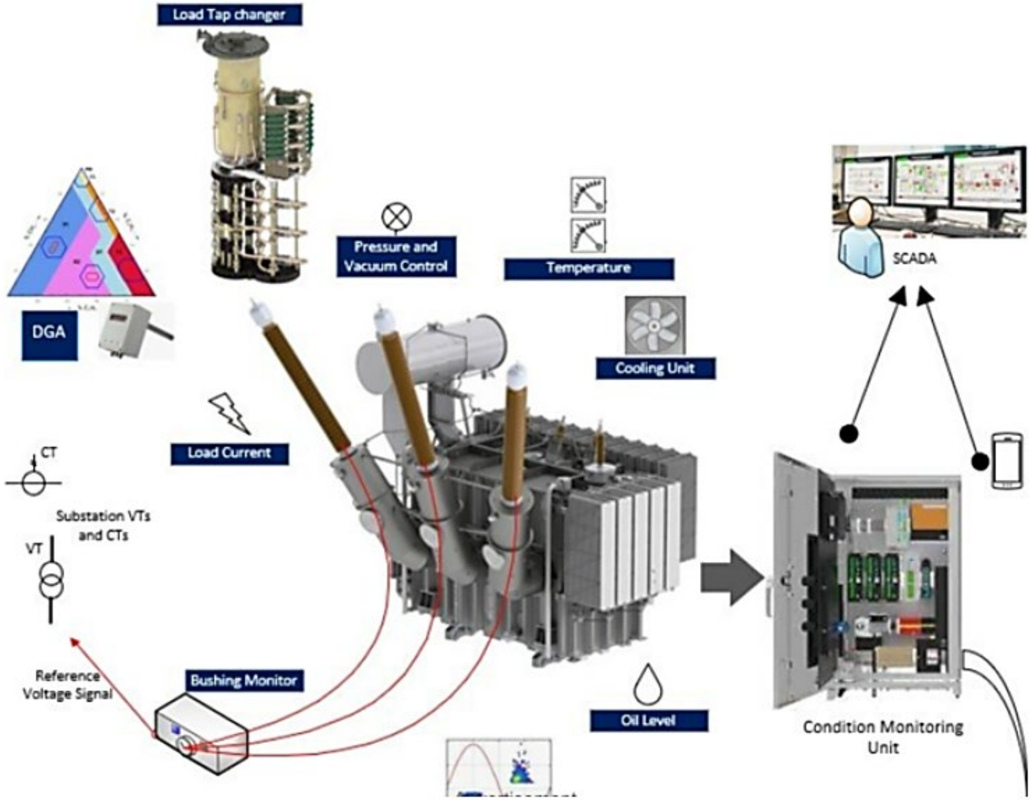
Mitigation and maintenance:

- **Regular inspections and testing:** This is crucial for detecting wear and other issues early on. This includes visual inspection of contacts and mechanical components, as well as electrical tests like static and dynamic resistance measurements.
- **Oil analysis and replacement**: Regularly analyzing the tap changer oil for moisture content, dielectric strength, and particle content can help identify problems and determine when oil needs replacing.
- **Contact replacement:** Replacing worn contacts is a vital part of maintaining the LTC's performance and reliability.
- **Using vacuum switch OLTCs:** These types of tap changers confine the switching arc in vacuum bottles, which helps to mitigate oil degradation and contact wear.

Transformer Monitoring Systems



Power Transformer Monitoring



Monitoring Main Functionalities

Key Parameters for OLTC Monitoring

- OLTC Tap Position Tracking
- OLTC Tap Changer Differential Temperature
- OLTC Motor Energy+ Tracking
- OLTC Contact Wear
- Reversing Switch Operation
- Traditional DGA and Physical Analysis (Lab) of Oil in External Compartment

Why Online Monitoring?

According to a recent CIGRE Transformer Reliability Survey, on load tap changers (OLTC) have one of the highest failure rates of any transformer component! If an OLTC fails, a transformer cannot regulate voltage. There are still many OLTCs in service today based on older technology. They are much more susceptible to significant wear and tear on critical elements. This wear is frequently the cause of mis-operation or even unexpected failures when not properly maintained.

Importance of Monitoring and Maintenance:

•Regular monitoring and testing, including oil analysis and frequency response analysis (FRA), can help detect potential problems early.

•Proper maintenance, including cleaning, lubrication, and replacement of worn parts, is crucial for preventing failures.

•Understanding different LTC designs, and their specific failure modes is essential for effective maintenance.

Transformer Monitoring Systems

What is a transformer monitoring system?

Transformer monitoring solutions are a set of programming monitoring software, sensors, and digital services, used to track the health and performance of transformers.

- Its goal is to collect data on factors like temperature, oil level, moisture, overheating, vibration,

There are mainly two types of monitoring:

Gas Monitoring

- Provides real-time monitoring of DGA (Dissolved Gas Analyzer) for early identification of most transformer faults.
- Monitoring oil moisture to prevent premature ageing.
- Basic analysis: hydrogen and moisture.

Transformer Overload Monitoring

- Measurement and monitoring of key transformer parameters.
- Based on the data obtained, algorithms are created following IEC or IEEE standards to warn of any sudden changes in transformer condition.

Specific Monitoring Techniques and Components:

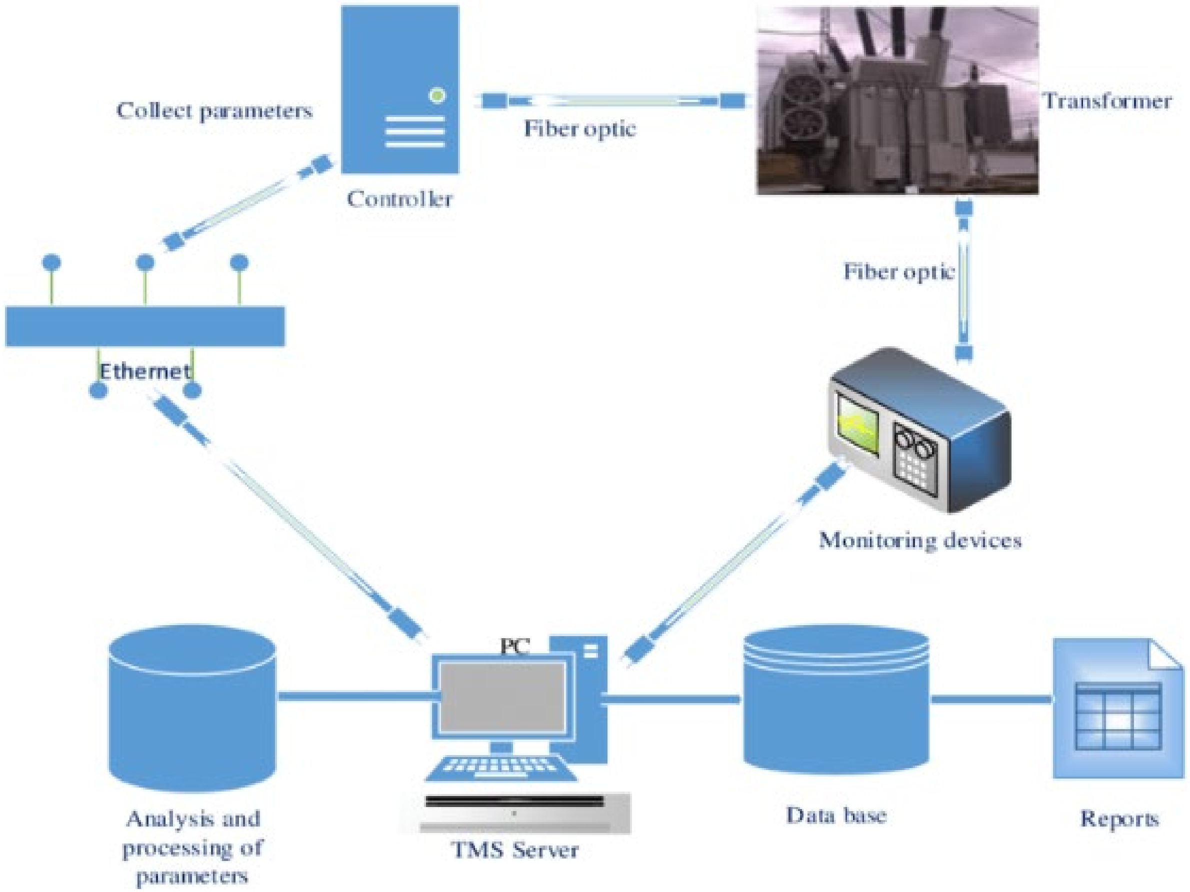
- **Dissolved Gas Analysis (DGA):** Analyzing gases dissolved in the transformer oil to detect insulation degradation and other issues.
- **Partial Discharge Monitoring:** Detecting partial discharges, which can indicate insulation problems and potential failure points.
- **Bushings Monitoring:** Tracking capacitance and power factor of bushings to identify potential failures.
- **Cooling System Monitoring:** Ensuring the cooling system is functioning properly to prevent overheating.
- **Load Tap Changer (LTC) Monitoring:** Monitoring the LTC's operation to ensure reliable voltage regulation.
- **Winding Temperature Monitoring:** Monitoring winding temperatures to prevent overheating and insulation breakdown.
- **Oil Level and Pressure Monitoring:** Detecting leaks and ensuring proper oil levels.

