



Studying PSO based voltage stability improvement in a Single Machine Infinite Bus (SMIB) system

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Abstract

Single machine infinite bus system is considered in this paper to study the voltage stability, in the work different controllers such as AVR, PSS and PID were used and compared, moreover to enhance the controllability of the system PID controller is twined by particle swarm optimization (PSO) and the result shows that the stability of the system is more improved using PSO optimized PID in the presence of AVR-PSS

Keywords: Voltage stability improvement; AVR-PSS; PSO;PID; Damping oscillation.

1. Introduction

In the past two decades, the voltage stability of a power system network (PSN) has become a critical concern with respect to system design, planning, and operation. Consequently, driven by market forces and profitability, the new power utility companies operate the power transmission corridors close to voltage stability limits. One of the cause of black out is voltage instability, on the other hand in a system with proper installed tap changer, with proper reactive power compensation, with proper voltage control it is a good way to maintain system equilibrium, in such away system voltage stability will be maintained [1].

So far there is no special attention which was given for voltage control in transmission line network but unless voltage stability assessment will be given special attention, it results in major blackouts. It is also good to classify power system in the region of voltage stability, after maintaining acceptable range of voltage in the system after disturbance as well as in normal operating condition. To analyze voltage stability, there are also some conventional methods such as P-V and Q-V curves techniques using load flow but these methods are not that match effective.

Continuous stability problems leads to system instability as a result black out was discussed in [2]. Voltage instability is the progression by which the voltage falls to a very low value or out of the predictable range of value as a result of sequence of events. The voltage instability occurred due to increasing power demand in the network and lack of new generation and transmission lines (i.e. high active

power loading on the system), inadequate reactive power support, during light load

(i.e. load characteristics at low voltage magnitude), response of transformer tap changers, etc. This voltage instability leads the problem like the blackout of the transmission line due to this the power system network needs the installation of a new transmission line, damaging power system equipment and loads, effect on socio-economics and industrialization development. so PSN needs to maintain that problem [3]. In [4] The paper assesses many ideas from the cause of voltage stability to the proper mitigations methods including existing and future planned semiconductor technologies to install in real world, more over the paper briefs how facts controllers are useful in application of voltage stability for that, a case study in Indian power system was taken and different facts devices were also compared.

In [5] this research presents a unique application concept for improving voltage stability in an isolated wind-diesel-micro hydro hybrid system using an artificial neural network (ANN) based SVC controller. A tiny signal linear model of the hybrid wind-Diesel-micro hydro model is taken into consideration with varying loading circumstances for a more thorough examination. A feed forward neural network with back propagation approach, intended to fine-tune the parameters of the SVC controller, further enhances the voltage stability analysis after it has been completely studied by an SVC controller.

Comprehensive stability study has been conducted using several criteria, including Eigen value synthesis, Bode, and Nyquist. The results of the simulation

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validate the operation of the separated systems, demonstrating that the system parameters reach steady state values faster and with less complexity.

In [6] the goal of the project is to increase the system's voltage stability when a wind farm is added to the grid. The controller combines the use of STATCOM with TCSC. The controller makes sure that there is adequate reactive power available to the system to keep it stable.

The built-in MATLAB/SIMULINK simulation model will be used. To demonstrate the effectiveness of the controller, the output voltages of the system without the controller—in which each component operates independently—as well as the combined control impact of TCSC and STATCOM—will be examined and compared in the simulated model. In many unusual situations, such as load and source disturbances, a 12-pulse two-level STATCOM is utilized to control the bus voltage at a particular bus bar. There is only one machine, one transmission line, and one load in the suggested system. The two recommended control methods are compared and the compensation procedure is carried out. The first control approach is the traditional one that uses a PI controller alone to improve the voltage profile. Second, a self-tuning fuzzy PI controller is used by the adaptive controller. The simulation findings demonstrate the two types' improved voltage profiles, and a comparison of them was discussed in [7].

