정지형 동기조상기의 역률개선을 위한 전류제어

°문건우 윤석호 전영수 장병훈 이기선 추진부
전력연구원 전력계통연구실 차세대전력전송그룹
대전광역시 유성구 문지동 103-16
Tel: 042-865-5394 FAX: 042-865-5404

Current Control For Power Factor Correction of Distribution Static Condeser (D-STATCON)

Gun-Woo Moon, Suk-Ho Yoon, Young-Soo Jun, Byung-Hoon Chang, Ki-Sun Lee, and Jin-Boo Choo
KEPRI Electric System Research Lab. FACTS Group

Abstract - In this paper, the theoretical foundation of distribution STATCON, the operating characteristicss of D-STATCON, the overview of control technologies for power factor correction of D-STATCON, and the PWM current control of D-STATCON and simulated results. are given to shows the practical feasibility of a Flexible AC Transmission System and Distribution Static Condenser.

1. Introduction

Static var compensators(SVCs) were developed in the late 1960s to provide fast reactive power compensation for large, fluctuating industrial loads, such as electric arc furnances. These compensators used either thyristor-switched capacitors (TSCs) or a thyristor-controlled reactor (TCR) with fixed (permanently connected) power factor correcting capacitors, which also provided, when combined with appropriate tunning reactors, harmonics filtering.. In the late 1970s the need for dynamic compensation of eletric power transmission system, to achieve better utilization of existing geration and transmission facilities, had become incresingly evident. Static var compensator schemes, using TCRs in combination with TSCs and fixed capacitive filters on the secondary side of a coupling transformer, were devised and successfully applied for the dynamic compensation of power systems to provide voltage support, increase transient stability, and improve damping[1-2].

The possibility of generating controllable reactive power by various power eletronic switching converter has long been realized and several cadidate schemes have been implemented in labaratory models with the use of then new gate turn-off(GTO) thyristors.. These converters are operated as voltage or current sources and they produce the reactive power essentially by circulating energy between the phases of the ac system. However, in order to be able to provide leading as well as lagging vars, the semiconductor switches in the converter must have an intrinsic turn-off capability, or an auxiliary circuit has to be

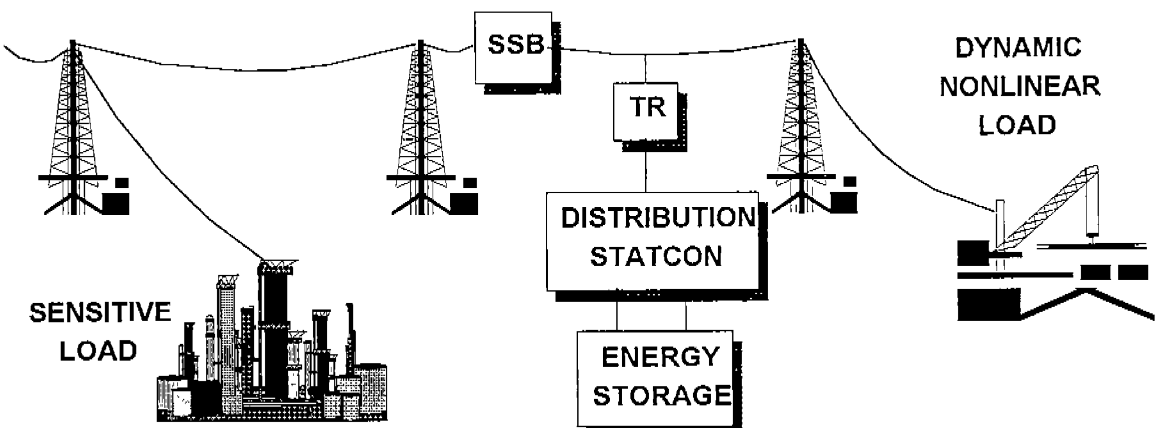

Fig. 1 Power quality improvement at distribution system by using the D-STATCON and SSB

