Transient Stability Impact of Short Circuit Fault System Based on SVC And PSS Applications

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Abstract. Researchers are currently focusing on two solutions, namely Static VAR compensator (SVC) and power system stabilizer (PSS), to address different power system stability issues in large area interconnected power grids. To enhance transient stability, researchers have suggested a combined approach involving SVC and PSS. In this method, SVC and PSS coordinate and cooperate with each other to provide better stability assurance. To verify the feasibility of this method, simulation experiments were conducted using MATLAB. Simulated the situation of single-phase ground fault, two-phase ground fault, and three-phase ground fault in the power system, and tested the effectiveness of SVC and PSS respectively. The simulation results show that the combined use of SVC and PSS can significantly improve the transient stability of power systems and effectively reduce the impact of faults on the system. In summary, the combined use of SVC and PSS can effectively solve various power system stability issues that may arise in large-scale interconnected power grids. By conducting simulation experiments in MATLAB, researchers have verified the feasibility of this method under different fault conditions, providing strong support for practical applications.

Keywords: Static VAR compensator; Power system stabilizer; Transient stability; MATLAB; Ground fault.

1. Introduction

As large-scale power systems continue to advance, regional interconnected grids have become prevalent in the national power grid. The Three Gorges Power Plant and Gezhouba Power Plant have facilitated the interconnection of hydroelectric power across different regions within the country.Due to the vast territory of China, long geographical distances between load centers and power generation resource centers, as well as extremely uneven distribution of mineral resources and water level differences, it is necessary to establish a regional interconnected power grid [1].

Low-frequency oscillations in power systems often arise in long-distance transmission lines with heavy loads or weakly interconnected lines between systems. These oscillations are more prone to occur when utilizing fast-acting and high-gain excitation systems [2]. The advancement of power electronics technology has significantly reduced the time constant of fast excitation regulators, leading to improved voltage regulation characteristics and enhanced transient stability of the system. Nevertheless, the additional damping introduced by automatic excitation regulators is negative, counteracting the inherent positive damping of the system. Consequently, the total damping of the system decreases or becomes negative. This persistent damping deficiency can result in prolonged power oscillations following disturbances, and may even lead to spontaneous low-frequency oscillations, typically ranging from 0.2 to 20Hz [3]. Power system stabilizers (PSS), serving as an additional feature of excitation regulators, effectively augment system damping, suppress the occurrence of low-frequency oscillations, and enhance power system stability. PSS has found widespread application in the excitation systems of most generators and has become an indispensable component of modern excitation regulators [4].

Moreover, the regional interconnected power grid faces challenges such as significant phase angle differences between sending and receiving end voltages and limited stability margin, primarily due to the long transmission distance and heavy load. Static Var Compensator (SVC) plays a crucial role as a parallel power device. Its installation in high-voltage transmission systems enables control of dynamic overvoltages resulting from load shedding and no-load effects in long-distance transmission lines. This contributes to improved system stability and suppression of power angle oscillations [5]. SVC has notable effects on adjusting load power factor, mitigating high-order harmonic currents entering the system, and balancing three-phase loads. It is characterized by high reliability, swift and seamless regulation. Furthermore, advancements in power electronics technology have led to reduced costs, optimized parameters, and favorable economic and technical indicators for SVC. As a result, it has been widely implemented and researched [6]. Parallel reactive power compensation devices hold significant practical value in power systems. In transmission networks, their primary function is to regulate the distribution of reactive power flow, thereby enhancing system stability and transmission capacity. In distribution networks, their primary function is to improve power quality and mitigate the adverse impact of loads on the power grid. Static Var Compensators address numerous challenges in reactive power compensation systems of power networks. They facilitate continuous adjustment from inductive to capacitive reactive power and operate without mechanical contacts. Notable features include rapid response and continuous dynamic reactive power compensation, making them an ideal solution for dynamic reactive power compensation. Presently, SVC is extensively employed in ultra-high voltage power grids and finds applications in industries with impact loads like steel, mining, and railway traction [7].

In summary, improving equipment such as PSS and SVC can effectively enhance the transient stability of power systems, reduce low-frequency oscillations, and solve the voltage collapse problem caused by a sudden increase in load. Ensuring the safe and stable operation of modern large-scale power systems holds immense significance.However, the literature rarely mentions the combined effect of PSS and SVC on the stability of power systems. This paper will conduct simulation experiments using Matlab. By introducing PSS and SVC in a two-machine system, it will observe the effects of these two control methods on the stability of power systems in the event of faults, focusing on suppressing low-frequency oscillations and increasing reactive power compensation.

2. Research Principles and Significance of PSS and SVC

2.1. Introduction to PSS Control Principles

PSS was initially postulated by American scholars F·P·demell and C·Concordi. Its fundamental principle is rooted in automatic voltage regulation, complemented by deviations in speed $\Delta\omega$, power ΔPe, and frequency Δf. One or two signals within f are employed as supplementary controls to generate $\Delta\omega$. The supplementary torque from the coaxial configuration augments the damping of low-frequency oscillations, thereby bolstering the dynamic stability of the power system.

Owing to the utilization of voltage as the control variable in the voltage regulator, coupled with the electromagnetic inertia of both the regulator and excitation system, an inherent lag in the excitation voltage begets a forced component within the excitation system. This detrimental effect exacerbates damping and may even incite oscillations. Consequently, in scenarios involving extensive transmission lines and heavy loads, if the rotor angle oscillates, the additional quantity provided by the voltage regulator lags behind the angle oscillation in phase. One of its components opposes the speed phase, engendering a counteractive damping torque that intensifies the angle oscillation. Should the additional quantity generated by the voltage regulator align or counterphase the swinging phase of the rotor angle oscillation, it can merely amplify or diminish the amplitude of the rotor angle oscillation, without eliminating it. Only by furnishing an additional quantity that leads the oscillation angle of the rotor angle in phase can a positive damping torque be engendered, thereby quelling the oscillation.

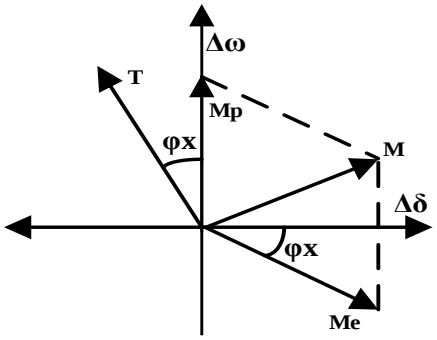


Fig. 1 Damping torque vector diagram (Photo/Picture credit: Original)

As depicted in Fig. 1, Me embodies the supplementary torque engendered by the voltage regulator, trailing the oscillating angular motion Δδ of the rotor. Its phase assumes the value of φx. In the event that we can summon forth an adequately substantial pure positive damping torque, denoted as Mp, the resultant amalgamation of Mp and Me shall reside within the auspicious first quadrant, with both of its constituents - synchronous and damping torque - basking in positivity. The aforementioned affirmative damping torque, Mp, materializes through the injection of an ancillary signal, T, at the voltage regulator's reference juncture, as showcased in Fig. 1. By virtue of the congruence between T's ingress locus and the voltage regulator's reference input nexus, in order for T to beget an unsullied positive damping torque (aligned harmoniously with the velocity delineated by the phase), T's phase must undergo advancement along the Δω axis, surpassing the threshold of φx. Following the sequence of electrical and excitation system hysteresis subsequent to the voltage regulator's intervention, an unadulterated reservoir of affirmative damping torque can be engendered.

