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Analysis of Voltage Regulation by DSTATCOM Using the EMTDC Program

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ABSTRACT

The DSTATCOM(Distribution Static Synchronous Compensator) is one of the Custom Power Devices that can regulate voltage. The DSTATCOM operates as a shunt connected static var compensator whose capacitive or inductive output current can be controlled independent of the system voltage. The magnitude of the compensated voltage is limited by characteristics of the system and the load. Compensation capability of the DSTATCOM which can inject 1 MVAR reactive power was simulated by EMTDC under several conditions. This paper analyzes the effect of the DSTATCOM's compensation considering the length and kind of distribution line, the power factor and magnitude of the load, and the duration and magnitude of the voltage variation.

Keywords: DSTATCOM, reactive power compensation, voltage regulation, EMTDC simulation

1. Introduction

As the concern for power quality grows, many electric utilities across the world are considering approaches to offer pure power to their customers, who have electric equipment and processes that are sensitive to power fluctuations, by the CPD(Custom Power Device).

EPRI, AEP, and SIEMENS are studying the PPP(Premium Power Park) by CPD which uses the FACTS(Flexible AC Transmission System) technique. The PPP consists of CPDs which include SSTS(Solid State Transfer Switch), DSTATCOM(Distribution Static Compensator), DVR (Dynamic Voltage Restorer), etc. In Japan, they are studying FRIENDS(Flexible, Reliable and Intelligent Electrical eNergy Delivery System). FRIENDS is an installation of power quality improvement facilities on the customer's side to supply multi quality power.

To improve operating technology for the Custom Power Device, we developed validation testing technology considering KEPCO's characteristics.

We installed Custom Power Device's validation testing system at Go-Chang, it consists of CPDs(DVR, SSTS, DSTATCOM), load, and SSFG(Sag, Swell, and Flicker Generator) which generates sag, swell, and flicker while controlling its magnitude, duration.

In addition, we developed the Custom Power Device's validation testing procedure. We also developed the EMTDC model for the Custom Power Device's validation testing system, and simulated with it.

In this paper, we executed the EMTDC simulation to analyze the effect of the device when installed and to determine the optimal magnitude of compensation for the

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DSTATCOM. We analyzed the measuring data by operating the DSTATCOM using Custom Power Device's validation testing system. We compared the results of the simulation and testing at Go-Chang

2. Custom Power Device Validation Testing System Composition

The Custom Power Device validation testing system is composed of the MVP(Medium Voltage Panel), the LVP(Low Voltage Panel), the DSTATCOM, the DVR, the SSTS, the diesel generator, the SSFG, the APF, and the load (resister and reactor). Fig. 1 and Fig. 2 are a one-line diagram and a layout of the Custom Power Device validation testing system.

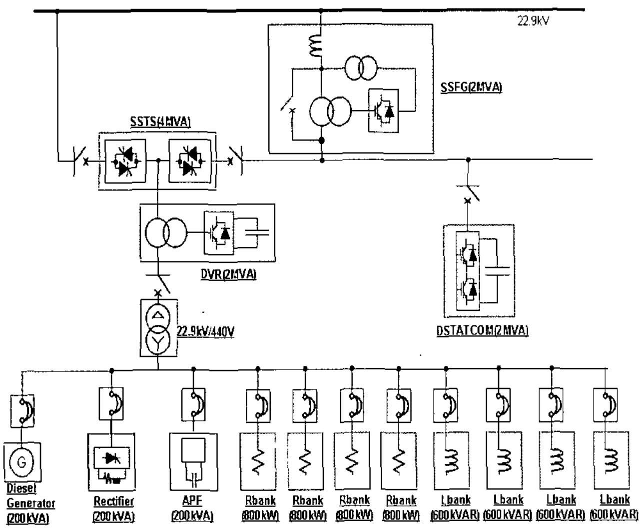

Fig. 1 One-line diagram of the Custom Power Device validation testing system

In Fig.1, the main facility of each component is as stated below.

2.1 DSTATCOM(Distribution STATic COMpensator)

The DSTATCOM is a voltage synchronous device which is shunt connected to the distribution system via a reactance. It can control reactive power with the distribution system by varying the amplitude and the phase angle of the voltage source with respect to the line terminal voltage. Table 1 is a spec. of the DSTATCOM at Go-Chang.

