DESIGN AND CONTROL STRATEGY OF THYRISTOR VOLTAGE REGULATOR FOR DISTRIBUTION LINE VOLTAGE REGULATION FOR EXPANSION OF DISTRIBUTED POWER SUPPLY

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ABSTRACT

The substation power system is designed considering the line impedance and the load, may have a problem of voltage instability in the distribution line due to the recent distributed power supply with intermittent output characteristics such as Photovoltaic (PV) system and wind power system. In order to solve the voltage instability problem, Step Voltage Regulator (SVR) can be installed so that Line Drop Compensation (LDC) control can operate the distribution line within the stable voltage range. However, it is difficult to control the voltage fluctuation due to the intermittent output of the distributed power source due to the tap adjustment delay time in the conventional mechanical SVR. In this paper, we propose modeling thyristor voltage regulator (TVR) using fast switching semiconductor device and voltage control method of distribution line to overcome the disadvantages of existing SVR. Simulation and verification of TVR modeling and proposed control method using PSCAD / EMTDC.

INTRODUCTION

The power system is designed to operate within a voltage range that takes into account the line impedance from the substation's transmission voltage to the distribution and distribution loads. However, when a distributed power source such as solar or wind power is connected to an existing system, intermittent output characteristics of a renewable energy source may cause voltage instability in the distribution line [1]. In order to stabilize the voltage with a distributed power supply line, SVR can be installed to operate the system within the stable voltage range by LDC control. However, as the distributed power sources such as PV system are connected, frequent change of output can lead to frequent tap switching of the SVR beyond the allowable voltage range, which can cause damage and shorten the lifetime of the device [2]. Recently, researches on the voltage instability problem in the distribution line connected with the PV system are being actively carried out [3,4].

In this paper, we introduce a thyristor voltage regulator (TVR) using a fast switching semiconductor switching device to compensate the shortcomings of conventional SVR. We also present a method for voltage control within a stable range of voltage to modeling and distribution lines.

In this paper, we verify that the voltage on the distribution line can be operated within the stable range after the TVR using the PSCAD / EMTDC when the TVR is installed in the middle of the extra high voltage distribution line.

HIGH-VOLTAGE DISTRIBUTION LINE DESIGN AND PARAMETERS

The high-voltage distribution system consists of a 45-MVA substation with a voltage rating of 154 kV / 22.9 kV and a single distribution line as shown in Fig 1. It is a distribution line connecting load and dispersed power for 30km from substation. The voltage of the distribution line is adjusted by installing the TVR in the heavy loading the voltage drop at the terminal by the distribution line. The load on the distribution line was set at 1.5MVA at the light load and 6MVA at the heavy load, and the PV capacity was designed at 6MVA. The total load capacity was divided by 1/10 and divided into two parts, front and back, based on the TVR standard. The TVR runs one for each phase and adjusts the voltage on the distribution line.

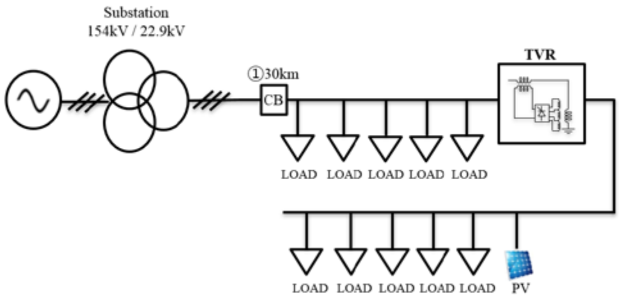

Fig 1. The high-voltage distribution system modeling

Single-phase TVR circuit design and configuration

The structure of the single phase TVR is shown in Fig 2 [5]. 1: 1 series transformer, 1: 20 parallel transformer for ±5% voltage control, and a thyristor switching circuit operating in response to the switching signal. The secondary side of the parallel transformer is divided by the 1: 3: 2 ratio and has a voltage level of 13 constant voltage ranges to control the ±5% voltage. In the thyristor switching circuit, a snubber circuit for protecting the device and a tap switching controller are constructed, and the controller is shown in Fig 3.

I_{meas} is the current flowing in the secondary side of the transformer in the TVR. When the tap controller receives the tap adjustment signal, the zero point of current is detected and the thyristor is opened. When the switch is opened, And the corresponding thyristor according to the tap signal is short-circuited to switch the tap.is a current flowing in the secondary side of the transformer in the TVR. When the switch controller receives a tap adjustment signal, it detects zero point of current and opens the thyristor. When the switch is opened, current flows to the snubber circuit for a short period of time Then, the corresponding thyristor according to the tap signal is short-circuited to switch the tap.