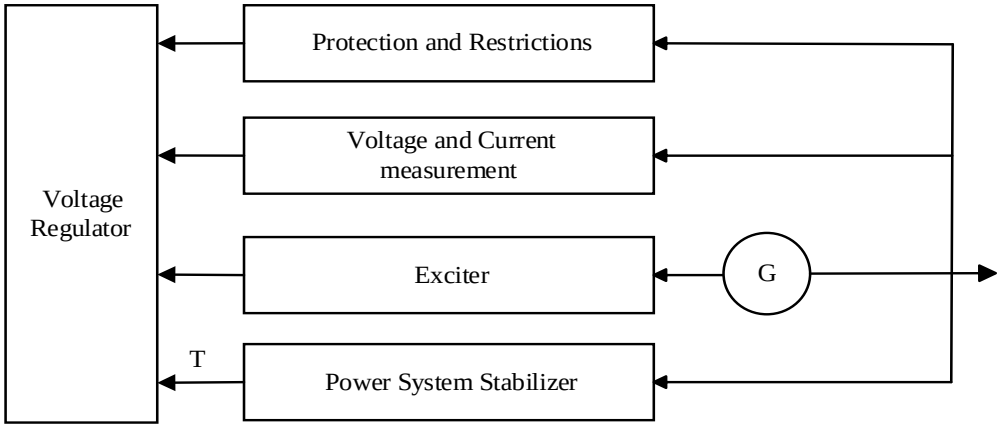


Fig. 2 Schematic diagram of excitation control system (Photo/Picture credit: Original)

In order to utilize high magnification excitation regulators while avoiding their negative damping effects, improvements have been made to traditional excitation systems, as shown in Fig. 2. The basic principle of PSS is to inject some additional control signals into an excitation regulator that may cause negative damping, so that it can provide positive damping and suppress oscillations. As an additional facet of excitation control, the PSS engenders a salutary damping torque within the excitation voltage regulator, countervailing the detrimental effects of negative damping engendered by said regulator. The control parameter encompasses various quantities, including electric power deviation (ΔP), frequency deviation of terminal voltage (Δf), excess power (ΔPm), generator shaft speed deviation (Δω), and their synergistic amalgamation. Not only does it ameliorate the pernicious effects of negative damping in the excitation regulator, but it also augments the realm of positive damping, thereby effectively enhancing the generator's prowess in suppressing low-frequency oscillations within the system [1, 5].

2.2. Types and working principles of SVC

SVC is a reactive power compensation device that emerged in the early 1970s and is a member of the FACTS family. It can control dynamic overvoltage, improve system stability, and balance three-phase loads. It has practical value in power systems, adjusting reactive power flow and improving system stability and transmission capacity. In distribution networks, it enhances power supply quality and reduces load impact on the grid. Static reactive power compensation devices have no mechanical contacts, fast response, and can achieve continuous and dynamic compensation, making them ideal for reactive power compensation [6].

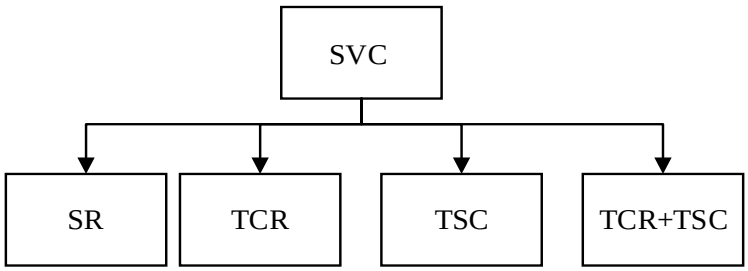


Fig. 3 Main Application Types of SVC [7]

Static VAR compensator (SVC) refers to the static var compensation equipment using thyristor, which has various types. The commonly used types currently include saturated reactor type (SR), thyristor control reactor type (TCR), Thyristor switched capacitor type (TSC), and TCR+TSC hybrid type, as shown in Fig. 3 [1, 7-10].

2.2.1 Saturated reactor type (SR)

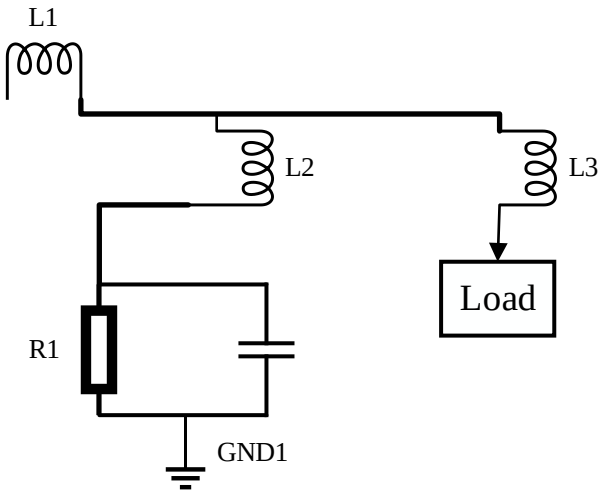


Fig. 4 Schematic diagram of SR type SVC [7]

The reactive power compensator known as the saturation reactor type, as shown in Fig. 4, can be categorized into self-saturation type and controllable saturation type. The self-saturated reactive power compensator relies on the inherent ability of the reactor to stabilize voltage. It utilizes the saturation characteristics of the iron core to adjust the inductive reactive power in accordance with the terminal voltage, controlling the emission or absorption of reactive power. On the other hand, the controllable saturation type reactive power compensator manages the saturation level of the iron core by modifying the working current in the control winding. This, in turn, alters the reactance of the working winding, leading to changes in reactive current.

2.2.2 Thyristor controlled reactor type (TCR)

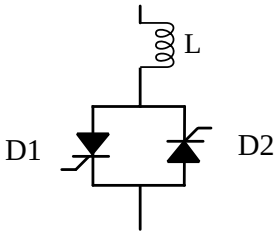


Fig. 5 Schematic diagram of TCR type SVC [7]

The thyristor-controlled reactor type reactive power compensator, as shown in Fig. 5, mainly plays the role of variable inductance, achieving fast and smooth adjustment of inductive reactive power. The thyristor-controlled reactor type reactive power compensator consists of a reactor connected in series with two reverse parallel connected thyristors, which control the conduction angle of the thyristorsβOr trigger angleαBy changing the current passing through the reactor, the fundamental reactive power absorbed by the reactor can be smoothly adjusted.

