PSS Tuning

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Abstract

One of the main characteristics of power systems is keeping voltages within given limits, done by implementing fast Automatic Voltage Regulators (AVR), which can increase generator voltage (i.e., excitation voltage) in a short time to ceiling voltage limits while simultaneously affecting the damping component of the synchronous generator electromagnetic torque. Also, Rotor angle stability in a synchronous machine is also affected. The efficient way to increase damping and keeping voltages within given limits in the power system is to implement a Power System Stabilizer (PSS) and Excitation control with AVR. This article discussed about PSS tuning in the power system.

1. Introduction

The Central Electricity Regulatory Commission (CERC) and the Central Electricity Authority (CEA) have regulations that require generating units to have PSS as part of their excitation systems.

According to Central Electricity Regulatory Commission (CERC) -Regulation 180, the tuning of AVR, PSS, Voltage Controllers including for low and high voltage ride through capability of wind and solar generators or any other requirement as per CEA (Central Electricity Authority) Technical Standards for Connectivity shall be carried out by the respective generating station:

– at least once in every five (5) years;
– based on operational feedback provided by the RLDC (Regional Load Despatch Centres) after analysis of a grid event or disturbance; and
– in case of major network changes or fault level changes near the generating station as reported by NLDC or RLDC(s), as the case may be.
– in case of a major change in the excitation system of the generating station.

Power System Stabilizers (PSSs), AVRs of generating units and reactive power controllers shall be properly tuned by the generating station as per the plan and the procedure prepared by the concerned RPC (Regional Power Committee). In case the tuning is not complied with as per the plan and procedure, the concerned RLDC shall issue notice to the defaulting generating station to complete the tuning within a specified time, failing which the concerned RLDC may approach the Commission under Section 29 of the Act.

1.1 PSS in India- Mandatory Requirement:

Regulatory Mandates: The Central Electricity Regulatory Commission (CERC) and the Central Electricity Authority (CEA) have regulations that require generating units to have PSS as part of their excitation systems. This is to enhance grid stability and meet dynamic performance requirements.

Grid Codes: Indian grid codes specify requirements for power plants, including dynamic response capabilities facilitated by PSS to ensure stability under varying conditions.

Utility Companies: Major utility companies and power plants, especially those involved in interstate transmission, are required to install and maintain PSS to comply with grid standards.

Power Producers: Independent power producers and state-owned generation companies use PSS to comply with regulatory requirements and improve system reliability.

1.2 Consequences of Not Using PSS

a. Stability Issues:

Inadequate Damping: Without PSS, generators might not have sufficient damping of electromechanical oscillations, leading to poor dynamic performance and potential instability during disturbances.

Oscillations: Increased risk of prolonged oscillations following disturbances, which can affect synchronism and lead to system-wide instability.

Regulatory Non-compliance:

Penalties and Sanctions: Generators not equipped with PSS or with improperly tuned PSS may face regulatory penalties or restrictions on grid access.

Operational Limitations: Non-compliant units might be subject to operational constraints, impacting their ability to participate fully in the electricity market.

b. System Reliability:

Reduced Reliability: The absence of PSS reduces the grid's ability to manage dynamic changes effectively, increasing the risk of blackouts or other reliability issues.

Network Vulnerability: A grid without adequate damping is more vulnerable to cascading failures and widespread outages.

The use of Power System Stabilizers (PSS) is widespread across the world, and their implementation varies depending on the region's specific regulatory requirements, grid characteristics, and the overall maturity of the power system infrastructure.

The use of Power System Stabilizers is a global practice essential for maintaining grid stability and reliability. While regulatory requirements and implementation practices vary across regions, the fundamental role of PSS in damping oscillations and enhancing dynamic response is universally recognized. As power systems continue to evolve with increased renewable integration and interconnected networks, the importance of PSS in ensuring stable and efficient operation remains critical worldwide [1-3].

IEEE Std 421.5 - Recommended Practice for Excitation System Models for Power System Stability Studies [4]:

- This standard provides recommended practices for modeling excitation systems, including PSS models, for power system stability studies.
- It outlines different PSS model types and their parameters, focusing on the system's dynamic performance.
- A Power System Stabilizer (PSS) is a device used in power systems to enhance the stability of the electrical grid. Its primary function is to provide damping

to the power system oscillations that occur due to disturbances such as changes in load, faults, or the disconnection of generators.

II. Conditions for Operation and Control with Grid:

2.1 Synchronization:

- ✓ Phase Angle Matching: The phase of the generator's output voltage must match the phase of the grid voltage.
- ✓ Voltage Matching: The output voltage magnitude must match the grid voltage.
- ✓ Frequency Matching: The generator speed must match the grid frequency.

2.2 Voltage Regulation:

- ✓ The AVR adjusts the excitation voltage to maintain the generator's terminal voltage within specified limits. It responds to changes in load and grid conditions to keep the voltage stable.
- ✓ Proper control of the excitation system ensures that the generator's voltage remains within the required range and can react to variations in load or grid conditions.

2.3 Reactive Power Management:

- ✓ Synchronous generators can supply or absorb reactive power, depending on the grid requirements. The generator's capability to control reactive power helps in maintaining voltage levels and overall grid stability.
- ✓ Generators are often required to operate within specified power factor limits (e.g., 0.8 lagging or 0.95 leading). This helps in balancing the reactive power in the system and ensuring efficient power delivery.

2.4 Stability and Damping:

- ✓ The PSS helps dampen power system oscillations and improve system stability by adding damping to the generator's control system. It enhances the dynamic response of the generator to grid disturbances.
- ✓ Rotor Angle Stability: The generator must maintain synchronism with the grid, which means it should remain in phase and continue to rotate at the same frequency. This is crucial for preventing loss of synchronism and potential grid instability.