Benefits of transformer monitoring controls:

- **Increased Reliability:** Proactive monitoring and early fault detection minimize the risk of unexpected outages.
- **Reduced Maintenance Costs:** Optimized maintenance schedules based on actual conditions reduce unnecessary maintenance and repair costs.
- **Extended Transformer Lifespan:** Early detection of issues allows for timely intervention, preventing major damage and extending the transformer's operational life.
- **Improved Safety:** Monitoring helps identify potential hazards and prevent accidents.
- **Reduced Downtime:** Fewer unexpected outages lead to increased system uptime and reduced costs associated with downtime.

How to Monitor On-load Tap Changers (Communications)

- Implementing online monitoring for an OLTC is relatively easy via communication systems allows for remote tracking of transformer health and performance, enabling predictive maintenance and faster response to issues.
- This is achieved through various communication technologies like wired connections, like Ethernet Wi-Fi, cellular, or specialized protocols such as DNP. Modbus or IEC 61850 or serial types such as fiber optic.



Primary aspects of power transformer monitoring include:

- **Parameter Monitoring:** Monitoring involves tracking various parameters like temperature (oil, winding hotspots), oil level, voltage, current, load, and partial discharge activity.
- **Data Acquisition and Analysis:** Sensors collect data, which is then processed and analyzed by monitoring systems or control systems like SCADA.
- **Alarming and Notification:** When pre-set thresholds are exceeded, the system generates alarms to notify operators of potential issues, allowing for timely intervention.
- **Preventive Maintenance:** Monitoring data can be used to predict potential problems and schedule maintenance, preventing unexpected outages and extending transformer lifespan.

Other Functions of Load Tap Changer Transformers

Voltage Regulation

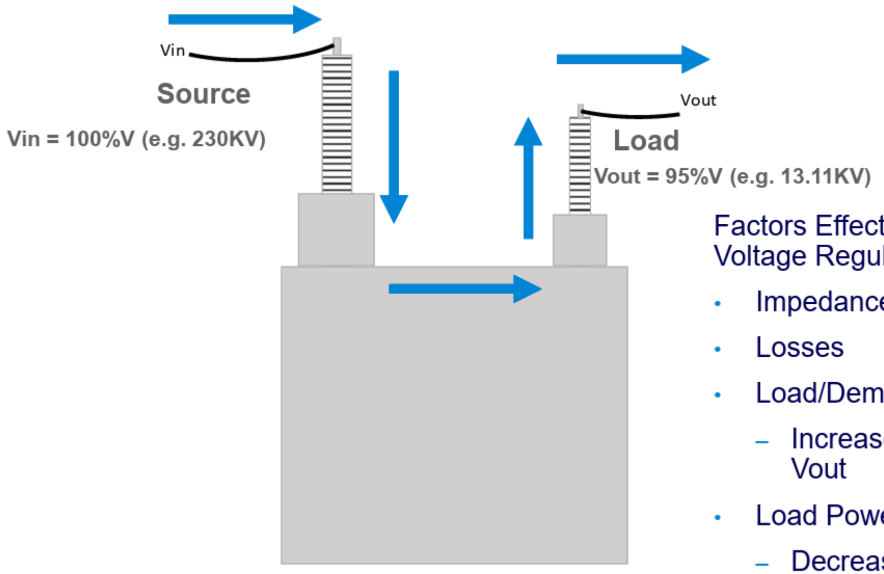
The primary function of a tap changer is to regulate the output voltage of transformers. Voltage fluctuations in the power grid can impact the quality of electricity supplied to consumers. Tap changers allow transformers to adapt and maintain a constant output voltage, ensuring a stable and reliable power supply.

Grid Stability

Tap changers play a critical role in maintaining the stability of the electrical grid. They respond to voltage changes and load variations promptly, reducing the risk of voltage sags or surges that can disrupt the power supply.

On –Load Tapchanger (OLTC) Voltage Regulation

Voltage Regulation



Factors Effecting Voltage Regulation

- Impedance
- Losses
- Load/Demand
  - Increase in load/demand means drop in Vout
- Load Power Factor
  - Decrease in load power factor means drop in Vout

- Transformers with typically 33 taps that can be changed under load conditions
- One neutral tap that does not impact the voltage
- 16 lower taps that lowers the outgoing voltage
- 16 raise taps that increases the outgoing voltage
- Each tap typically increases/decreases the outgoing voltage by either 0.75 volts or.625 volts on a 120-volt base
- A controller typically is used to dynamically raise/lower taps as the voltage varies but the LTC can also be controlled remotely

Voltage Regulation Principals

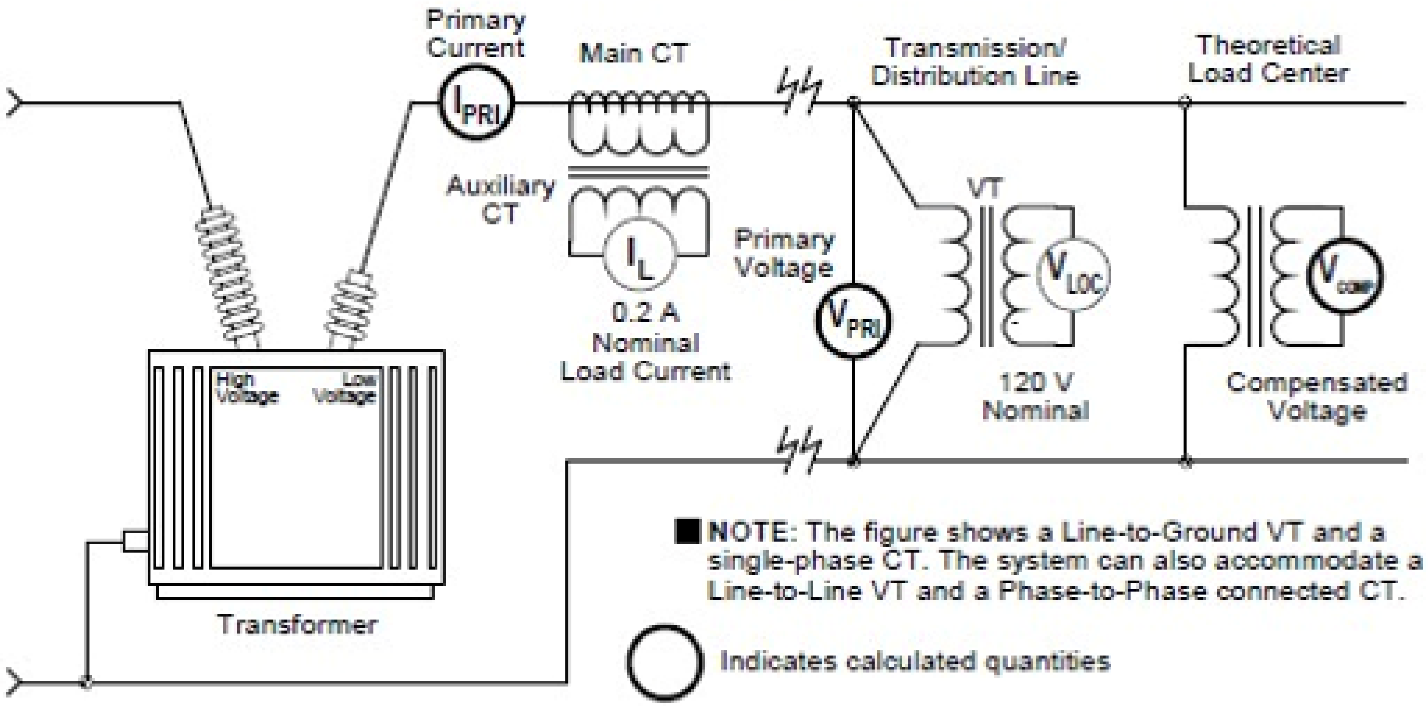
Step-voltage regulation is today most commonly accomplished using LTC transformers or regulators which provide for the output (secondary) voltage to be regulated about the range of 90% to 110% of the voltage at the input (primary). This regulation is accomplished in 32 discrete steps, so that each step represents