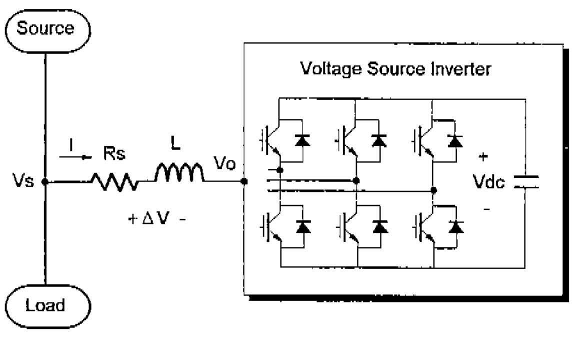

Fig. 2 Basic circuit of STATCON

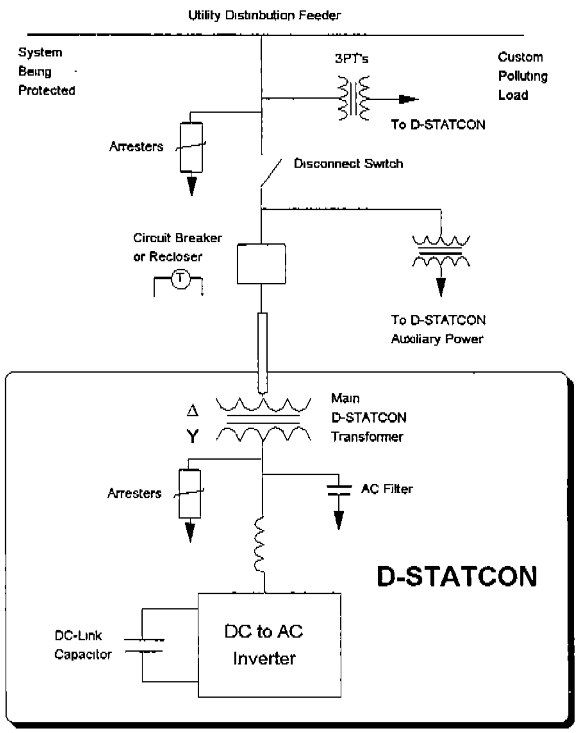

Fig. 3 Typical system interconnection

used to provide forced commutation. The unabailability of sufficiently large gate turn-off devices through the 1970s, and the complexity of forced commutation, hindered the development of pratical all solide-state var compensators.. In 1981, a 20MVA experimental static var compensator installation, using force-commutated thyristor in a ac to ac converter scheme was reported.. In th e1980s, there were dramatic advances in GTO thyristor development and the voltage and current ratings of the available devices rapidly increasd. To demonstrate the practical feasibility of a new generation of reactive power compensators using GTO thyristors, an experimental 1MVA installation employing devices with a voltage rating of 2500 volts and current rating of 2000 amperes in 12-pulse inverter configuration was built in 1986. Futher extensive development

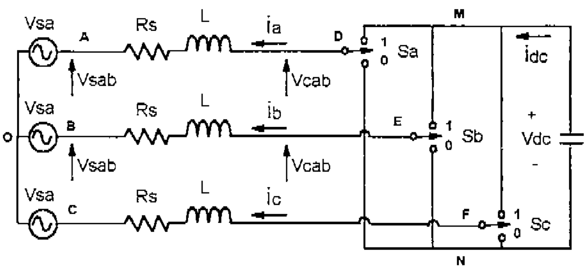

Fig. 4 Simplified cirrcuit of D-STATCON

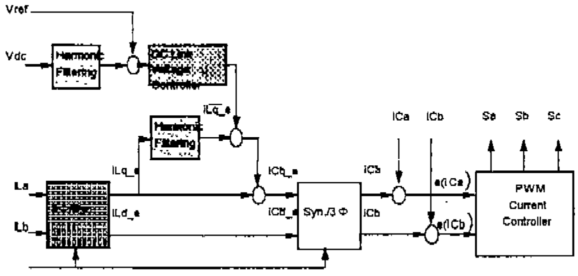

Fig. 5 Controller for power factor correction

efforts in the areas of high power GTO valves and inverter topologies, together with advanced control technique were carried out under EPRI sponsorship. These new technologies are being applied to 100MVA system, presently being developed at TVA. In the meantime, a 80MVA installation using 4500V, 3000A GTO thyristor in a 48-pulse, classical hrmonic neutral inverter arrangement was reported from Japan.

The application of modern semiconductor device, power converter circuit and control technologies have resulted in a solid-state var source of fundmentally diferent operating and functional characteristics than those obtained previously with conventional static var compensator. Since the solid-state converter approach considered in this paper can be represented as an ac voltage source behind a small coupling reactance, its V-I characteristic is similar to that of the rotating synchronous condenser and, for this reasion, it is called a STATic CONdenser or STATCON.

The objectives of this paper are to describe briefly (1) the theoretical foundation of distribution STATCON (2) the operating characteristicss of D-STATCON (3) the overview of control technologies for power factor correction of D-STATCON, and (4) the PWM current control of D-STATCON and simulated results.

