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Performance Analysis for the Modified Excitation System of Synchronous Machine Connected to HVDC System

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Abstract - This paper analysis the transient performance of the modified excitation system using 4-quadrant chopper for a synchronous machine connected to HVDC system. Conventionally, capacitors are used to supply reactive power requirement at a strong converter bus. And the installation of a synchronous machine is essential in an isolated weak network to re-start after a shutdown of HVDC and to increase the system strength. However, a conventional static excitation system has some problems which are harmonic instability and the system stress due to overvoltage. To reduce these problems, the new excitation system, which has 4-quadrant chopper, is proposed. As the proposed system provides the capability to allow reverse current and isolate between AC network and excitation power, problems of overvoltage and harmonic instability can be solved. The investigation is performed and confirmed by the time domain digital simulation using PSCAD/EMTDC program.

Keywords - adjustable speed drives, sliding mode control

1. Introduction

Over long distances bulk power transfer can be carried out by HVDC connection cheaper than by a long distance AC transmission line. Also, bulk power of HVDC transmission scheme may be transmitted through very long cables or across borders where the two AC systems are not synchronized or operate at different frequencies.

HVDC converters (both rectifiers and inverters) draw the lagging reactive power from the AC system in the amount of about 60% of the real power. Usually HVDC systems are fully compensated for the reactive power at the converter bus to improve the system regulation and reduce transmission losses. Variation in the DC power changes the required Mvar by the converter and hence tends to cause AC voltage fluctuation. For a strong AC system, it is tolerable by using fixed capacitors to provide the reactive power. However, if the AC system is weak these changes are particularly significant because they can lead to system instability. Hence we must use dynamically adjustable compensator schemes. Static Var Compensator (SVC), Static Compensator (STACOM) or Synchronous Compensator are the commonly used dynamic compensator schemes. Among these, the installation of a synchronous machine is essential in an isolated weak network to re-start after a shutdown of HVDC system and increase the system strength. For the extreme case of a receiving system of zero inertia (no generation), a conventional inverter cannot start after even a momentary interruption of DC power. A synchronous machine in the receiving system is generally the only practical solution in such situations.

In this case where the dynamic performance of a synchronous machine depends on the characteristics its excitation system, the operation of a synchronous machine with a static excitation system can cause several problems like harmonic instability, torsional vibration and the thyristors failure of a excitation system.

Both harmonic instability and torsional mode instability through an excitation control may be caused by a terminal voltage limiter which uses the feedback of terminal voltage to control the excitation through a very high gain. Since the output voltage of the static excitation system is dependent on the generator terminal voltage controlled by the static excitation system, Both harmonic instability and torsional mode instability mainly are generated in static excitation system. And the thyristors failure of excitation system fault due to self-excitation can be caused by the HVDC system trip, since HVDC system has big capacitors or filters.

In this paper, the new excitation topology is proposed to reduce several problems that can be generated in HVDC system. It is the method using 4-quadrant single chopper to allow reverse current in the field circuit and isolate the power source between AC network power and the excitation power.

2. AC network oscillation due to static excitation system

The IEEE has classified excitation systems currently in use into 12 types. From a viewpoint of system characteristics, the excitation system is classified into 3 types - DC, AC, and a static type. Because DC-type exciters have gradually being phased out, this paper deals with both an AC rotating type excitation system and a static type. Fig. 1. (a) shows an AC rotating excitation system that consists of a Permanent Magnet Generator (PMG) with a controlled rectifier and an

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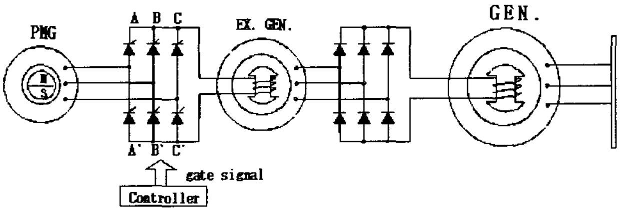
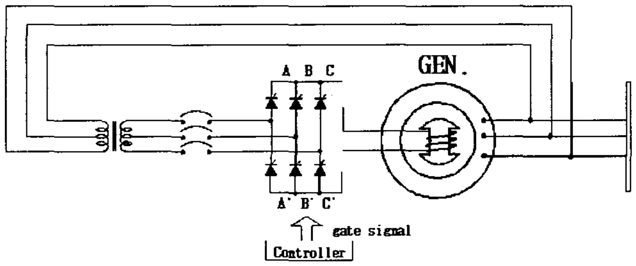
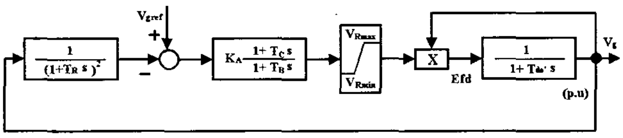
exciter generator with a non-controlled rectifier. In this system, the exciter has on the same shaft that the turbine generator. The AC output of exciter system is rectified by either a controlled or a non-controlled rectifier to produce the direct current needed for the generator field. The rectifiers may be stationary or rotating. This system is more stable than a static excitation system because the excitation system power is not supplied by the generator terminals. The excitation system shown in Fig. 1 (b) consists of a synchronous generator and a controlled converter. The static excitation system power is supplied through a transformer from the generator terminals. Some advantages of this system include small inherent time constant, lower cost and easy maintenance. However, during system-fault conditions, the available excitation system ceiling voltage is diminished because the excitation output voltage is dependent on the AC system input voltage.



