# Field Test Result of Thyristor Type Step Voltage Regulator


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As the 6.6kV distribution system in Japan is a single lapped type, a system is structured so that multiple distribution lines can be connected and switched for system operation convenience. Due to this, the power flow direction of the distribution line changes due to the system changeover, and in recent years, the flow direction and amount changes have increased due to the incorporation of dispersed type power supplies.

We have developed a new type of voltage regulator that incorporates a thyristor for the tap changer. With this type, frequent tap-changing can be done at a high-speed and the changes in flow can be accepted swiftly. This new type SVR incorporates a digital system in the control unit to enhance high accuracy, furthermore ample fault protection functions and operation/display functions are employed which makes automatic operation possible.

Satisfactory results were obtained in all aspects as a result of field testing this new type SVR for two and a half years.


## 1.Introduction

Most of automatic step voltage regulators (we call, SVR) installed in the 6.6kV distribution lines in Japan employs a mechanical type switch for the tap changer to adjust the voltage fluctuation. Due to this, the periodical inspection and maintenance shall be required for switching contact every 100,000 tap-changing.

On the other hand, cases of dispersed type power supplies, such as co-generation, wind generated power and solar power being installed in parallel to the system have increased in recent days. In this case, the power flow direction and amount greatly and frequently changes, and it is anticipated that the conventional SVR can't be dealt with this environment which makes an appropriate voltage control difficult.

In order to correspond to these system conditions, we developed a thyristor type SVR that carries out high-speed and frequent automatic voltage adjustment to the double-way flow, and which enables a high-speed frequency tap-changing by using a thyristor switch. This maintenance-free regulator was mounted on actual distribution lines, and was field tested for two and a half years. The favorable results we achieved are introduced in this paper.

## 2.Construction of thyristor type SVR

The basic specifications of the thyristor type SVR are shown in Table 1, and the relay characteristics of the control unit are shown in Table 2.

Table 1 Basic specifications of thyristor type SVR

| Item | Specifications |
|---|---|
| No. of phases | 3-phase |
| Frequency | 60Hz |
| Line capacity | 3000kVA |
| Rated capacity | 140kVA |
| Rated primary voltage | 6720V |
| Primary adjustment voltage | ±300V<br>100V step<br>7 taps |
| Rated secondary voltage | 6720V |
| Rated secondary current | 258A |
| Connection | Star connection (Indirect changing method) |
| Tap changing system | Thyristor switch |
| Detection target | Voltage |

Table 2 Relay characteristics of thyristor type SVR

| Type | Setting /Adjustment elements | Setting value | Details |
|---|---|---|---|
| Voltage regulating relay | Standard voltage setting value (Forward feed, reverse feed, independent setting) | | The no-sensing zone is fixed to 0%. The operation time characteristics are the inverse time characteristics |
| | No-sensing zone setting value | | |
| | Cumulative time setting value | 0%sec 100%sec 300%sec 500%sec | |
| Reverse feeding detection relay | Operation current setting value | 4% of rated current | At a region less than the operation current setting value, the 67 relay is locked, and the tap is set at the through tap. The tap is changed to the through tap every forward feed and reverse feed detection |
| | Operation time | Instantaneous operation (within 0.2 sec.) | |
| | Phase characteristics | Lead 95deg. Lag 85deg. | |

This SVR consists of the voltage regulating transformer, series transformer, and control unit. The appearance is shown in Fig. 1, and the circuit diagram is shown in Fig. 2.

