



Technical guide

Type VRLTC™ load tap changer

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General information

ABB designed, developed and will manufacture the type VRLTC load tap changer (LTC) at its facility in Alamo, Tennessee. The LTC meets all of the required specifications according to IEEE C57.131 and IEC 60214. The LTC is an on-tank, vacuum reactance type suitable for either automatic or manual control.

Three major components make up the LTC: the tap changing components, the driving components, and the decision making/monitoring components. The tap changing components are contained in an oil-filled steel tank. The transformer's tap leads and preventive autotransformer (PA or switching reactor) leads are connected to the back of the LTC terminal board. The driving and decision-making components are contained in a separate steel air compartment mounted below the oil-filled tank with a drive shaft connecting it to the tap changer.

The drive motor is a digitally controlled servo motor which precisely responds to the commands from the digital drive. Cam switches and electromechanical relays are not used in this tap changer. The entire system is monitored and controlled by the Tap Logic Monitoring System (TLMS™) mounted in the motor compartment.

The components of the tap changing circuit are:

- The preventive autotransformer - a separate device mounted inside the transformer which provides the switching impedance
- The tap changing module - consists of the tap selector and reversing switch
- The load switching module - consists of the by-pass switch and the vacuum interrupter (VI)

These components work together so that the transformer load is not interrupted at any time during a tap change operation.

Tap changer type	VRLTC-1500/25
Operating voltage phase-to-phase and to ground (maximum)	up to 25 kV
Design	3-phase, preventive autotransformer (reactor) with vacuum interruption
Tapping Arrangement	Plus/Minus or Coarse/Fine or Linear
Three phase kVA of regulation	72,000 kVA
LTC through-current	1,500 A
Tap-to-tap voltage (V_T)	1,000 V
Impulse withstand voltage (full wave) phase-to-phase and to ground	150 kV
Power-frequency test voltage phase-to-phase and to ground	50 kV rms
Impulse withstand voltage (full wave) across tap range (V_R)	75 kV
Power-frequency test voltage across tap range (V_R)	26 kV rms
Impulse withstand voltage (full wave) tap-to-tap (V_T)	45 kV
Power-frequency test voltage tap-to-tap (V_T)	15 kV rms
Physical characteristics	
Number of positions (standard)	33
Regulating winding sections	9 (8 effective)
Tank	Withstand full vacuum (± 18.0 psi)
LTC tank dimensions ¹ (W x H x D) (in.)	68 x 50 x 32
Total weight including oil ¹ (lb.)	5,250
Volume of oil ¹ (gal.)	351
Tap change speed ²	Less than 2 seconds

Table 1 – VRLTC characteristics

¹ Approximate parameters — check outline drawing for exact details.

² Less than 1 second available as special order.

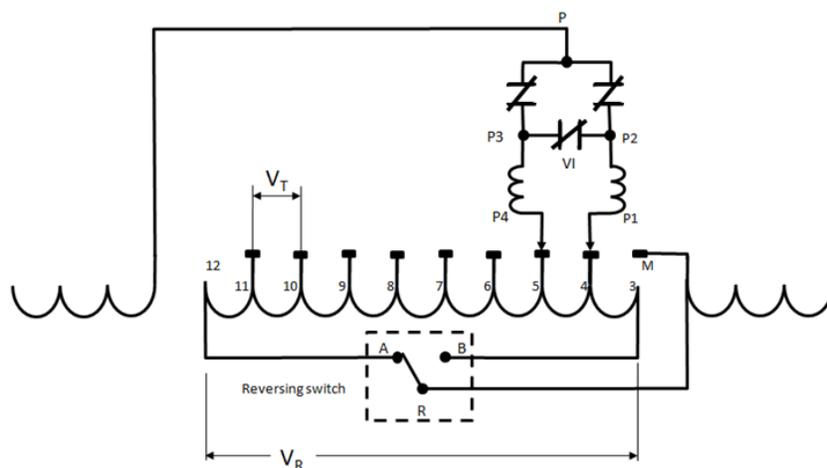


Figure 1 — LTC configuration

Switching sequence

The tap changer must sequence the opening and closing of its various switches and selectors such that the load current is only broken inside of the vacuum interrupter. Additionally, the flow of electricity out of the transformer must not be interrupted. The following is a description of a tap changing sequence:

Step 1: Steady state condition with tap changer set on a bridging position number 15L. The vacuum interrupter is closed. Both by-pass switches are closed. The PA windings are connected in series and the voltage at their midpoint is one-half of the voltage per tap section. Circulating current flows in the PA. The load current flows through the two selector switches and the two by-pass switches.

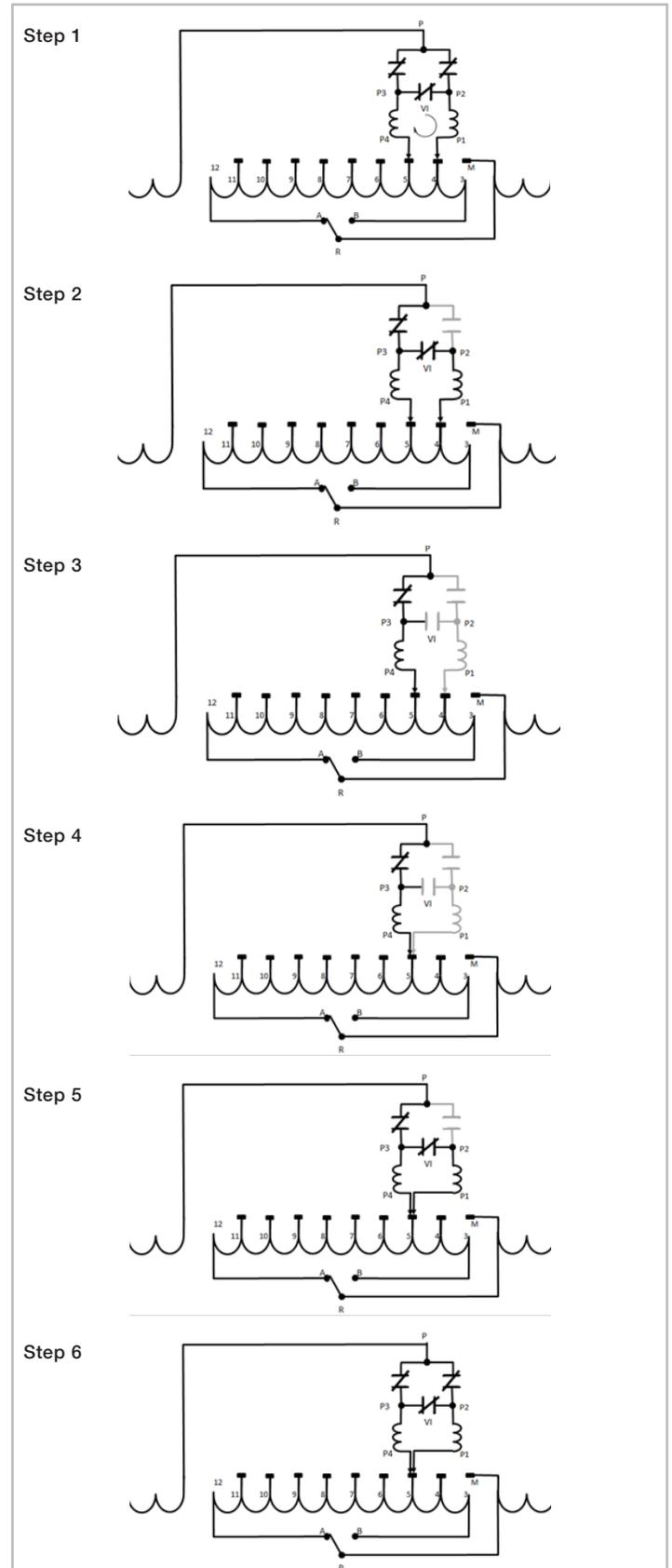
Step 2: The start of a tap change. The P2 by-pass switch opens. The load current flows through the two selectors, through the PA windings, through the vacuum interrupter and through the P3 by-pass switch.