$$\frac{20\% \text{ voltage total range of regulation}}{32 \text{ steps}} = 0.625\% \text{ voltage / step}$$

or $\frac{5}{8}$% voltage per step.

Since all modern controls sense the output of a 120 V ac potential device, a one-step change of the LTC is seen to result in a voltage change of 0.75 volt at the control potential input.

Voltage Regulation Principals



This mode of voltage regulation is commonly referred to as 1) bus or 2) feeder regulation, being indicative of aspects of the system for which the regulation is oriented.

1. **Bus regulation:** A single bus voltage is regulated by an LTC transformer, three-phase step-voltage regulator or three single phase step-voltage regulators. The objective is to regulate the voltage of the substation low voltage bus assuming this will satisfy the voltage requirements of all feeders fed from the regulated bus. There will commonly be several (perhaps four or more) three-phase distribution feeders emanating from the regulated bus.

2. **Feeder regulation:** Each feeder is separately regulated by single phase step-voltage regulators out on the distribution feeders, or in the substation.

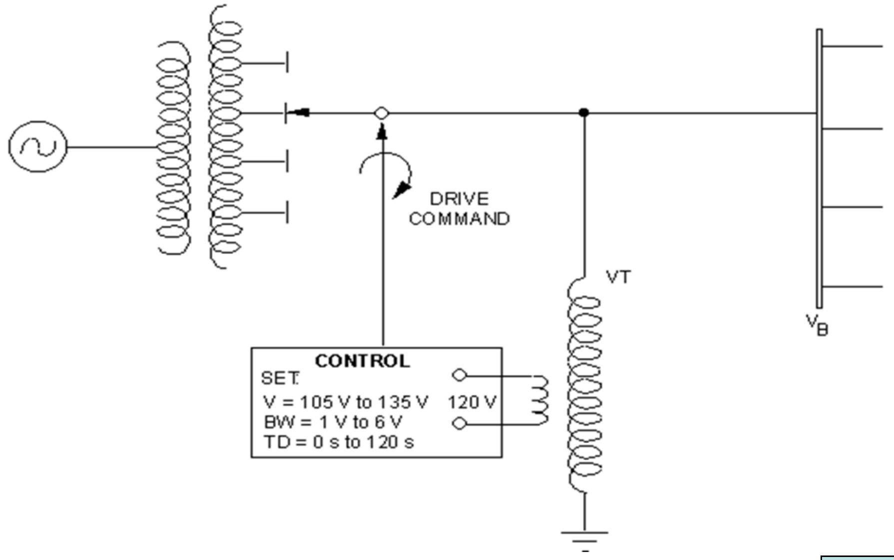
3. Combinations of 1 and 2 may be used if feeders are long.

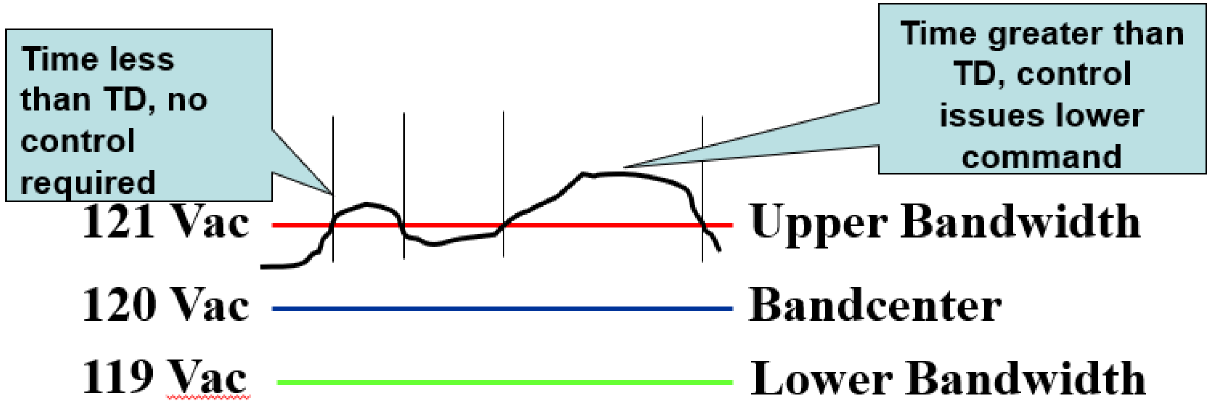
How Does an OLTC Work to Regulate Voltage?

Voltage Regulation through Tap Changes: The primary purpose of the OLTC is to maintain a stable output voltage. If there is a drop in voltage due to increased demand, the OLTC shifts to a tap with a higher voltage by adding more turns to the winding, compensating for the drop. If the voltage is too high, the OLTC switches to a lower voltage tap by reducing the number of winding turns.