Static VAR Compensator (SVC), which was proposed in [8] in this work, has been used as an additional controller to enhance the system's transient stability and power oscillation damping. The goal of the SVC with fuzzy logic controller used in this research is to increase its compatibility with the current load demand in order to preserve system stability on the power system network under both heavy and light loading scenarios. The low-cost alternative to a traditional capacitor bank for enabling continuous and flexible nodal voltage adjustment is a static VAR compensator. In [9] the application of this kind of non-disruptive load control to raise voltage stability is discussed in the study. A model predictive control (MPC)-based control technique is suggested. MPC forecasts the dynamic behavior of a system over a limited time by using an internal model. Optimizing that anticipated reaction forms the basis of control decisions. Since MPC is a discrete-time control method, errors in the expected behavior are adjusted at the subsequent control interval. This control approach is demonstrated using a typical 10 bus voltage collapse example. In [10] there is a strong correlation between the variation in reactive power at the center load and the variation in voltage at the generator terminal. The power system

contains a number of reactive power sources, such as field amplifiers that are managed by devices known as Automatic Voltage Regulators (AVR). The voltage profile, including the voltage at the generator terminal, will vary in response to variations in the system's reactive power. The AVR needs to be correctly set in order to maintain the voltage level on the generator terminal. The AVR's ability to stabilize the voltage is mostly determined by the value of the amplifier gain on the device. A different generator equivalent model (GEM) for voltage stability analysis is presented in [11]. In order to represent the dynamic behaviors of generators, time-varying internal voltages and impedances are used to model generators based on their dynamic models and real-time observations. Moreover, GEMs are added to the conventional L-index for system voltage stability analysis. Simulation tests have been conducted to demonstrate the effects of GEM on voltage stability analysis and to confirm the efficacy of the newly suggested index. Four test systems' worth of simulation results demonstrate that, depending on the situation, using GEM is essential and can greatly increase the precision of voltage stability analysis. Fault current in [12] causes imbalances in voltage and reactive power, which are serious issues for power systems. This study demonstrates how the Unified Power Flow Controller (UPFC) can increase transmission system stability and clear a single line to ground fault. One of the most kinds of Flexible Alternating Current Transmission System (FACTS) devices is the one under consideration. The distribution static compensator provides voltage stability. The allocations A voltage absorber and converter that injects current into the system make up the shunt-connected static compensator. D-STATCOM is the word for the STATCOM that is connected at the distribution side or load end. To try and achieve voltage stability. The PI controller that controls the D-STATCOM was covered in [13]. Model Predictive Control (MPC) is a control approach for AVR that is suggested in [14] to increase voltage stability in power systems. According to the study, under various operating situations, the MPC-based control method may successfully improve the voltage stability of the system. Backstepping control was used to create a nonlinear control method for an AVR system in [15]. The study's findings demonstrated that, in a variety of operating scenarios, backstepping control can significantly increase the system's voltage stability. Furthermore, research has been done on how well various controller types work with AVR to improve voltage stability. For example, simulation was used to assess how well PID and LQR controllers used AVR to improve voltage stability. The study's findings demonstrated that both controllers could increase the system's voltage stability, with the LQR controller performing better in terms of settling time and

overshoot, as was covered in [16]. Furthermore in [17], several studies have also investigated the impact of renewable energy sources on voltage stability in power systems using AVR. For example, in a study by Arulmozhiyal et al. (2019), the impact of photovoltaic (PV) integration on voltage stability using AVR was investigated. The study suggested a control technique to improve the voltage stability and demonstrated how the integration of PV might have a substantial impact on the system's voltage stability. One such study by S. H. Hosseinian and M. Abedi, published in the journal "Electric Power Systems Research," compared the performance of an ideal AVR with that of a practical AVR in a power system with multiple synchronous generators. The study found that the ideal AVR provided better voltage regulation and stability than the practical AVR, particularly under high-load conditions (Hosseinian & Abedi, 2010) was discussed in [18]. In [19] Another study by F. M. Bashi and M. H. Ali, published in the journal "International Review of Electrical Engineering," analyzed the performance of different AVR models, including an ideal AVR, in a power system with a single synchronous generator. The study found that the ideal AVR provided the best voltage regulation and stability compared to other models tested (Bashi & Ali, 2012). As reviewed in the literature, there is no much work which was studied voltage stability improvement by using intelligent controller such as PSO, fuzzy and GA, so this paper aimed to optimize the PID controller by using PSO in order to reduce power oscillation and enhance the voltage stability of power systems in single Machine Infinite Bus (SMIB) systems, automatic voltage regulator (AVR) and power system stabilizer (PSS) technologies are used in conjunction with Matlab code that integrates with Simulink.