2. Distribution STATCON(D-STATCON)

New technologies utilizing power elctronics-based concepts have been developed for advanced distribution to provide additional options for the

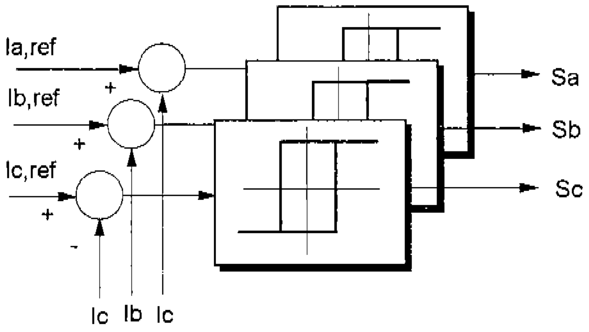

Fig. 6 Hysteresis current controller

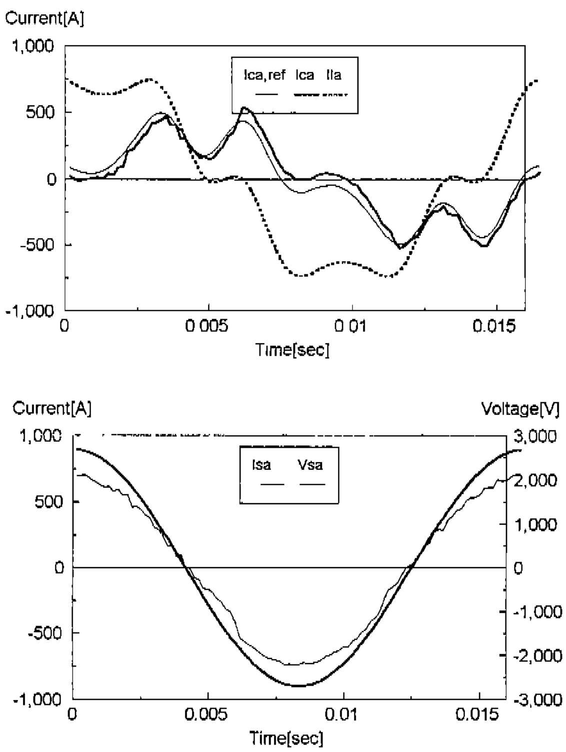

Fig. 7 Dynamic responses for the inductive load using hysteresis current control

utility and large commercial and industrial customers.. Known as Custom Power Products, the technologies described provide the utility with the ability to offer individual customers or groups of customers oppotunity to obtain specified levels of power qualityfrom standard sevice utility distribution system.s. A custom power specification may include provision for no power interruptions, tight voltage regulation including short duration sags or swell, and low harmonic voltages. The family of power electronics devices being offered to achieve these custom power objectives includes Distribution Static Condenser (D-STATCON) to protect the distribution system from effects of a polluting, Dynamic Voltage Restorer(DVR), and Solid-State Breaker (SSB). Fig. 1

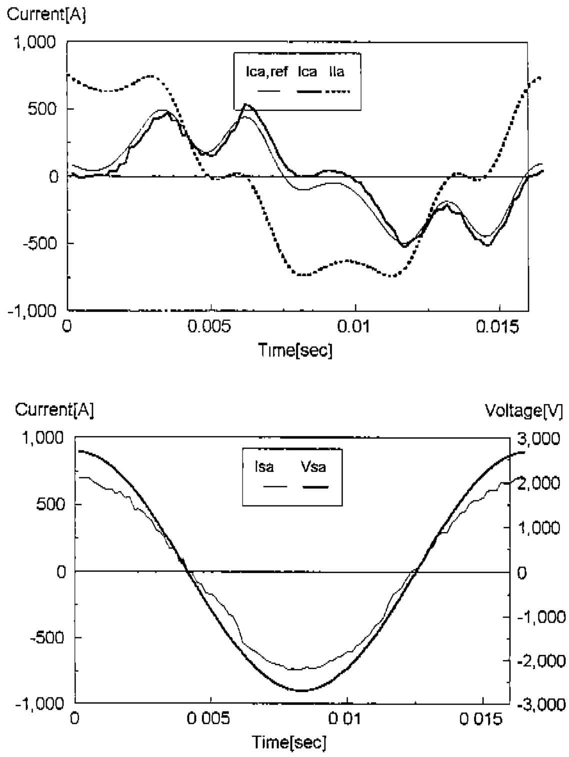

Fig. 8 Dynamic responses for the capacitive load using hysteresis current control

shows how D-STATCON can deployed on the distribution system to provide power quality improvement at the distribution feeder level for sensitive customers.