(a) AC Rotating Excitation System



(b) Static Excitation System.



(c) Static Excitation System Model

Fig. 1 Excitation System.

In a static excitation system, the torsional mode instability may be caused by a terminal voltage limiter which have the feedback of terminal voltage to control excitation through a very high gain. Dr. Kunder urged that the filter algorithm is a good solution for this in CIGRE workshop. However, this method is difficult to tune the filter gains and not a best solution.

2.1 Controller Design of Static Excitation System

The controller design of static excitation shown in Fig. 2.(b) is as follow:

The steady state gain ( ) of the excitation, is designed in equation (1). The secondary voltage of excitation transformer (V_2) is designed in equation (2).

$$K_A \ge \frac{V_{fN}-V_{fo}}{V_{fo}} \times \frac{100}{\varepsilon} \tag{1}$$

$$V_2 = \frac{\pi(V_p \times V_{fo} + V_{fD})}{3\sqrt{2}(\cos\alpha - 0.15 \times Z_T)} \tag{2}$$

where, V_{fN} is full-load field voltage, V_{fo} is no-load field voltage, Z_T is transformer impedance, V_{fD} is thyristor voltage drop, V_p is ceiling voltage and ε is a voltage variation rate(%).

The excitation system controller has the lead-lag compensator which has the time constants T_c and T_b. The transient gain K_T of this controller expressed in terms of K_A, T_b and T_c is as given by equations (3 ~ 6) using gain margin and phase margin method of analysis. These equations are given below:

$$K_T = K_A \frac{T_C}{T_B} \tag{3}$$

$$K_T \ge V_R \max / \Delta V_g \tag{4}$$

$$K_T / T_{do}' = \omega_c \tag{5}$$

$$1/T_c \le \omega_c / n, \ (n \ge 2) \tag{6}$$

As it can be seen from these equations, the transient gain is also a function of the ceiling voltage V_R max. This ceiling voltage is a significant factor in determining the dynamic performance of the excitation system.

Fig. 2. shows the inverter side of the study system. The DC control of the study system is identical to the CIGRE benchmark model. The study system models a 1000MW, 500KV, 12 pulse, Monopolar HVDC system connected to a weak AC system. The inverter Short Circuit Ratio (SCR) is 2.0∠-80 and Effective SCR (ESCR) is 1.5∠-60. Fixed capacitors provide 500Mvar at rated voltage and the remaining reactive power requirement of the converter is supplied by the synchronous condenser of rating -165/+300 Mvar.

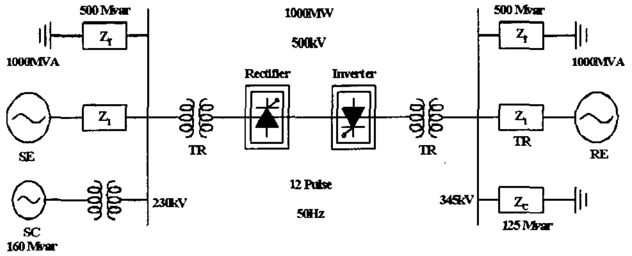


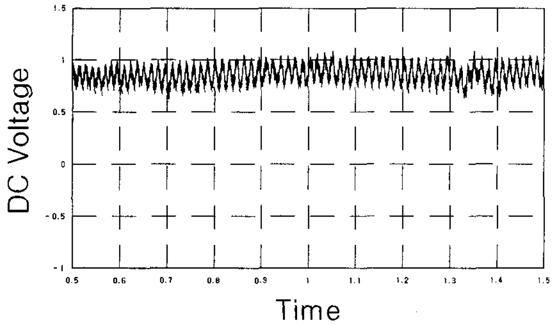
Fig. 2 Test System Based on the CIGRE Model.