Methodology

To preserve the dependability and security of the power system, voltage stability is a critical component of system operation. A simplified model of a power system called the Single Machine Infinite Bus (SMIB) system can be used to examine how the power system behaves in various operating scenarios. Using a Power System Stabilizer (PSS) and Automatic Voltage Regulator (AVR) with a Proportional-Integral-Derivative (PID) controller is one way to increase voltage stability in a SMIB system. While the PSS dampens the oscillations of the generator rotor, the AVR controls the voltage at the generator terminal. The following methodology can be used for voltage stability improvement of SMIB systems using AVR PSS with PID and PSO:

1. Model the SMIB system: The first step is to model the SMIB system using appropriate mathematical equations and simulation

software. The model should include the generator, the AVR, the PSS, the load, and the transmission line.

2. Design the AVR: The AVR regulates the voltage at the generator terminal. The design of the AVR should be such that it can maintain the voltage within the acceptable limits under all operating conditions.
3. PSO optimization, optimizing the parameters of the AVR and PSS with PID control systems using the PSO algorithm. The PSO method is used to find the ideal set of control settings that raises the SMIB system's voltage stability. The control parameters are iteratively updated by the algorithm in order to minimize the objective function, which depicts the system voltage's departure from the target value.

2.1 . Automatic voltage regulator

The primary function of the AVR is to keep the generator terminal voltage constant when the load varies gradually and subtly. The AVR loop's primary component is an exciter. It supplies the generator field with DC electricity. The exciter is built with sufficient margins so that, even in an emergency, it can deliver strong excitation level boosts. The output voltage of a synchronous generator in a power system is controlled by an Automatic Voltage Regulator (AVR). The generator's excitation system, which is in charge of supplying the rotor with the field current required to generate the requisite output voltage, is not complete without the AVR. In voltage stability improvement, the AVR plays a critical role in regulating the generator's output voltage to maintain the voltage level within a specified range. The generator's terminal voltage is continuously monitored by the AVR, which then compares it to a predetermined reference voltage. The AVR modifies the output of the excitation system to control the generator's output voltage in the event that the terminal voltage differs from the reference voltage. The main job of the AVR is to keep the generator's output voltage within a predetermined range when the load changes. By preventing voltage breakdown and maintaining a steady voltage level, the AVR contributes to the stability of the power supply. This is particularly important during periods of high demand, when the power system may be operating close to its limits. Moreover the AVR can also provide additional damping to the power system by incorporating a Power System Stabilizer (PSS). The PSS introduces a signal that is proportional to the generator's speed deviation, which improves the system's damping characteristics by introducing additional damping to low-frequency oscillations. Overall the AVR is an essential component of the

excitation system, and its proper operation is critical to maintaining voltage stability in a power system.

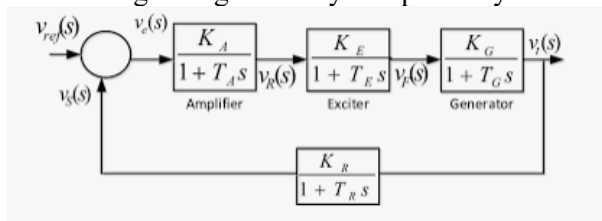


Figure 1 Block diagram of AVR

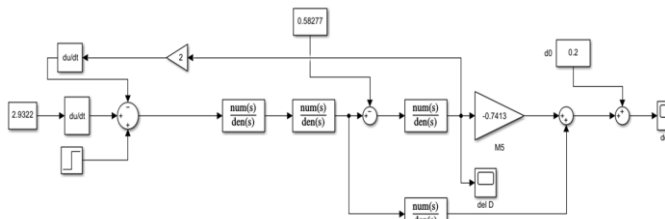


Figure 2. Simulink model of AVR

In Figure 2, T_E is the field circuit time constant, S_e is the saturation curve, $V_f(s)$ is the output field voltage, and K_A and T_A are the amplifier gain and time constant, respectively. On the feedback circuit, K_R and T_R are the stabilizer gain and time constant.