Step 3: The vacuum interrupter opens and breaks the load current that was flowing through the P1 selector and PA winding. All of the load current now flows through the left side of the circuit.

Step 4: The P1 Selector moves to the adjacent tap position (during this step, no current is flowing through this selector).

Step 5: The vacuum interrupter closes. This allows current to again flow through the PA windings (P1-P2) and the P1 selector. Now the tap changer is on a non-bridging position with both selectors on the same tap.

Step 6: The P2 by-pass switch closes and the tap changer returns to a steady state condition. The tap changer is now on position number 14L. No current flows through the vacuum interrupter. There is no circulating current.



Connective configurations

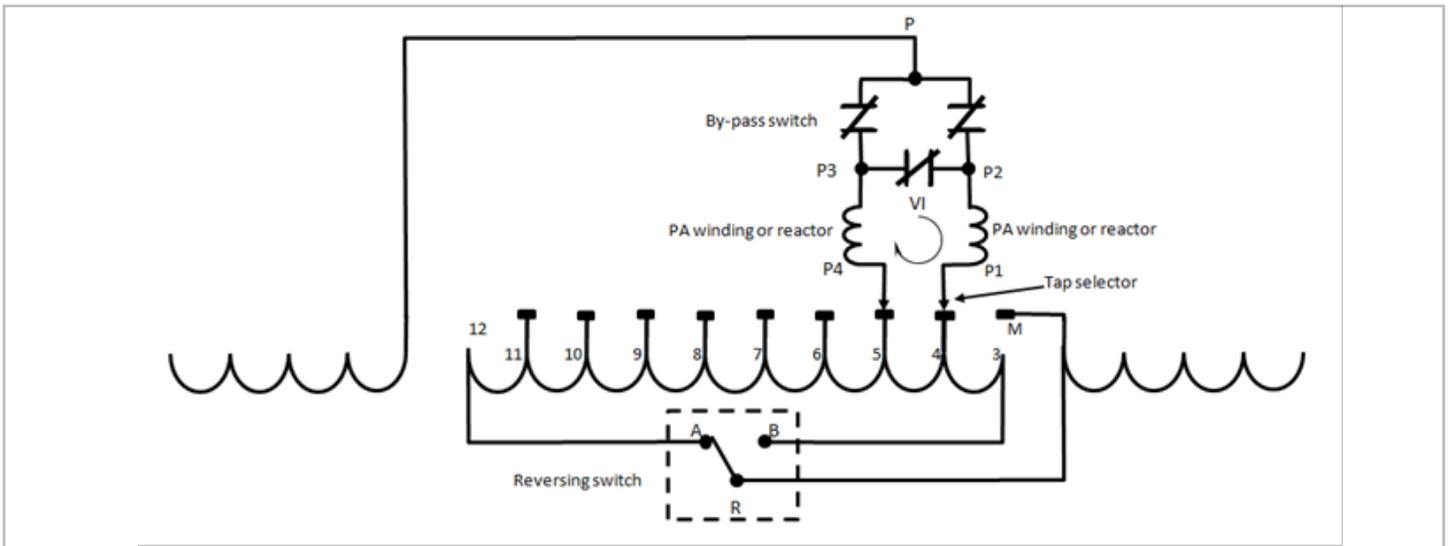


Figure 2 — Plus/minus

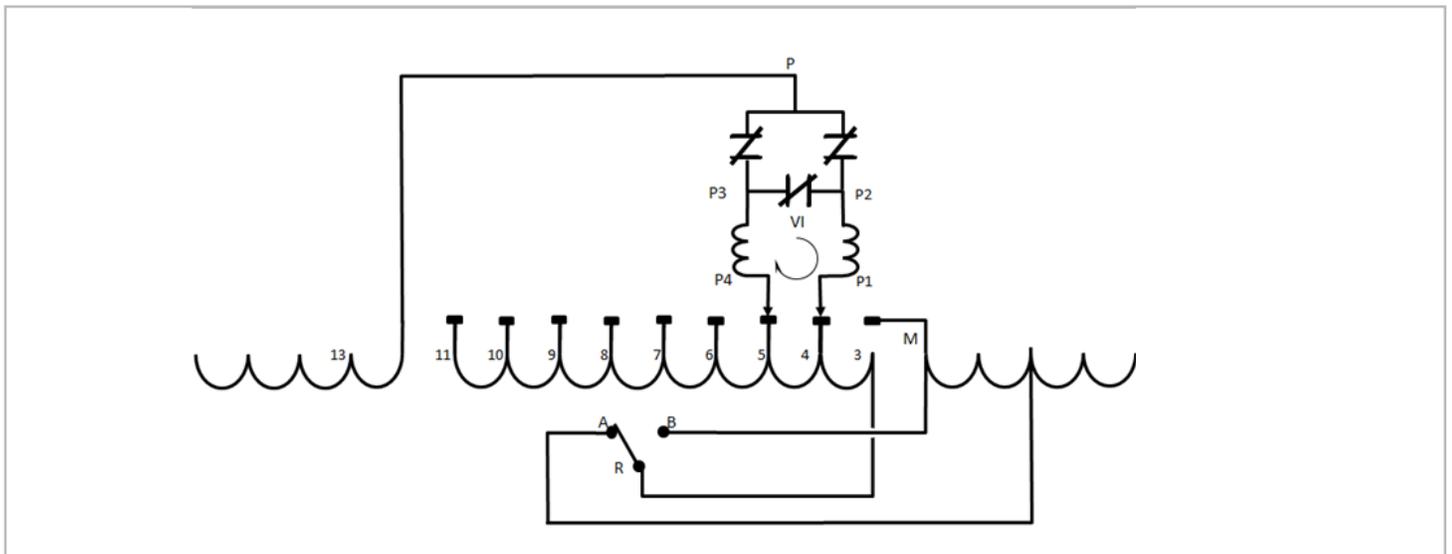


Figure 3 — Course/fine

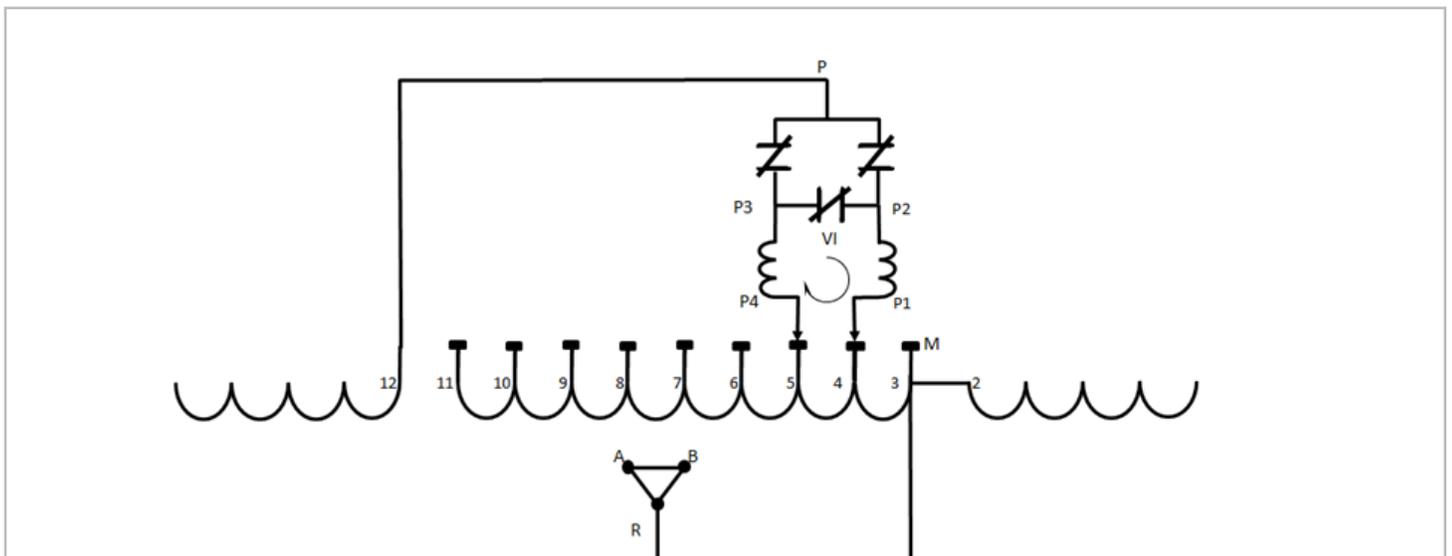
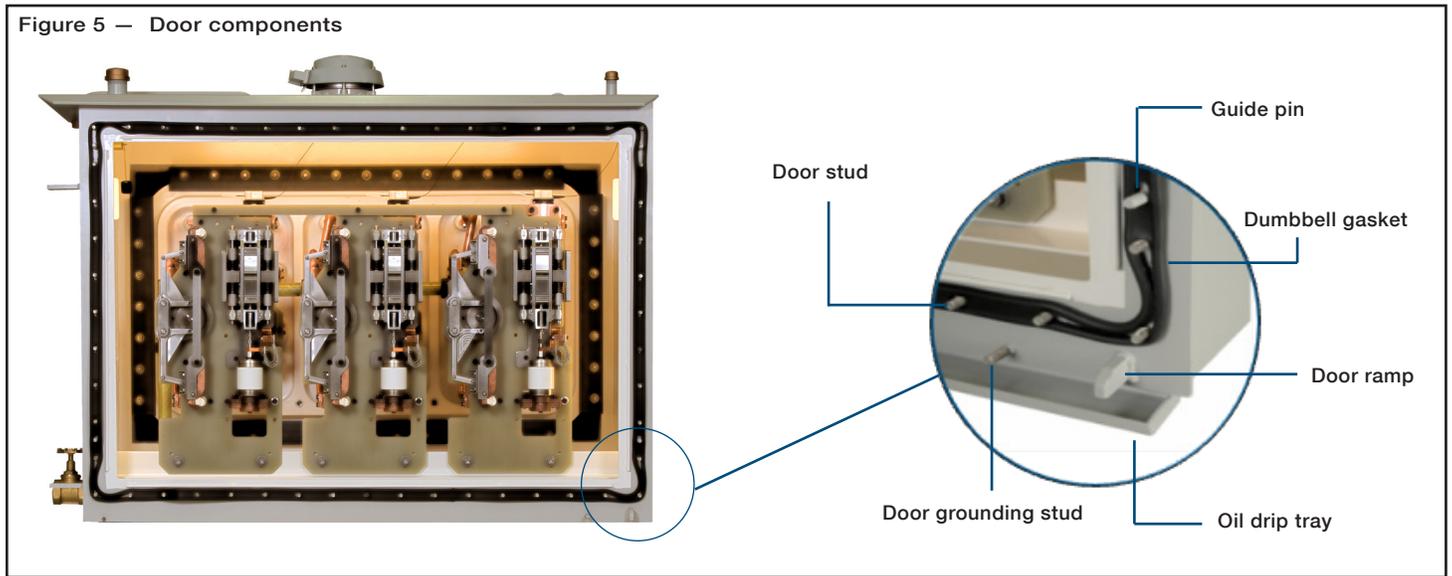


Figure 4 — Linear

Figure 5 — Door components



Tank characteristics

The tap changer is housed in a heavy duty, oil tight steel tank. The internal and external surfaces of the tank are coated with a two-part white epoxy primer. The external surface will require a final finishing coat by the transformer manufacturer. The tap changer tank has a flange at the rear for welding to the transformer. The door on the front of the tap changer is sealed with a reusable dumbbell-type gasket and there are stops to prevent over compression of the gasket. A stainless steel ramp is used to lift the door until it can align with four stainless steel guide pins prior to engaging the mounting studs. This feature insures that the door will not damage the threaded studs during the door attachment process. The tank is equipped with a retractable oil drip tray to collect the residual oil in the bottom of the tank (see Figure 5).

The standard tank is supplied with a dehydrating breather, liquid level gauge, 2-inch drain valve, and provisions for the following:

- 1-inch gravity fill port
- 2-inch vacuum fill port
- pressure relief device
- rapid pressure rise relay
- liquid temperature gauge

Terminal board

A one-piece molded epoxy terminal board (see Figure 6) acts as the oil tight barrier between the transformer and the tap changer. The transformer tap leads and the PA leads connect to the bus bars molded into the board. The bus bars have 9/16" through holes to accept standard bolts for attaching the transformer leads. The tap selector and the reversing switch assemblies are attached to this board.

