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The Enhanced Performance SVC for Transient Instability Oscillation Damping

Phinit Srithorn[a]*, Natthawut Theejanthuek[b]

[a]*Rajamangala University of Technology Isan, 744 Suranarai Rd, Muang, Nakhonratchasima,30000, Thailand*
[b]*Synchotron Light Research Institute (Public organization),* *Nakhonratchasima,30000, Thailand*

Abstract

To utilise green energy, renewables have penetrated into utility. However, its intermittent nature affects on power quality and network stability. Static var compensators (SVCs) have been installed in order to gain power quality improvement. Nevertheless, lacking of real power support, the SVCs cannot minimise any instability. This paper presents a technique to provide the SVCs the ability to enhance their performance. Dynamic oscillation damper is co-located with a typical SVC, offering ability to damp oscillations. Simulation shows the proposed system performance was greatly enhanced. This envisages future applications, where a combination of distributed generators and renewables causes severe interaction.

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Keywords: SVC; electromechanical interaction; frequency overshoot; transient instability; renewables disadvantage.

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1. Introduction

Over the past ten years, applications of renewable energy in power systems have been the most common issue mentioned amongst operators, and also encouraged with governmental policies, in order to utilise more green energy. However the penetration of renewable energy into the grid brings with it an intermittent characteristic that usually results in power quality problem [1]-[2], and possibly leading to stability concerns. As most of power

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* Corresponding author. Tel.: +66(0)-4425-2659; fax: +66(0)-4425-2659.
E-mail address: phinit.sr@rmuti.ac.th

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networks employ rotating generator, which in normal situations its speed and field excitation control system will able to cope with gradual variations supplying power to loads with a constant frequency and voltage.

But if any transient events like sudden load switching, renewable discontinuing, and fault occurring in the systems, it is inevitable that generators will have to cope with more stress; generators try to regulate the incoming mechanical power in order to match its output change. Inside the generator the relevant speed controller, which is responsible for regulating the system frequency, will try to keep the generator tracking the instant real power change [3]. However some limitations due to the mechanical movement result in generator delay to respond to an immediate variation of the electrical output; severe oscillation instability may occur, and can be classified as one of the critical situations further leading to failure operation of the whole system [3]-[4].

This instability is one of considering problems in the system employing a combination of one distributed generator and renewables as the main power supply; the system protection may detect the above mentioned abnormal condition as a problem and separates the involved source components out of the network. Furthermore, any modern sensitive components may suffer from this swing of the system frequency. Hence, to have an ability to minimize the transient instability inside the system is one of the most desirable features. Recently this requirement, in conjunction with the aim to have the system voltage stabilized instantaneously, has introduced the use of flexible ac transmission system devices (FACTS) in power networks [4]-[8]. Static var compensator (SVC), the ubiquitous FACTS devices that can perform fast respond to the change in power systems [9]-[11]. Compared with the others, despite of its voltage dependence, it can be applied without any complicated control system, and installed inexpensively.

The main objective of this paper is to present a technique to enhance power system dynamic behavior using a SVC plus a variable power absorber. A typical SVC installed for power quality improvement is incorporated with the absorber enhancing the overall system operation capability. The attractive feature of this implementation is highlighted through a tight control of a collaborating process of reactive power compensation and real power support instantly. To illustrate the enhanced performance, generator interacting to a critical stress due to fault was simulated using Simulink; the real separate system supplying electrical energy to a sensitive process in synchrotron light research institute was modelled in the simulation, and was carried out in order to analyze for system security enhancement. Brief details of why the excess power during transients should be absorbed immediately are also included in this paper.

