Cooperative Control Method for Voltage Control Equipment Considering Interconnection of Distributed Generators

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Abstract: This paper presents a new cooperative control method using both step voltage regulator (SVR) and unified power flow controller (UPFC) considering interconnection of distributed generators. The proposed method can regulate the line voltage within the prescribed voltage ranges against steep voltage fluctuations. The method requires little capacity and low cost of the voltage compensating equipment and can be effective to regulate the line voltage with existing SVRs. The feasibility of the proposed method is demonstrated on distribution system models by steady-state analysis based on power flow and instantaneous analysis using EMTDC with promising results.

Key words: Distribution systems, Cooperative control, Distributed generator, Voltage control, FACTS

1. INTRODUCTION

In order to regulate the line voltage in distribution systems, transformers with the line drop compensation (LDC) function at substations and automatic tap changer installed in distribution feeders, which are called step voltage regulator (SVR) in Japan, are utilized.

In recent years, distributed generators (DGs), which may have steep fluctuations of power generation, been introduced in distribution systems. Therefore, the introduction of DGs may cause steep voltage fluctuations in distribution systems. SVR has a dead band value for a target control voltage and time delay from a few seconds to a few minutes to avoid frequent tap changing. On the contrary, wind generators may reach full power output from zero output within one minute, in which SVRs cannot regulate because of the time delay. Therefore, it becomes difficult to regulate the line voltage within the prescribed voltage ranges with only SVRs.

The voltage compensating equipment applying power electronics technology, called FACTS, is effective against steep voltage fluctuations, because the equipment can respond quickly to the fluctuations. The equipment includes a series voltage compensating equipment, which can add compensation voltage to line voltage, a parallel voltage compensating equipment, that is to say, static var compensator (SVC), and series-parallel voltage compensating equipment utilizing combination of both series and parallel functions, that is to say, Unified Power Flow Controller (UPFC). However, if only the equipment is installed to regulate line voltage, it requires large capacity to regulate the line voltage. Therefore, cooperative control method using both existing SVR and newly installed voltage compensating equipment applying power electronics technology has been eagerly awaited.

This paper presents a new cooperative control method using both SVR and UPFC considering interconnection of distributed generators. The proposed method can regulate the line voltage within the prescribed voltage ranges against steep voltage fluctuations. The proposed method requires little capacity and low cost of the voltage compensating equipment and can be effective to regulate the line voltage with existing SVRs. The proposed method has features as follows:

a) Using the proposed method, a gradual voltage fluctuation is compensated by SVRs and a steep voltage fluctuation is compensated by UPFC.
b) It can select a certain reference voltage value of the series and parallel part of UPFC, which is appropriate to each voltage fluctuation condition. It allows to regulate the line voltage within the prescribed voltage ranges against steep voltage fluctuations by UPFC with minimum capacity.
c) It can modify the reference voltage value of the parallel part of UPFC. It allows to regulate the line voltage with SVRs by shifting voltage compensation form UPFC to SVRs.

The feasibility of the proposed method is demonstrated on distribution system models by steady-state analysis based on power flow and instantaneous analysis using EMTDC with promising results. The results indicate that the proposed method can decrease the voltage compensation amount of series and parallel part of UPFC by tap changing of SVRs. The voltage compensating equipment capacity is different by target distribution systems, target loading conditions, and a distributed generator capacity. According to the result, the UPFC capacity can be decreased by about ten percent in comparison with SVC capacity, especially for a certain model system.

2. OVERVIEW OF VOLTAGE CONTROL METHOD

2.1 Characteristic of Voltage Control Equipment

Since SVRs have time delay from a few seconds to a few minutes to avoid frequent tap changing, they cannot handle steep voltage fluctuations. On the contrary, newly installed voltage control equipment can quickly respond to the voltage fluctuations compared with SVRs and it may over-compensate voltages in which SVRs handle because of slow fluctuations. Therefore, there is no chance for SVRs to operate against the fluctuations and large capacity of new voltage compensation equipment is required. Considering these characteristics cooperative control between SVR and new voltage control equipment. Moreover, UPFC is the most appropriate for the new control equipment with small capacity and limited cost.

2.2 Role of Voltage Control Equipment for Cooperative Control

Considering difference of characteristics between SVR and UPFC, SVR handles slow voltage fluctuations and UPFC handles steep voltage fluctuations.