2.2.3 Thyristor switched capacitor type (TSC)

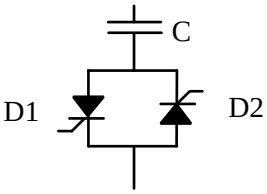


Fig. 6 Schematic diagram of TSC type SVC [7]

The thyristor switched capacitor type reactive power compensator, as shown in Fig. 6, consists of a capacitor connected in series with two reverse parallel connected thyristors, which are connected in parallel to the power grid. The key technology of TSC is the selection of capacitor switching time.

2.2.4 Hybrid (TCR+TSC)

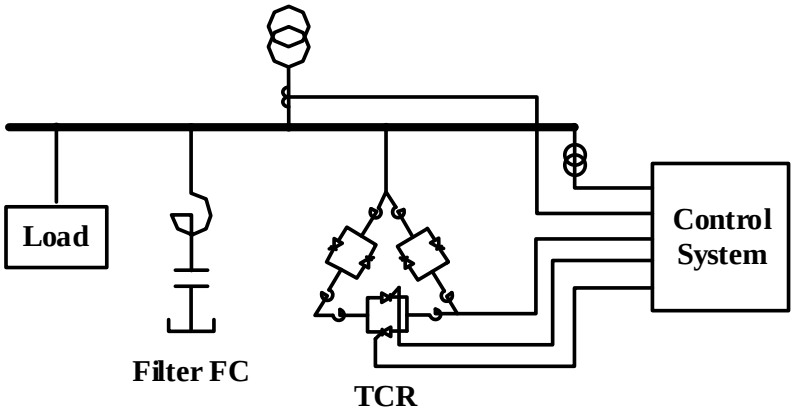


Fig. 7 Schematic diagram of hybrid SVC [7]

The TCR+TSC hybrid static VAR compensator, as shown in Fig. 7, operates based on the following principle: if the system voltage falls below the set operating voltage, a specific number of capacitor banks, slightly overcompensating, are activated based on the allowable reactive power value to be compensated. At this point, the inductive reactive power generated by the thyristor phase-controlled reactor is utilized to offset the excess capacitive reactive power. Conversely, when the system voltage exceeds the set operating voltage, all capacitor banks are deactivated, and only the TCR component of the device remains active. This configuration of the reactive power compensation device combines the benefits of both TCR and TSC.

The TSC branch is controlled by power electronic devices and has two operating states, that is, capacitors are directly connected in parallel to operate in the power system branch or capacitors are removed from the system operation.

Generally speaking, in order to expand the reactive power adjustment range of static VAR compensator, multiple TSC branches can be used in the static VAR compensator device, and in order to ensure the continuity of adjustment, the capacity of TCR is generally slightly larger than that of a group of TSCs. If the total capacitance value of TSC input is C, the equivalent reactance of static VAR compensator is:

$$\frac{\pi\varpi I}{2\beta-\sin 2\beta-\pi\varpi^2 LC}. \tag{1}$$

3. Simulation experiments

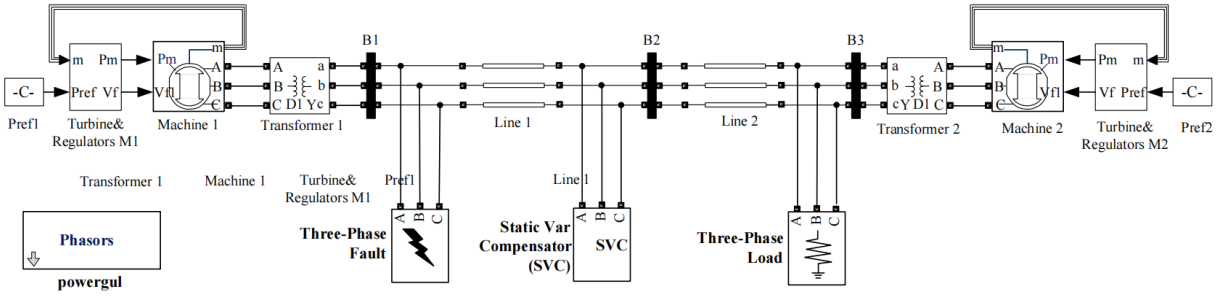
3.1. Simulation Principles

In the depicted diagram, a PSS and a SVC are incorporated into a two-machine system to investigate their impacts on the transient stability of the power system. The PSS module aims to dampen low-frequency oscillations, while the SVC module focuses on enhancing reactive power compensation.

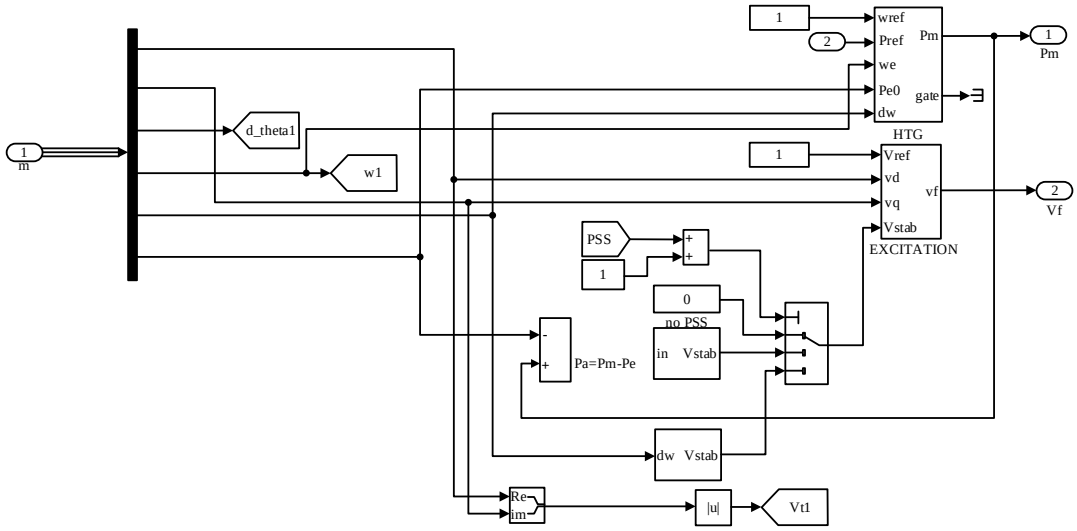
The PSS is essentially an excitation system which uses the negative electromagnetic power deviation or rotor angular velocity deviation as an input signal through PID control to generate positively damped low frequency oscillations after phase shifting, amplification and limiting of the torque increment, which is offset by the negative damping generated by the generator to mitigate or even eliminate the low frequency oscillations.

The part of Fig. 8(a) shows that a generator is configured at each end of the transmission line and the SVC is connected to the transmission line to compensate the reactive power online in real time to ensure the reactive power compensation as well as the stability of the load voltage. During simulation operation, different transient processes can be simulated by adjusting the parameters of the fault module to better understand the effectiveness of the SVC for different short-circuit situations. Figure 8(b) shows the simulation diagram of the PSS connection in the generator excitation control system, which is the main part of the PSS in the operating connection acting on the generator control link. The part in Fig. 8(c) is the control switch of the PSS, by controlling the opening and closing of the gate knife, the operating mode of the PSS as well as the on-off can be selected.