2. Dynamic oscillation damping

The system configured with a typical SVC plus a dynamic power absorber unit installed near a generator is shown in Fig. 1; the generator (G) and its relevant turbine (TB) are located at bus 1 supplying the demanded power to the grid through a feeder line R+jX (a simplified transformer and line impedance) linking to bus 2. The generator's ancillary system is modelled as a local load R_A shunted at bus 1. Generator's speed and field excitation are controlled adequately with standard requirements as described in [3]; speed will be regulated relating to real power (P) transmitted from the generator to load, whilst field excitation will regulate terminal voltage corresponding to reactive power (Q) compensated at any time.

In principle, the generator will track the change of output variations in order to keep balance of the incoming mechanical power (P_{in}) and the output electrical power (P_{out}) as in (1); P_{loss} is power loss due to the insights of generator structure and its operation as described in [3]-[4]. If P_{out} is varied (electrical power varied according to load conditions), the governor will start adjusting input power P_{in} in order to give the generator an ability to track the change; the overall turbine control system will consequently respond to the modulation command. As a result, if the change of power flow is not significant, the variation of generator rotating speed will be in an acceptable behavior; depending on the controls, the system itself will resume back in the intact condition within a short period. This reaction is the process that the system frequency can be regulated - constant frequency can be seen directly relating to generators' speed. Some partial swings may be noticed during this critical period, resulting in accelerated rotating when $P_{in} > P_{out} + P_{loss}$, and if $P_{in} < P_{out} + P_{loss}$ the generator rotating will be decelerated [3].

$$P_{in} = P_{out} + P_{loss} \tag{1}$$

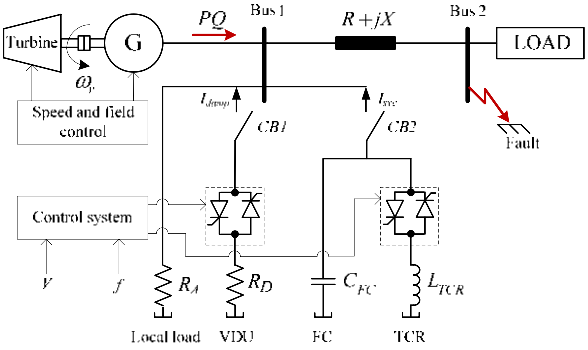

Fig. 1. System configuration

However, as mentioned previously, when the system has to deal with any significant power variations like sudden change of heavy loads and the critical situation due to a fault nearby, generator‘s burden will be changed immediately. During this obvious transient period, according to mechanical inertia of the turbine ancillary system, the incoming power will still be fed with the pre-change input; there will be some excess power on the generator at the moment the fault occurs. Instability spinning can be seen, and can further affect the whole system eventually.

To minimise the mentioned instability behavior, for this project, the SVC consisting of a fixed capacitor (FC) and a thyristor controlled reactor (TCR) that already installed for a dynamic power quality improvement at bus 1 will be enhanced by co-locating a dynamic oscillation damping unit as shown in Fig. 1; damping resistor (R_D) is used for dissipating the excess power. In this paper, bus 1 is then set as the point of common coupling (PCC) of the system.

Damping actions will be modulated by adjusting the triggering of anti-parallel SCRs connected series with the resistor. From the system shown in Fig. 1, the inductor L_{TCR} current will be adjusted according to the control of reactive power compensation. The fixed capacitor rating can be determined using the same concept as designed for power factor correction, rated depending on the reactive power (Q) to be compensated using (2). And as the controlled reactor will be used for fine-tune cancellation of this capacitance, the same rating is provided for calculation of the thyristor controlled reactor as in (3).

$$C = \frac{Q}{2\pi f V^2} \tag{2}$$

$$L = \frac{X_c}{2\pi f} \tag{3}$$

Damping resistor rating is designed with an approach concerning a mixture of the maximum transferred power and the rule of thumb that any faster response can be achieved using a higher power resistor for bursting out the excess energy. For the enhancement, both of the system frequency (f) and voltage (V) have to be monitored and passed to the controller; errors of these two quantities will be used for providing compensating actions as described with the conceptual control detailed in the following sections.