During operation, the tap changer tank must be vented to atmosphere through a dehydrating breather. The tap changer tank and backboard are designed to withstand pressure differences of one atmosphere in either direction at temperatures below 125 °C. The terminal board is designed to withstand full vacuum at a maximum pressure differential of 18.0 psi.



Figure 6 — Terminal backboard (transformer side)

Tap selector

The tap selector consists of two sets of geneva gear driven moving contacts. The geneva gear is uniquely designed to provide more cam dwell during a tap change cycle which adds additional precision when in a locked position. The moving contacts bridge between the copper stationary contacts and the collector rings. The moving contacts of the selector switch consist of a set of independent spring loaded contact fingers. The hard copper contact fingers terminate into buttons fabricated from fine (99.9% pure) silver. The contact buttons engage the stationary copper contact bars and the stationary copper collector ring. The motion of the contacts provides a wiping action each time a contact position is changed.

Stationary contacts

The stationary contacts are substantial copper segments, which are bolted to the bus bars that pass through the epoxy backboard. The transformer end of the bus bar connects to the appropriate transformer winding lead or reactor (PA) lead. Two stationary contacts are attached to each of the nine copper bus bars (per phase). When both sets of moving contacts engage stationary contacts on the same bus bar, the tap changer is in a “non-bridging” position (see Figure 7). When the moving contact sets engage stationary contacts mounted on adjacent bus bars, the tap changer is in a “bridging” position (see Figure 8).

Reversing switch or change over selector

The reversing switch assembly is mounted above the selector switch assembly. When the transformer uses the plus/minus tap circuit configuration, the reversing switch is used to change the polarity between the regulating winding and the main winding such that the regulating winding is either added to or subtracted from the main winding. The reversing drive mechanism is coupled to the P1 selector switch geneva gear drive. As moving selector switch contact P1 moves in the raise direction from position 1L to neutral (or in the lower direction from neutral to 1L), the reversing switch operates.