2.2. Power system stabilizer

In order to improve the damping of rotor oscillation caused by signal disruption, PSS, or generator control, is fed back. A tiny variation in the reference voltage regulator exciter, which causes the rotor oscillations to increase over time, could be the source of the disturbance. The issue of power system stabilizers (PSS) includes the design of PSS controllers, techniques for integrating PSS with AVRs, analysis of various input signals, and the wide range of tuning approaches.

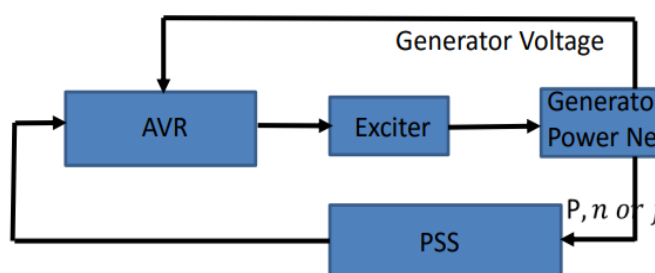


Figure 3: Structure of power system stabilizer (PSS)

Through the generator excitation, a PSS adds additional damping to the oscillation of synchronous machine rotors, extending the limits of angular stability for a power system. An electric torque that is given to the rotor in phase with the speed variation provides this damping. The temperature limit of the tielines in the system may then be approached when the oscillations have been dampened. It is very helpful to have this additional control during massive power transfers and line interruptions. However, the PSS's

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detrimental dampening effects on the rotor can occasionally lead to power system instability. This is because PSSs are only effective in dampening minor excursions around a steady-state working point, around which they are adjusted. In an attempt to regulate its excitation field, a PSS may actually cause the generator it controls to lose synchronism during strong shocks.

A generator control called a power system stabilizer is used in feedback to improve the dampening of rotor oscillation brought on by signal disturbances. Rotor oscillations may become more frequent as a result of the disturbance, which can be brought on by even slight adjustments to the reference voltage regulator exciter. By regulating its excitation, the generic PSS can be utilized to increase damping to the synchronous machine's rotor oscillation. The electromechanical oscillation of the power system, also known as power swing, needs to be damped in order to preserve stability. Machine speed deviation ($\Delta\omega$) is the PSS's input signal, and additional input (V_{stab}) to the excitation system is its output signal. The nonlinear system depicted in Figure 4 models the generic power system stabilizer. Due in large part to its low cost, PSS has replaced other damping controllers in all synchronous generators as the most widely used method of managing the excitation of the generator rotor oscillation. By adding a signal to the reference voltage signal, which is based on the automatic voltage regulator (AVR), PSS is used to perform this crucial function of damping oscillations. By combining additional torque coaxial with power, speed, or frequency deviations, PSS can enhance the damping of low frequencies and develop dynamic stability.

2.3. Traditional Power System Stabilizer Architecture

The main function of a PSS is to control the excitation of the generator rotor with an auxiliary stabilizing signal in order to reduce rotor oscillations. To provide damping, the stabilizer needs to produce an electrical torque component in proportion to the rotor speed variation. To keep things simple, a two-stage, identical lead/lag network with a stabilizer gain and two time constants is used to replicate a conventional PSS. Figure 4 illustrates how this network is linked to a time constant's washout circuit.

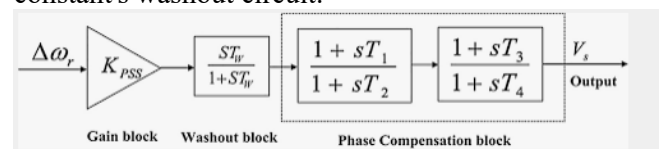


Figure 4: Block Diagram of PSS

The phase lag between the exciter input and the generator's electrical torque is compensated for in figure 4 by the phase compensation block, which offers the proper phase lead characteristics. A high pass filter is provided by the signal washout block.

