Active Power Control For Preventing Voltage Instability Using an Adjustable Speed Machine

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Abstract: One cause of power system voltage instability is the loss of short-term operation equilibrium after a disturbance. This paper proposes an active power control method for preventing short-term voltage instability. The active power control is implemented by means of an adjustable speed machine, which is primarily used as a synchronous condenser, but includes a flywheel for short-term active power injection into the system. This adjustable speed machine can support the power system to avoid voltage collapse or excessive voltage dips by compensating both active and reactive power supply to the system immediately after a disturbance. The focus of this paper is a proposed active power control method, illustrated with simulation results. A power system consisting of a synchronous machine, a hybrid-load, and an adjustable speed condenser is used as an example.

Keywords: Power Systems, Voltage Instability, Adjustable Speed Machine, Synchronous Condenser, Active Power Control, Load Characteristics.

I. INTRODUCTION

Voltage instability problems are attracting more and more attention in the areas of power system operation, planning, and control. These problems are becoming a more serious concern with the ever-increasing utilization and higher loading of existing transmission systems, particularly with increasing energy demands, and competitive generation and supply requirements.

It is well known that enhancing the reactive power supplying ability of a power system by means of Static Compensators (STATCOM) and Static Var Compensators (SVCs), or with voltage control utilizing Load Tap Changers (LTCs), or other methods such as Primary Side Voltage Regulation (PSVR), High Side Voltage Regulation (HSVC), or Advanced Over Excitation Limiters (A-OEL), all contribute to the improvement of voltage stability [2, 3, 4, 5, 6, 7, 8]. However, another emerging method for the improvement of voltage stability is the adjustable speed machine (ASM).

In recent years, several major power system outages can be explained by voltage collapse or severe voltage dip after a major disturbance in the power system, particularly when stressed by heavy load [1, 2, 3]. To avoid voltage instability, it is imperative to return the power system to a stable operating equilibrium as quickly as possible after a disturbance. This paper proposed an active power control method to prevent voltage instability and severe voltage dips by compensating the power system load. This active power control is implemented by means of an adjustable speed machine (ASM), which is primarily used as a synchronous condenser, but includes a flywheel for short-term active power injection into the system. Since an ASM is of high response it is able to supply both reactive power and active power rapidly, as needed by the power system.

In this paper, the ability to prevent voltage instability by active power control is discussed first. Then, the advantages of the ASM operated as a synchronous condenser are given. Finally the control method is illustrated and identified based on an application example with simulation results.

II. ACTIVE POWER CONTROL FOR PREVENTING VOLTAGE INSTABILITY

1) Voltage Instability

Voltage instability involves various phenomena over different time frames. This paper focuses on the scenario of the loss of short-term operation equilibrium of a power system after a disturbance.

A power system must operate at a stable equilibrium point, which can be described by the intersection of a specific transmission system characteristic and load characteristic [1]. This is illustrated in the Power-Voltage (PV) curve of Figure 1. The transmission system characteristic (C11) and the load characteristic (C21) of the power system intersect at the point A for steady-state operation. If the transmission system characteristic C11 is reduced to C12, and assuming that the loads characteristic described by C21 can only be migrated back to C22 slowly by, say, LTC action, then after a disturbance, then the system will lose voltage stability because of a lack of intersection between the transmission system characteristic (C12) and load characteristic (C22).

The characteristics of loads are ever-increasing in a trend towards constant power, induction motor, and various sensitive power electronic loads. Thus, the load characteristics of power systems are becoming more and more rigid. This is leading to tripping and/or stalling of loads whenever severe voltage dips or deficiencies in electric power supply occur [9].

When such strong non-linear loads occupy a large percentage of the total system load, it is increasingly likely that a loss of the operation equilibrium point after a large disturbance will occur.

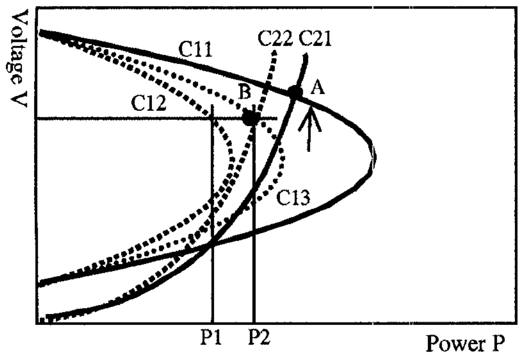


Figure 1. PV curve of a power system

2) Possibility of Direct Power Control

As shown in Figure 1, if the transmission system characteristic C12 could be changed to C13 after a disturbance, the transmission system characteristic would intersect the load characteristic C22 at point B. In other words, if the active power supplied by the transmission system is extended sufficiently after the disturbance, a short-term equilibrium operation point can be achieved, even if the load characteristic is rigid. Hence, rapidly supplying active power to a transmission system is critical to avoid short-term voltage instability.