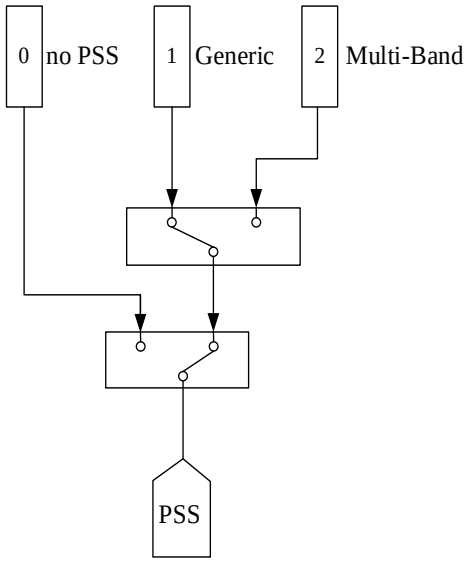
During the experiment, the PSS control switch is first closed by the gate knife to ensure that the power system is not destabilised by the negative damping effect of the generator. Set up the fault module, enter the parameters to select a fault mode, and then compare the waveforms of the machine end oscilloscope and the bus line oscilloscope when the SVC is installed and removed, respectively, to compare whether the SVC is effective for the transient stability of the power system.



(a)



(b)



(c)

Fig 8. Simulation platform:(a) Two-machine system short-circuit simulation diagram, (b) PSS plus excitation system simulation simulation diagrams, (c) PSS switch simulation diagram. (Photo/Picture credit: Original)

3.2. Single-phase ground fault

The three-phase fault module is configured to simulate an a-phase ground fault that transpires at 0.1seconds and is resolved at 0.2seconds. The simulation is conducted for a duration of 50 seconds. The objective is to evaluate the efficacy of the power system stabilizer (PSS) in enhancing the damping of system vibrations.

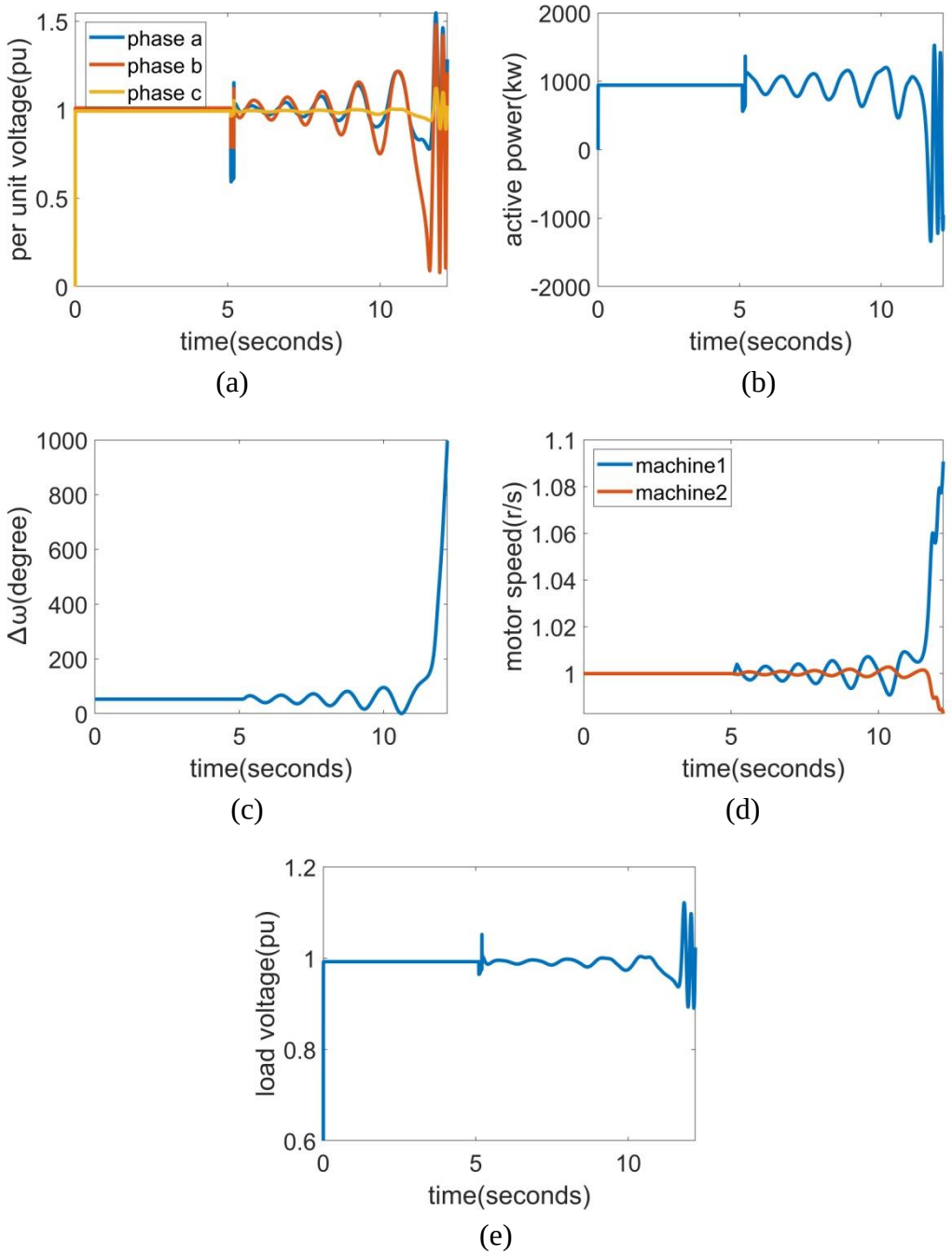


Fig 9. Single-phase ground fault without PSS simulation result :(a) Voltage at bus B1-B3 without PSS,(b) Active power on the system line without PSS,(c) Inter-rotor phase angle without PSS,(d) Motor speed without PSS,(e) Voltage at load without PSS. (Photo/Picture credit : Original)

3.2.1 Without PSS

From Figures 9(a) to (e), it can be seen that the system is transiently unstable in the absence of PSS when a single-phase ground fault occurs.In the 12.2s tends to collapse:

As shown in Fig. 9(a), the voltages of B1, B2, B3 show a steep drop during the occurrence of an earth fault in the system and oscillate violently after the fault is cleared, and the voltage stability cannot be maintained. The active power on the line also fluctuates violently and drops significantly after a single-phase fault, as shown in Fig. 9(b). As shown in Fig. 9(c), the phase angle difference between the rotors after a single-phase ground fault exceeds 90° at about 3.8s and shows a steep increase. When the phase angle difference between the rotors is 90°, the electromagnetic power output from the generator reaches its maximum value. If the system is operated for a long time at a power angle greater than 90°, the motor will lose synchronisation and the system will become unstable. As

shown in figure 9(d), the two motor speeds are gradually desynchronised after the fault. As shown in Fig 9(e), the voltage at the load also starts to oscillate violently after a single-phase ground fault occurs in the system, and the voltage instability has a serious effect on the load, which is unable to meet the load's requirements for voltage quality.