Start with Basics

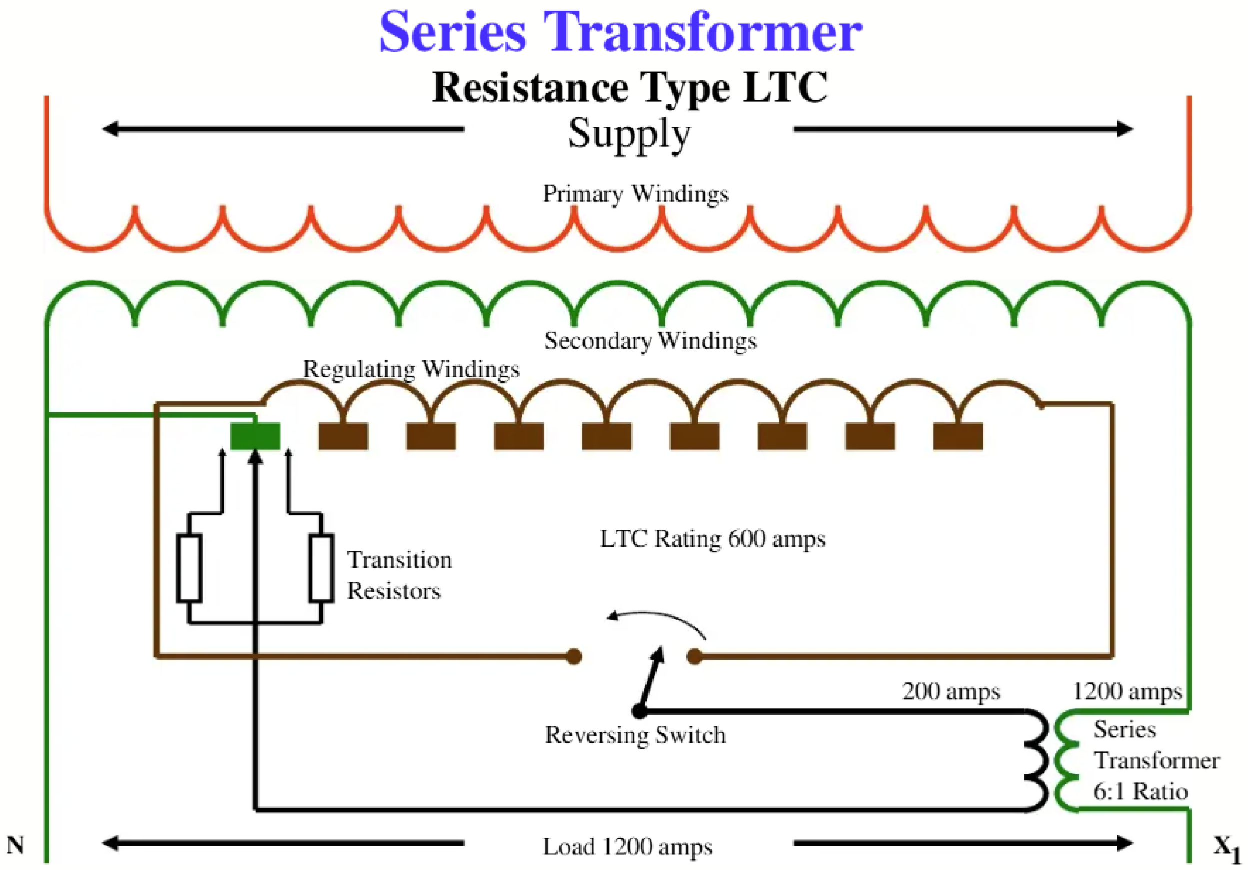
1. The basic function of an LTC or Regulator control is to regulate a system or bus voltage
2. Typical voltage regulation is +/- 10% of nominal over 32 taps or 0.625% voltage change per tap.
3. To accomplish this the following parameters must be defined
   1. Bandcenter
   2. Bandwidth
   3. Time Delay
   4. Type of Output





Understanding the Calculation

- LTCs adjust the transformer's turns ratio by accessing different "taps" on one winding, thereby changing the output voltage.
- A common configuration for LTCs involves a range of 90% to 110% of the nominal voltage, with 32 discrete steps.
- This setup results in a voltage change of approximately 0.625% per step.
- For a transformer with a 120V potential input, a single LTC tap change leads to a voltage change of about 0.75V.
- The voltage change per tap is typically considered a step change, with a defined "bandwidth" around the target voltage level that the control deems acceptable.

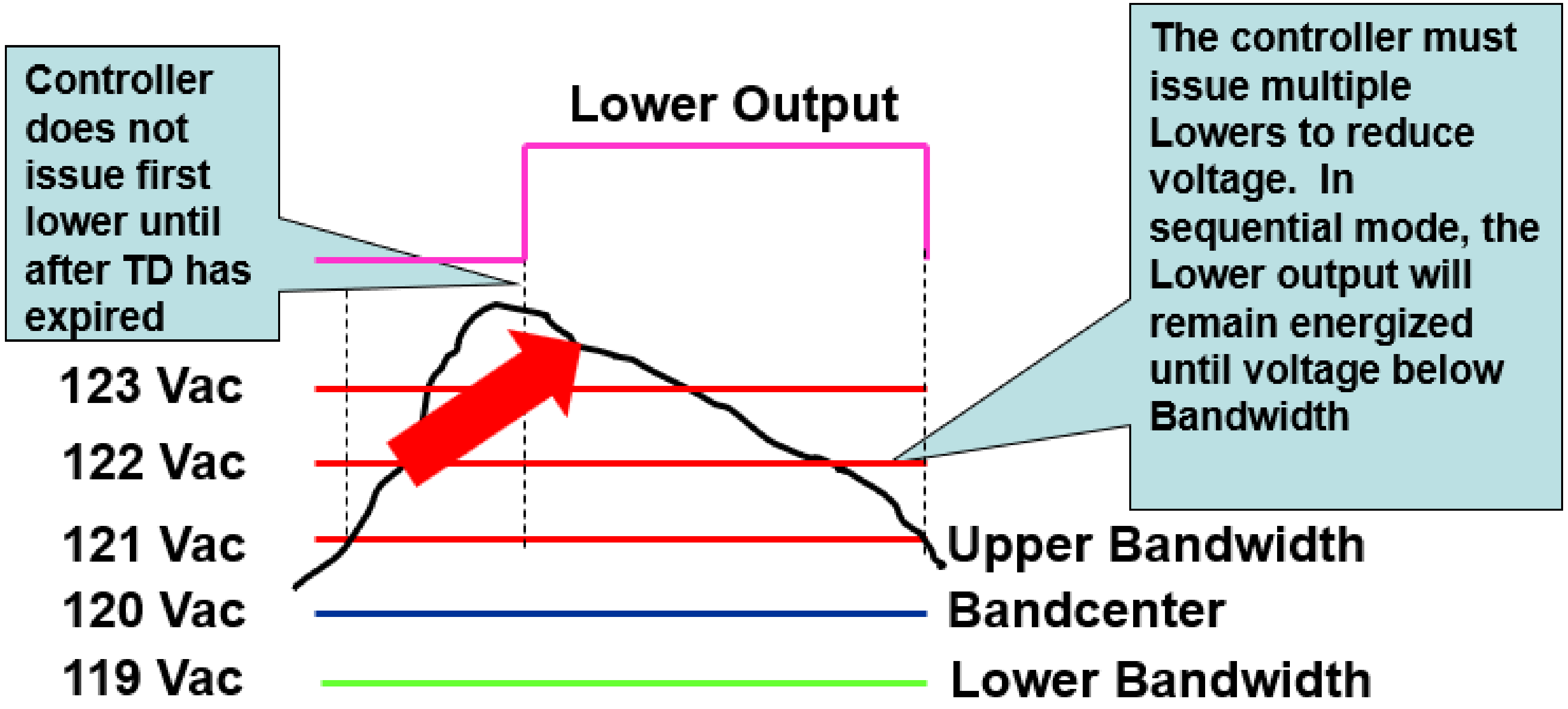


Three Output Modes of AVR Control & LTC Tap Changer Operations

- Sequential output operation follows a strict order of tap positions.
- Non-sequential output operation allows for interruptions and resets of the tap changing process.
- Pulsed output: Pulse transformers are designed to transmit precise electrical pulses, often with a rectangular or square waveform.