Table 1 DSTATCOM Specifcation

Items	contents
Rated Power	1MVA
Phase number	3 phase
Frequency	60Hz
Current(secondary)	229A
Primary, Secondary Voltage	22.9kV, 3.3kV
% Impedance	7%
TR Coupling	Y-delta
Harmonic content	5% under

2.2 DVR(Dynamic Voltage Restorer)

The DVR is capable of generating or absorbing dependently controllable reactive power at its ac output terminal. The DVR injects a set of three phase ac output voltages in series with the distribution feeder in synchronism with the voltages of the distribution system. Table 2 is a spec. of the DVR at Go-Chang.

Table 2 DVR Specification

Items	contents
Rated Power	2MVA
Primary Voltage	22.9kV
Frequency	60Hz
Running temperature	+40 °C / -15 °C
Rated Power	2MVA
Frequency Fluctuation Max/Min	+5 / -5 %
Voltage Fluctuation	+15 % (Maximum)
	-20 % (Minimum)
Power Factor	0.8 Lag
3 Phase Dip	50 %
1 Phase Dip	50 %
Compensation time	160 ms(10 Cycles)
Charging time	3 minute under

2.3 SSTS(Solid State Transfer Switch)

The SSTS can instantaneously transfer sensitive loads from a normal supply that experiences a disturbance to an alternate supply that is unaffected by the disturbance. Table 3 is a spec. of the SSTS at Go-Chang.

Table 3 SSTS specification

Items	contents
PCC point Voltage	22.9kV
Frequency	60Hz
Running temperature	+40 °C / -15 °C
Rated Power	4MVA
3 Phase auxiliary voltage	220V
% Impedance	7%
Frequency fluctuation Max/Min	+5 / -5 %
Power Factor	0.8 Lag

2.4 SSFG

The SSFG can generate a disturbance such as sag, swell, and flicker while controlling its amplitude and duration. Table 4 is a spec. of the SSFG at Go-Chang.

Table 4 SSFG specification

Fault Type	Duration	Voltage Magnitude
Sag	10 cycle	0.9~0.5 P.U.
Swell	10 cycle	1.1~1.3 P.U.
Under Voltage	5 min	0.8~0.9 P.U.
Over Voltage	5 min	1.1~1.2 P.U.
Flicker	continuity	0 ~ 0.07 P.U.

Fig. 2 is a layout of the Custom Power Device validation testing system

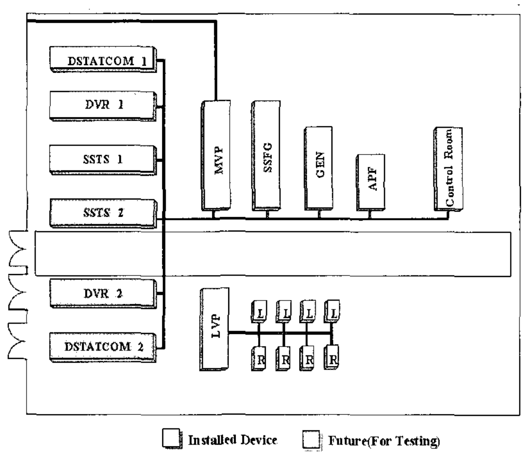

Fig. 2 Layout of the Custom Power Device validation testing system

In Fig. 2, facilities are classified as below.

1) Panel
  - MVP(Medium Voltage Panel) : the MVP consists of the VCB(Vacuum Circuit Breaker) for the SSFG, the SSTS, the DVR, and the DSTATCOM.
  - LVP(Low Voltage Panel) : the LVP consists of an M.TR (22.9kV/440V, 4MVA, Y-Δ), the ACB(Air Circuit Breaker) for the Generator, the APF, and the load (resister and reactor)
2) Custom Power Device : DVR, DSTATCOM, SSTS
3) Power Quality Disturbance Facilities : the SSFG, the PCR(Phase Control Rectifier) with the APF(APF controls the magnitude of harmonic by PCR)
4) Generator : Diesel Generator(200kW)
5) Load : resister(800kW * 4 set) and reactor (600kVAR *4 set)
6) Control Room : at the control panel, control facilities and monitor the test data.

3. Compensation of DSTATCOM

The DSTATCOM is a DC/AC switching power-converter composed of an air-cooled voltage source converter. Basically, the DSTATCOM is used to suppress voltage variations and control reactive power in phase with the system voltage. The DSTATCOM produces phase- synchronized output voltage, therefore, it can compensate for inductive and capacitive currents linearly and continuously.

