High-Reliability Control Device for the Load Tap-Changers

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1. Introduction

A stable source of electrical power increasingly demanded by the public has required improvements in the reliability of substation equipment. Among them, the transformer is intrinsically more reliable than switchgears, such as circuit breakers or disconnecting switches, due to its few moving parts. The load tap-changer system is the sole moving control part in a naturally cooled transformer, in which neither cooling pump nor fan is needed. The conventional motor operating mechanism for the load tap-changer, the LTC drive, is composed of cam switches for detecting position, electromagnetic contactors for on-off control of the traction motor and auxiliary relays, which cause a decline in reliability due to faulty contact and inevitable maintenance and inspection for applying oil and grease.

To solve these problems, a high-reliability control device for the load tap-changers has been recently developed to eliminate faulty contact through a contactless electronic control system and simplification of the gear mechanism.

The authors will in the following describe the high-reliability control device for the load tap-changers and its application to a gas-insulated transformer.

2. Basic Concepts and System Configuration

2.1 Basic concepts

The LTC drive has been developed to meet future requirements including the saving of manpower during maintenance and inspection, improved reliability of the device, and environmental adaptation (noise reduction). Such basic concepts are summarized in **Fig. 1**.

2.2 System configuration

Specifications and system configuration of the new LTC drive are given in **Table 1** and **Fig. 2**.

The system includes an "LTC drive box" (**Fig. 3**), in which mechanisms such as a traction motor, gears and a drive shaft and optical position sensing devices such as optical limit switches and rotary encoders are installed, as well as an "LTC drive control cabinet" (**Fig. 4**), in which control circuits such as programmable controller (PC), a drive unit with solid state relays (SSR), optical-electrical transducers, fault and state indicators and operating switches are installed.

The LTC drive box is mounted on the transformer, and the LTC drive control cabinet is an enclosed, self-standing outdoor cubicle.

Fig. 1 Basic concepts

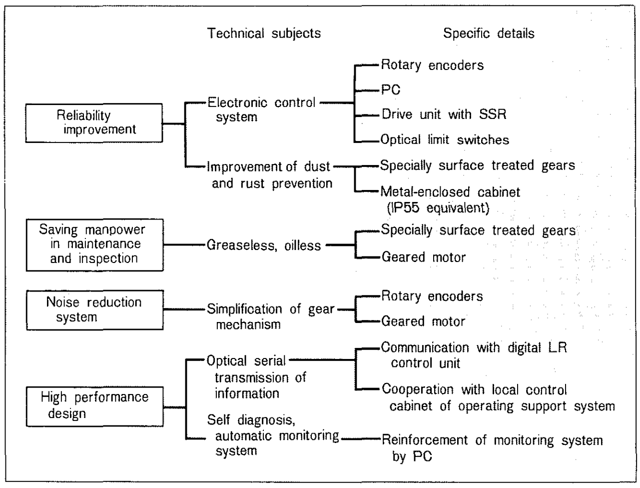


Table 1 Specifications of the LTC drive

Items	Basic specifications
Operating power supply	Three-phase AC 200 V 50/60 Hz
Control power supply	Single-phase AC 100 V 50/60 Hz and DC 100 V
Operating time of tap changing	at 50 Hz about 5 sec/1 tap changing at 60Hz about 4 sec/1 tap changing
Number of revolutions at motor operating	number of revolutions of drive shaft 1 time/1 tap changing number of revolutions of motor 125 times/1 tap changing
Number of revolutions at manual operating	10 times/1 tap changing
Rated torque of drive shaft	at 50 Hz 64.8 N-m (6.61 kgf-m) at 60 Hz 53.7 N-m (5.48 kgf-m)