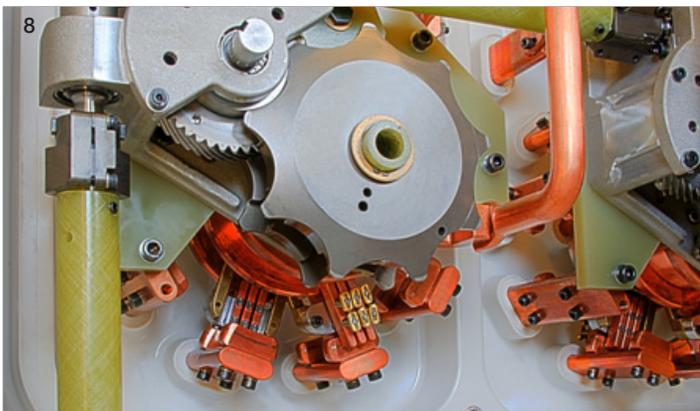
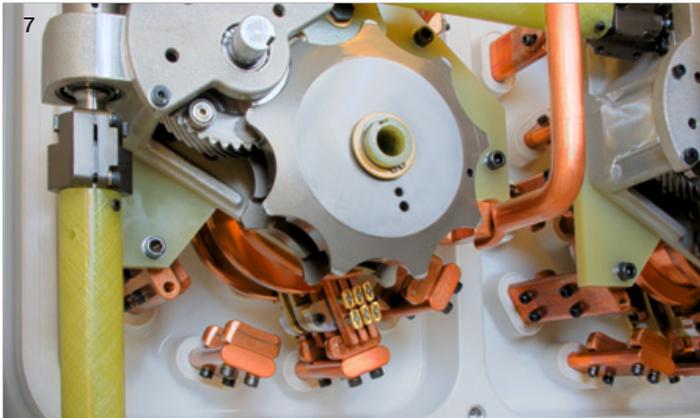
The reversing switch uses the same type of contact fingers as the tap selector. The number of fingers is dependent on the current rating of the LTC. The reversing switch never breaks load current.

When the transformer uses the coarse/fine tap circuit configuration, the reversing switch is referred to as the change-over selector. The change-over selector is isolated from the regulating winding and is connected to a fixed winding section on the main winding. This winding section plus the regulating winding can be added to the main winding in tap voltage steps, as desired.

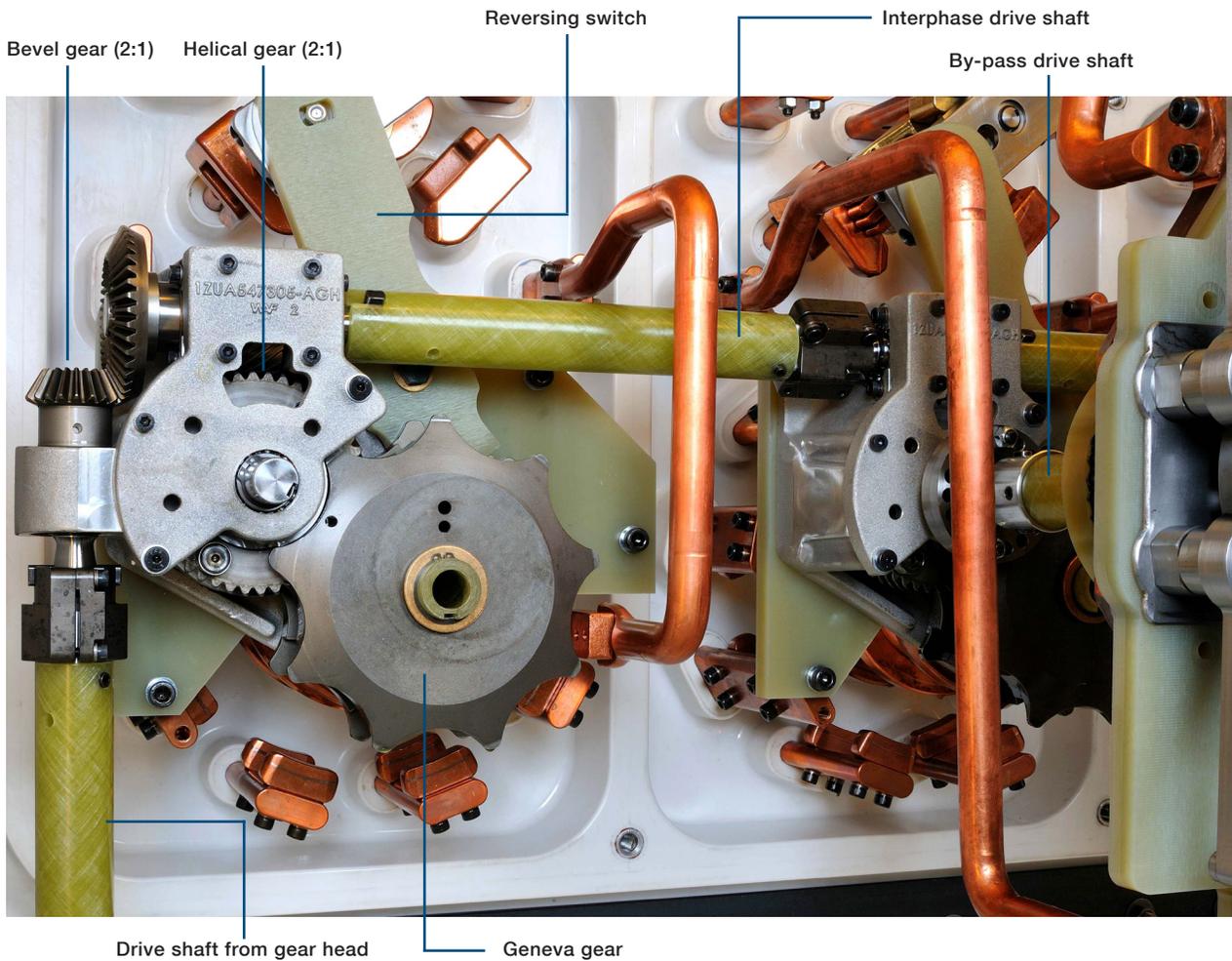
NOTE: On the transformer side of the terminal board:

- For the plus/minus configuration, the M to R connector is mounted on each phase.
- For the coarse/fine configuration, the M to B connector is mounted on each phase.

Figure 7 — Non-bridging position | Figure 8 — Bridging position | Figure 9 — Reversing switch on position A
Figure 10 — Reversing switch on position B



11 — Shaft and phase configuration



Drive shaft

The main drive shaft rises out of the motor drive enclosure and into the tap changing tank on the left side of the tap changer. Within the tap changing tank the vertical drive shaft terminates into a bevel gear set. This shaft turns the rotation 90 degrees and drives the individual tap selectors, reversing switches, by-passes, and vacuum interrupters via the gear sets attached to each phase of the tap changer. The motor drive shaft originates in the motor drive enclosure where it is the output shaft of the planetary gear set. The entire gearing system results in a 40:1 gear reduction ratio between the servo motor and tap selector such that one tap change requires 20 revolutions of the servo motor drive shaft.

By-pass switch and vacuum interrupter assemblies

Each phase of the by-pass switch assembly and the vacuum interrupter (VI) assembly is mounted on a common insulating board. These are located in front of each tap selector phase and are directly accessible once the tap compartment door is opened. This assembly is also known as the "diverter assembly". The by-pass switches are on the left side of each mounting board and the VI assembly is on the right side.

The function of the by-pass switches is to short the VI while on each position. One or the other of the switches will open to insert the VI into the circuit to be interrupted. As a by-pass contact opens, it removes the short across the VI. This will produce a minimal amount of arcing on the by-pass contact.