2.3 Role of Each Compensation Part of UPFC

UPFC only compensates voltage fluctuations, which violate predetermined voltage ranges for reduction of cost. Parallel part of UPFC mainly compensates up-stream parts of distribution systems within predetermined voltage ranges. On the contrary, serial part of UPFC only compensates down-stream parts of distribution systems within predetermined voltage ranges.

3. OVERVIEW OF CONTROL METHODS

3.1 Cooperative Control Method

Currently, since SVR is set using a calculation method, which assumes current flows from S/S to the end of feeders, SVR cannot be set appropriately under distributed generators installed distribution systems. The authors developed a new setting method for SVR under such conditions [2] and the method is utilized for SVR setting. Fig. 1 shows a block diagram of the proposed voltage control method. UPFC detects line voltage of installed point. When steep voltage fluctuations, which violate predetermined voltage ranges, are appeared in the target distribution systems, UPFC chooses the cooperative control mode by the operation mode selection. The cooperative control part chooses either reference voltages between upper and lower values of parallel and serial part of UPFC. The parallel part gradually decreases reactive power output in order to move voltage compensation by UPFC to SVR. Namely, when UPFC compensates line voltage, the reference voltage of SVR is within its dead band. After the decrease of reactive power output of UPFC, the reference voltage of SVR can go out from the dead band and SVR can change tap to regulate the voltage. The serial part of UPFC regulates the down-stream side voltage of the part at a certain value and the compensation values decrease by SVR tap operations. Consequently, while UPFC compensates the steep voltage fluctuations at the beginning, after that, SVR changes taps and the main compensation role is moved to SVR. Therefore, voltage compensation by UPFC cannot maintain for a long time and UPFC can wait for the next steep voltage fluctuations. The cooperative control between SVR and UPFC can be described as follows:

Step. 1 Quick voltage compensation by UPFC

UPFC compensates steep voltage fluctuations by sudden output changes of various DGs.

Step. 2 Correction of reference voltage of the parallel part of UPFC

The reference voltage value of the parallel part of UPFC is gradually corrected and the compensation amount by UPFC is gradually decreased. The voltage reference value for the serial part of UPFC is constant.

Step. 3 Constant voltage compensation by SVR

The reference voltage value of SVR goes out from the dead band by the decrease of compensation amount of the parallel part of UPFC. The operated time outside the dead band reaches the SVR's operation time, the tap of SVR is changed.

Step. 4 Standby condition of UPFC

The compensation amount by UPFC changes to the steady state amount by the tap change of SVR. Then, the UPFC becomes the standby condition at which the UPFC can handle the next steep voltage fluctuations.

3.2 Mean Value Control Method

Wind generator is said to have little power output fluctuations because of "tower shadow phenomena". Considering this kind of little voltage fluctuations, the mean value control method is operated and correct the fluctuations. The control is performed independently without SVR.

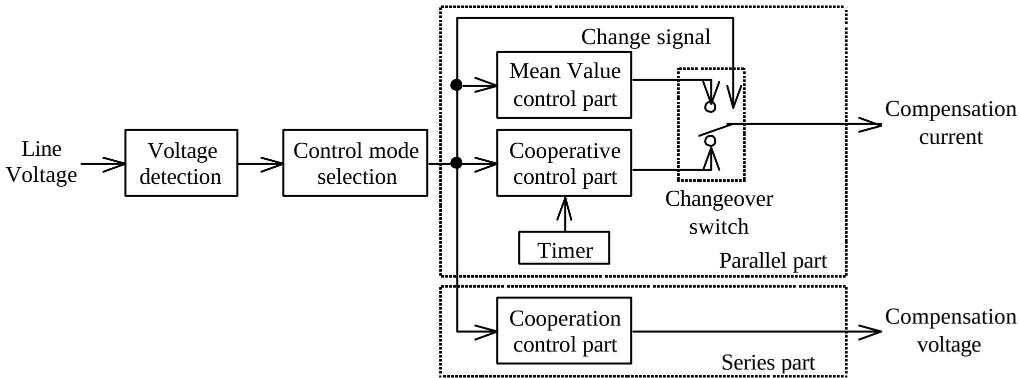


Fig.1 A block diagram of the proposed control method.

4. NUMERICAL EXAMPLES

4.1 Simulation Conditions

Fig. 2 shows a distribution model. Line length of the distribution model is about 6.8 [km]. SVR is installed at about 3.6 [km] point and UPFC is installed at about 5.2 [km] point from the substation. Capacity of distributed generator is 2000 [kW] and the generator is installed at the end of the feeder.