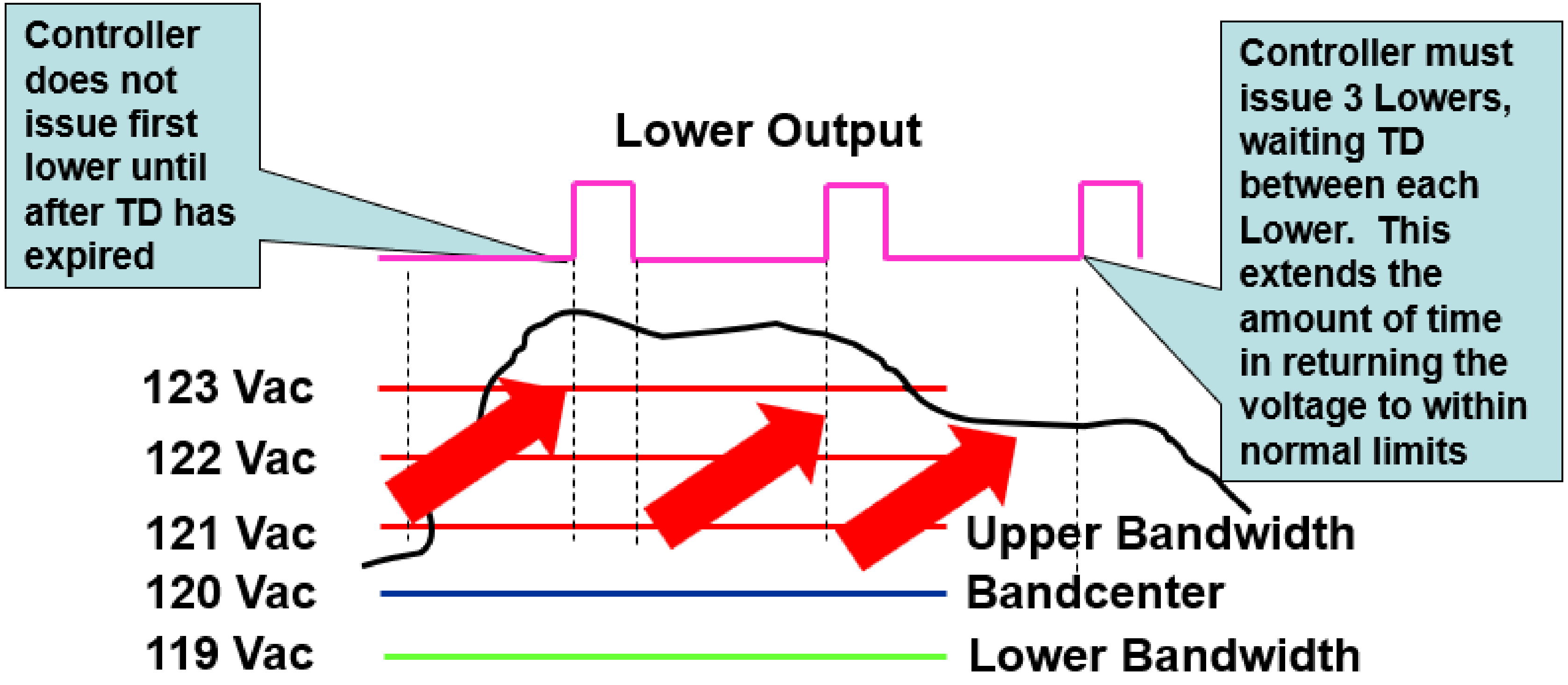
Sequential Mode (Continuous Output)

- The default mode. The controller will leave the appropriate output energized until the voltage falls within the bands.

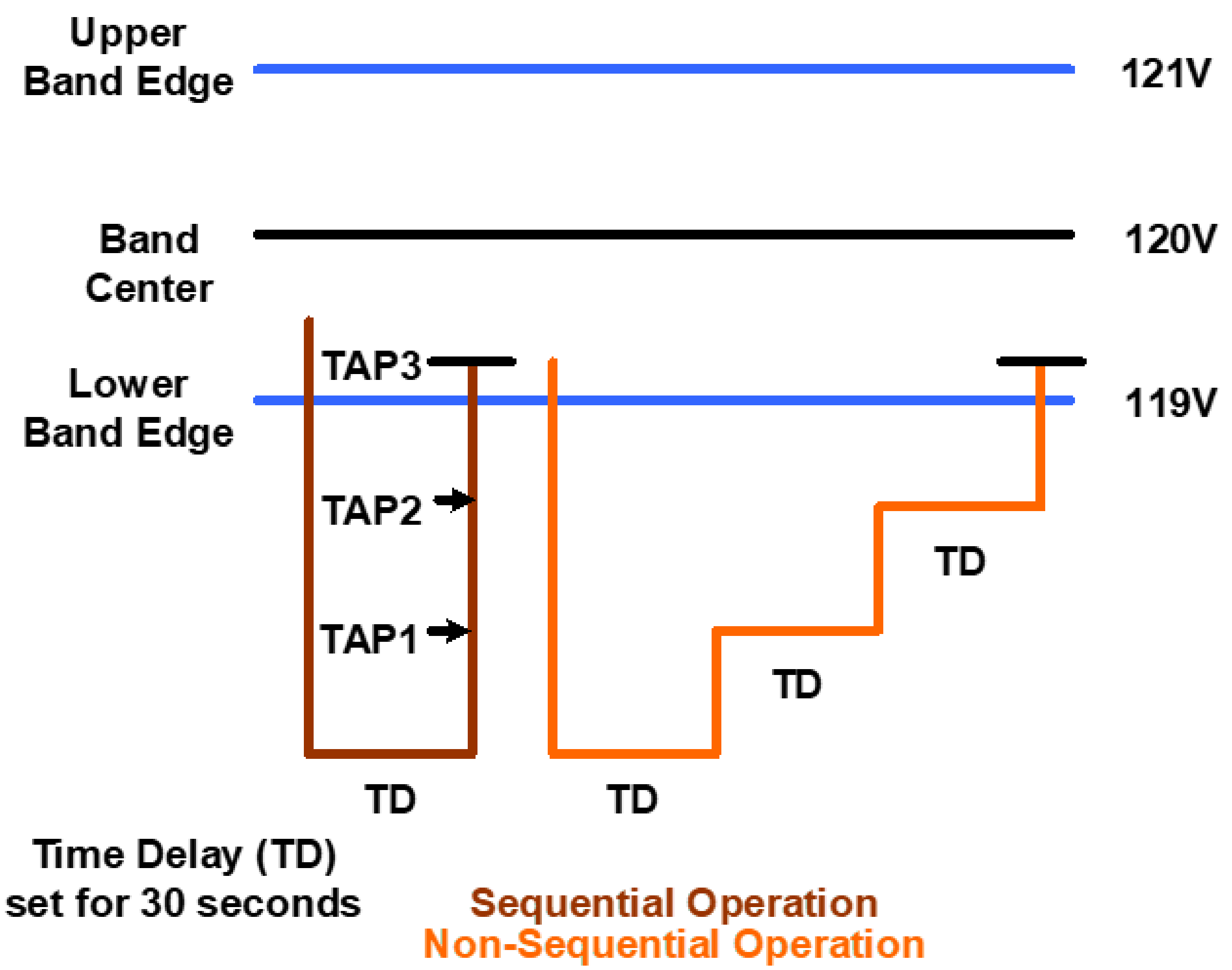


Non-Sequential Mode

- The controller waits the TD between each output
- Output is reset by Operation Counter Input activating the non-sequential input on control.