By-pass switch assembly

The by-pass switch assembly consists of two sets of moving and stationary contacts (Figures 13 and 14). The moving contacts engage the stationary contacts when on position. The moving contacts consist of six contact fingers. The outermost finger in each contact assembly has an arcing tip. The stationary contact also has an arcing tip. The opening and closing action of the by-pass switch is such that these arcing contacts are the first to make and the last to break. Opening the by-pass contacts diverts the current through the VI allowing it to interrupt the current through the selector switch moving contact prior to movement. The by-pass contact re-closes to short the VI, completing the tap change. Each opening and closing of the by-pass switch creates a wiping action between the moving contact fingers and the stationary contact posts.

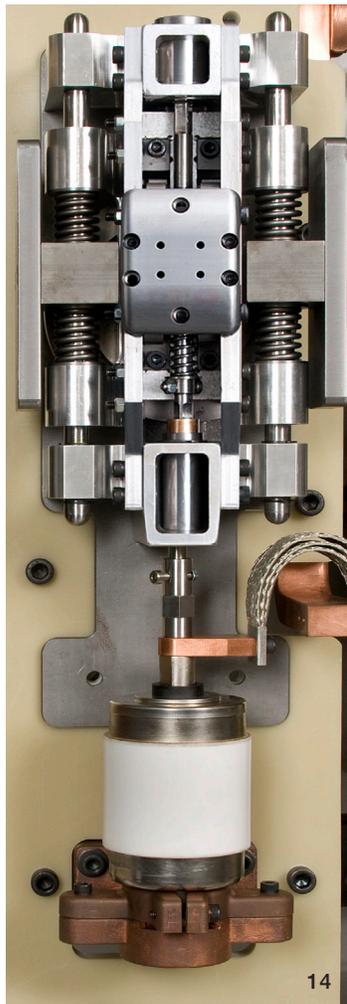
Vacuum interrupter assembly

The vacuum interrupter (VI) assembly (Figure 14) consists of the VI (Figure 15), mechanical actuators, mechanical dampers and the current sensing optical transducer (not shown). The VI is specifically designed for LTC application with internal contacts appropriate for the durability requirements of tap changer operation. As part of enhancing the durability of the VI, the assembly uses a dual damping system. This system controls

the velocity of the moving contact during opening and closing of the interrupter contacts. The VI is a sealed ceramic cylinder, which contains a set of contacts. The contacts consist of a stationary contact and a moving contact sealed from the oil by a flexible bellows and the insulating ceramic cylinder. The VI has been tested in excess of one million operations while breaking rated load current.

The VI assembly is a cam-operated, spring-driven mechanism. The spring-operated mechanism impacts the shaft and piston assembly which is connected to the interrupter's moving contact. This impact action provides the necessary force to open the contacts and control the opening velocity to complete the operation. When the interrupter reaches its full open position, it is latched in place until the selector switch changes taps. The spring loaded design also incorporates a mechanical direct-drive that will open the contacts if they have welded severely enough not to open normally. Upon completion of the selector switch movement, the VI closes under the force of atmospheric pressure, the head of oil against the moving contact bellows, and the spring force applied against the closed contacts. The closing speed is also controlled by a dashpot.

Figure 12 — By-pass switch closed | Figure 13 — By-pass switch open | Figure 14 — Vacuum interrupter module
Figure 15 — Vacuum interrupter mechanism



Current detector module

The current detector module detects current flow through the VI. Current flow through the VI is only appropriate during certain portions of the tap changing sequence; at other times, current flow indicates that a problem exists. The current detector module transmits this information via light pulses through fiber optic cable to a differential signal processor, which is located at the bottom of the tap changer compartment. The signal processor changes the light pulses into a differential signal and transmits it to the TLMS module (see Figure 20). The use of

a differential voltage signal is important because this type of signal is immune to disruption from the electric fields and transient disturbances that exist within the substation environment. This signal advises the TLMS module of the status of current flow, which in turn determines if current flow should or should not exist. The TLMS will take appropriate action based on the presence or absence of current.