(1) Case No.1

Step power output change of the DG is assumed. Namely, it is assumed that the DG is at full power output at the steady state and the output is changed to zero output at 5 [sec]. The proposed cooperative control method handles this steep voltage fluctuation. The operation time of the SVR is set to 60 [sec].

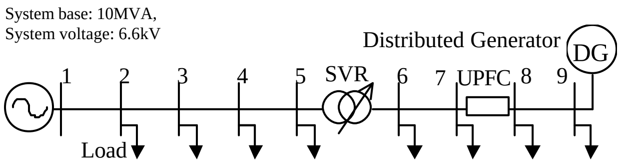
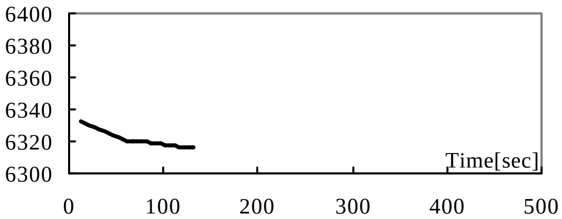
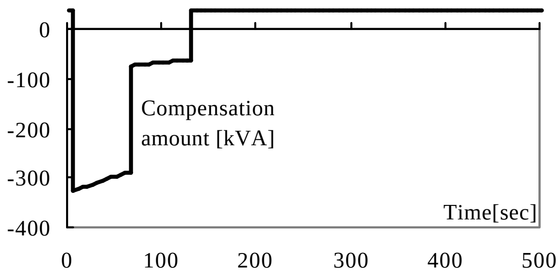


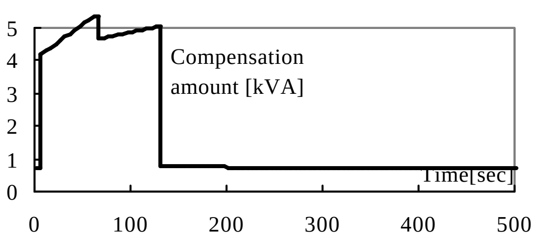
Fig.2 A typical distribution model.



(a) Reference voltage value of parallel part.



(b) Compensation amount of parallel part.



(c) Compensation amount of series part.

Fig.3 Voltage compensation operation of UPFC.

(2) Case No.2

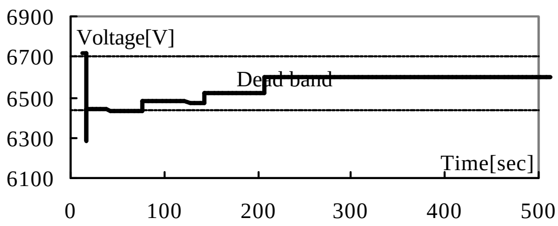
Ramp type plus flicker (frequency: 1 [Hz]) power output change of the DG is assumed. Namely, DG output is decreased from full power output to zero output gradually with little fluctuations. The operation time of the SVR is set to 10 [sec] especially for short computation time of EMTDC. The proposed cooperative and mean value control methods handle this steep voltage fluctuation.

4.2 Simulation Results

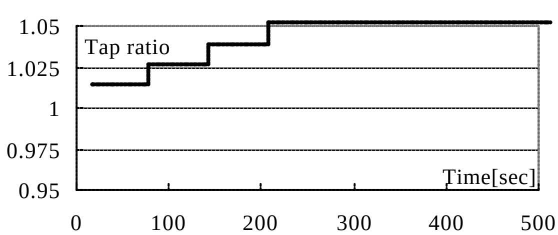
(1) Case No.1

Fig. 3 (a) – (c) show the compensation operations of UPFC and Fig. 4 (a)(b) show the operations of SVR. Fig. 5 shows voltage profiles at node 6,7,8,and 9, which are down-stream side nodes of the SVR As shown in the figure, at the beginning after the step power output change, line voltages go out from the predetermined voltage ranges. However, the voltages suddenly come back to the ranges by UPFC.