3. Control of a dynamic oscillation damping

As the objectives of this project are to regulate the voltage and to enhance the overall system stability during the transients, voltage regulating will be achieved dynamically by controlling the SVC current; while the dynamic absorber offers a fast dissipation of the excess power in order to minimise the mentioned instability. Therefore, the absorber needs a tight control that can provide real power support incorporated with reactive power compensation, and able to deal with transients precisely. The control concept for the enhanced system is then designed as shown in Fig.2 and 3.

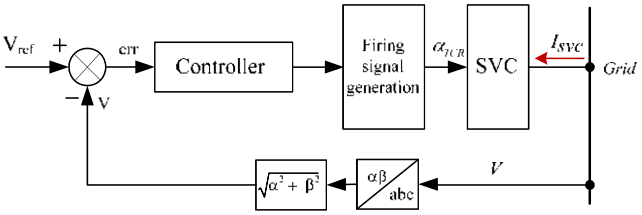

Fig. 2. Voltage control loop

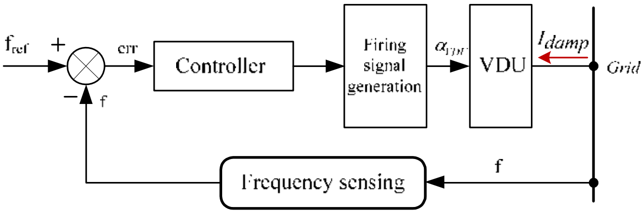

Fig. 3 Frequency control loop

As illustrated in Fig. 2 the monitored a-b-c frame of reference voltage is transformed to $\alpha - \beta$ reference frame before calculating for the error; the voltage is therefore examined instantly. Loop controller will provide the thyristor controlled reactor firing angle (α_{TCR}). This compensated angle is then passed to controlling reactive power compensation. As a consequence, during the transients, I_{SVC} which represents the flow of reactive power will track the instant change, and resulting in fast regulation of the voltage magnitude. To add the proposed ability in order to absorb the excess power during the period of fault, system frequency f is monitored and directly passed to the controller in order to provide a precisely modulated angle for the oscillation damper thyristor.

During the fault oscillation, whenever the system frequency rises up exceeding the nominal value of 50Hz, the absorbing process will be activated automatically. Although these two control loops are designed to function independently from each other, damping current (I_{damp}) and the SVC current (I_{SVC}) will be synchronised with the instability oscillation. For this project, both the loop controllers are designed and tuned using standard Ziegler – Nichols heuristic approach [12].

According to the above mentioned, the inductor and capacitor current will be cancelled each other related to controlling trigger pulse [5]-[8]. The dynamic oscillation damping unit will be controlled according to the system frequency regulation. Damping current will then be modulated accurately corresponding to generator's electromechanical oscillation during the transients. Damping current is indicative of how the excess power being minimised, which highlights the additional ability of the improved system. The instability oscillation originated from critical situations in power system will then be minimized instantly.

4. Simulation

A single-line diagram of the power system configured with a typical SVC employed for power quality improvement is shown in Fig.1, which is conformed with a real distributed system supplying energy to sensitive equipment. The SVC had been installed at bus 1, where some components may suffer from frequency fluctuations. Hence, aiming to stabilize this system, the dynamic oscillation dumping was added, and the overall system as shown in Fig. 1 was modelled in Simulink. Brief details of the important components are listed in Table 1. Both the standard speed and field excitation control loops for the generator were implemented as explained in [3, 4, 13]. Critical situation caused a fault inside were simulated and described comparatively as in subsection 4.1, 4.2, and 4.3 respectively.

Table 1. System components.