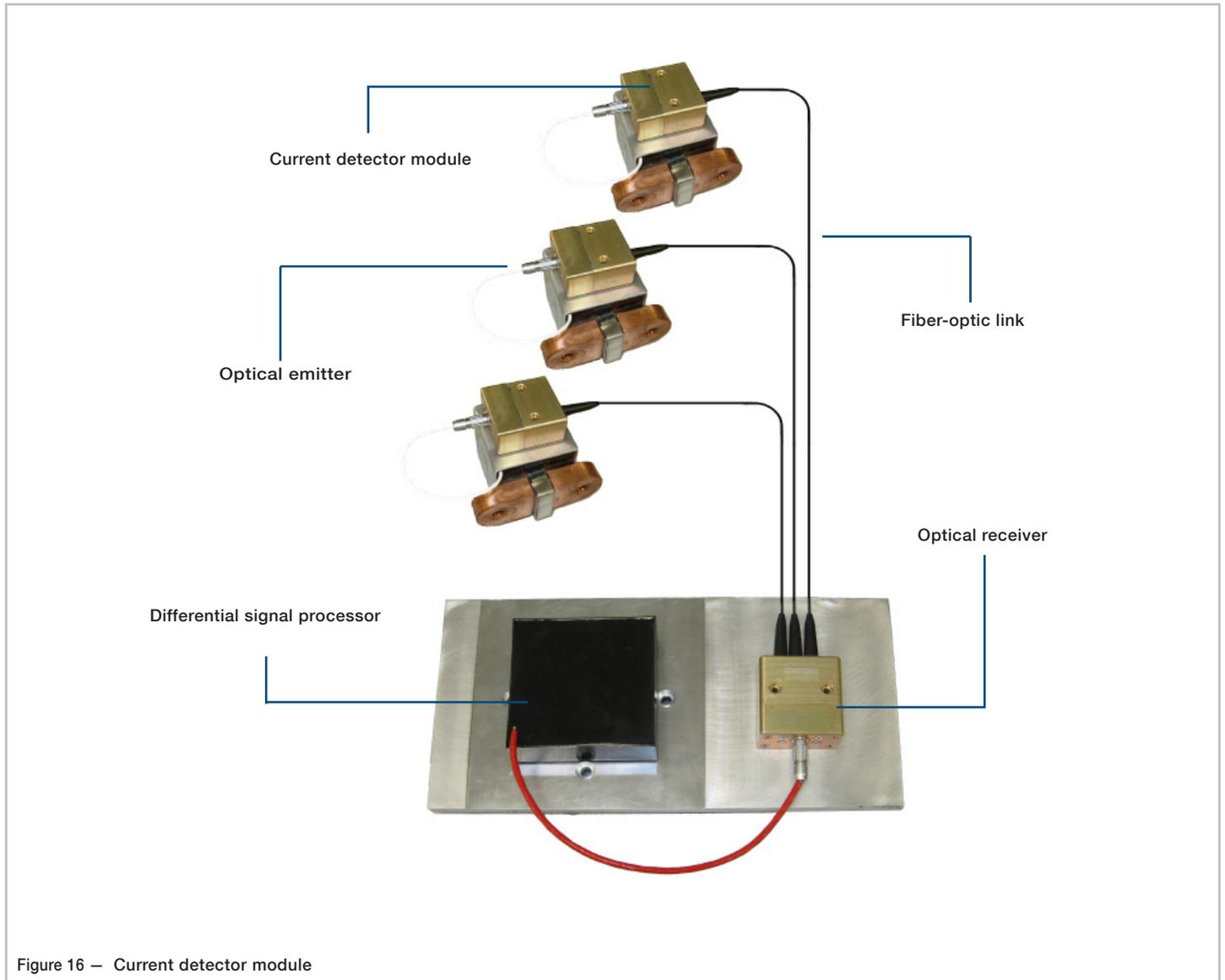
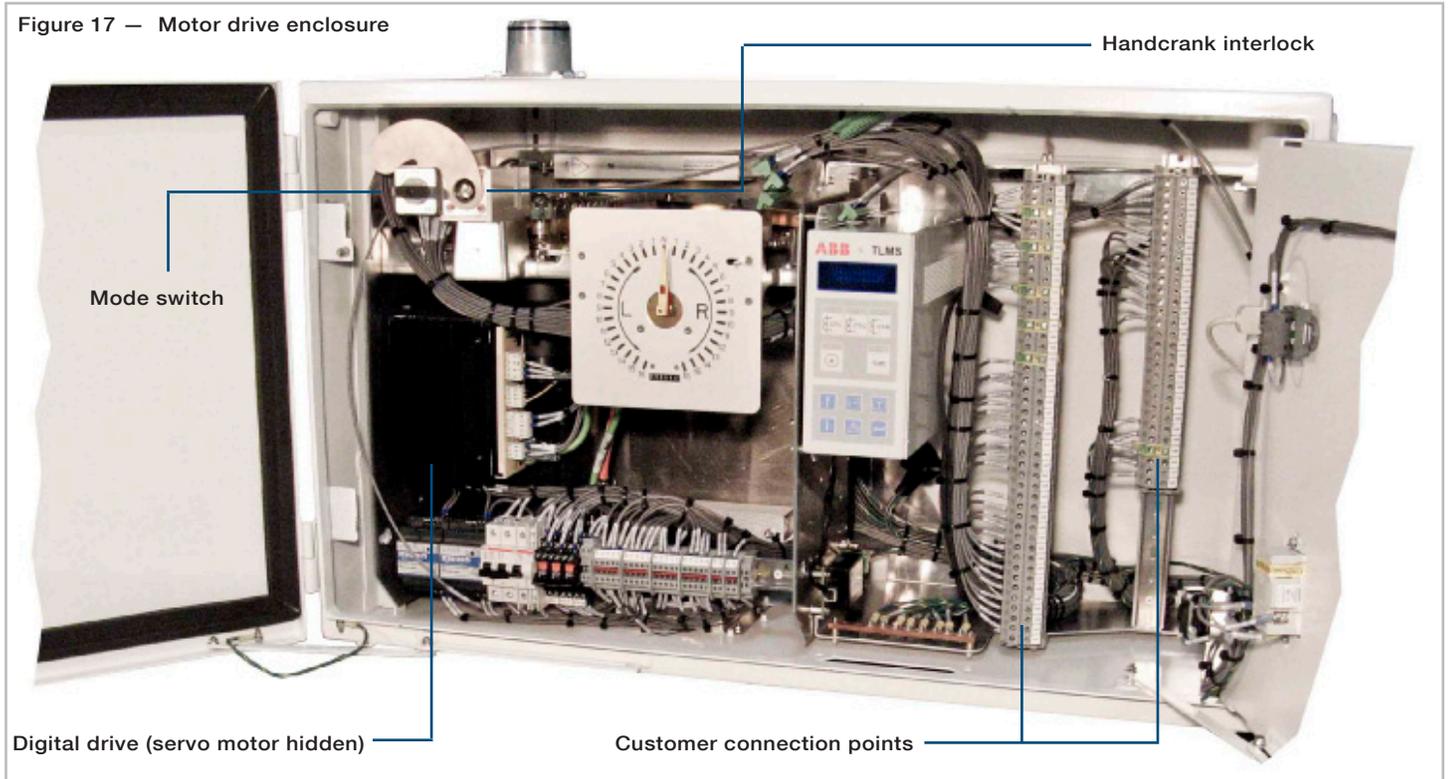


Figure 16 – Current detector module

Figure 17 — Motor drive enclosure



Motor drive enclosure

The motor drive (see Figure 17) is housed in a vented, NEMA 3R, 12-gauge steel enclosure. The internal and external surfaces are coated with a white epoxy primer, with the internal surfaces receiving a final finishing coat of paint. The external surface will require a final finishing coat by the transformer manufacturer. The enclosure can be mounted just below the oil-filled tap changer tank, up to 78-inches below the tap changer, or inside the transformer control cabinet. The outer door has a UV resistant inspection window to allow direct

reading of the position indicator and operations counter. Behind the outer door is a moveable panel (see Figure 18) that can be swung open. This panel allows direct access to the control switches, the TLMS front panel and the hand crank. This panel also creates a physical barrier between the operator and the energized and moving components of the drive system. The panel can be opened to gain access to the internal components of the drive system.