Fig. 2 System configuration

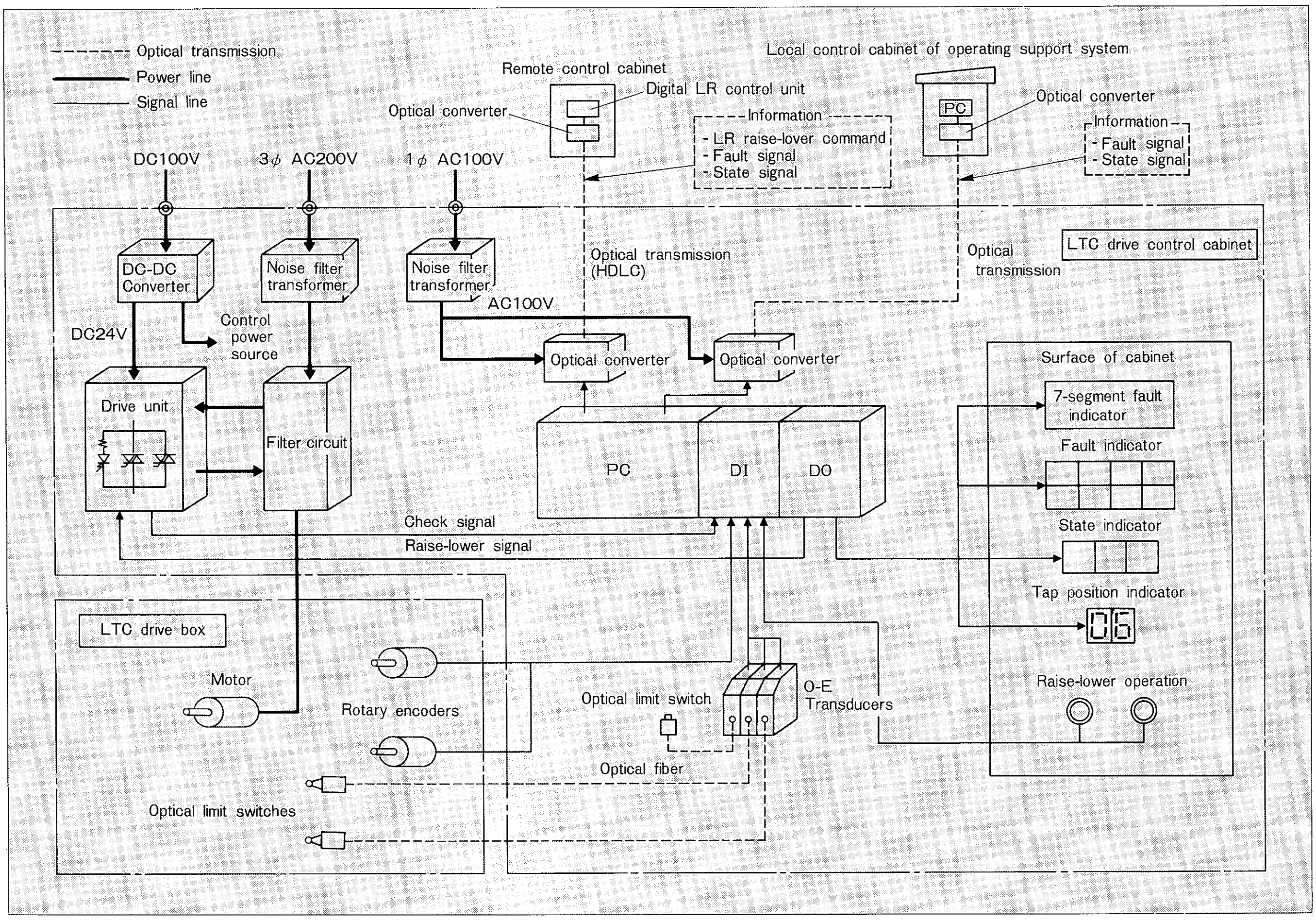


Fig. 3 LTC drive box

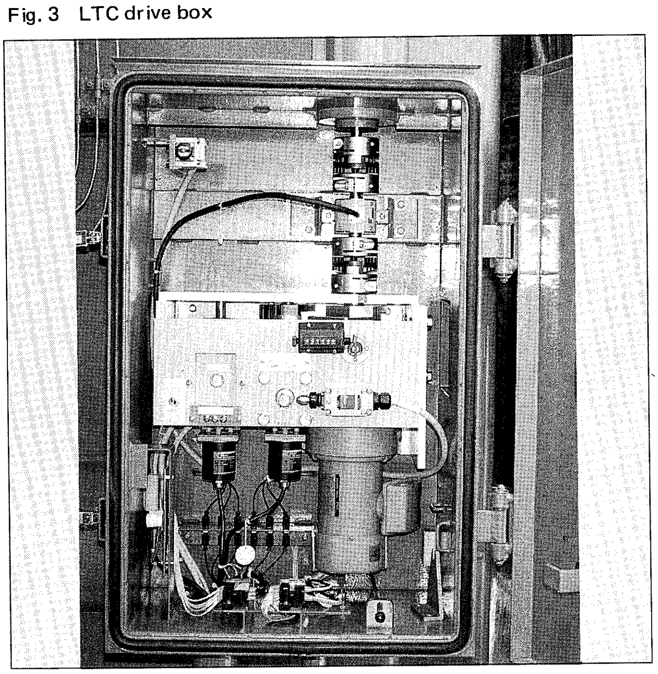
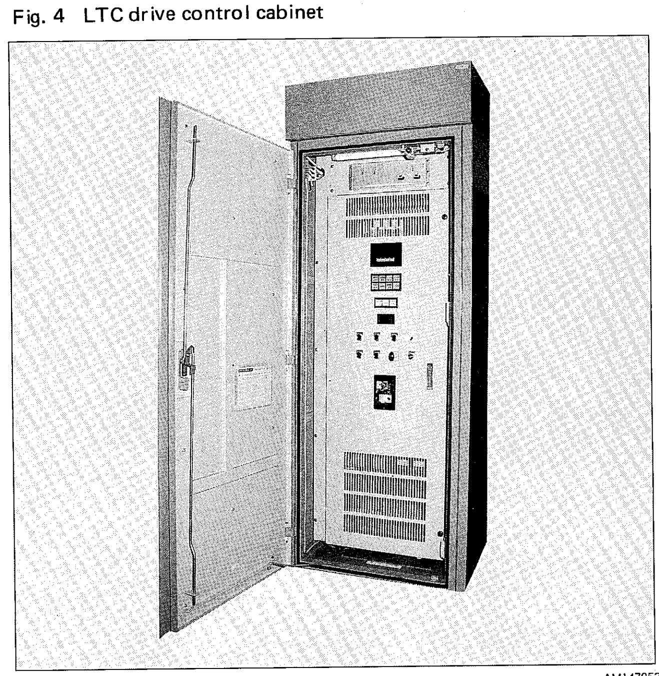