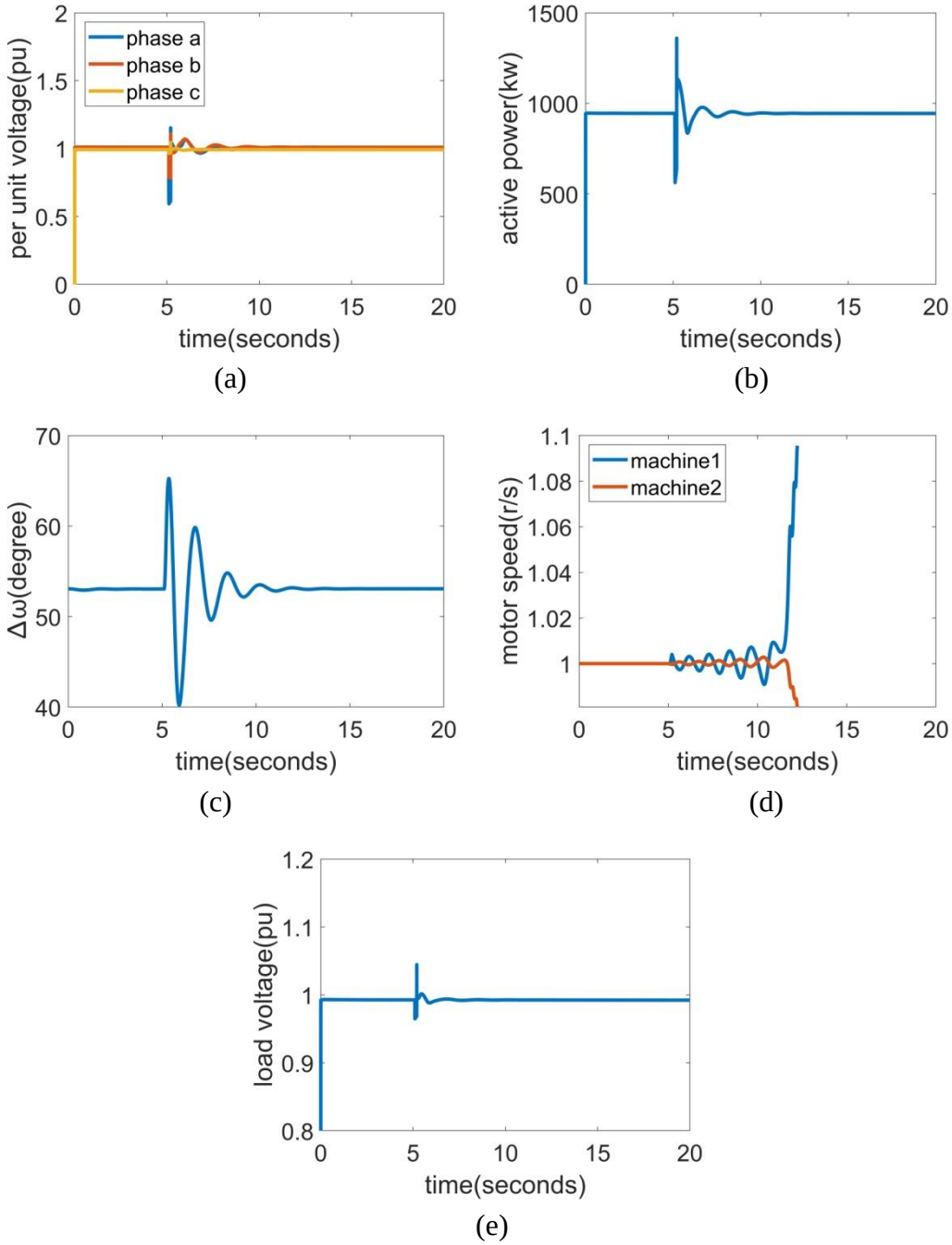


Fig 10. Single-phase ground fault with PSS simulation result: (a) Voltage at Bus B1-B3 with PSS, (b) Active power on system lines with PSS, (c) Inter-rotor phase angle with PSS, (d) Motor speed with PSS, (e) Voltage at load with PSS. (Photo/Picture credit: Original)

3.2.2 With PSS

From Figures 10(a) to (e), it can be seen that the system is transiently stabilised in the case of single-phase ground fault when a single-phase ground fault occurs with the inclusion of PSS:

As shown in Fig. 10(a), the voltages on buses B1, B2, B3 return to stabilisation in about 5.0s after a short oscillation following the addition of PSS. As shown in Fig. 10(b), the active power on the line also stabilises after a short oscillation. As shown in Fig. 10(c), the maximum inter-rotor phase angle

difference is 67.8° after a single-phase ground fault occurs in the case of a PSS installation, and it reaches stability again at around 53° after 5s. The phase angle difference is also stable after a short oscillation, as shown in Fig. 10(c). As shown in figure 10(d), the two motor speeds remain synchronised after the fault. As shown in figure 10(e), the voltage at the load also regains stability within 5s. It stabilises at around 0.993 pu.

3.3. Two-phase ground fault

At 0.1seconds, a two-phase ground fault is deliberately induced using the three-phase fault module, and the fault is resolved at 0.2seconds. The simulation duration is 50seconds. Evaluate the PSS's effectiveness in enhancing system vibration damping.

3.3.1 Without PSS

From Figures 11(a) to (e), it can be seen that the system is transiently unstable in the absence of PSS when a two-phase ground fault occurs.In the 7.7s tends to collapse:

As shown in Fig. 11(a), the voltages of B1, B2, B3 show a steep drop during the occurrence of a ground fault in the system and oscillate violently after the fault is cleared, and the voltage stability cannot be maintained. As shown in Fig 11(b), the active power on the line also fluctuates violently and drops significantly after a two-phase ground fault. As shown in Fig 11(c), the phase angle difference between the rotors exceeds 90° at about 0.37 s after the two-phase ground fault and shows a steep increase. As shown in Figure 11(d), the speeds of the two motors are gradually desynchronised after the fault. As shown in Fig 11(e), the voltage at the load also begins to oscillate violently after a two-phase ground fault occurs in the system, and the voltage instability has a serious effect on the load, which is unable to meet the load's requirements for voltage quality.

In summary, it can be seen that the system instability is faster and has a more serious effect on the system when a two-phase ground fault occurs compared to a single-phase ground fault.

3.3.2 With PSS

From Figures 12(a) to (e) it can be seen that the system is transiently stabilised with the inclusion of PSS when a two-phase ground fault occurs:

As shown in Fig. 12(a), the voltages on buses B1, B2, B3 return to stability within 10s after a short oscillation following the addition of PSS. As shown in Fig. 12(b), the active power on the line also returns to stability after a short oscillation. As shown in Fig. 12(c), the maximum phase angle difference between the rotors after a two-phase ground fault occurs is 95.5°, as shown in Fig. 12(c), and it returns to stability within 10s at about 53°. As shown in figure 12(d), the speeds of the two motors can still be synchronised after the fault. The voltage at the load also regains stability within 5s, as shown in Figure 12(e). It stabilises at around 0.993pu.