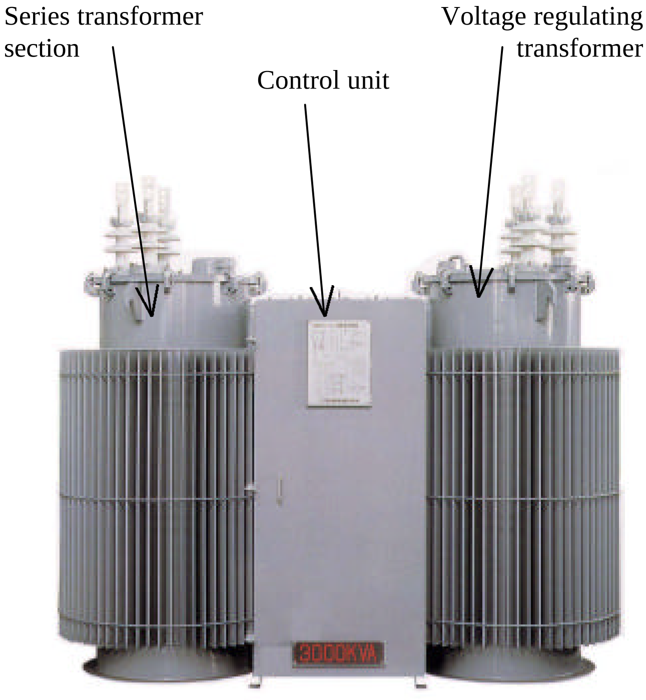


Fig.1 Appearance

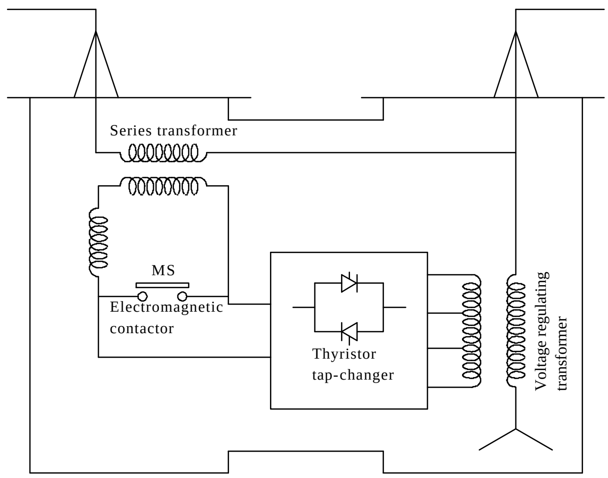


Fig.2 Circuit diagram (One Phase)

The voltage regulating transformer section consists of the voltage regulating transformer and thyristor type tap changer. The series transformer consists of the series transformer and current limiting reactor. Each is stored in an integrated tank.

The control unit consists of the MS unit, thyristor switch gate amplifier unit, control unit and operation unit. These are stored in the control box installed on the side of the integrated tank.

## 3. Principal function

### <3.1> Double-way automatic voltage regulation

For this SVR, a method that compares the voltage phase and current phase displacement, automatically judges the forward feed and reverse feed power flow. After judgment this SVR detects the voltage at output side (load side) and change the tap accordingly.

### <3.2> Thyristor type tap changer

For the tap changer, a no-contact changing method, using a thyristor capable of high-speed and frequent changing was incorporated for the following reasons.
**(a) High-speed tap changing** Where the time for tap-changing in the mechanical switch is 8 seconds, the thyristor switch requires only about 0.05 seconds. This allows speedy correspondence to the frequent power flow fluctuations.
**(b) Maintenance-free** With the mechanical switch, the contact wears with the arc, and thus, the contact needed to be inspected every 100,000 operations. However, by using the thyristor switch, which is a no-contact changing type, the number of changing is limitless.

### <3.3> Voltage adjustment without no-sensing zone

As the thyristor switch has no limit to the number of operations, there is no need to establish a no-sensing zone to suppress the number of operation times. The voltage at load side is constantly supervised, and when the deviation with the standard voltage and the cumulative time reach the setting value, the tap changing command is issued. When controlled with this method, hunting occurs as there is no no-sensing zone, but the operation time is proportionally controlled, so the average output voltage matches the standard voltage.

### <3.4> Indirect changing method

The conventional SVR uses a direct changing method that adjusts the voltage by changing directly a tap of autotransformer connected to the distribution line. For this SVR, an indirect changing method is incorporated, in which the tap voltage of the voltage regulating transformer, connected in parallel with the line, is applied on the series transformer connected in series to the line. It’s because that as this SVR uses a thyristor switch for the tap changing, the thyristor switch must be protected from the surge voltage and short-circuit current of the distribution line.

The tap changing circuit is connected to the low-voltage circuit side of a double winding voltage regulating transformer and a series transformer, so line voltage is never directly applied to it.