Fig. 4 LTC drive control cabinet



3. Technical Features

Features of the LTC drive include the following:

(1) Elimination of problems due to faulty contact (contactless electronic control circuit)

(2) Maintenance-free operation (greaseless and oiling-free)

(3) Noise reduction system
(4) High performance design

3.1 Elimination of problems due to fauty contact (contactless electronic control circuit)

The electronic and conventional control systems are compared in **Table 2**.

Table 2 Comparison of electronic and conventional systems

Item	Function	Electronic control system	Installed in	Conventional control system
Detection of state	Tap position Upper and lower limits of tap position	Rotary encoder (absolute type)	LTC drive box	Dial switches Mechanical limit switches
	Stop position of the revolving drive shaft	Rotary encoder (absolute type)		Cam switches
	Insertion of driving handle Opening of door	Optical limit switches		Mechanical limit switches
	Switching of local control and direct control	Optical-electrical (O-E) transducers	LTC drive control cabinet	
Operating circuit	Drives motor	Drive unit with SSR		Electromagnetic contactors
Control circuit	Sequence	PC		Auxiliary relays Timer relays

3.1.1 Rotary encoder

Absolute angle type rotary encoders are used for detecting tap position and stop position of the revolving drive shaft. The rotary encoder has no contacts such as dial switches or cam switches, and is thus free from the problems due to faulty contact. The absolute angle type rotary encorder outputs the binary code signal of the absolute position and gives correct revolving angle readings even when the electric power supply is interrupted and then restored. Further, an even parity signal is also provided for fault detection.

3.1.2 Optical limit switch

Instead of a limit switch with contacts, an optical limit switch with self-diagnostic capabilities has been utilized as an electronic control circuit.

3.1.3 Programmable controller (PC)

Electronic controllers, in the form of PCs, have been used to replace the auxiliary relays. Thus, high performance has been achieved by the automatic monitoring function and the optical transmission system, not included in the conventional LTC drive.