Primarily, almost all countermeasures for improving voltage stability relate to reactive power compensation or voltage control [1, 2, 3, 4, 5, 6, 7, 8]. Active power control has only recently been considered. (Note this is in part due to the fact that active power control response of synchronous generators is too slow to be beneficial for short-term voltage instability mitigation). However, by means of the ASM, active power control for preventing voltage instability can be implemented. The active power control method using an ASM is described in the following sections.

III. ACTIVE POWER CONTROL METHODS USING ASM

1) Advantages of ASM [10]

<u>Adjustable Speed</u>: An ASM is excited by its AC excitation system, which is fixed on the rotor of the ASM. Hence, the value of the rotor speed is determined by the frequency difference between the power system and the excitation system. It is possible to control the rotor speed of the ASM to a desired value according to the system operation requirements, by regulating the frequency of the excitation system.

<u>Condenser Ability</u>: An ASM can be used as a synchronous condenser to supply reactive power. However, unlike a conventional synchronous condenser, the ASM condenser can transform its rotational energy into active power. Hence, with a flywheel corresponding to required capacity, the ASM condenser is able to provide active power on a short-term basis.

<u>P-Q Independent Control</u>: By means of the d-q axis individual excitation method, the active power P and reactive power Q of the ASM can be controlled independently.

<u>High Response of Power Control</u>: Making use of the rotational energy of the ASM, an extremely high response is possible (at least 300 times higher than a synchronous generator), thus active power control can be realized by the excitation system.

<u>High Stability</u>: The transient stability and dynamic stability of an ASM system are excellent, since the angle of the ASM can be controlled directly.

2) Benefit of ASM Condenser for Voltage Stability

An ASM operated as a synchronous condenser contributes to long-term voltage stability because it extends transmission system limitations by way of compensating reactive power and improving voltage control. However, by taking advantage of its high power control response, the ASM can also contribute to short-term voltage stability.

As an example of the benefits of an ASM, Figure 2 shows an ASM located between the sending-end and receiving-end of a power system. In steady-state operation, the ASM compensates reactive power according to the system requirements and suppresses voltage fluctuations. A voltage dip detecting function can be added to the active power control system of the ASM. Thus, once an abrupt voltage drop or frequency drop is detected, the ASM rapidly outputs active power to compensate the deficiency in active power supplied to the load, until the system recovers. The output value of the active power is determined according to the voltage drop level and frequency variation level. The maximum output electrical energy of the ASM is determined by the capacity of its flywheel.

IV. APPLICATION EXAMPLE

1) System Model

As an application example, the ASM with the proposed active power control function is used in a single synchronous generator-to-hybrid-load power system as shown in Figure 3. Here, the synchronous generator supplies the two constant impendence loads and one constant power load through 4 transmission lines. The ASM is located at a bus at the midpoint of the transmission system.

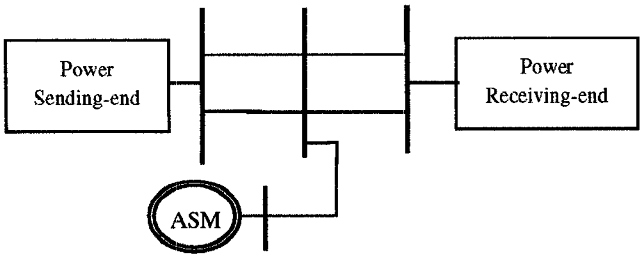
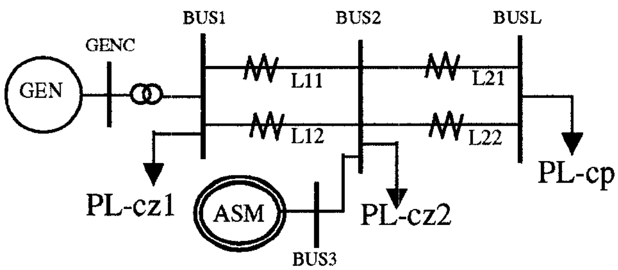


Figure 2. Example of an ASM condenser in a power system

The synchronous generator is equipped with an automatic voltage regulator (AVR). The ASM is equipped with a voltage control system, a reactive power control system, and an active power control system with a voltage dip detecting function. The main constants of the synchronous generator and the ASM are listed in Table 1.