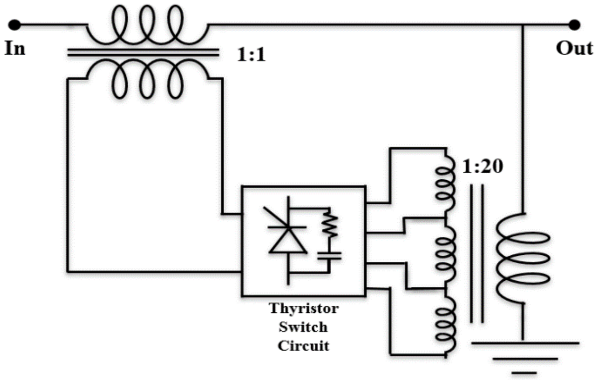

Fig. 2. Single-phase TVR circuit

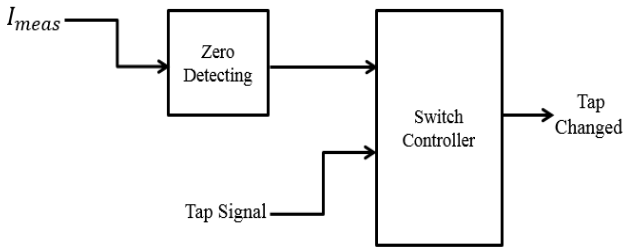

Fig 3. Tab Switch Controller

PV Controller

The photovoltaic system is controlled by DC / DC converter MPPT, so that the maximum power according to the power generation can be obtained. The inverter controls the DC bus voltage and sends the output to the distribution line through the 380V / 22.9kV transformer.

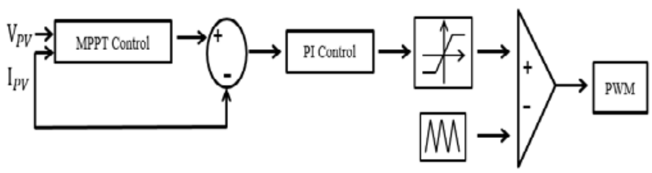

Fig 4. Current Controller for a PV system

LDC VOLTAGE CONTROL

In the distribution system, the voltage of all distribution lines below SVR is adjusted by the voltage regulator using LDC method as shown in Fig 5. The LDC method is a method of adjusting the transmission voltage by a tap so that the voltage of the regulation point becomes a certain desired reference voltage. In order to adjust the delivery voltage, the LDC voltage regulator is determined by line configuration and load characteristics of R_{set} , X_{set} corresponding to line equivalent impedance R_L, X_L up to regulation point. The equation of the measurement voltage V_{LDC} for controlling the constant voltage of the regulation point is as follows.

$$V_{PT} = V_{LDC} + I_{CT}(R_{set} + jX_{set}) \qquad (1)$$

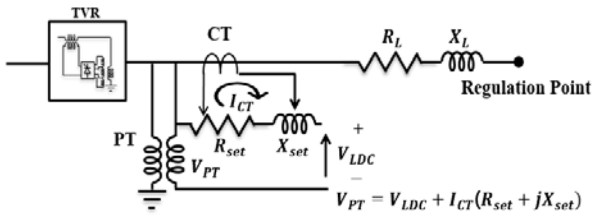

Fig 5. Voltage regulation method by LDC

CONSTANT VOLTAGE RANGE CONTROL METHOD

Conventional LDC method controls constant voltage of regulation point. However, it may cause intermittent output due to concentration of PV system in arbitrary section in existing distribution line system, or it may happen that it deviates from the mid-range voltage range. Therefore, in the section after the TVR, the voltage at the point where the load and the photovoltaic system are connected is sensed and a stable voltage range is set and operated. The voltage control method is shown in Fig. 6, and Fig. 7 shows the flow chart for constant voltage range control. When operating with a limited set of voltage MAX setpoint and MIN setpoint, the PV system with load variation and intermittent output characteristics can be operated within the tap adjustable range.