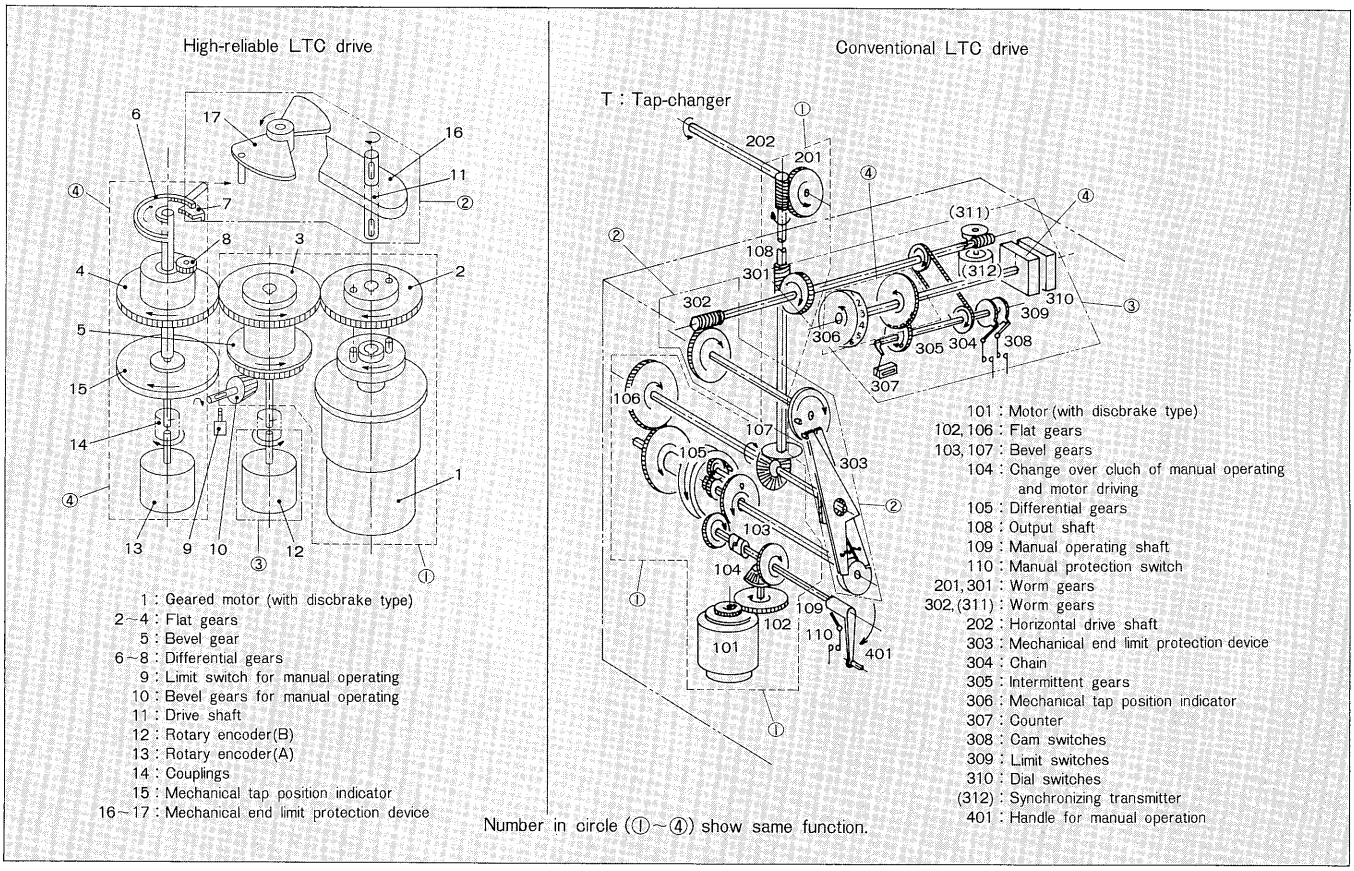
3.1.4 Drive unit

The drive unit, which consists of semiconductor logic circuits, SSRs, etc, performs on-off control of the traction motor with a raise-lower command.

3.2 Maintenance-free operation

In comparison with the conventional, rotary encoders for position detection and a geared motor have greatly simplified the gear mechanism, shown in **Fig. 5**.

Fig. 5 Comparison of electronic and conventional systems



The basic developmental concepts are as follows:

(1) Gears with low surface stress, which do not directly transmit driving torque, are specially surface-treated and thus do not require greasing-up.

(2) The mechanical coupling system is used for the mechanical clutch of the motor and transmission shafts.

(3) The reduction gears, which directly increase the driving torque, are devised with geared motor, whose gears are oil-immersed in an enclosure.

3.2.1 Greaseless

It has been standard practice to grease up the gear teeth for "lubrication" and "rust prevention." The gear's load is comprised solely of the rotary encoder, so that gear stress is extremely low. Expectedly, operation without the use of grease is possible. In addition, special coating on the gear surface helps reduce friction and assures operation without using grease.

3.2.2 Oiling-free

The gears, which directly transmit the driving torque, are confined to the enclosed gear mechanism of the geared motor, where oiling or the changing of grease is not needed.

Fuji's compact geared motor uses grease that is exclusively adapted for oxidation stability, mechanical stability and heat resistance, and thus eliminates fears of leakage and insufficient lubrication.

The load tap-changer installed in the gas-insulated transformer uses roller contacts for the moving contacts of the tap selector, so that the required driving torque is small enough to drive a traction motor with an output of 100 W.

3.3 Noise reduction system

Audible noise of the LTC drive box is generated not continuously but intermittently during tap-changing. This noise causes problems, especially at midnight or during the early morning hours.

The new LTC drive has reduced the noise from 70-80 dB to about 50 dB through simplifying the mechanism, thus reducing the number of gear parts as well as adopting a low-noise geared motor.