Active and reactive power trade between the power system and the DSTATCOM is accomplished by controlling the phase angle difference between the two voltages. If the output voltage of the DSTATCOM V_I is in phase with the bus terminal voltage V_T, and VI is greater than V_T, the DSTATCOM provides reactive power to the system. If V_I is smaller than V_T, the DSTATCOM absorbs reactive power from the power system. Ideally, V_T and V_I have the same phase, but actually V_T and V_I have a little phase difference to compensate for the loss of transformer winding and inverter switching, so it absorbs some real power from system.

Fig. 3 shows the DSTATCOM vector diagrams, which show the inverter output voltage V_I, system voltage V_T, reactive voltage V_L and line current I in correlation with the magnitude and phase α. Fig. a and Fig. b explain how VI and VT produce inductive or capacitive power by controlling the magnitude of the inverter output voltage VI in phase with each other. Fig. c and Fig. d show that the DSTATCOM produces or absorbs real power with VI and VT having a phase difference ±α.

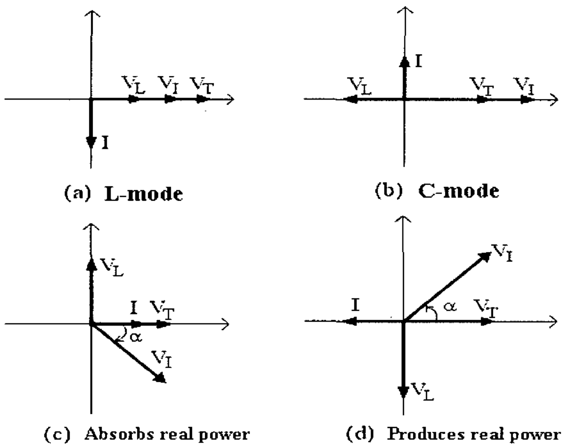

Fig. 3 Vector diagrams of DSTATCOM

4. EMTDC Simulation for DSTATCOM

The EMTDC/PSCAD simulation is carried out to analyze the D-STATCOM characteristics. Fig 4 shows a schematic diagram of the simulation. The SSFG, the DSTATCOM, the transformer (22.9kV/440V, 4MVA), and the load (resistor : 0.8MW, rector : 0.6MW) are in service. The other devices are disconnected. The transformer(45MVA, Y-Y) which is located at the substation, and the reactor(0.1H) which is located between SSFG and the transformer(4MVA) are connected. SSFG and DSTATCOM operates Table 5, Table 6 .

Table 5 Spec. of SSFG

Items	Spec.
Voltage	22.9kV
Injection Tr.	6.6kV/728V, 2MVA
Tr. (rectifier side)	22.9kV/800V, 0.5MVA
Switching Frequency of Inverter	2,000Hz
DC Capacitor	176,000uF
Switching Filter	L : 360uH, C : 1,175uF, R : 0.05Ω

Table 6 Spec. of DSTATCOM

Items	Spec.
Voltage	22.9kV
Switching Frequency of Inverter	3,060
Coupling Transformer	22.9kV/2.52kV, 3MVA
Switching Filter	L : 100uH, C : 750uF
Inter Phase Tr.	1 MVA