To identify the effectiveness of the active power control using an ASM for preventing short-term voltage instability, the follows numerical simulations were performed.



GEN: Synchronous generator (1000MVA)
PL-cp: Constant power load (600MW)
PL-cz1: Constant impedance load (200MW)
PL-cz2: Constant impedance load (200MW)
ASM: ASM condenser (400MVA)

Figure 3. Simulation model

Table 1
Constants of Synchronous Generator and ASM

Synchronous Generator		
M=19.1sec	Xd=1.16pu	Xd'=0.29pu
Xd"=0.17pu	Xq=1.16pu	Xq"=0.17pu
Tdo'=9.6sec	Td"=0.035sec	Tq"=0.035sec
Xt=0.15 (Impedance of Mr.T)		
ASM Condenser		
M=10.7sec	Tr=7.86	Xs=1.71pu
Xr=1.69pu	Xm=1.62pu	Td"=0.1sec

2) Simulation of Transmission Line Tripping

The first simulation condition considered is for a case where the system transfer impedance increases. Here, the transmission line L12 is tripped at t=1.17sec and re-closed at t=2.17sec (See Figure 3). To distinguish the effect of active power control for preventing voltage instability from the basic voltage control, the simulations with and without the voltage dip detecting function of the ASM are performed separately.

With the active power control voltage dip detecting function of the ASM not active, voltage collapse of the system occurs after the line L12 is tripped. For this case, the total impedance of the transmission lines is extended to 0.25PU. The simulation results are shown in Figure 4. The voltage drops abruptly after the L12 is tripped, and then the system collapses since there is insufficient active power supply to the constant power load.

Adding the voltage dip detecting function to the active power control of the ASM, the voltage collapse is avoided even with the total impedance of the transmission lines extending to 0.47PU. The simulation results are shown in Figure 5. After the line L12 tripped, the ASM outputs active power instantly to compensate the lost power from the sending-end by reducing its rotational speed. Hence, the voltage dip recovers sooner as well. After the line L12 is re-closed, the system returns to its original operating state and the active power of the ASM is reduced to zero within 1 sec.

3) Simulation of Load Dispatch Changing

An unexpected load dispatch change may occur with a fault or an operating condition variation. As an example, the following simulation condition is assumed as switching the constant impedance load PL-cz1 from BUS1 to BUS2 at t=1.17 sec.

By means of the reactive supplying ability of the ASM, the transmission system capability can be greatly extended. However, a sudden large load variation may still render the system voltage unstable. To distinguish the control effect of active power on preventing voltage instability from the voltage control effect, the simulations with and without the voltage dip detecting function of the ASM were performed separately.

Without the voltage dip detecting function in the active power control, the voltage collapsed after the load dispatch was changed. Here, the total impedance of the transmission lines is extended to 0.4PU. The simulation results are shown in Figure 6. The voltage dropped abruptly after the load dispatch was changed, and system collapsed due to the dramatic increase of power transfer from BUS1 to BUS2.