Fig. 3. shows the HVDC system waveforms as a result of simulation. In this case, the effective ceiling voltage for the static excitation is 6 p.u and the control parameters of the excitation system are given in Table 1.

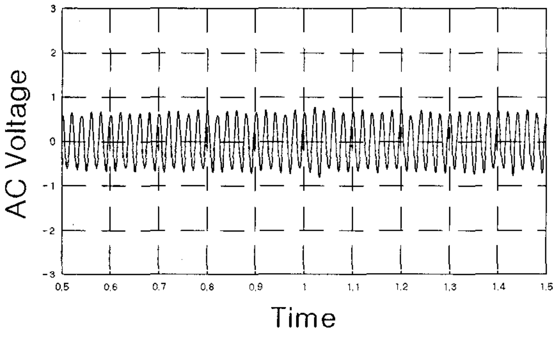
In Fig. 3.(a), the DC voltage shows the oscillation (near fundamental frequency) of the considerable magnitude as a result of the AC voltage fluctuation. Fig. 3.(b) shows that the AC system voltage has the sub-harmonic modulation as a result of the interaction of the excitation system on the terminal voltage. If the AC system is strong, the effect of the interaction would have been negligible. But, in a weak AC system, these interactions could easily lead to system instability after faults as shown in Fig. 3.(c). Fig. 3.(d) shows the same case in steady-state as in Fig. 3.(a) except that the effective ceiling voltages of the excitation system is changed V_R max to 8 p.u.

Table 1 Static Excitation System Parameter.

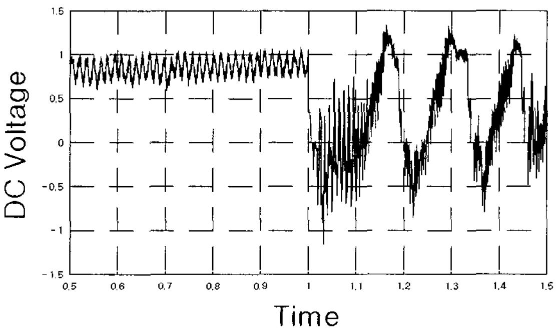
K_A	150
K_c	0.1[s]
K_b	0.375[s]
K_{do}'	2[s]
ω_c	10[dB]



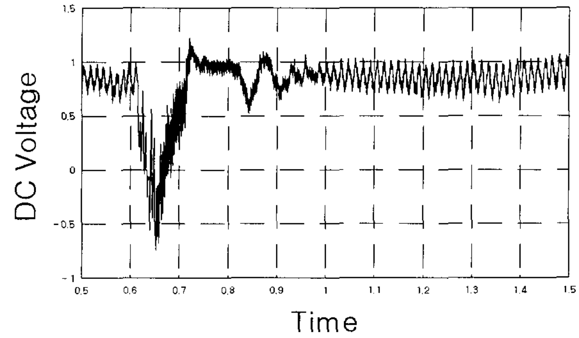
(a) DC Voltage waveform



(b) AC Voltage Waveform



c) DC Voltage after AC line Fault



d) DC Voltage according to changing ceiling voltage

Fig. 3 Waveforms of HVDC system response.

3. Stress of excitation system in HVDC system

Due to the nature of HVDC System, converters of an HVDC transmission line consume large amounts of inductive Vars while converting AC power to DC power. The reactive power required for the conversion is in the range of 50 - 60% of the active power to be converted. The conversion of AC power also generates high magnitude current harmonic components. The common practice is to design and install filters at the converter AC busbar to suppress the harmonics and, at the same time, to supply a greater part of the reactive power required for the AC/DC conversion. When there is a full load rejection, synchronous machines are left connected only to the filters and hence experience a sudden change both in active power and reactive power. The large capacitive Vars of the AC filters, previously consumed by the rectifiers, will have to flow into the synchronous machine. This exposes the synchronous machine to the danger of self-excitation and consequent system overvoltage.

To explain the self-excitation, let's introduce the time constants. The time constants for d-axis and q-axis are:

$$T_d = T_{do}\frac{X_c - X_d'}{X_c - X_d} \quad \text{and} \quad T_q = T_{qo}\frac{X_c - X_q''}{X_c - X_q} \qquad (7)$$

where, X_c is capacitor impedance, X_d' is transient d-axis reactance, T_{do} is d-axis open circuit time constant, T_{qo} is q-axis open circuit time constant and X_q'' is q-axis subtransient reactance.