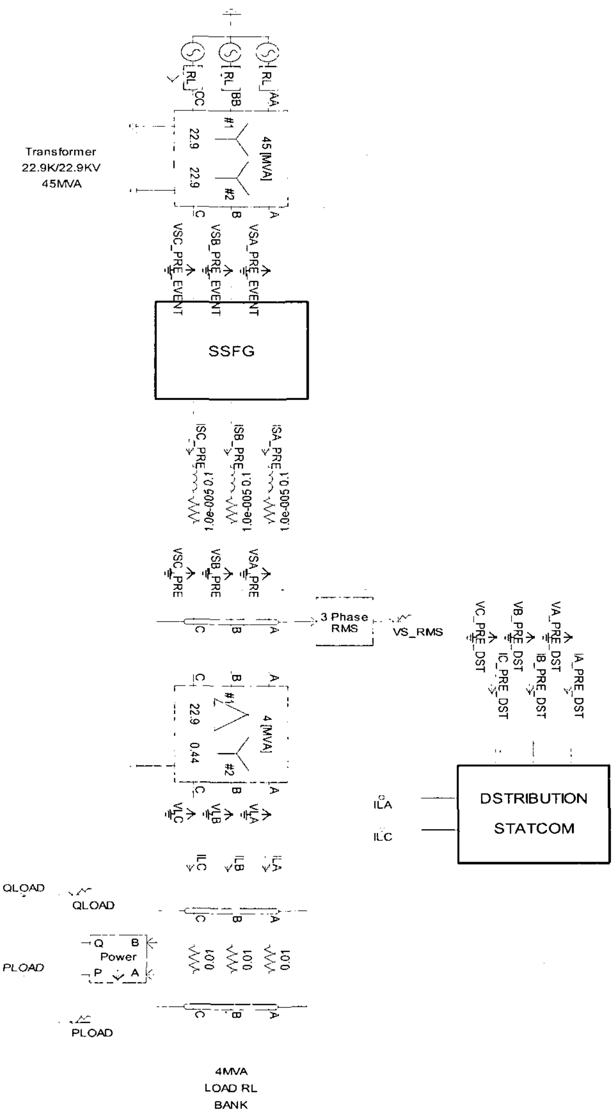

Fig. 4 Schematic Diagram for DSTATCOM

Fig. 5 shows a control block diagram to compensate for voltage and harmonics. The controller transforms the picked-up voltage of PCC into the synchronous rotating voltage to calculate the reference current for compensating for the voltage of PCC. In addition, 5^{th} and 7^{th} compensating signals are added to that reference current for the compensation of 5^{th} and 7^{th} harmonics.

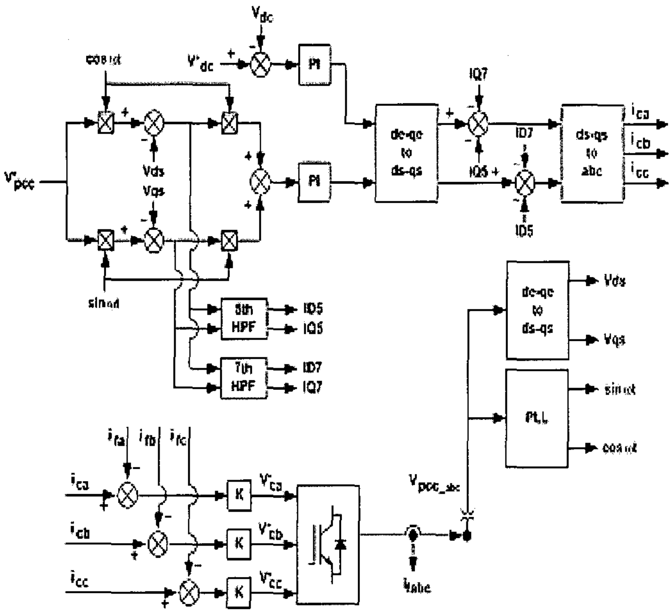

Fig. 5 Control block diagram to compensate for voltage and harmonics

Fig. 6 and Fig. 7 show the rms value of the Custom Power Device validation testing system, when the SSFG(Sag, Swell, and Flicker Generator) generates a 5% sag, and the DSTATCOM compensates for the sag.

Fig. 6, shows the EMTDC simulation result, after the sag event; the voltage is recovered by the DSTATCOM's compensation.

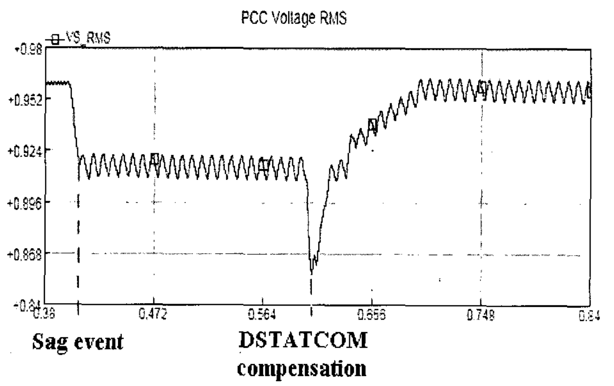

Fig. 6 DSTATCOM compensation at 5% sag by EMTDC

Fig. 7, shows a test result of the Custom Power Device validation testing system at Go-Chang; after the sag event the voltage is recovered by the DSTATCOM's compensation.