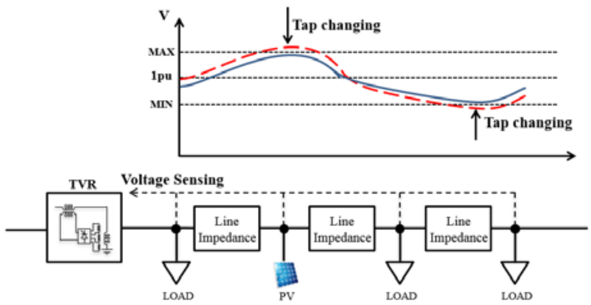

Fig 6. Constant voltage range control

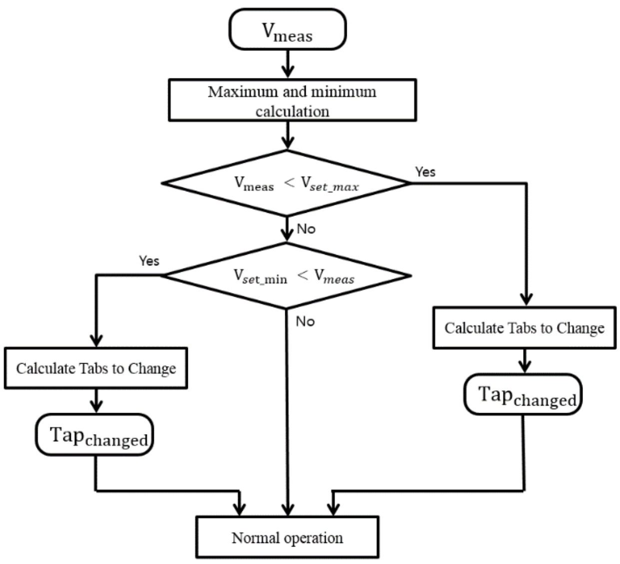

Fig 7. Constant Voltage Range Control Flowchart

SIMULATION RESULTS AND SCENARIOS

The simulation configuration is shown in Figure 8, where the impedance and load to the distribution line are divided by section. TVR using a semiconductor device controls the voltage at the end of the distribution line using LDC control and constant voltage control. The single-phase thyristor circuit is composed of 16 thyristors in total, and four of them are connected to the secondary side of the parallel transformer by four legs. The configuration is shown in Fig 9. In the 380V low-voltage distribution line, the solar power system is designed to have a power output of 500kW. PV of 6MVA capacity is used by parallel connection of several PVs.

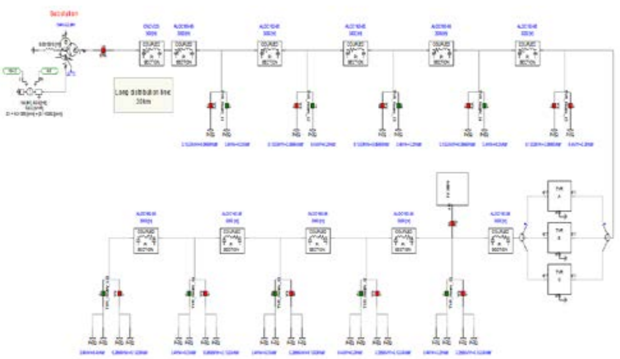

Fig 8. Modeling of high-voltage distribution system designed using PSCAD / EMTDC

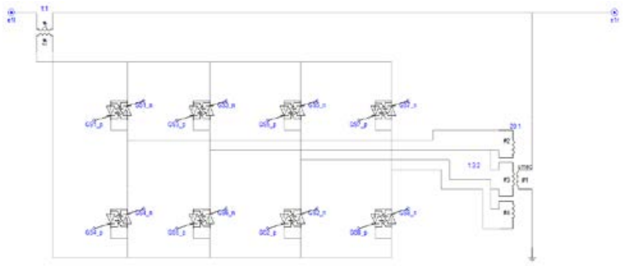

Fig 9. Single-phase TVR scheme designed using PSCAD / EMTDC

The total load capacity of distribution line is 6MVA and the PV capacity is 6MVA, and the load is divided by TVR. The simulation scenarios are shown in Table 1 and load and generator are set to operate within a certain voltage range. The simulation simulates the case where the output of the distributed power source increases and the voltage to the distribution line increases and the voltage drop at the end of the line decreases due to the decrease of the power source or the increase of the load.

Table Ⅰ. Simulation scenarios

Time (sec)	Situation	Power Variation
0~0.5	Normal Operation	-
0.5	TVR Operation	-
0.8	PV Power Increased	0.6MVA
1.0	PV Power Increased	0.6MVA
1.2	PV Power Increased	0.3MVA
1.4	Load Increased	1.5MVA
1.6	PV Disconnected	6MVA
1.8	Load increased	0.45MVA
2.0	Load increased	0.45MVA

The results of voltage fluctuation from the midpoint of the distribution line are shown in Fig. The voltage directly under the TVR is V_{MAX}, and the voltage at the end of the line is V_{MIN}. V_{MAX} and V_{MIN} should be operated within the normal voltage range when assuming that the set voltage range of the distribution line is 0.95 ~ 1.025pu in 1pu standard range. When the TVR uses LDC voltage control, the V_{LDC} setpoint can be divided into two situations. Figure 11 shows the high V_{LDC} setting, and Figure 12 shows the low V_{LDC} setting. Figure 13 shows the case where constant voltage range control is used. Simulation results show that the LDC method should set the appropriate voltage setpoint when a sudden load variation and intermittent distributed power supply are connected. However, the constant voltage range control can be controlled to operate within a range of rapid voltage fluctuations.