The 1MVA-class D-STATCON has been developed by KEPRI for advanced distribution. The D-STATCON is a solid-state dc to ac switching power converter that consist of a three-phase, voltage-sourced forced air-cooled inverter. Fig. 2 shows the basic STATCON scheme with an elementary six-pulse voltage-sourced inverter. In this basic form, the D-STATCON injects a voltage in phase with the system voltage, thus providing voltage support and regulation of VAR flow. Because the device generates a synchronous waveform, it is capable of generating continuously variable reactive or capacitive shunt compensation at a level of the maximum MVA rating of the D-STATCON inverter. The D-STATCONcan also be used to reduce the level of hamonics on a line. The use of high frequency pulse-width modulated inverter to synthesize the necessary signal means that the device can inject complex waveforms to canceal out current harmonics generated by non-linear loads. Because the D-STATCON continuously checks the line waveform with respect to a reference ac signal, it always provides the correct amount of harmonic compensation. By a similar argument the

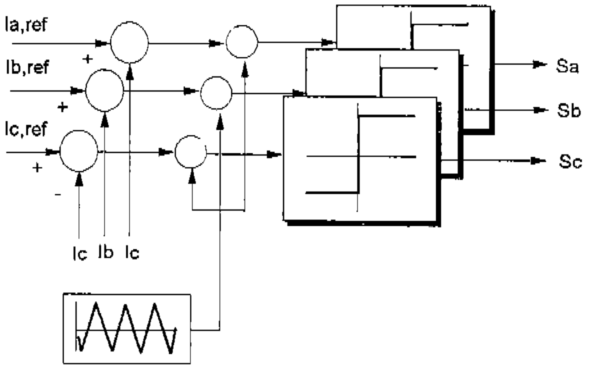

Fig. 9 Ramp comparison current controller

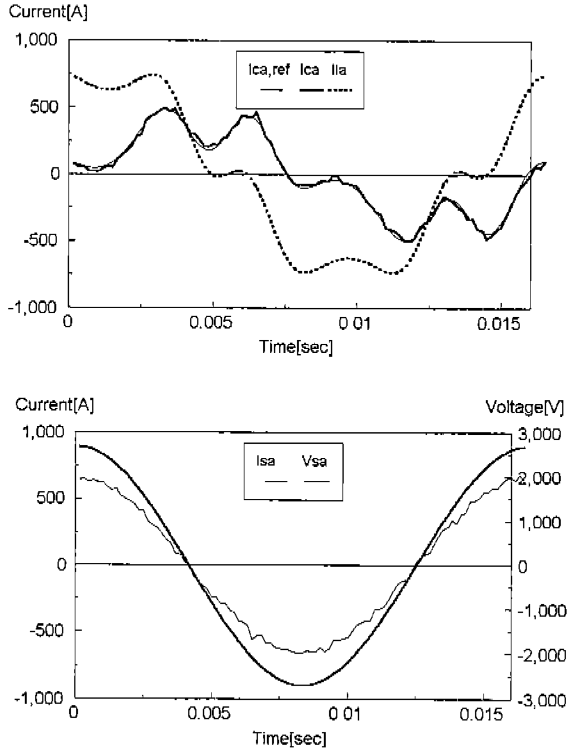

Fig. 10 Dynamic responses for the inductive load usingramp comparison current control

D-STATCON is also suitable for reducing the impact of voltage transients.. When coupled with the Solid-State Breaker installed on the line side of the D-STATCON and energy storage, the D-STATCONcan be used to provide full voltage support to a critical load during operation of feeder breaker that protects the distribution feeder on which the D-STATCON is installed.. In the event of a source disturbance or feeder beraker operation in SSB isolates the D-STATCON and the connected load downstream from the breaker and the amount of load that can be supported is determined by the MVA

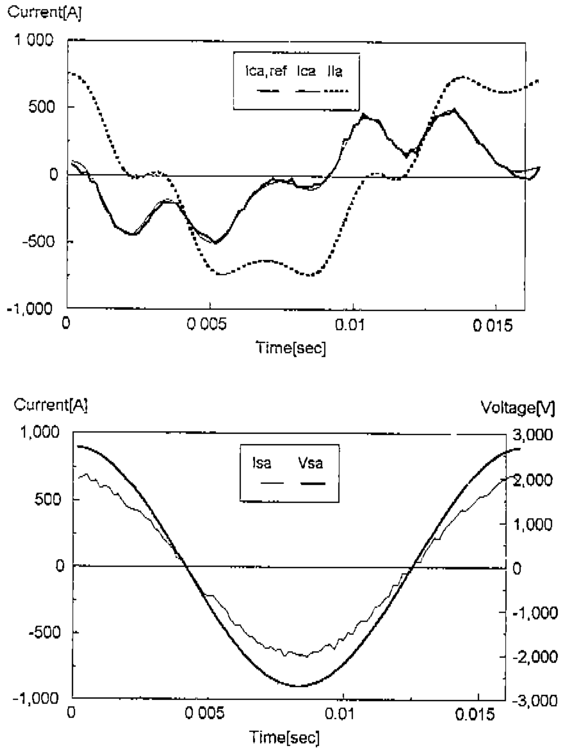

Fig. 11 Dynamic responses for the capacitive load usingramp comparison current control