The simulation results of the EMTDC model of the DSTATCOM compared favorably to the test results of the Custom Power Device validation testing system at Go-Chang.

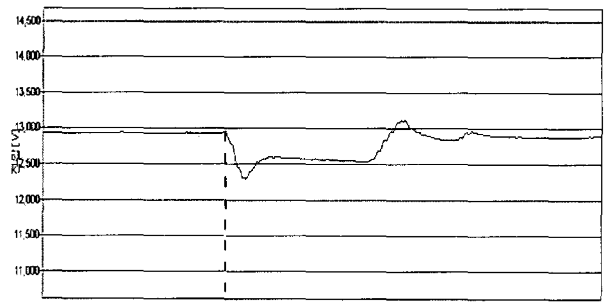

Fig. 7 DSTATCOM compensation at 5% sag using the Custom Power Device's validation testing system at Go-Chang

Fig. 8 and Fig. 9 show the instantaneous values of the Custom Power Device validation testing system, when the SSFG(Sag, Swell, and Flicker Generator) generates a 5% sag, and the DSTATCOM compensates the sag.

Fig. 8, shows the EMTDC simulation result, after the sag event; the voltage is recovered by the DSTATCOM's compensation.

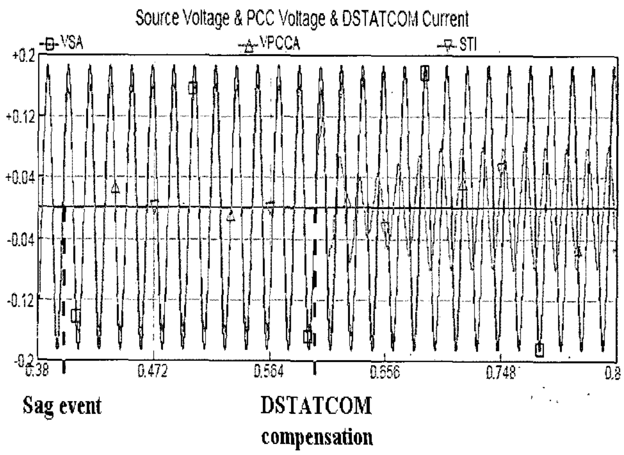

Fig. 8 Source, PCC voltage and injected current of DSTATCOM by EMTDC

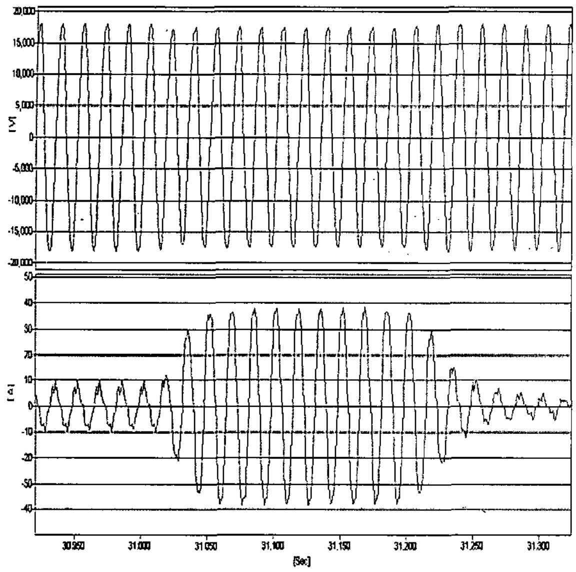

Fig. 9 PCC voltage, injected current of the DSTATCOM using Custom Power Device's validation testing system at Go-Chang

Fig. 9, shows a test result of the Custom Power Device validation testing system at Go-Chang; after the sag event the voltage is recovered by the DSTATCOM's compensation.

n Fig. 9, the upper side shows the instantaneous value of the voltage with the DSTATCOM's compensation after the sag event, the lower side shows the instantaneous value of the current which the DSTACOM injects to compensate for the sag.

5. Conclusion

In this paper, we analyzed the effect of the DSTATCOM's compensation considering the length and kind of distribution line, the power factor and magnitude of the load, and the duration and magnitude of the voltage variation. To verify the EMTDC models of the DSTATCOM, we compared the simulation results and the test results using Custom Power Device's validation testing system. In the future, we will verify EMTDC models of other devices, and test CPDs(DVR, SSTS, etc.) using Custom Power Device's validation testing system.

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