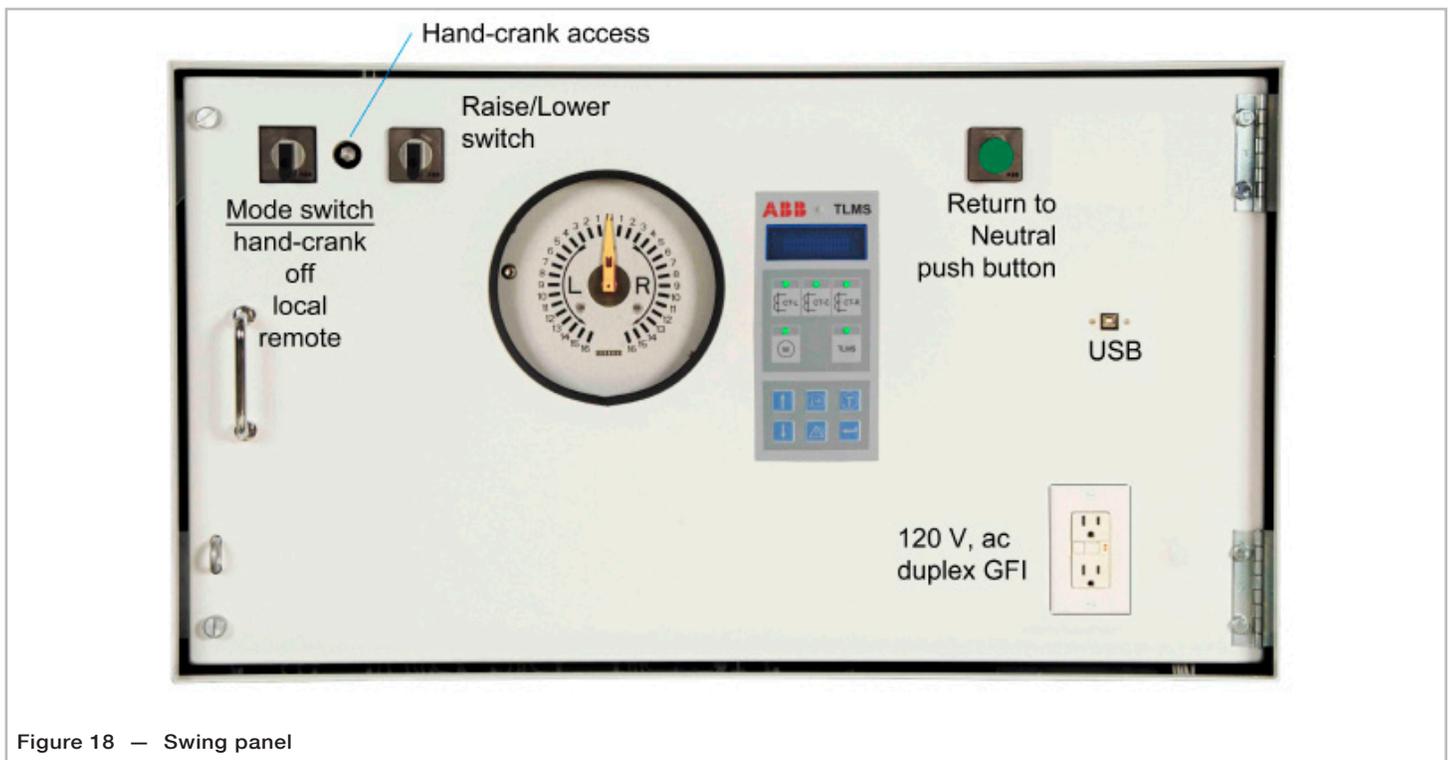


Figure 18 — Swing panel

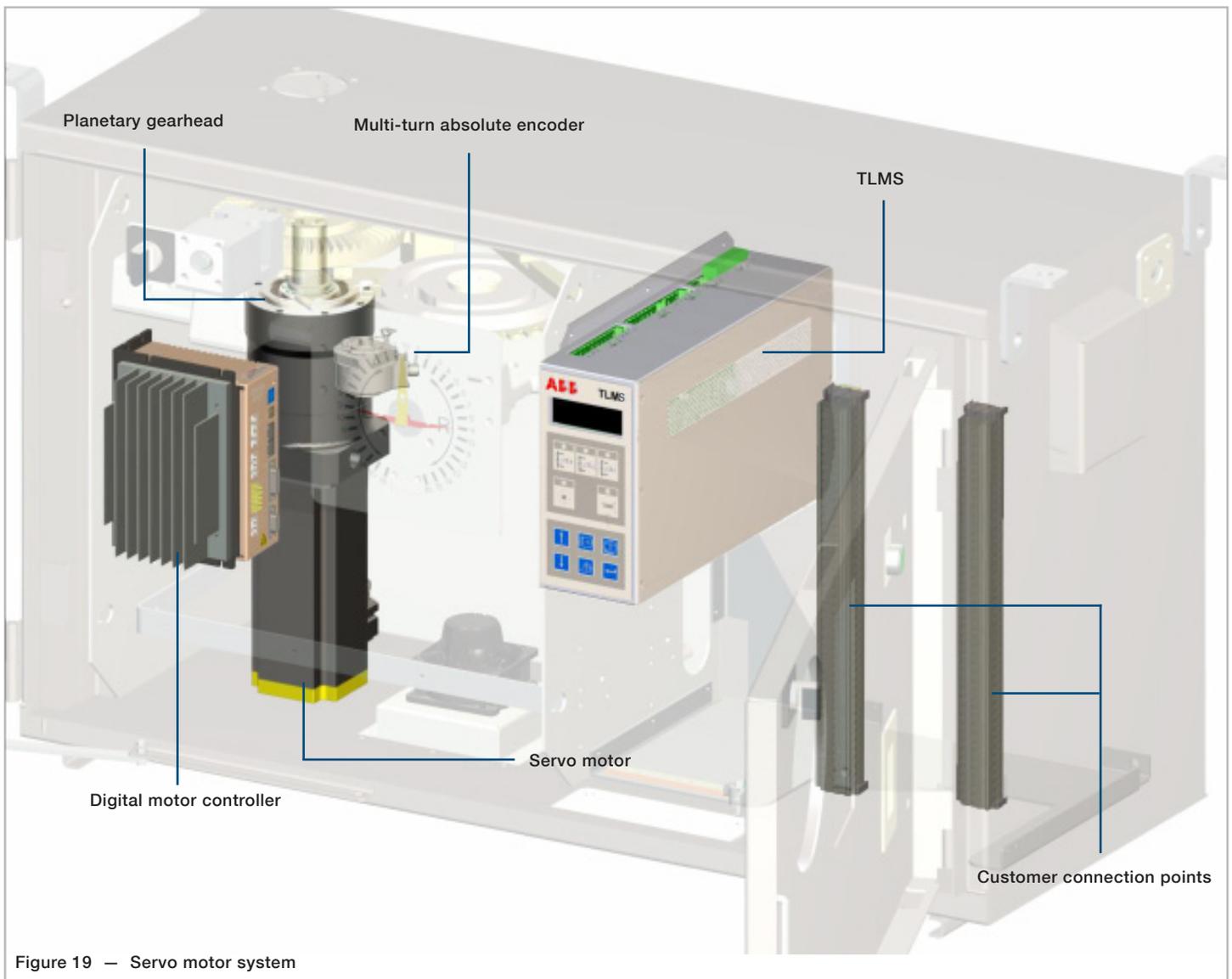


Figure 19 — Servo motor system

Digital servo motor system

The digital servo motor system consists of the servo motor, digital motor controller, multi-turn absolute encoder, and planetary gear set (see Figure 19). This system allows for precise control of the LTC. For example, the servo motor can be slowed down during certain intervals of a tap change cycle to allow the TLMS controller to evaluate operating conditions before sending the system on to the next tap position.

Servo motor

The servo motor is an AC brushless servo motor mounted vertically in the compartment and directly connected to the planetary gear head.

Multi-turn absolute encoder

The encoder uses multiple code rings with each having a different binary weighting. These rings provide a data word representing the exact position of the encoder within 0.00001 degrees. This data word is reported to the TLMS allowing it to know, at all times, exactly where the LTC is in the tap changing sequence. In the event of power loss, the encoder reports its absolute position to the TLMS immediately upon power-up without the need of indexing.

Digital motor controller

The motor controller is a digital servo drive for brushless servo motors. The drive is certified to mil-Spec 461, 704, 810, 1275 and 1399 as well as IEC 60068 and 60079. There is two-way communication between the servo motor and the digital motor controller. In addition to providing the motor power and control signals, the digital motor controller also monitors the condition of the servo motor by evaluating the motor's power demand and response. The digital motor controller communicates with the TLMS module. It will advise the TLMS module if abnormal conditions are developing within the servo motor or digital motor controller.

Planetary gear head

The motor is coupled to a sealed planetary gear system that provides a single stage 10:1 reduction ratio. This reduces the torque output requirements of the motor and the current output requirements of the servo amplifier. The resulting combination of motor and gear head provides a maintenance free, low-backlash system. The output shaft of the gear head rotates two revolutions per tap change.



Figure 20 — TLMS

Decision making and monitoring

The type VRLTC load tap changer is digitally controlled and as such, does not use many of the traditional analog control devices such as cam switches. The key component in the digital system is the Tap Logic Monitoring System (TLMS) monitoring and control module mounted inside the motor compartment. The TLMS module provides the intelligence for the tap changer. It receives and analyzes data from the servo motor controller, the multi-turn absolute encoder, the environmental sensors and the VI current sensors. It issues commands based on its analysis. Remote user access to these commands, alerts and warnings from the TLMS module is provided through terminal blocks mounted in the motor compartment. The TLMS module has a vacuum fluorescent display screen, indicator LED's and push buttons all of which allow operators to interact with the TLMS system.

Monitoring functions

The TLMS module monitors the condition of the VIs via the current flow data from current detector modules. The vacuum fluorescent display will indicate that an alarm or alert condition has occurred or that all is normal. Six push buttons allow user-friendly navigation so that other critical tap changer information may be viewed (for detailed information regarding working with the TLMS module, please consult the TLMS Instruction Manual).

If a VI malfunctions, the TLMS module will issue VI failure commands to stop a tap change, return it to the previous tap setting, lock out the tap changer and issue an alarm.

The condition of the drive components are monitored via data that it receives from the servo motor controller. The TLMS module will register an alarm and lockout the LTC on position if there is any impending failure of the drive system.