Component	Details	Value
Generator and turbine	Nominal power Nominal voltage Nominal frequency	470kVA 400V 50Hz
Feeder line	R+jX	0.03+j0.1885 Ω
SVC	FC-TCR	350kVar
LOAD	Magnet bending Generator ancillary and	15kW
R_A	local load	1kW
R_D	Damping load resistor	12kW

4.1. System without compensation

The system previously mentioned as shown in Fig. 1, but consisting of power source (generator and turbine with its ancillary system), feeder line, and load were modelled in Simulink [13]; both the SVC and oscillation damping unit were not included in the system. Simulation of this uncompensated system was carried out with an impact of a fault imposed on the system at bus 2. The system voltage magnitude and frequency variation before, during, and when the fault was cleared are shown in Fig. 4 and 5 respectively.

As expected, the voltage magnitude illustrated in Fig. 4 shows that generator control system can stabilise both the system voltage and frequency gradually. However, overshoots of the voltage due to a sudden change of the current can be seen when the fault occurred at time t = 7s; instant drop of the voltage occurred before the generator control system detected and provided a proper compensation. Also when the fault was cleared at t = 9s, the same excitation controller responded to the overshoots by adjusting field current; which results in the overshoot mitigated, and approached the command value within a period of around 2s.

Similarly, the system frequency overshoots occurred during this transient. Although the generator speed loop detected this variation, but its mechanical slow response caused the overshoots appear as depicted in Fig. 5; the control functioned to mitigate it, but slowly in process. When the fault was cleared, the generator oscillation damping process took around 5s to achieve normal frequency value.

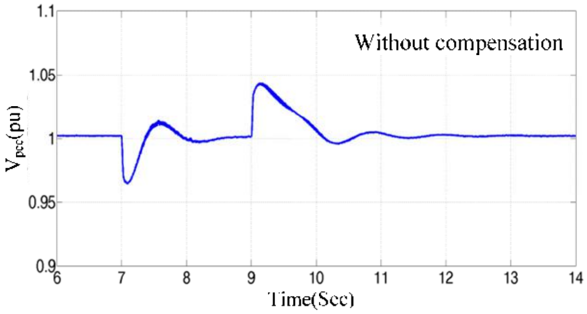

Fig. 4 V_{pcc} of the system without any compensation

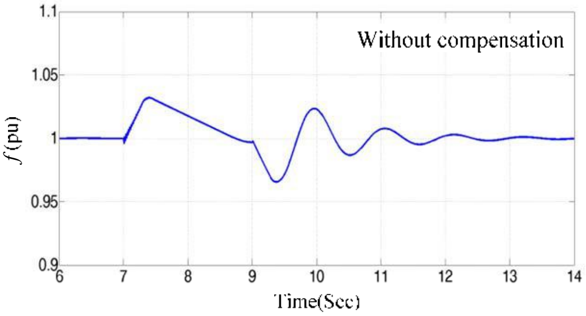

Fig. 5 Frequency of the system without any compensation

4.2. System with a typical SVC

With the aim to stabilise the voltage, a plan to install an ordinary SVC had been considered, and was modelled in the system at the PCC for simulation and analysis. The relevant results illustrated in Fig. 6, the trace marked “with SVC”, shows that the SVC able to provide reactive power precisely to the grid, even during situation under stress due to fault, magnitude of the voltage at PCC was regulated around the set-point instantly. The overshoot of the voltage was reduced to the demand level by around five times faster than that of the uncompensated system did as described in subsection 4.1. Only a slight variation appears on V_{PCC} waveform at the time when the fault occurred and was cleared off as illustrated.

However, in terms of system stability, the trace marked “with SVC“ illustrated in Fig. 7 shows that the ordinary SVC could not provide an adequate real power support to the system; as can be seen that system frequency was still being oscillated during and after the fault. Furthermore, during the fault period, the generator had been controlled to circulate more power in order to keep the voltage stabilised, resulting in an obvious variation of the system frequency.

Owing to results shown in Fig.7, the ordinary SVC is not a recommended solution for improving this power system stability, especially during transient events. Therefore, real power support should be prepared to give ability to coping with instability due to any instant mismatched power to the system.