3.4 High performance design

Fault and state signals of the load tap-changer and the transformer are transmitted to a remote digital LR control unit and a local control cabinet of operating support system. A torque sensor installed in the LTC drive box and in the associated section of the local control cabinet enables monitoring of the LTC driving torque. A 7-segment fault indicator installed in the LTC drive control cabinet performs self-diagnosis and automatic monitoring. It also indicates the detected fault as a failure code to immediately invoke countermeasures.

4. Reliability Improvement

4.1 System redundancy

The system is reinforced with the following redundancies in order to make it more costeffective and reliable:

Table 3 Automatic monitoring system items

Objects and devices		contents	Monitoring method
Continuous monitoring	Driving mechanism	Tap over running	Monitoring of motor operating time
	PC	Heavy failure, Light failure, Device malfunction	Self-diagnostic function of PC Watch dog timer
	Optical limit switches and O-E transducers	Monitoring of output signal	Comparison between the two output signals
	Drive unit	Short-circuit mode fault	Voltage detection at state without raise-lower command
	Electrical power supply (DC-DC converter)	Monitoring of DC power source	Self-diagnostic function (over-current, overvoltage)
Confirmation of response to operation and control commands	Rotary encoder	Failure of light emitting elements and light receiving elements	Even parity check
		Abnormal coupling	Monitoring of change of rotary angle in proportion to operating time
	Drive unit	Open-circuit mode fault	Voltage detection at state with raise-lower command
	Driving mechanism	Incomplete tap changing	Detection of operating time by rotary encoder
	Main circuit	Disconnection, fault phase	Detection of constrained current by thermal relay

Table 4 Verification test items

Items		Test conditions	Objects
Environmental test	Dustproof test	Based on JEM-1267/IEC529 Left for 8 hours under talcum powder. Talcum powder to be used is 2 kg per cubic metre	LTC drive box
	Waterproof test	Based on JIS C 0920/IEC529 Sprayed from all directions Distance: 3 m, Delivery rate: 12.5 ℓ/min, Water pressure: 31 kPa, Minimum test duration: 3 min	
	High and low temperature test	Mechanical operation R.T.~+70°C (2h)~R.T. & R.T.~−35°C (2h)~R.T. (R.T.: Room temperature)	
		Heat cycle and heat shock test for drive unit	LTC drive control cabinet
Surge withstand Capability test	Damped oscillatory wave test (oscillatory SWC test)	Voltage of first half wave: 3 kV Frequency: 1 MHz	Combination test
	Square-wave test (fast transient SWC test)	Pulse width: 100 ns Rise time: 1 ns Applied voltage: 1 kV	
	Immunity test	Application of noise by transceiver 5 W/150 MHz, 400 MHz, 900 MHz	

(1) Redundant transmission (two times) of the input signal by the PC
(2) Duplication of the logic circuit in the output control section of the PC
(3) Duplication of the output (D/O) module of the PC
(4) Parallel connection of the SSR in the drive unit

Accordingly, one unit of the PC has a redundant software input and a redundant hardware output. Parallel connection of the semiconductor devices in the drive unit is based on the principle: "Priority to control signals to guard against missing operation." This principle assures that each of the two elements works altermately for each step of tap-changing, assuring mutual operation back-up and early fault detection.

4.2 Automatic monitoring

Automatic monitoring is usually performed by "continuous monitoring" and "automatic checking." Because of frequent tap-changing operations, the load tap-changer is monitored not by "automatic checking" but by "confirmation of response to operation and control commands." Automatic monitoring items are listed in **Table 3**.

5. Reliability Verification Test

As part of the performance test, mechanical durability was tested by 1,200,000 operations, more than prescribed by the JEC standard. After the test, the grease in the geared motor was taken out and inspected. The results showed no deterioration. A salt water spray test of the gear section has also proved satisfactory in resistance to rust and corrosion.

In order to adapt the electronic devices to the substation, it is necessary to consider environmental factors like dust, humidity, and direct sunlight, and to take further measures to guard these devices against malfunction or breakdown by noise or surge.

After the performance test, the reliability verification test shown in **Table 4** was conducted to verify the measures of the designing stage. The results have proved satisfactory.

6. Conclusion

The newly developed, highly-reliable LTC drive has eliminated problems due to fault contact and has successfully realized a maintenance-free operation.

The gas-insulated transformer with this LTC drive is currently in commercial operation. The field data collected thus far will help improve reliability of the system.

The LTC drive is operated by an optical-serial transmission link in conjunction with operating support system and LR control system. Such a system differs from that of the conventional substation.

The authors are now investigating ways in which to optimize the practical application of the LTC drive, making it feasible for the conventional substation.