rating of the inverters, and the length of time that the load can be maintained by the amount of energy storage provided. Connection to the distribution network is via a standard distribution transformer thereby allowing the D-STATCON to be applied to all classes of distribution voltages. At the point of connection, the D-STATCON will, within the limits of its inverter, provide a highly regulated stable terminal voltage. The D-STATCON ia avalable in ratings from 2 to 10MVA in modular 2-MVA increments.. The power elctronics equipment, coupling transformer and disconnecting switchgear is available in indoor lineup or outdoor pad-mount design. Futher portable trailer enclosure is available. Fig. 3 shows the typical system interconnection diagram.

3. Modeling and Control of D-STATCON

The simplified circuit of PWM inverter is shown in Fig. 4. For phase a:

$$L\frac{di_a}{dt} - Ri_a = (v_{DN} + v_{NO}) - V_{Sa} \quad (1)$$

the switching function is defined as

$$Sa = \begin{cases} 1 & \text{for } \textit{upper switch ON} \\ 0 & \text{for } \textit{lower switch ON} \end{cases} \quad (2)$$

and

$$v_{DN} = V_{dc} \quad (3)$$

The equation (1) become

$$L\frac{di_a}{dt} = -Ri_a + (Sa\,V_{dc} + v_{NO}) - V_{Sa} \quad (4)$$

$$L\frac{di_b}{dt} = -Ri_b + (Sb\,V_{dc} + v_{NO}) - V_{Sb} \quad (5)$$

$$L\frac{di_c}{dt} = -Ri_c + (Sc\,V_{dc} + v_{NO}) - V_{Sc} \quad (6)$$

For three-phase system without neutral line,

$$i_a + i_b + i_c = 0 \ . \quad (7)$$

If the ac supply is balanced source,

$$V_{Sa} + V_{Sb} + V_{Sc} = 0 \ . \quad (8)$$

The voltage v_{NO} can be obtained by adding (4) and (6) together:

$$v_{No} = -\frac{V_{dc}}{3}(Sa + Sb + Sc) \quad (9)$$

Another differential equation can be written by inspection::

$$C\frac{dV_{dc}}{dt} = -(Sa\ i_a + Sb\ i_b + Sc\ i_c) \quad (10)$$

Equation (4)-(6) and (10) comprise a complete differential equation set to describe the STATCON.

Fig. 5 shows block diagram of power factor correction controller of D-STATCN. The controler of D-STATCON is based on d-q transformation and the instantaneous powers definded in p-q theory. In Fig. 5, below harmonic filters separate the average values of the real power.

4. PWM Current Control and Simulated Results of D-STATCON

4-1. Hysteresis Current Control

The signal flow diagram in Fig. 6 shows three hysteresis controllers.. Each controller determine the switching-state of one inverter leg such that the error of the corresponding phase current is maintained within the hysteresis band. The main advantage of this control is simple implementation, and its dynamic performance is excellent.. However, there are some inherent drawbacks such as no intercommunucation between the individual hysteresis controller and varied switching frequency. The dynamic responses of this control are given in Fig. 7-8.

4-2. Ramp Comparison Current Control

Constant switching frequency PWM can be easily obtained by a so-called ramp comparison modulator. The signal flow diagram in Fig. 9 shows three ramp comparison controllers.. The dynamic responses of this control are given in Fig. 10-11. Fig. 12 shows the transient responses of the D-STATCON before and after the power factor correction control technique is employed..

5. Conclusions

This paper describes the theoretical foundation of distribution STATCON, the operating characteristicss of D-STATCON, the overview of control technologies for power factor correction of D-STATCON, and the PWM current control of D-STATCON and simulated results.. The 1MVA D-STATCON prototype installation of KEPRI will be a major mile-stone in bringing the FACTS technology to practical use in Korea..

REFERENCES

[1] I.A. Erinmez, Ed, "Static Var compensator " Working Group 38-01, Task force N0. 2.

[2] L. Gyugui,"Reactive power generation and control by thyristor circuits," IEEE Trans. IA, vol. IA-15, no. 5, pp. 521-532, Sept. 1979.