When these time constants are positive, any sudden change of the field flux will be damped. However, if they become negative, sudden change will cause the filed flux to build-up exponentially, and system voltage to rise ups, which limited only by transformer saturation.

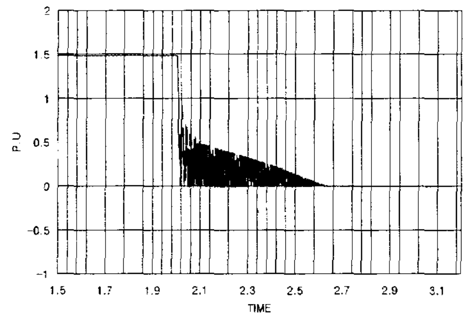
When negative current is not allowed to flow in the generator exciters, the system voltage starts to rise immediately after generators become self-excited. And the self-excitation of the d-axis corresponds to the exciter current going from positive to negative. At this time, since thyristor has a capability of one-way current flow, overvoltage at the thyristor of excitation system is generated.

The thyristors of static excitation system are made to fail in the short-circuit mode if the following condition occurred.

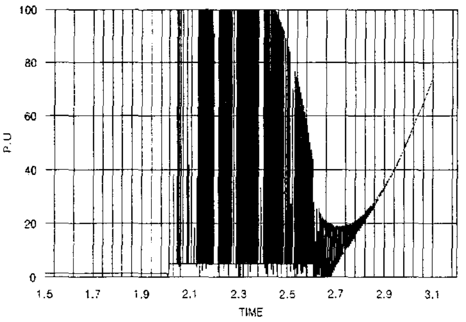
$$\int |V_{rev}| \, dt > BD \quad \text{for} \quad V_{rev} \succ V_{bd} \qquad (8)$$

where, V_{rev} is the reverse voltage of excitation system, BD is a scale factor representing an energy absorption capability, and V_{bd} is the peak reverse voltage of thyristor.

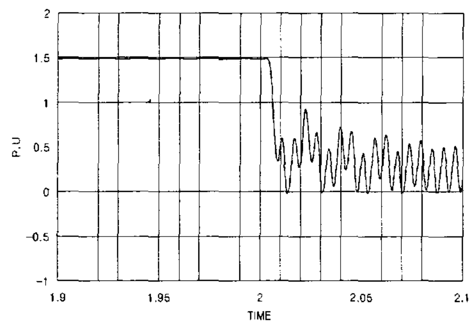
If negative current by way of crowbar or another methods is allow to flow, over-voltage and self-excitation can be reduce. Fig. 4 shows that the generator terminal voltage starts to increase immediately after a generator becomes self-excited. Fig. 4 (c) enlarge a part of Fig. 4 (a), and it shows the oscillation due to resonance between the reactance of synchronous machine and a capacitor of AC network. Also, Fig. 4 d) enlarge a part of Fig. 4 b), the duty ratio of over voltage



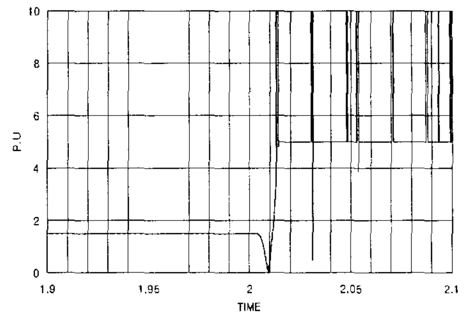
a) Excitation System Current



b) Excitation System Voltage

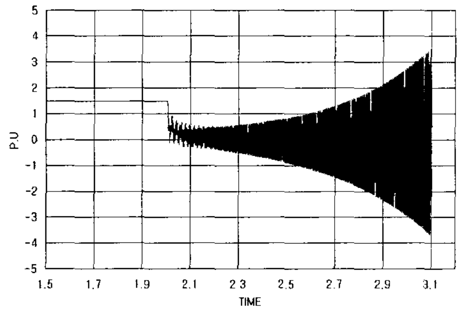


c) Excitation System Current (Enlarged)

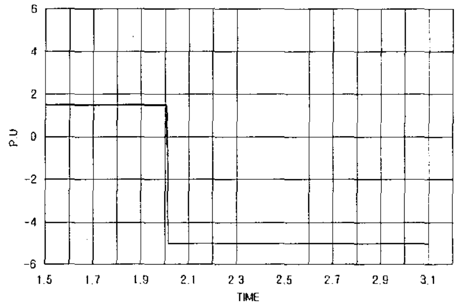


d) Excitation Voltage (Enlarged)