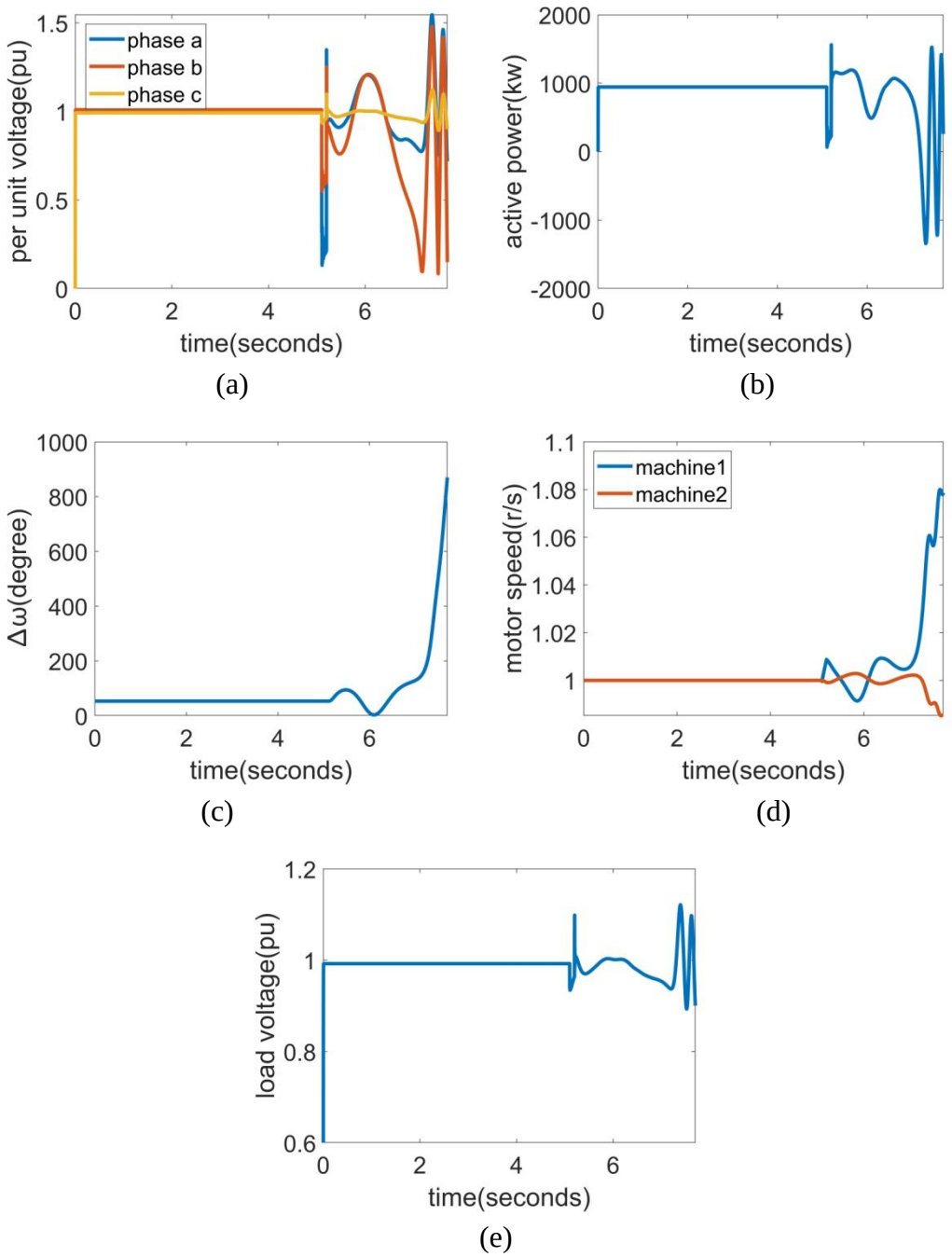


Fig 11. Two-phase ground fault without PSS simulation result: (a) Voltage at bus B1-B3 without PSS, (b) Active power on the system line without PSS, (c) Inter-rotor phase angle without PSS, (d) Motor speed without PSS, (e) Voltage at load without PSS. (Photo/Picture credit: Original)