As shown in fig. 3, the compensation amount of the parallel part of UPFC is decreased by correction of the reference voltage of the parallel part of UPFC, and the compensation amount of the serial part of UPFC is increased because the down-stream side voltage of UPFC is decreased. Moreover, as shown in fig. 3 and 4, the compensation amount of both parallel and serial parts of UPFC is decrease as the tap of SVR is changed. Namely, compensation for the steep voltage fluctuation is firstly handled by UPFC and, after that, the main role of the compensation gradually moves to SVR. The reference voltage value of the parallel part of UPFC is disappeared at around 120 [sec] in fig. 3 (a). SVR changes the tap positions twice and voltage at the UPFC installed point is within the predetermined voltage ranges. Therefore, this means that the voltage compensation by the parallel part of UPFC become unnecessary at the time. As shown in fig.5, the



(a) Observed point voltage



(b) Tap ratio

Fig.4 Voltage control operation of SVR

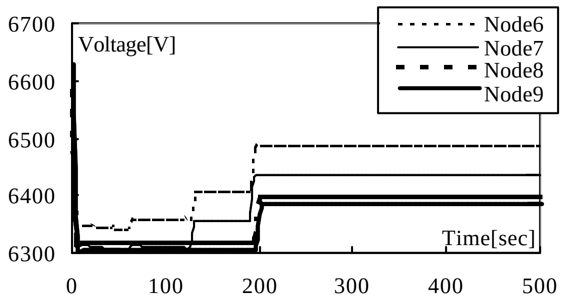


Fig.5 Voltage transitions at the cooperative control.

whole line voltage profiles can keep within the predetermined voltage ranges even for the steep voltage fluctuation, which makes some of the node voltage go out from the predetermined voltage ranges.

The above simulation results indicate the efficiency of the proposed method.

(2) Case No.2

Fig. 6 shows voltage transitions by only SVR. Fig. 7 shows voltage transitions by the proposed method (the cooperative control between SVR and UPFC, and the mean value control).

Observed voltage of the SVR swerves from the dead band by the ramp type power output change of the DG and tap of SVR is changed. However, as shown in fig. 6, the voltage transitions by only SVR swerve from the predetermined voltage range (lower limit) and voltage violation is occurred in section 5 to 8 before the SVR tap operation. Namely, voltage control by only SVR cannot maintain voltage profiles of the target distribution systems within the predetermined voltage range. On the contrary, as shown in fig. 7, the proposed method can weaken the voltage flicker.

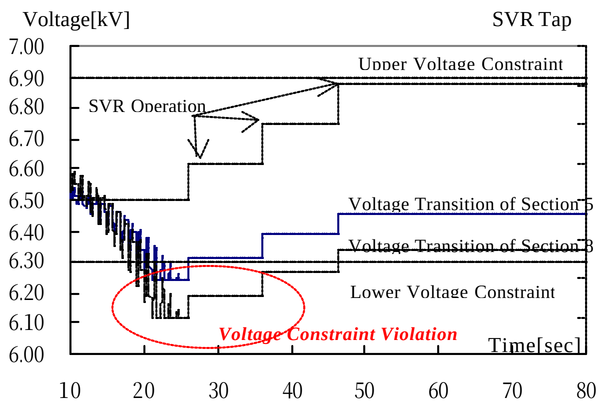


Fig. 6 Voltage transitions by only SVR.

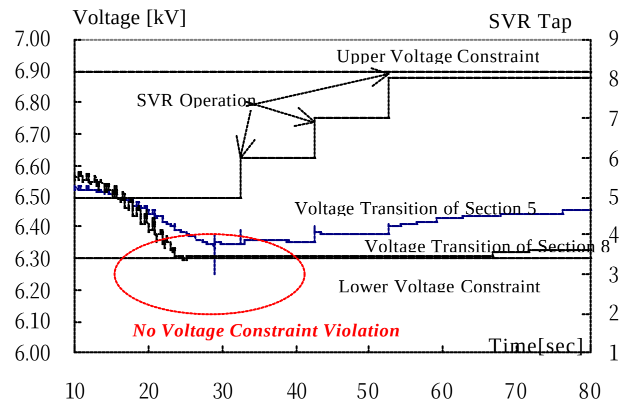


Fig. 7 Voltage transitions by the proposed control method.

5. CONCLUSIONS

This paper presents a new cooperative control method with existed voltage control equipment (SVR) and new voltage control equipment (UPFC). The proposed method can handle steep voltage fluctuations caused by the steep power output changes of distributed generators in distribution systems. The proposed method applied to a typical distribution model system. The simulation results indicate the efficiency of the proposed method for steep voltage fluctuations. The practical implementation of the proposed method is going to be considered as future works.

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BIOGRAPHIES

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