To prevent thermal damage of the thyristor switch, caused when the short-circuit current generated in the line shifts to the tap changing circuit, a current limiting reactor and magnetic switch (MS) are installed in the tap changing circuit. The current limiting reactor saturates the flux density of the serial transformer core, and reduces the shift of short-circuit current to the tap changing circuit. By turning ON the MS, the overcurrent that flows the thyristor is rerouted to the MS side.

### <3.5> Protection devices

As an indirect changing type thyristor switch is used for the tap changer, this SVR is provided with the following protection devices.

#### <3.5.1> External abnormality protection

This SVR protects each device from abnormalities in the line, and at the same time has the following protection functions to continue healthy operation of the SVR even after the distribution line is correctly recovered.
**(a) External short-circuit protection** As explained in the previous section, the thyristor switch is protected from the line's short-circuit current using a current limiting reactor and MS.
**(b) Overload protection** The overload current is supervised with a CT inserted in the secondary side circuit. When a current exceeding the setting value is detected, the tap is changed to the through tap position, and the MS is turned ON.
**(c) Surge voltage protection** A surge absorbing circuit and ZnO arrester are installed on each thyristor to protect the thyristor from surge voltage.
**(d) Overvoltage protection** If the line voltage reaches a voltage exceeding the preset operable voltage, the changing command is locked and the tap changing operation is stopped.
**(e) Undervotlage protection** If the distribution line voltage reaches a voltage lower than the preset operable voltage, the changing command is locked and the tap changing operation is stopped.
**(f) Instantaneous service interruption protection** To prevent malfunctions caused by an instantaneous service interruption in the line, a backup capacitor is installed in the control power supply. Control is possible with the capacitor for a power failure within 100ms.
**(g) Service interruption protection** If the secondary side circuit of the series transformer is opened during a power failure, the line current will become an excited current at recover. The increase in flux will induce an excessive voltage in the secondary circuit, so when a power failure occurs, the tap is changed to the through tap position, the MS is turned ON and fixed, and the secondary side is short-circuited to prevent this.

After the MS is turned ON and fixed with the abnormalities described in (a), (b) and (g), when the distribution line is recovered to the normal, this SVR will automatically return to normal operation after approx. 120 sec.

### <3.5.2> Internal abnormality protection

The following protection functions are provided to prevent faults in this SVR from affecting the line and other devices.

**(a) Control power loss protection** When the control power is lost, the tap is changed to the through tap position, and the MS is turned ON and fixed. The control power until the MS is turned ON is backed up with the capacitor.

**(b) Control section abnormality protection** Each control section is constantly supervised. When an abnormality is detected, the tap is changed to the through tap position, and the MS is turned ON.

**(c) MS abnormality protection** As the MS is an important device that protects the thyristor switch for thermal damage caused by an overcurrent, and prevents the secondary side circuit of the series transformer from opening, a duplex MS and driving unit are employed. Furthermore, the correct operation of the MS is judged by supervising each auxiliary contact. The MS is periodically operated (when set to the through tap position after approx. 1000 hours), to confirm that the operation is not abnormal. When an abnormality is detected, the tap is controlled to the through tap position, and the MS is turned ON and fixed.

**(d) Tap open protection** If a secondary side circuit opening accident should occur, the bridge thyristor is self-ignited and conducted, to detect this abnormal current. The tap is then changed to the through tap position, and then the MS is turned ON and fixed.

**(e) Tap short-circuit backup protection** Each thyristor gate signal is provided with an interlock to prevent short-circuits between the taps. To protect the thyristor in case a short-circuit accident occurs between the taps, a high-speed current limiting fuse is installed serially with the tap changing thyristor.

## 4. Field tests

This SVR was mounted on 6.6kV distribution line installed by Chubu Electric Power Co. for two and a half years from February 1996 to October 1998, and various data was collected.

### <4.1> Configuration of distribution line for field tests

The configuration of the 6.6kV distribution line tested in the field is shown in Fig. 3. The length of the distribution line was approx. 21km, and this SVR was installed at a point approx. 15km from the substation.

Each setting value taken during this field measurement is shown in Table 3.