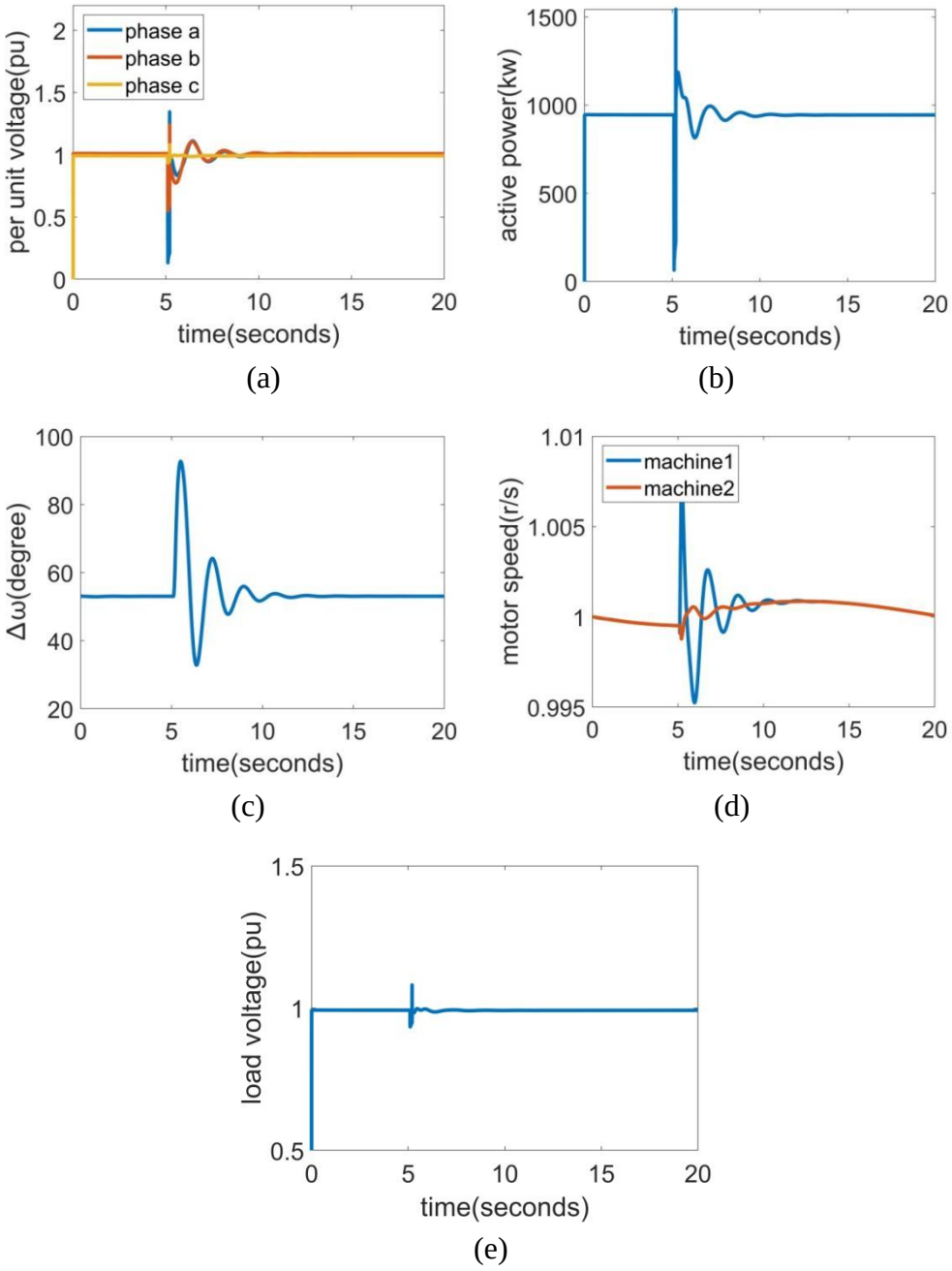


Fig 12. Two-phase ground fault with PSS simulation result:(a) Voltage at bus B1-B3 with PSS,(b) Active power on the system line with PSS,(c) Inter-rotor phase angle with PSS,(d) Motor speed with PSS,(e) Voltage at load with PSS. (Photo/Picture credit: Original)

3.4. Three-phase ground fault

At 0.1seconds, a three-phase ground fault is intentionally triggered using the three-phase fault module, and the fault is rectified at 0.2seconds. The simulation duration is 50seconds. Evaluate the SVC's capability in enhancing system oscillation damping.

3.4.1 With PSS but without SVC

From Figures 13(a) to (f) it can be seen that when a three-phase ground fault occurs, the PSS alone is no longer able to maintain the transient stability of the system.In the 6.3s tends to collapse:

As shown in Figures 13(a) and 13(b), the voltages on buses B1, B2, B3 and the active power on the transmission lines oscillate violently. As shown in Figs. 13(c) and 13(d), the system loses synchronism at 0.1 s after the phase angle difference between the generator rotors exceeds 90° at 0.3

s and gradually increases rapidly. As shown in Fig 13(e), the voltage at the generator end collapses at 1.2s. As shown in Fig 13(f), the voltage at the load drops sharply to 0.79 pu after the fault occurs at 0.1s. After the fault is cleared at 0.2s, there is a violent oscillation in the voltage and the voltage quality does not meet the load requirements.

In summary, compared to a two-phase ground fault, a three-phase earth fault causes the system to become unstable more quickly and has a more severe effect on the system.

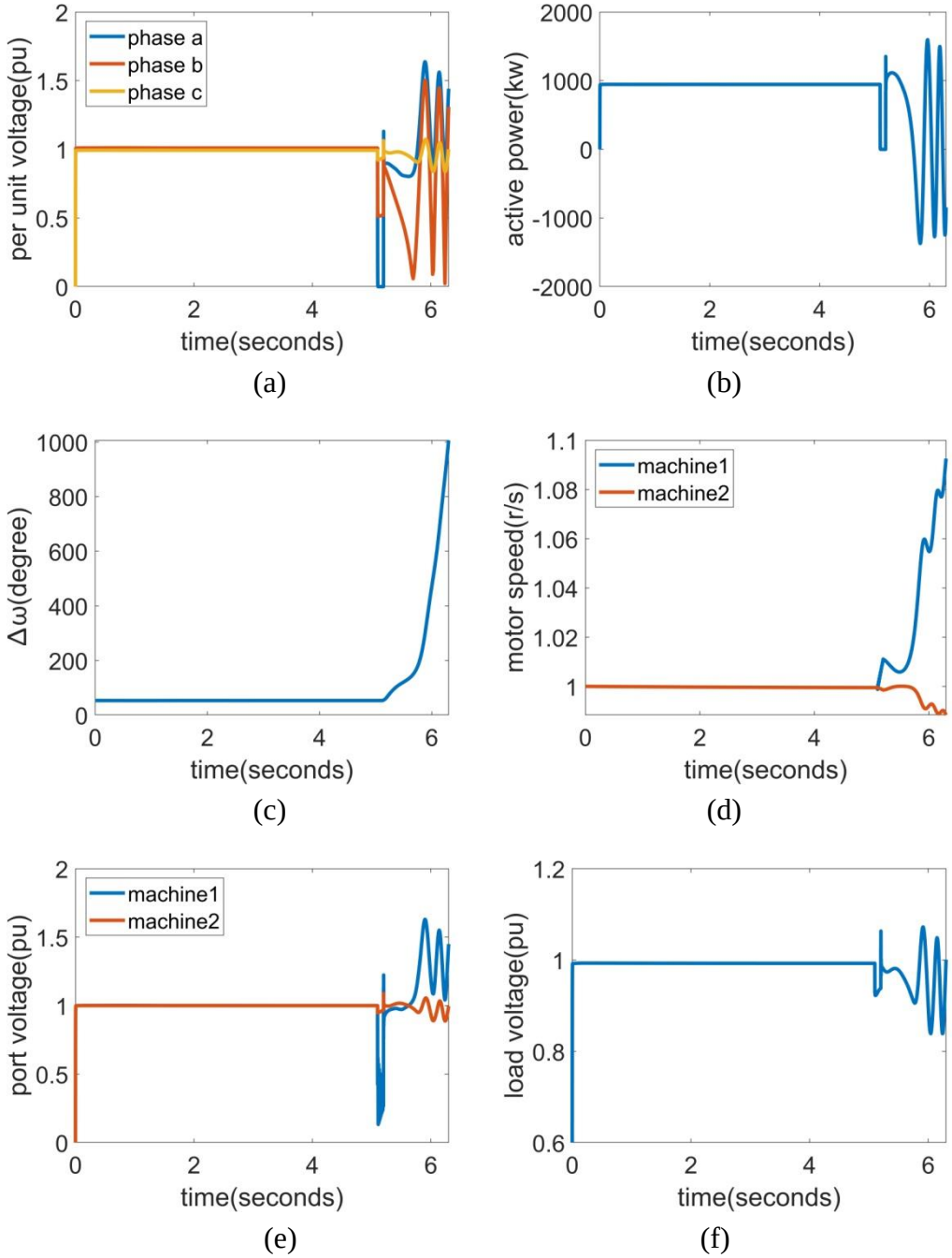


Fig 13. Three-phase ground fault with PSS but without SVC simulation result: (a) Voltage at bus B1-B3 with PSS but without SVC,(b) Active power on the system line with PSS but without SVC, (c) Inter-rotor phase angle with PSS but without SVC, (d) Motor speed with PSS but without SVC, (e) Voltage at generator ports with PSS but without SVC, (f) Voltage at load with PSS but without SVC. (Photo/Picture credit : Original)