4.3. System with a typical SVC plus a dynamic oscillation damping

A planned solution for this project to keep the generator operated in a condition that can deal with future critical situations like fault and load switching is to add a dynamic oscillation damping unit (DDU) co-located with the SVC installed for power quality improvement as shown in Fig. 1; shunt-connected to the SVC. With these components, reactive power compensation is modulated by the SVC, while the damping unit is responsible for real power absorption and results in the waveform marked “with SVC & Dynamic Absorber” shown in Fig. 6 and 7 respectively.

The system voltage was regulated similarly to the result described in previous section (with a typical SVC). Fast response of the SVC to the voltage change kept the variation of the V_{PCC} in a narrow range, and approaching steady state within a short period. At the same time, the DDU was controlled to get rid of the excess power instantly. As described previously, when the excess real power was forcibly passed to the generator, the DDU absorbed that power immediately. The power was then dissipated correspondingly to generator’s oscillation.

As shown in Fig. 7, with this ability added to the system, frequency overshoot was obviously damped by approximately five orders of the magnitude. This damped system implies that a smooth running of the generator during the fault can be seen. However, when the fault was cleared, lacking of an ability to inject real power, fast change of the system frequency was not minimised as seen during the period from t=9s to 10s of the waveform shown in Fig. 7. However any instability overshoots after that period was precisely obvious damped.

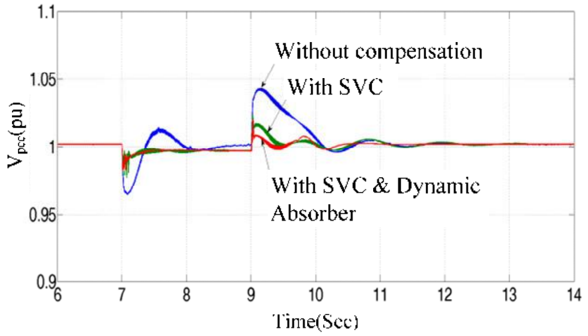

Fig. 6. V_{pcc} of the system with and without compensation

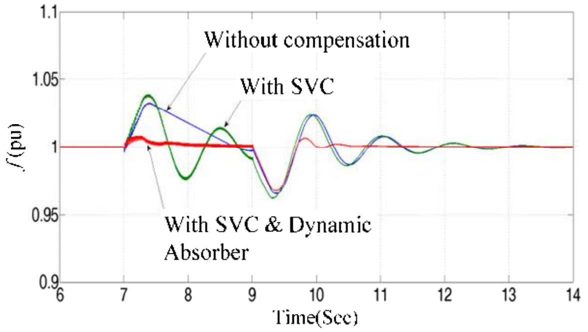

Fig. 7 Frequency of the system with and without compensation

5. Conclusion

The combination of a typical SVC and a dynamic oscillation damping unit has been described for enhancing transient performance of a separate power system in order to cope with an instant imbalance power. Providing this electronically damping ability aims to compensate for the delay inherited from the mechanical input of the system generator. The dynamic damping unit works as an energy absorber respecting to electromechanical oscillation of the source generator. Closed loop controls of the SVC and the co-located absorber have been designed in order to modulate power circulating between the grid and the SVC. As illustrated, the reactive power loop control has been achieved the aim to regulate the system voltage. Whilst closed loop control of the oscillation damping unit has been accomplished using the modulation of thyristor trigger angle, tracking the system frequency, which reflects the generator swing damped precisely.

From the results it can be said that, during fault, the overall control system provides the combined set ability to interacting to the critical situation instantly. Not only reactive power was compensated, but also a precise amount of the excess power was absorbed and dissipated out; clarity of the synchronised damping pattern has been mentioned. This tuned interaction results in the generator's oscillation damped electronically and satisfactorily. Also, it can be concluded that co-locating the typical SVC with the DDU can offer the benefits to power systems, preventing instability oscillation due to their own inevitably mechanical delay.

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