Fig. 4. System Waveforms according to Self-Excitation Condition(Without Allowing Reverse Current).



a) Excitation System Current

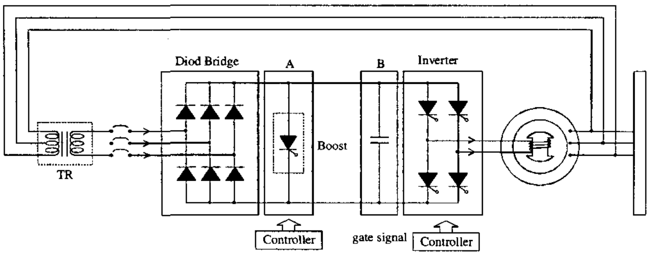


b) Excitation System Voltage

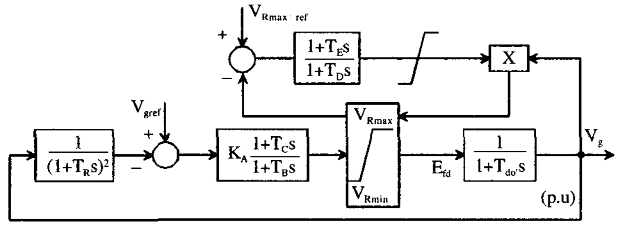
Fig. 5 System Waveforms according to Self-Excitation Condition(With Allowing Reverse Current).

4. Modified Excitation system using 4-quadrant single chopper

In order to solve the above-represented problem, the following method is proposed. The proposed excitation system shows in Fig. 6. The system response of this system is shown for a single phase to ground fault in Fig. 7 and it is in the same case as in Fig. 3 d). This excitation system shows improved steady state and post fault response. Also, Fig. 8 shows excitation system response when HVDC system connected to a synchronous machine is tripped. Since the proposed system makes the reverse current to flow, we know that overvoltage do not appeared and self-excitation is postponed.



(a) System Hardware



b) System Modelling

Fig. 6 Excitation System Using 4-quadrant Single Chopper.

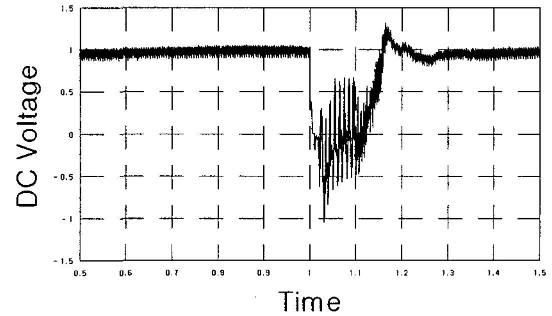
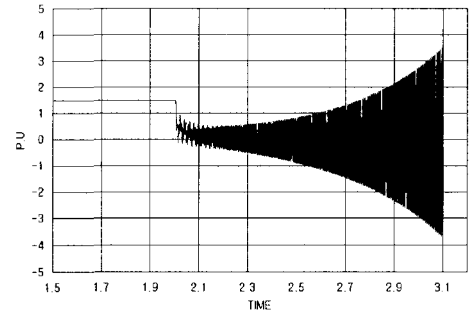
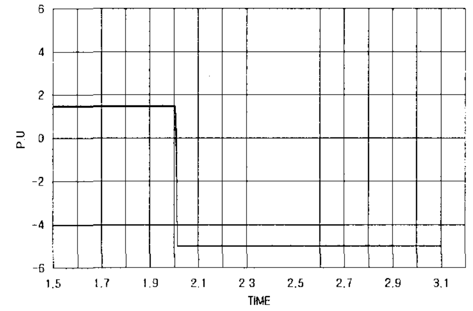


Fig. 7 HVDC Response in Case of Using 4-quadrant Single Chopper.



a) Excitation System Current



b) Excitation System Voltage

Fig. 8 System Waveforms in case of using single chopper (with Allowing Reverse Current).

5. Conclusion

The results of this paper are as follows:

1) Since the excitation system using 4-quadrant chopper has a capability to allow reverse current, overvoltage due to self-excitation at excitation system is not generated.

2) Since the system characteristics of this system isolate between AC network and excitation system due to the capacitor of the chopper, harmonics instability or sub-resonance are not generated.

Acknowledgment

Thank Dr. A. Gole of Manitoba Univ. for supporting and advising for this paper.

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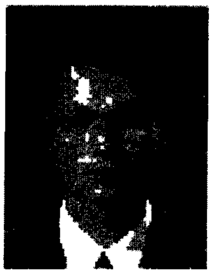

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