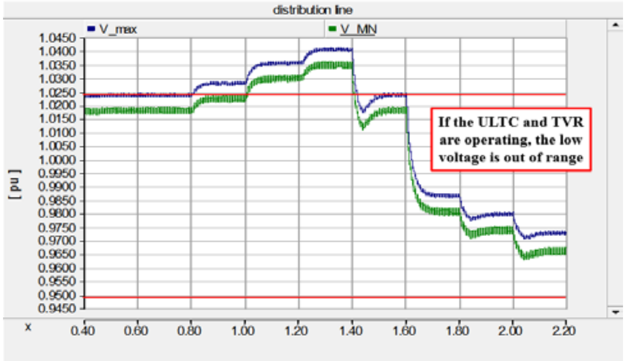

Fig 10. Simulation of operation with distribution line without voltage control of TVR

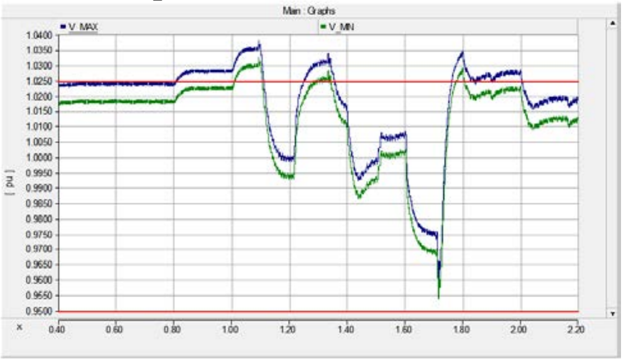

Fig 11. Simulation of Voltage Control of LDC Method1

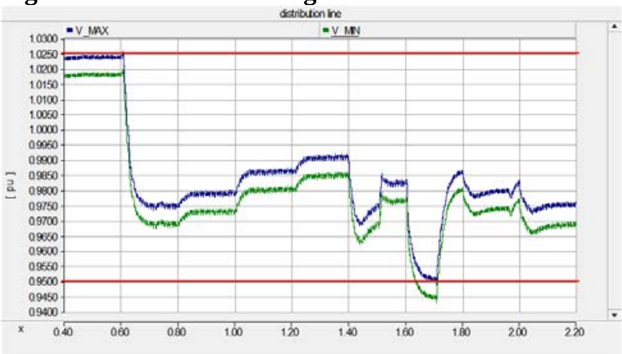

Fig 12. Simulation of Voltage Control of LDC Method2

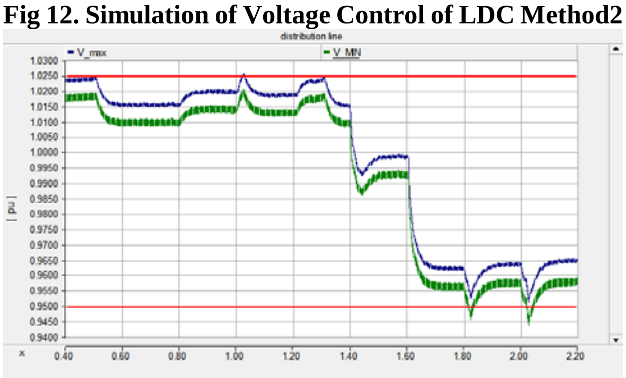

Fig 13. Simulation with constant voltage range

Conclusion

Multiple distribution lines can be connected to the high-voltage distribution system and each line must be operated within a stable range. In the case of the longest distribution line, the influence of the voltage drop and the distributed power source is greater, so we propose one way to install TVR in the middle of the line. In this paper, we introduce the method of circuit design and control method of single phase TVR. When LDC method is used, it suggests constant voltage range control although voltage range may be out of range of sudden voltage change. The required voltage can be compensated without switching.
This paper deals with the voltage control of TVR in long distribution lines, but if the voltage control is difficult with only TVR, it will work on interconnection operation by exchanging voltage information with upper substation.

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