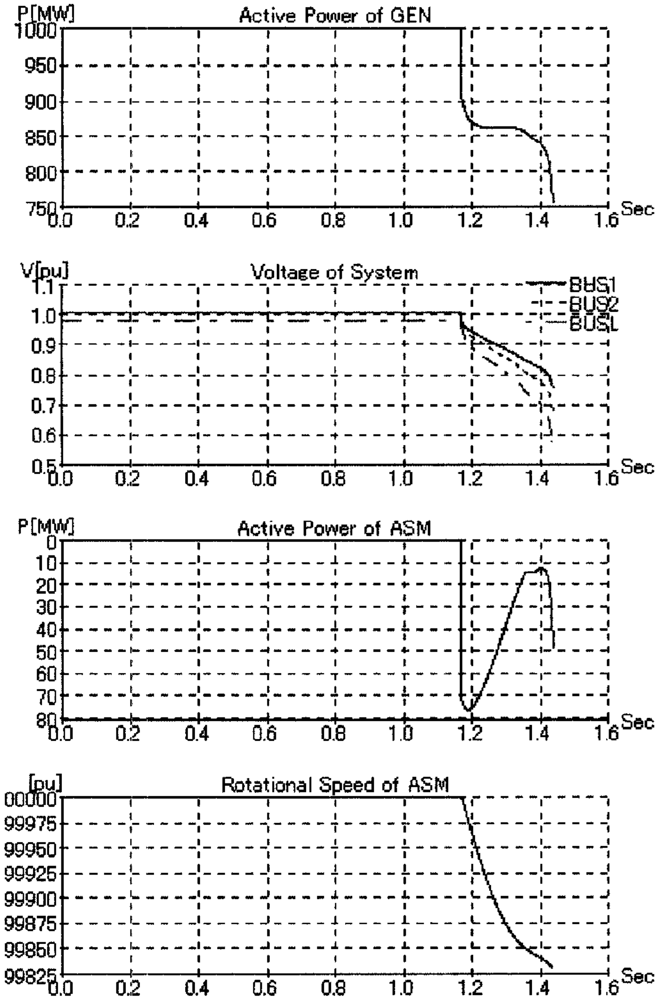


Figure 4. System responses after 1 line tripped (Without voltage dip detecting function)

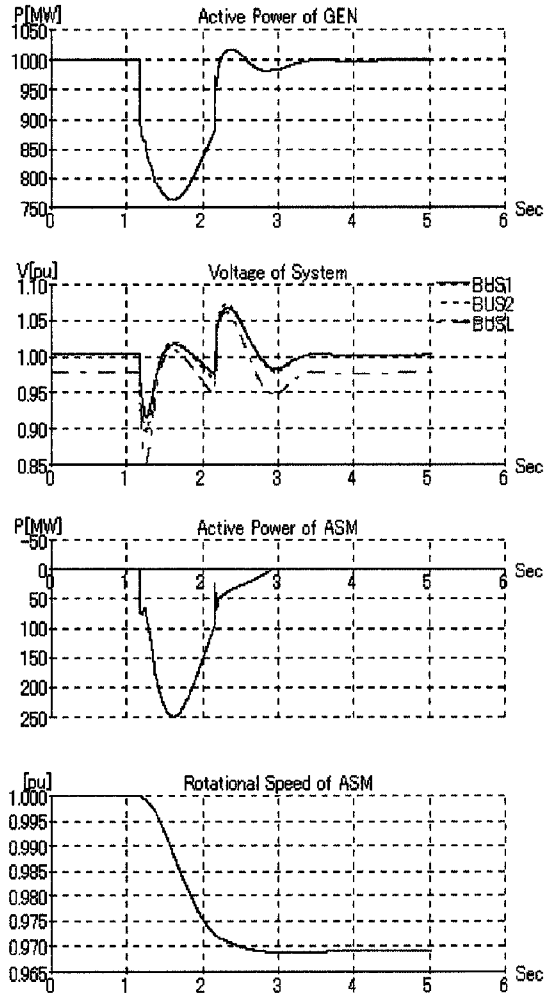


Figure 5. System responses after 1 line tripped (With voltage dip detecting function)

With the voltage dip detecting function, the active power control of the ASM operated after the load dispatch is changed, and the ASM supplies active power to the loads temporarily until the system voltage recovers as the simulation results show in Figure 7.

Under the active power control, the impedance limitation value can be extended close to the steady transmission impedance limitation of the system.

V. CONCLUSIONS

In this paper, an active power control method for preventing short-term voltage instability was proposed. The active power control is implemented by means of an adjustable speed machine, which is primarily used as a synchronous condenser, but includes a flywheel for short-term active power injection into the system. This adjustable speed machine can support the power system to avoid voltage collapse or excessive voltage dips by compensating both active and reactive power supply to the system immediately after a disturbance.

As an application example, an ASM with the proposed active power control function was used with a single synchronous generator and hybrid load power system. The two scenarios examined, namely a transmission line tripping and load dispatch change, were simulated with and without the proposed active power control function. Both of the simulation results showed that the power system survived from voltage collapse after the disturbances for the case where the active power control function was in-place. Therefore, the effectiveness of the active power control by means of an ASM condenser for preventing short-term voltage instability was identified.

This paper introduced the basic concept of active power control using an ASM condenser. Future work will include more detailed simulation analysis and a refined control procedures for the active power control of an ASM.

The adjustable speed machine technology discussed in this paper focused on the application to a synchronous condenser rather than a generator for the application at a midpoint of a transmission system. In cases where an adjustable speed generator can be applied, the effect of improving voltage stability will be more significant than with the adjustable speed condenser.