Kstab: impact on rotor oscillation dampening. Damping rises with stabilizer gain until a certain degree, after which it starts to fall. The ideal setting for gain would be the maximum damping. Usually, it is set to a value that, when combined with other system modes' stability and avoids unduly amplifying signal noise, produces a high damping of the critical system modes.

Washout Filter

It is a high pass filter designed to stop the field voltage from being altered by consistent speed fluctuations. TW, or the washout time constant, should be set high enough to permit signals corresponding to rotor speed fluctuations within a range of 1 to 20 seconds to pass through unaltered. Long enough to allow stabilizing signals to be transmitted at target frequencies essentially unaltered, but not so long that the stabilizer's action causes undesired generator voltage excursions. If the phase lead at low frequencies is not adjusted for, lower time constants will result in a reduction of the synchronizing torque component at inter-area frequencies.

Phase-Lead Compensation

The PSS must generate an electrical torque component in step with the rotor speed variation in order to dampen rotor oscillations. Utilized to make up for the time lag that exists between the electrical torque that is produced and the exciter input, or PSS output. In order to improve the damping of inter-area oscillation modes or local plant modes, the PSS is frequently needed. The speed deviation is a natural signal to utilize for managing generator excitation since the goal of a PSS is to introduce a damping torque component.

2.4. Automatic voltage regulator with power system stabilizer (AVR-PSS)

The Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) in a Single Machine Infinite Bus System (SMIBS) collaborate to increase voltage stability. By modifying the field current of the excitation system, the AVR controls the generator's output voltage. The excitation system's output is continuously monitored by the AVR, which also modifies the output to keep the voltage level within a predetermined range. This helps to maintain the stability of the power system by ensuring that the voltage level remains constant, even under varying load conditions. The PSS is a supplementary control device that is added to the AVR to improve the system's damping characteristics. The PSS introduces additional damping to the system by adding a signal that is proportional to the generator's speed deviation

into the excitation system. This signal helps to improve the system's damping characteristics by introducing additional damping to low-frequency oscillations. Together, the AVR and PSS work to improve the voltage stability of the SMIBS by regulating the generator's output voltage and introducing additional damping to the system. This helps to maintain the stability of the power system and prevent voltage collapse, particularly during periods of high demand.

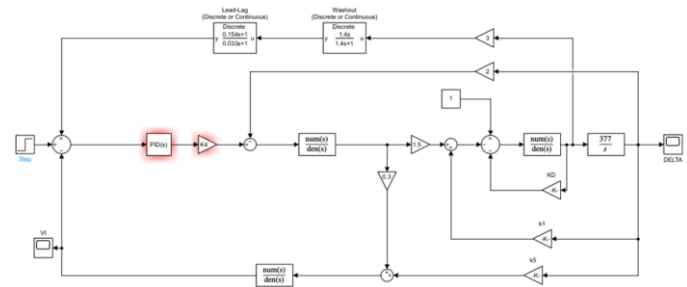


Figure. 5. AVR-PSS block diagram model

Overall, the use of an exciter voltage transducer in the field circuit of the AVR with PSS model in voltage stability improvement of a SMIBS offers several advantages, including improved accuracy, faster response time, reduced system losses, and improved system reliability.

2.5. PSO (Particle Swarm Optimization)

Inspired by the social characteristics of fish schools or flocks of birds, the Particle Swarm Optimization (PSO) method is essential to enhancing the voltage stability of a Single Machine optimization technique. It is employed to look out the ideal combination of control settings to raise the SMIB system's voltage stability. The PSO method is used to optimize the settings of the Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) with PID control systems in the context of improving the voltage stability of the SMIB system. The AVR control system is responsible for regulating the voltage of the generator and maintaining it within acceptable limits, while the PSS with PID control system provides supplementary control signals to the AVR and regulates the voltage using a feedback control mechanism.