The TLMS module will also issue alert signals to warn of non-standard conditions within the motor drive or the TLMS before these conditions deteriorate to the point of tap changer malfunction and lockout of the LTC.

Recording functions

The TLMS module records, time-stamps and retains information about each tap change and associated environmental conditions. This information can be downloaded to help understand actual field operating conditions.

Communication functions

The TLMS module is capable of communicating via three different means: relay outputs, tap position indicators and USB. Relay outputs consist of raise/lower indicators, alarms, and alert conditions. Dual 4-20 mA outputs, which are self powered up to 24 volts, are used to indicate tap position. This signal can be fed directly to the Beckwith 2025 C eliminating the need for a position transducer, e.g., Selsyn, and signal conditioning components in the control cabinet. USB connectivity allows for event log downloads.

Maintenance and inspection features

The combination of the servo motor, servo motor controller and the TLMS module will readily permit the following actions while performing maintenance or inspection at the transformer.

Jog mode

The tap changer can be put into a slow motion jog mode using the TLMS module. In this mode, the tap changing action is greatly slowed down so that the actions of all of the mechanical components can be easily observed. The tap changer can also be stopped at any point in the tap changing cycle for additional inspection.

Expandability

The TLMS design is capable of being expanded to meet the evolving data communication needs of the electric utility industry. In the future, the TLMS system will be able to transmit tap changer data such as alarms, tap position and environmental details through the following protocols: IEC 61850, Distributed Network Protocol (DNP 3.0), ST Fiber Optic Port, Modbus ASCII and RTU. This information will be able to transmit wirelessly or over existing communication networks.

Event log

The TLMS module records all tap changer events. This information can be downloaded directly from the TLMS via the USB interface. Once downloaded, the data can be analyzed for maintenance or technical purposes. At a minimum, the following data will be available: time stamp of each recorded event, every tap change (tap position, time of change, date of change), temperature and humidity in motor drive compartment, alarm data and alert data.

Return to neutral

Operating the return to neutral switch located on the motor drive cabinet panel or a remotely located switch will return the LTC to the neutral position. This feature eliminates the tedium of moving the LTC back to neutral one step at a time via the Raise/Lower switch.

Service recommendations

The elimination of many trouble prone electro-mechanical devices in favor of digital controls will eliminate just about all maintenance issues. We recommend the following schedule:

- Inspection interval - one-half million-tap changes
- Service/maintenance interval - one million tap changes.

In typical transformer service, it will take about 40 years to reach the inspection interval and more than 50 years to reach the maintenance interval. In Table 2, the number of years required to get to both the first inspection period and the first maintenance period are shown vs the number of tap changes per day.

Operations per day	Operations per year	Maintenance interval (years)	Service interval (years)
20	7,300	69	137
30	10,950	46	91
40	14,600	34	68
60	21,900	23	46
80	29,200	17	34
100	36,500	14	27
120	43,800	11	23
140	51,100	9.8	20
160	58,400	8.6	17
180	65,700	7.6	15

Table 2 — Estimated service intervals versus tap operations

Mechanical components

The output shaft of the gear head drives both the motor drive output shaft and the standard and optional support components. When the existing load tap changer standards IEEE and IEC were written, the concept of digital control was not considered. The digital control and operation of the type VRLTC tap changer renders redundant many of the electro-mechanical controls which are required by standards or by historical usage. These components include the hand crank, on tap position switch, end position switches, mechanical end stops, position indicator, and rotary position indication boards. Regarding tap position indication: the TLMS knows the exact position of the tap selectors at all times. The position can be read directly from the TLMS screen or via the position output signal from the TLMS.

The gear head and auxiliary components are mounted to a cast aluminum plate. All shafts (except the indicator shaft and the stop arm shaft) are mounted into the plate with sealed ball bearings.

Manual hand-cranking of the tap changer is possible through the 5:1 bevel gear set connected to the output shaft of the gear head. Ten revolutions of the hand crank move the tap changer one position. Access to the hand crank mechanism is blocked during normal operation. In order to access this feature, the mode switch must be turned to hand-crank mode. Handcranking is rendered redundant by the jog feature of the TLMS.

The shaft that drives the on-tap position cam and the multi-turn absolute encoder is connected to the output of the gear head through a 2:1 spur gear reduction. This shaft rotates 360° per tap change operation.

A geneva mechanism is used to operate the other mechanical components and is driven by a pin connected to the single turn gear. While the tap changer is on a tap position, the geneva driver pin is engaged in the slot. This method of operation allows motion of the geneva gear upon immediately beginning a tap change operation. This implementation also results in a two step motion during each tap change, with rotation of the geneva gear halting in the middle of each operation as it engages the locking surface.

The end position switches and the mechanical end stops are both driven by a cam mounted to the geneva gear. The outer surface of the cam triggers the end position switches, while the mechanical end-stops are driven by a closed track cam and cam follower. These switches are not used to control the position of the servo motor drive system. Rather, these are used for customer signaling only.

Electrical engineering information

The Reactor (PA or preventive autotransformer)

The preventive autotransformer (PA) is a gapped core reactor which provides the switching impedance for a reactance type LTC. It is part of the transformer design and is located in the transformer oil compartment as an auxiliary device. It is furnished by the transformer manufacturer. It must meet the following requirements:

- The P1-P2 and the P3-P4 coils must be insulated from each other by 110 kV BIL.
- With the LTC on a bridging position, the RV winding tap voltage should produce a PA circulating current, ideally, of 50 % of the transformer rated current.

Tie-in resistors

When the reversing switch or change-over selector operates, the tapped winding is disconnected for a short time. The voltage of that winding is then determined by the voltage of and the capacitances to the surrounding windings or tank wall/core. For certain winding layouts, voltages and capacitances, the capacitive controlled voltage will reach a magnitude of 20 kV for the change-over selector. In these cases potential controlling resistors, so called tie-in resistors, should be connected.

The tie-in resistor is connected between the middle of the tapped winding and the connection point on the back of the LTC compartment. This means that power is continuously dissipated in the resistors, which adds to the no-load losses of the transformer. Therefore, the resistors must also be dimensioned for the power dissipation.

Type tests

The VRLTC tap changer and all of its components have been life tested for durability. ABB has tested the tap changer in accordance with the following International Standards:

- IEEE C57.131
- IEC 60214

In addition to these required design tests, the servo drive system and the TLMS monitoring and decision making system have been life tested according to ANSI C37.90 and EN 61000.

The specific tests that were performed as well as a summary of the results are enumerated in the table.

	Test	Description
Tap changing compartment	Mechanical endurance	100 operations @ -25 ° C 2,000,000 operations @ 80 ° C
	Short circuit	Reversing switch 25 kA (2 sec RMS), 70 kA peak Selector 12.5 kA (2 sec RMS), 35 kA peak By-pass contact 12.5 kA (2 sec RMS), 35 kA peak
	Temperature rise	1.2 times rated load current with 50% circulating current
	Dielectric	Tap-to-tap, phase-to-phase Phase-to-ground and across the tap changer
	Breaking capacity	Tested according to IEEE C57.131 and IEC 60214
	Service duty	Tested according to IEEE C57.131 and IEC 60214
	Motor drive enclosure	Mechanical load test
Mechanical over run		Demonstrate that mechanical end stops prevent operation beyond end positions
Weather tightness		Tested to NEMA 3R and IP 44
EMC emission		Meets EMC emission requirements per IEC 61000-6-4:2006
EMC immunity		Meets EMC immunity requirements per IEC 61000-6-2:2005

Table 3 – Description of type tests

Notes

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