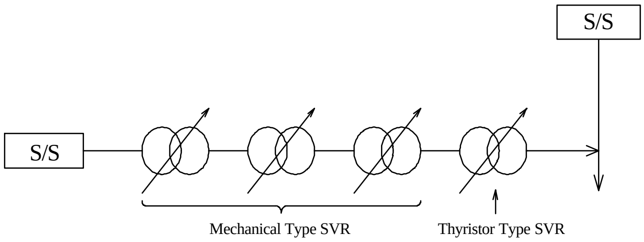


Fig. 3 Distribution line diagram

Table 3 Setting value for field operation

| Item | | Setting value |
|---|---|---|
| Standard voltage setting | Forward feed | 6570V |
| | Reverse feed | 6720V |
| Cumulative time setting | | 100%sec |

### <4.2> Test results

Approx. 300,000 tap-changing were carried out during the test period but there were no abnormalities at all, and the operation was carried out correctly.

The number of tap-changing operations per day was approx. 400 times (approx. 150,000 times per year), which was very high compared to the conventional SVR (approx. 10,000 times per year), but there is no problem.

The power side voltage, load side voltage, and the 30 minute average voltage chart of these are shown in Figs. 4 to 7.

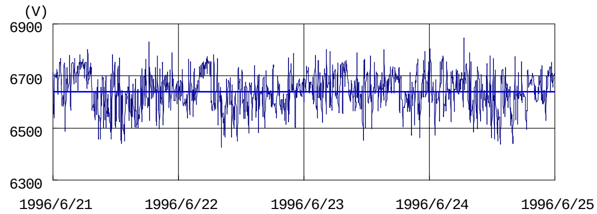


Fig. 4 Power side voltage

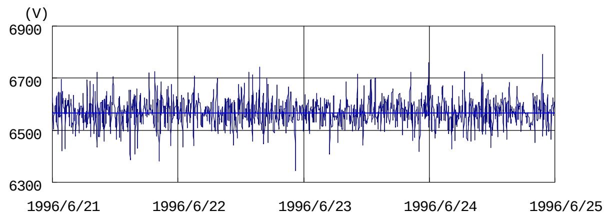


Fig. 5 Load side voltage

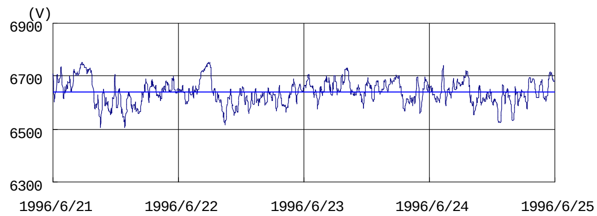


Fig. 6 Power side 30 minute average voltage

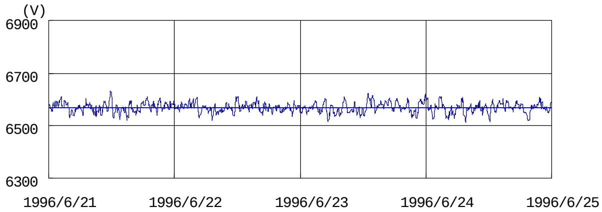

Fig. 7 Load side 30 minute average voltage

When the power side voltage and load side voltage graphs are compared, it can be seen that while the power side voltage fluctuates, the fluctuation of the load side voltage is small and matches the standard voltage value (6570V). The difference is apparent when the 30 minute average voltage graphs are looked at. This is because of the frequent tap changing carried out by this SVR.

Regarding the protection functions, we were able to confirm that the MS turned ON for power failure protection during a line fault and when the control voltage was insufficient. We also confirmed that the tap was set to the through tap position and fixed when a light load was detected. This SVR re-operated without trouble even when the line fault was recovered. Furthermore, we were also able to confirm the MS set periodic operation <3.5.2.C>, and were able to confirm that this SVR's protection functions operated correctly on the actual distribution line.

## 5. Conclusion

As a result of verification of this new type SVR on the field, we confirmed that the voltage fluctuation was sufficiently suppressed compared to the conventional mechanical type SVR, and that a stable and reliable operation was achieved. This SVR has sufficient capacities as a SVR installed in distribution systems of future environments.