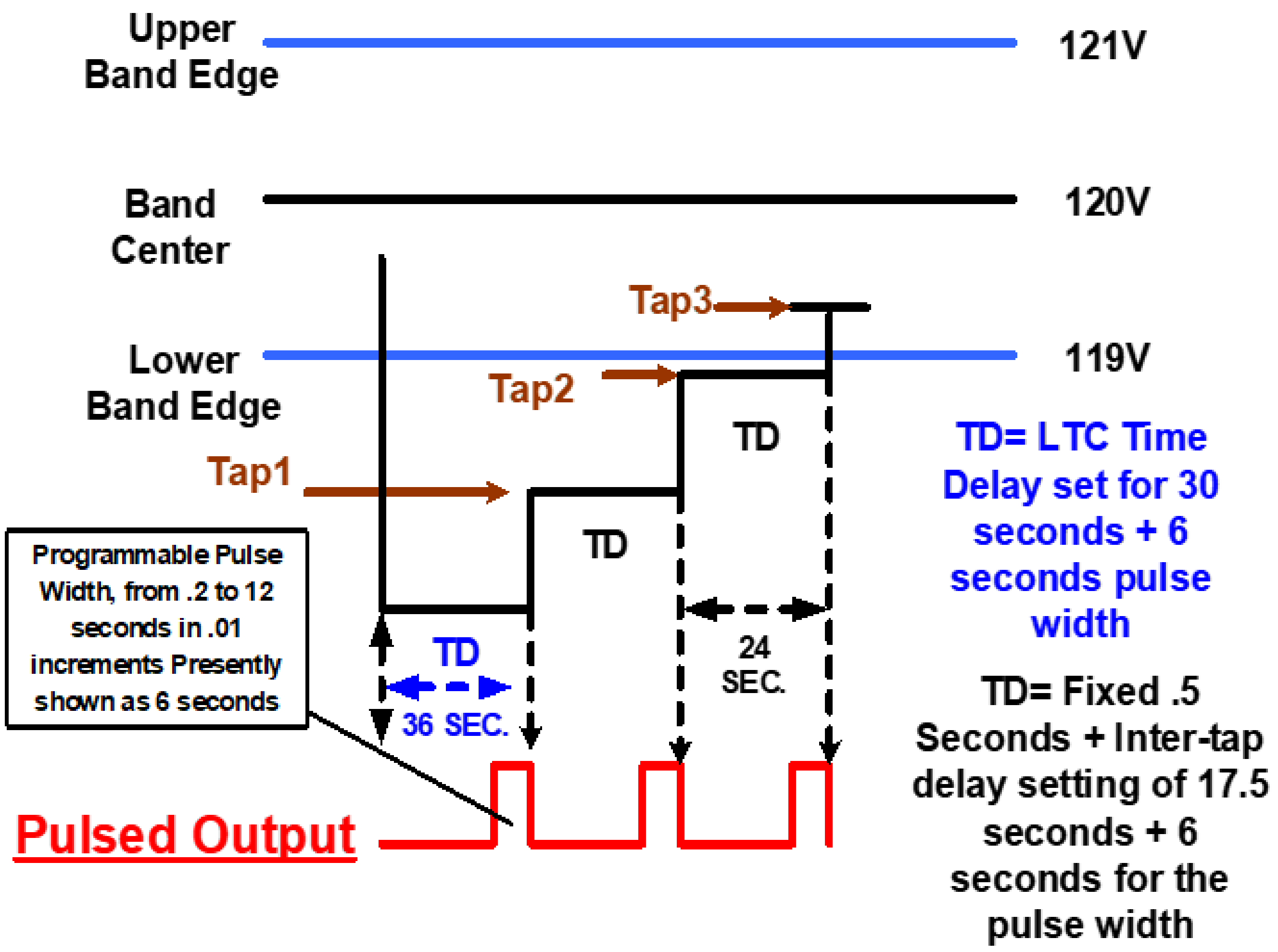
Traditional Tapchanger Operations



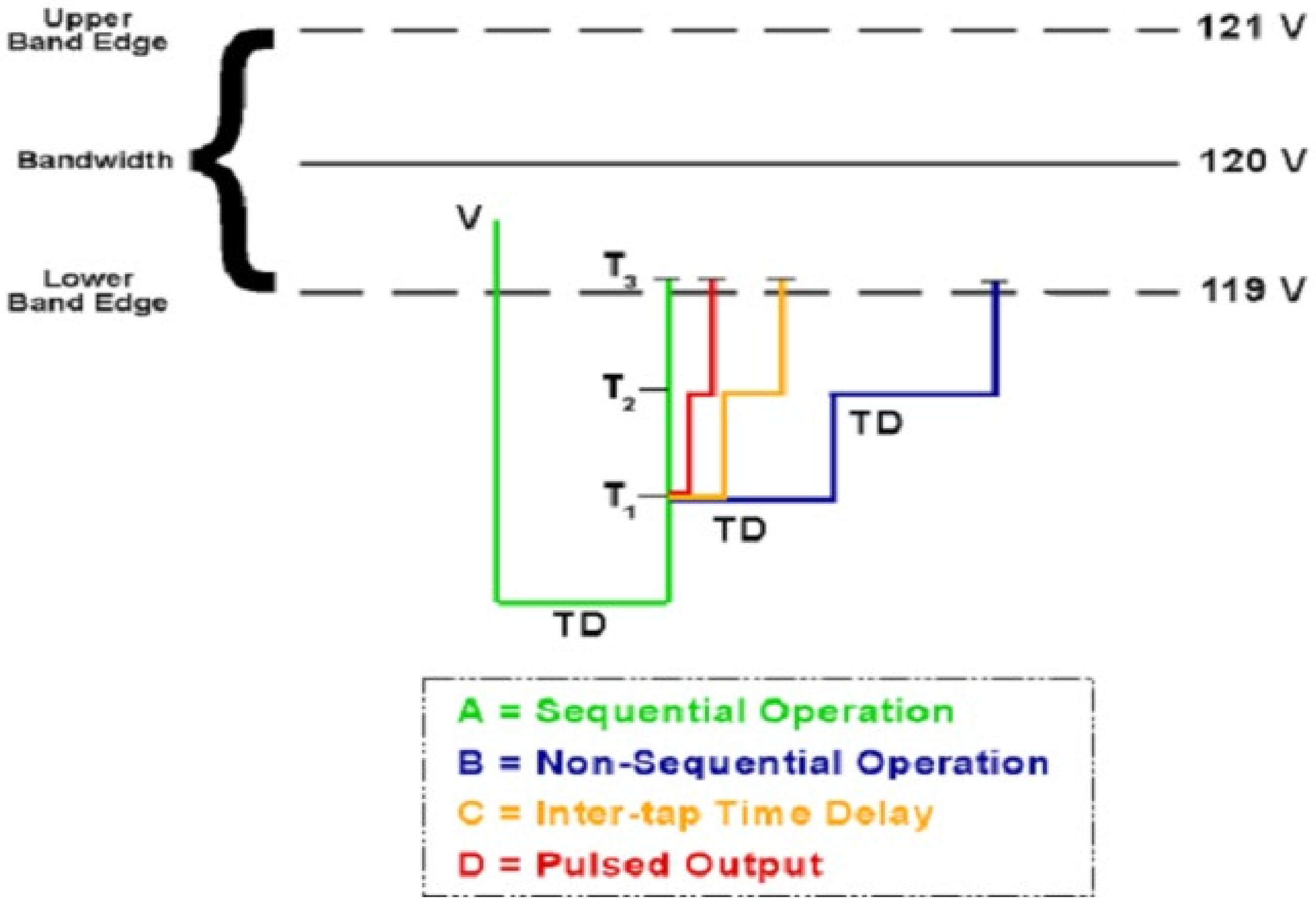
Pulsed Outputs

- Does not require Counter Input to reset output as it will remain energized for a configurable amount of time
- Use with mechanisms such as Reinhausen /MR VACUTAP RMV II
- Set as 0.2 – 12 seconds in 0.1 second increments
- Will use Counter input to reset if available and Counter Input updates before Pulse Timer has expired
- If Counter Input is not used, Pulse Time must be less than 1 Tap position or hunting can occur.