The PSO algorithm uses PID control systems to iteratively update the AVR and PSS control parameters in order to minimize the objective function, which represents the system voltage's divergence from the target value. A swarm of particles is used by the PSO method to move about the search space and change their positions in response to information about the best solution thus far discovered. The fitness function is used by the algorithm to assess the quality of the solution and identify the optimal set of control parameters. The PSO algorithm is preferred over other

optimization techniques because of its simplicity, efficiency, and ability to avoid getting stuck in local optima. The PSO algorithm can handle a large number of variables and non-linear objective functions, making it suitable for optimizing the complex control systems of the SMIB system. in this project we use Population=20,Maximum iteration=50.

term, and responses to the rate of change of the error are given by the derivative term. By adjusting the output of the reactive power device in real-time, the PID controller can help to maintain stable voltage levels in the power system, even in the face of changing loads or other disturbances. PID controllers are widely used in power system control and are an important tool for maintaining the stability and reliability of the power grid.

3. Results and discussion

To enhance the AVR + PSS model for voltage stability improvement PID controller gains optimized by Particle Swarm Optimization (PSO) was used, in the optimization 20 population and 30 iteration with minimum and maximum range of 1 and 10 respectively were used, in the optimization the gain parameters of PID and PSO were given in Table 1. in Table 2 Comparison of rotor angle in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS was clearly notified, Table 3 and Table 4 describes change in voltage comparison in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS and Comparison AVR alone with AVR + PSS for rotor angle were described, further more thus comparison also shown from **figure. 7.** to figure 10, and from the figures in all for rotor angle change and for change in voltage, the time response parameters such as rise time, settling time, overshoot and undershoot including oscillation damping is better improved in cases where PID controller optimized by PSO in the presence of both AVR and PSS

Kp	Ki	Kd	K4
4.5022	7.6571	8.3587	6.4038

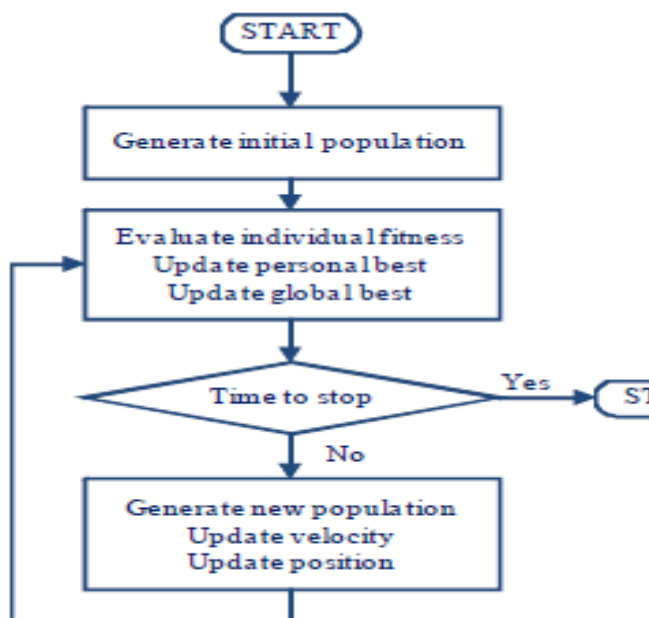


Figure. 6. flow chart of particle swarm optimization

2.6. PID controller

The PID controller modifies the reactive power device's output based on the continuous measurement of the voltage differential between the intended and actual levels. Responses to the current error are given by the proportional term of the controller, responses to the cumulative error over time are given by the integral

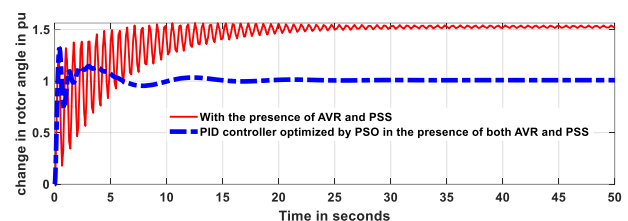


Figure 7 comparison of rotor angle in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS

Table 1 Gains values of PID and PSS optimized by PSO

Table 2 Comparison of rotor angle in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS

Types of model	Rise time	Settling time	Undershoot	Overshoot
Only AVR+PSS	1.6205	27.4146	0.4653	1.5636
PID	0.182	13.235	0.7329	1.3214

controller optimized by PSO in case of AVR+PSS	4	4		
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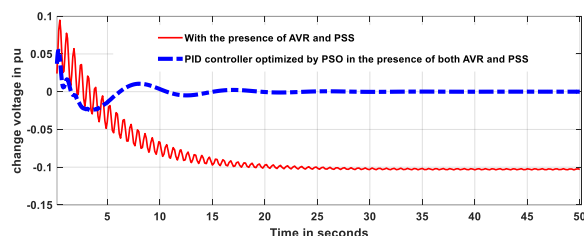


Figure 8. change in voltage comparison in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS

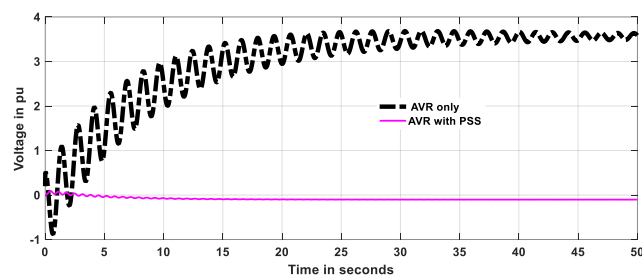


Figure 10. Comparison AVR alone with AVR + PSS for change in voltage in pu

Table 5. Comparison AVR alone with AVR + PSS for voltage in pu

	Rise time	Settling time	Settling min	Settling max
AVR only	12.5391	49.1353	2.5322	3.6825
Only AVR+PSS	10.1900	23.5170	-0.1035	-0.0834

Table 3. change in voltage comparison in case of AVR+PSS with added PID controller optimized by PSO with AVR+PSS

Types of model	Rise time	Settling time	Undershoot	Overshoot
Only AVR-PSS	10.1900	23.5170	-0.1035	-0.0834
PID controller optimized by PSO in case of AVR+PSS	7.6815e-05	18.6101	-0.0244	-0.0105

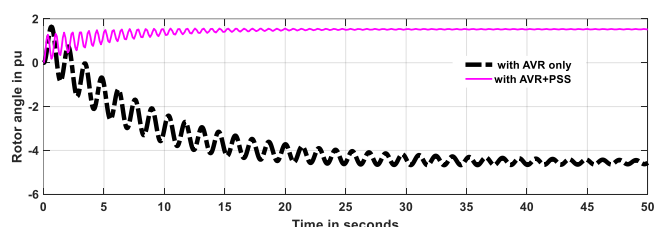


Figure 9. comparison AVR alone with AVR + PSS for rotor angle

Table 4. Comparison AVR alone with AVR + PSS for rotor angle

4. Conclusion

The literature that is currently available suggests that a Single Machine Infinite Bus (SMIB) system's voltage stability can be greatly increased by using an Automatic Voltage Regulator (AVR), a Power System Stabilizer (PSS), a Proportional-Integral-Derivative (PID) controller, and Particle Swarm Optimization (PSO). The generator's voltage is controlled by the AVR, and oscillations in the system are lessened by the PSS with PID controller. Better performance is achieved by optimizing the PID controller's parameters using the PSO method. In comparison to AVR alone and AVR+PSS, the simulation results of the SMIB system with the suggested AVR+PSS with PID optimized by PSO controller demonstrate that the system has superior voltage stability and greater power oscillation damping. The system oscillations are effectively dampened by the controller, which also keeps the voltage within allowable bounds. Overall, the use of an AVR+PSS with PID optimized by PSO controller can be a promising approach for improving voltage stability in power systems.

References

	Rise time	Settling time	Undershoot	Overshoot
AVR only	12.5518	47.7175	-4.6708	-3.1477
Only AVR+PSS	10.1900	23.5170	-0.1035	-0.0834

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