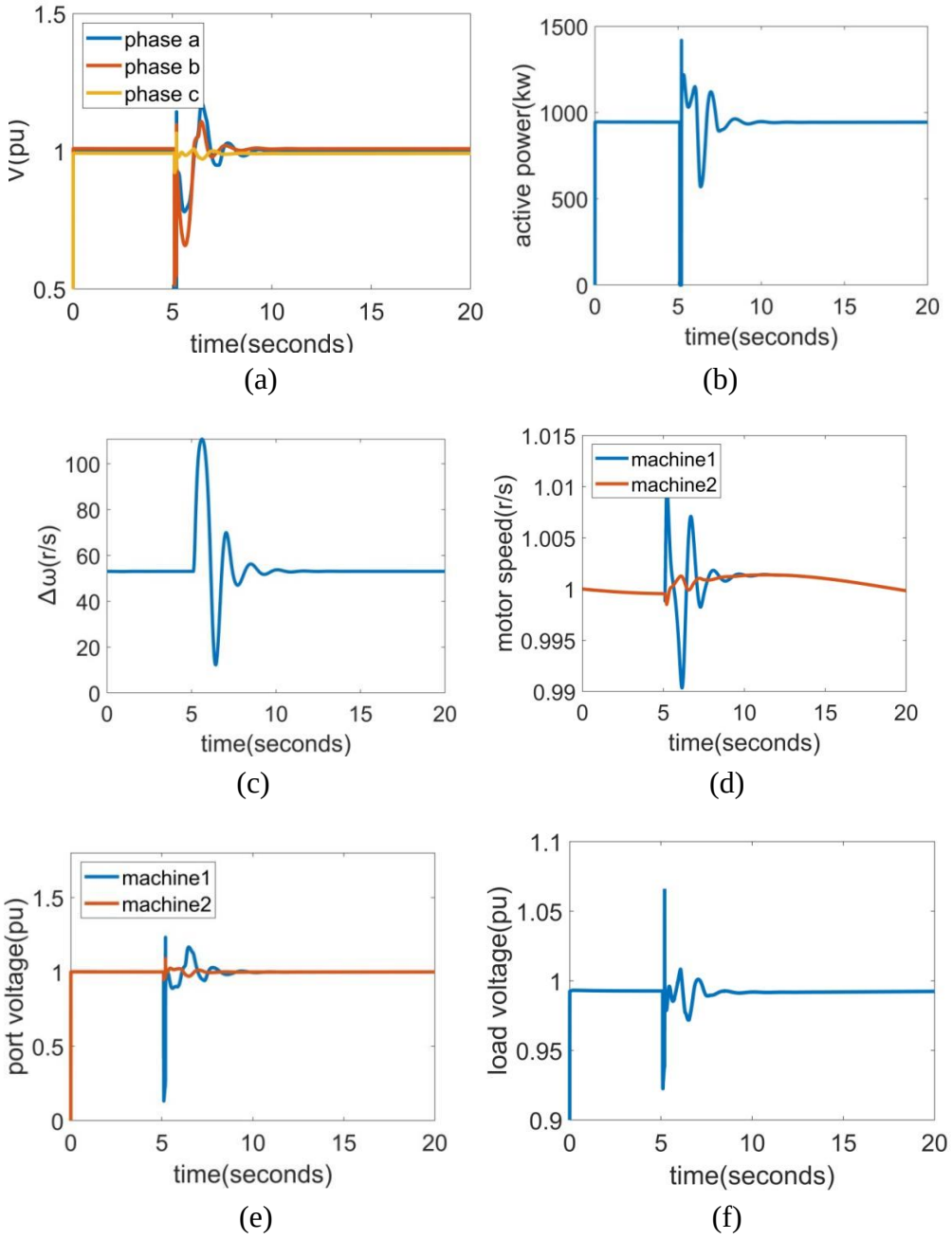


Fig 14. Three-phase ground fault With PSS and with SVC simulation result: (a) Voltage at bus B1-B3 with PSS and SVC, (b) Active power on the system line with PSS and SVC, (c) Inter-rotor phase angle with PSS and SVC, (d) Motor speed with PSS and SVC, (e) Voltage at generator ports with PSS and SVC, (f) Voltage at load with PSS and SVC (Photo/Picture credit : Original)

3.4.2 With PSS and SVC

From Figures 14(a) to(f), it can be seen that the PSS and SVC are relied upon to maintain the transient stability of the system despite the occurrence of a severe three-phase grounded fault in the system:

As shown in Figures 14(a) and 14(b), the voltages on buses B1, B2, B3 and the active power on the transmission lines become stable again after a short period of oscillation following a three-phase ground fault in the system. As shown in Fig. 14(c) and 14(d), the phase angle difference between the generator rotors reaches a maximum value of 115° at 0.7s, but after a short oscillation period it is stable again and the phase angle difference is stabilised at 53° at 8.0s and the two generators are back in synchronous operation. As shown in figure 14(e), the motor terminal voltages also return to

equilibrium after a short fluctuation. As shown in Fig 14(f), the voltage at the load also fluctuates for a short time and returns to stability at 5.0s.

3.5. Summary of simulation experiments

From the above test results, we can see that the two-machine system tends to collapse in 5.5s for the single-phase ground fault, but only in about 2.1s for the two-phase ground fault, and in about 0.8s for the three-phase ground fault, even with PSS modulation. It can be seen that various short-circuit faults in single-phase, two-phase and three-phase ground faults tend to deteriorate, and the system collapse speed is accelerated and the degree of instability is deepened. Under the regulation of PSS, single-phase and two-phase ground faults return to stability within 5s and the motor tends to be synchronised, while for three-phase ground faults, under the dual use of PSS and SVC, it also returns to stability in about 4s.

Based on the aforementioned analysis, it is evident that both PSS and SVC significantly reduce the system's restoration time during a short-circuit fault, preventing system collapse and minimizing voltage fluctuations caused by the fault. PSS and SVC are crucial in preserving transient stability of the system and ensuring voltage quality.

4. Conclusion

This paper presents a MATLAB simulation experiment investigating the impact of SVC and PSS on power system stability. The experiment tests the stability restoration of a two-machine system with and without the modulation of SVC and PSS under single-phase, two-phase, and three-phase short-circuit conditions. The results demonstrate that the system tends to collapse rapidly without the modulation of SVC and PSS, whereas stability is restored faster with their modulation.

From the simulation, it is evident that the combined system of SVC and PSS complements each other and enhances the transient stability of the power system. In scenarios where PSS modulation is not feasible and the fault conditions are severe, SVC serves as a supplement, ensuring system stability. SVC promptly responds to the reactive power demand, thereby improving voltage stability. On the other hand, PSS enhances system stability by adjusting the generator excitation system, making it more resilient to external disturbances. During external disturbances like faults or sudden load changes, SVC maintains voltage stability by swiftly adjusting reactive power, while PSS suppresses system oscillations by regulating the generator excitation system.

In conclusion, the combined system incorporating SVC and PSS enhances transient stability by swiftly adjusting reactive power and suppressing system oscillations. Moreover, it improves voltage stability and regulates system frequency capability, thus offering significant practical value in power system applications.

5. Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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