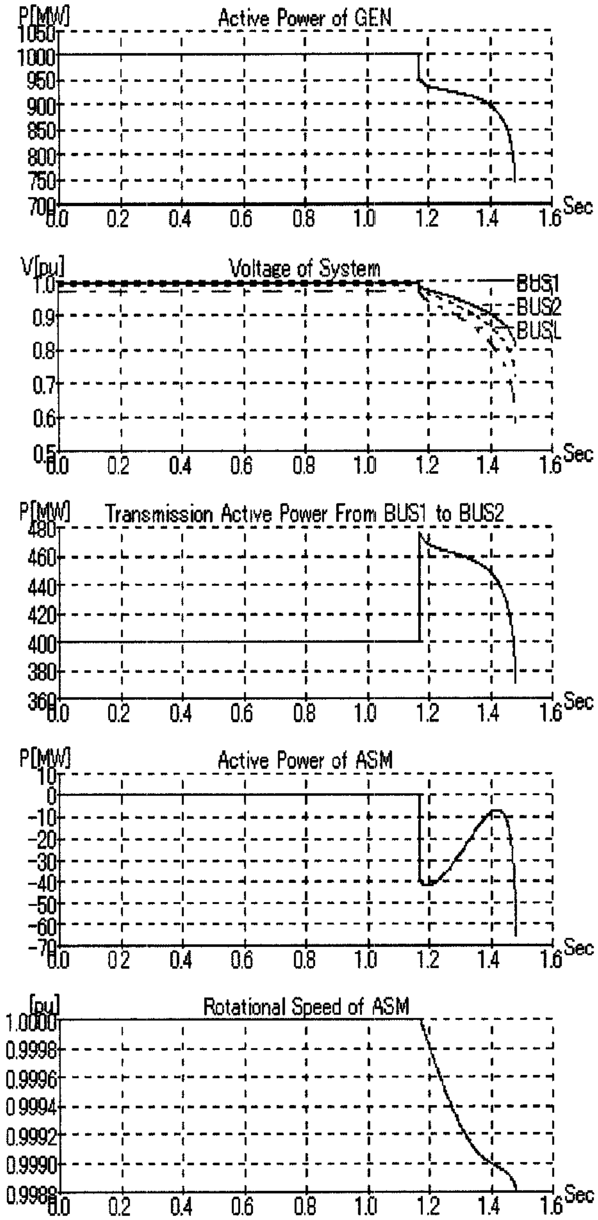


Figure 6. System responses after load dispatch is changed (Without voltage dip detecting function)

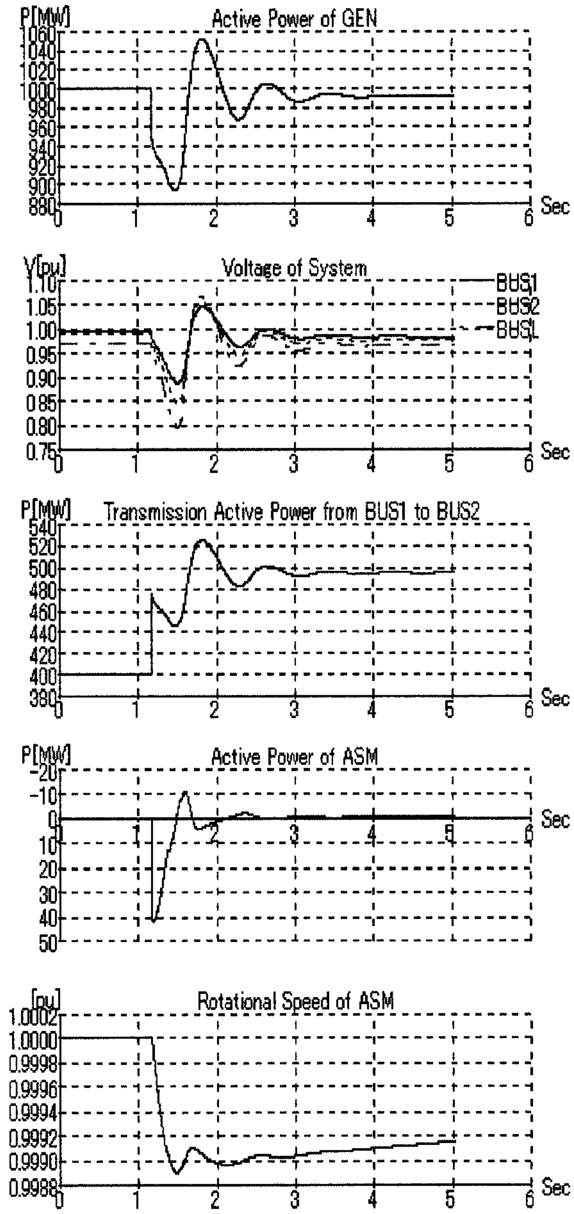


Figure 7. System responses after load dispatch is changed (With voltage dip detecting function)

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VII. BIOGRAPHIES

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