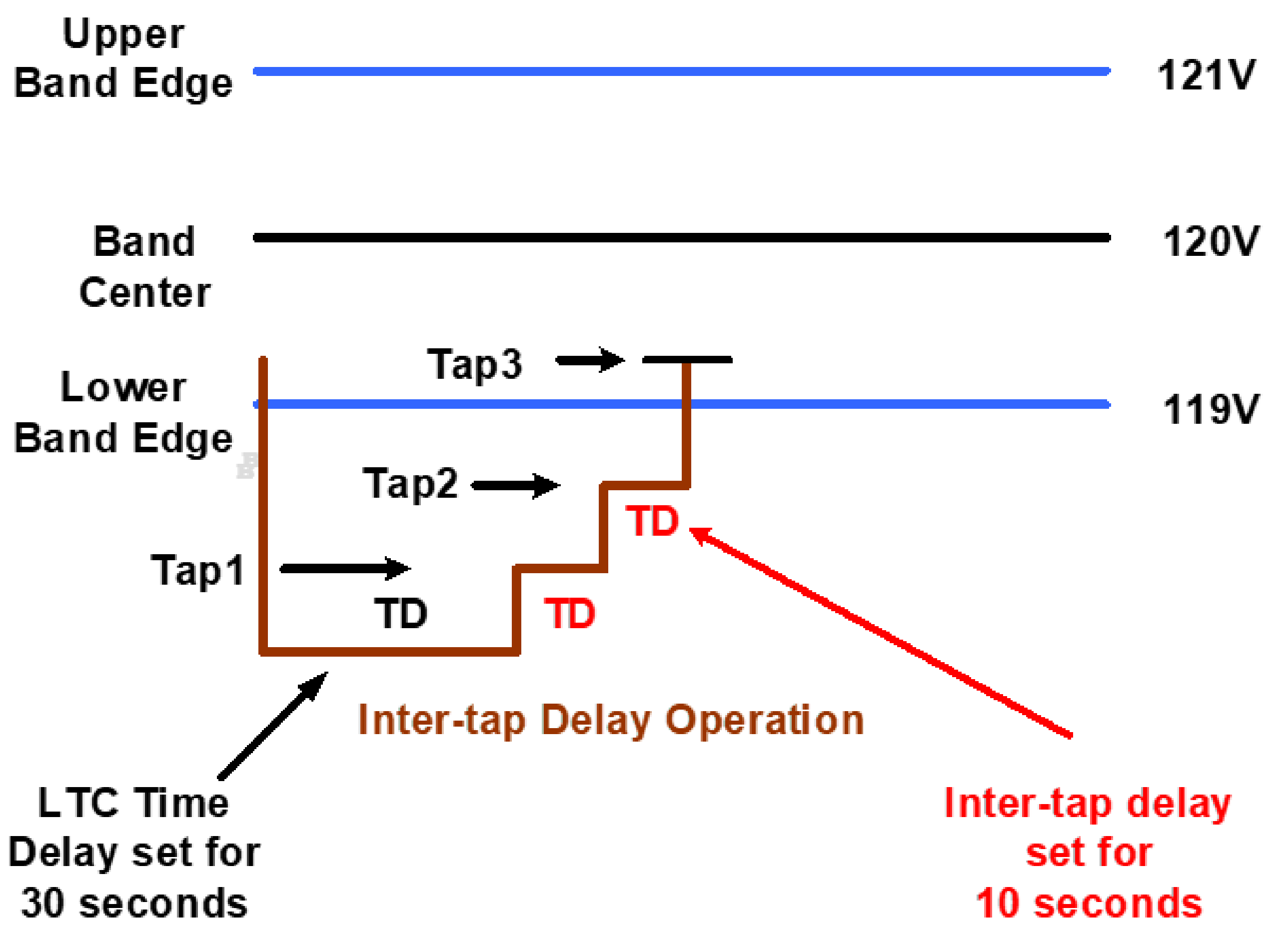
Non-Traditional Tapchanger Operations



Timing Options



Non-Traditional Tapchanger Operations



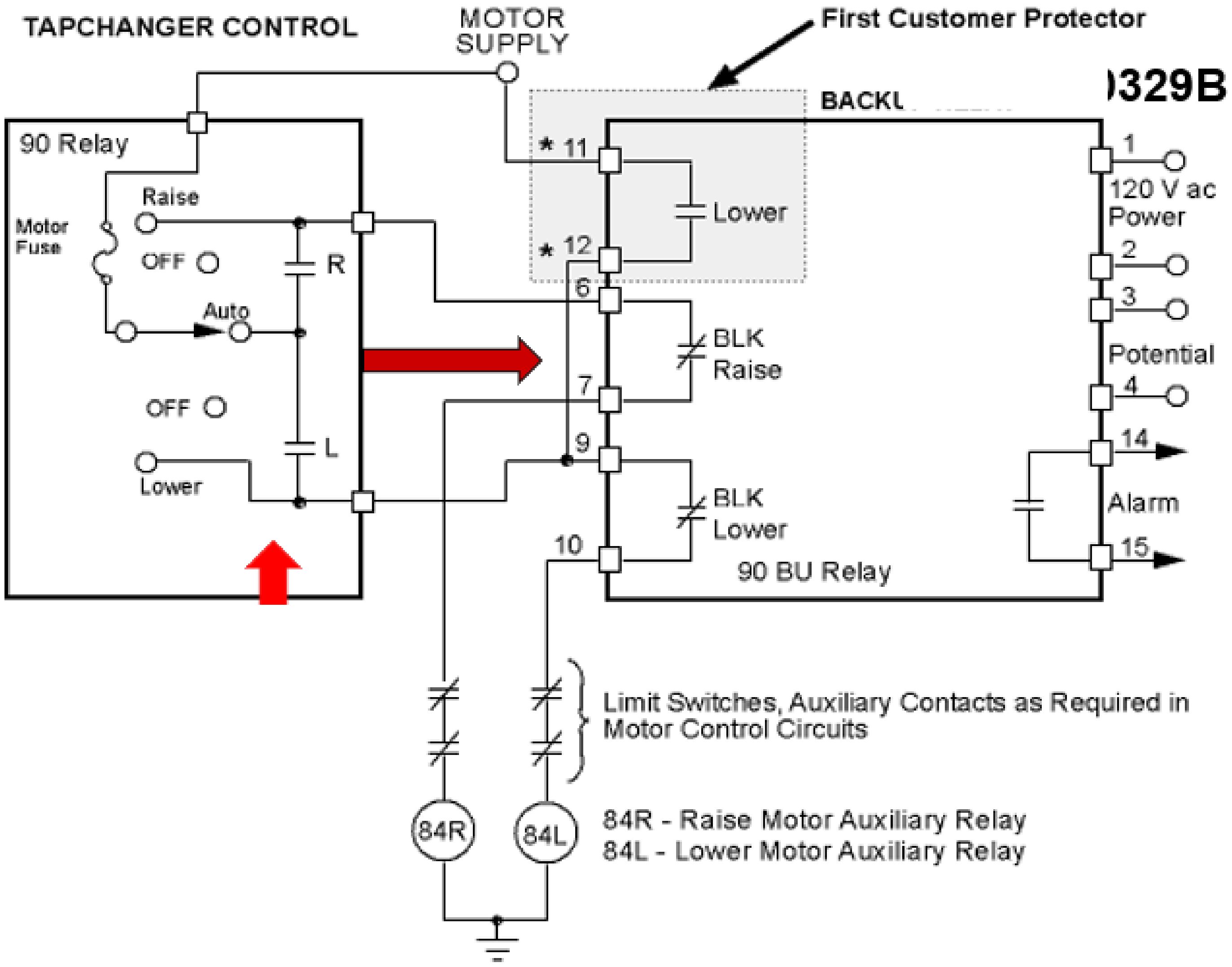
LTC Voltage Regulation Backup Supervision (90B)

Defective tapchanger controls can create either too high or too low a voltage along the line, possibly damaging customer's motors, computers or televisions.

An LTC Backup Control (90B) can be installed as a solution to these problems and has three basic main functions:

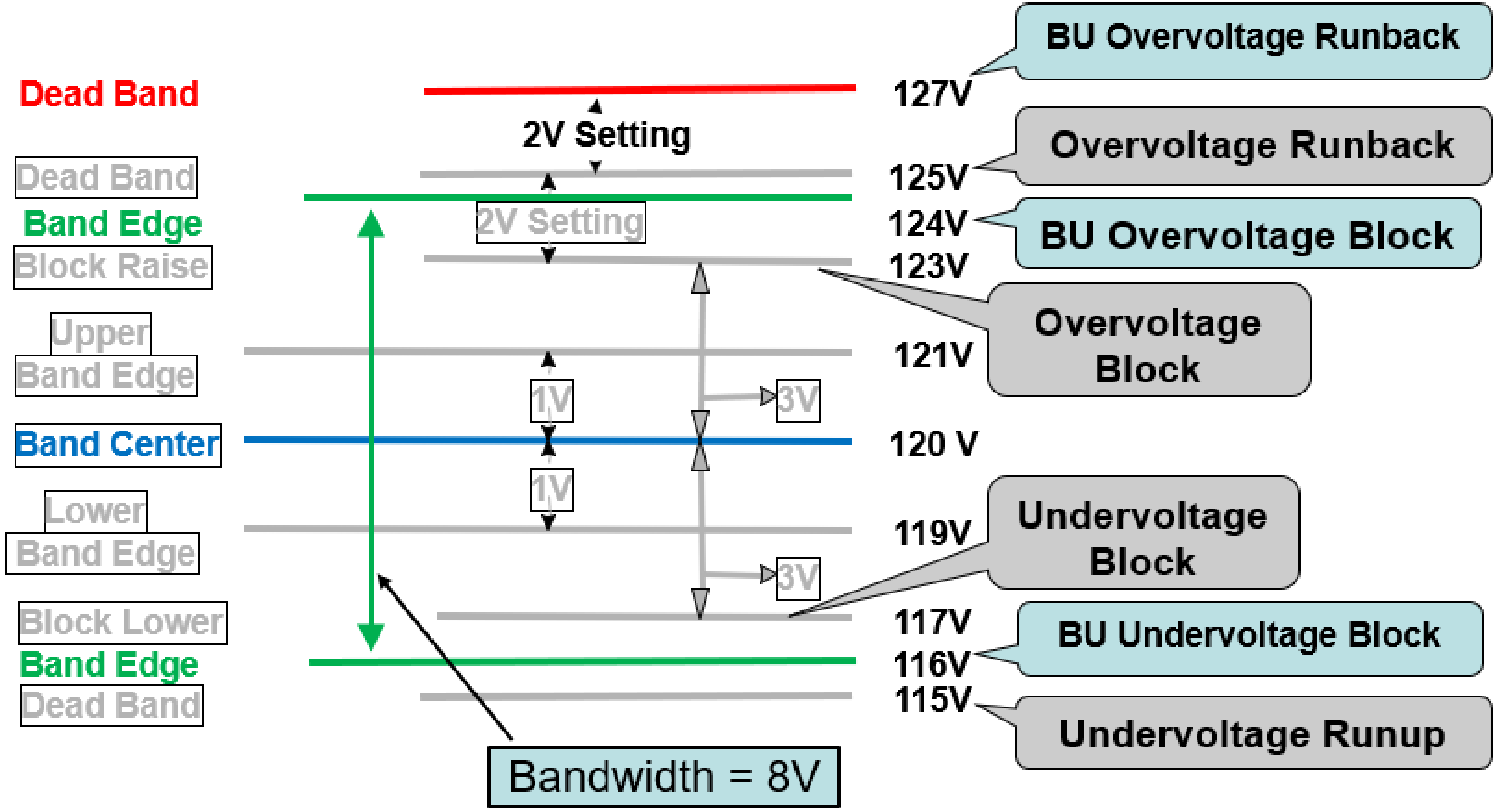
- Prevent a defective LTC tapchanger control from running the voltage outside the upper and lower voltage limits.
- Prevent the line drop compensator from raising the voltage too high under full load or overload conditions.
- Lower the voltage if the regulated voltage goes above the Block Raise setpoint by a fixed bandwidth,

Tapchanger Control Interconnections to LTC Backup Relay



* NOTE: If first customer protection is not required delete these connections.

Blocks and Runbacks with Backup Device



In Conclusion

As we have discussion throughout this presentation the featured design and applications involving load tap changing transformers illustrates the importance of their respective design, mechanical operations, voltage regulation principals and monitoring devices that are critical for maintaining utility and system voltage stability along the power grids serving our customer, industrial and commercial expectations.

QUESTIONS AND ANSWERS

BECKWITH ELECTRIC

- # REFERENCES:

MPScholar. *Transformer Protection and Maintenance* (2025, June 18)

https://www.monolithicpower.com/en/learning/mpscholar/ac-power/transformers/transformer-protection-and-maintenanc

Kapli Singh (2025 June 18) *Operation and maintenance of Transformer*
https://www.slideshare.net/slideshow/operation-and-maintenance-of-transformer-88240710/88240710#6

UTB Transformers (2024 October 24) *Load Tap Changers Maintenance for Substations: Ensuring Grid Stability and Longevity*

https://utbtransformers.com/load-tap-changers-maintenance-for-substations-ensuring-grid-stability-and-longevity

Edvard Csanyi (2017 September 2nd) Electrical Engineer -Energy and Power 4 Essential Features of Transformers On-Load Tap Changer (OLTC)

https://electrical-engineering-portal.com/4-essential-features-of-transformer-on-load-tap-changer-oltc

Waukesha Electric Systems (SCRIBD) *Waukesha LTC Theory*
https://www.scribd.com/document/359002359/Waukesha-Ltc-Theory

Elie Tawil P.E. LEED AP (CEDengineering) (2025 June 18) *Introduction to Transformers Course No: E05-013*

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cedengineering.com/userfiles/E05-013%20-%20Introduction%20to%20Transformers%20-%20US.pdf

Alex Roderick (2021 May 25th) EE Power -Constructing and Operating an Autotransformer
https://eepower.com/technical-articles/constructing-and-operating-an-autotransformer

HUBBELL

REFERENCES:

Hitachi Energy: (2025 July 12) *Conventional on-load tap changers*
https://www.hitachienergy.com/us/en/products-and-solutions/insulation-and-components/transformer-insulation-components/tap-changers/conventional-on-load-tap-changers

Steve Skinner (2017 August 23rd) Doble Engineering-Understanding Load Tap Changers
https://www.doble.com/understanding-load-tap-changers

Dynamic Ratings (2025 July 12) *Transformer Monitoring*
https://www.dynamicratings.com/solutions/transformer-monitoring/

Maddox (2023 May 22nd) *Transformer gauges, indicators and monitoring devices*
https://www.maddox.com/resources/articles/transformer-gauges-indicators-and-monitoring-devices

saVRee (2025 July 12) On Load Tap Changer (LTC)
https://savree.com/en/encyclopedia/on-load-tap-changer-ltc

Daelim (2025 June 27th) What Is An OLTC Transformer and How Does It Work?
https://www.daelimtransformer.com/what-is-an-oltc-transformer-and-how-does-it-work.html

Reinhausen (2025 June 27th) *On-load tap-changers for power transformers*
https://www.reinhausen.com/newsroom/mr-knowledge-base/tap-changer-basics

Science Direct (2025 July 5th) *On-Load Tap Changer*
https://www.sciencedirect.com/topics/engineering/on-load-tap-changer

Electrical Topic (2025 July 5th) OLTC- On Load Tap Changer transformerTypes, Parts, Working Procedure.
https://electricaltopic.com/OLTC.html

REFERENCES:

Maddox Transformer (2023 June 9th) *What are transformer voltage adjustment taps?* *https://www.maddox.com/resources/articles/transformer-tap-changers-and-voltage-adjustment-taps*

Dharam Vir -Waukesha (2024 August 15th) DETC/LTC Applications for Voltage Regulation efaidnbmnnnibpcajpcglclefindmkaj/https://www.prolec.energy/wp-content/uploads/2024/08/Tap-Changers.pdf

TestGuy (2021, December 6th) Transformer Tap Changers: Basic Principles and Testing Explained https://wiki.testguy.net/t/transformer-tap-changers-basic-principles-and-testing-explained/63/1

Voltage Disturbance (2021 December 7th) TRANSFORMER TAP CHANGER: HOW TO SELECT TRANSFORMER TAPS?

HTTPS://VOLTAGE-DISTURBANCE.COM/POWER-ENGINEERING/TRANSFORMER-TAP-CHANGER-HOW-TO-SELECT-TRANSFORMER-TAPS

ASP (2025 March 10th) What is an Off-Load Tap Changer (DETC)

https://www.appareils-precision.fr/sp_faq/what-is-an-off-load-tap-changer

Weschler Instruments (2022 October 27th) LOAD TAP CHANGER OPERATION AND MONITORING. HTTPS://WWW.WESCHLER.COM/BLOG/LOAD-TAP-CHANGER-OPERATION-AND-MONITORING