  Rotor angle stability in a synchronous machine refers to the ability of the machine to maintain synchronism with the grid during and after disturbances. It is a critical aspect of the stability of power systems. In a synchronous machine, the rotor rotates at the same speed as the magnetic field produced by the stator, maintaining a constant rotor angle relative to the grid. This synchronous operation is essential for stable power generation and transmission. The rotor angle is the angular position of the rotor relative to a reference point, typically the grid voltage. It represents the phase difference between the generator's internal voltage and the grid voltage.

2.5 Protection and Safety:

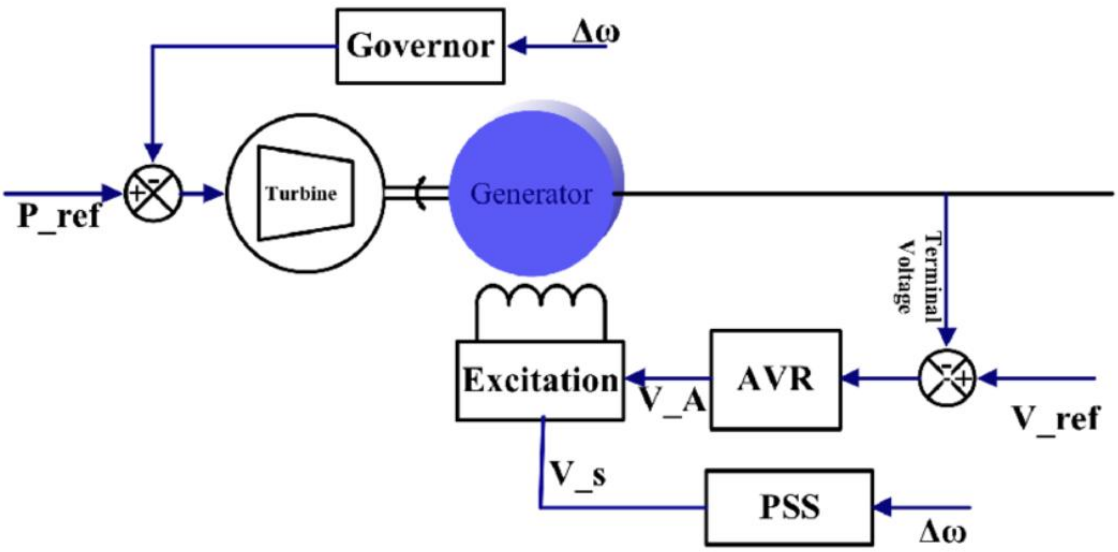
Protection systems, such as overcurrent relays, under/over-voltage relays, and frequency protection devices, safeguard the generator and grid from abnormal conditions and faults.

2.6 Compliance with Standards and Regulations

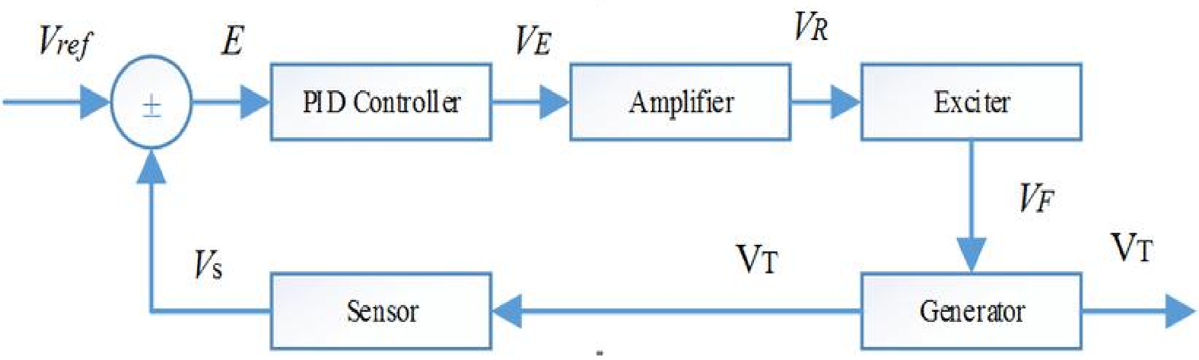
3. To achieve these conditions, the key components required are,

- ✓ AVR: Primarily focused on voltage matching and stability.
- ✓ PSS: Enhances stability by damping oscillations, supporting overall system performance, and indirectly aiding in synchronization and stability.
- ✓ Excitation Control: Adjusts excitation to support both voltage and reactive power, indirectly aiding phase matching and rotor angle stability.
- ✓ Governor Control: Directly manages frequency matching and supports rotor angle stability through speed regulation.

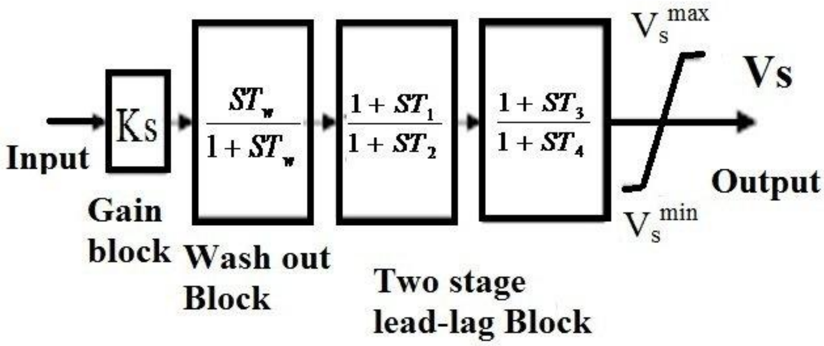
Overall block diagram



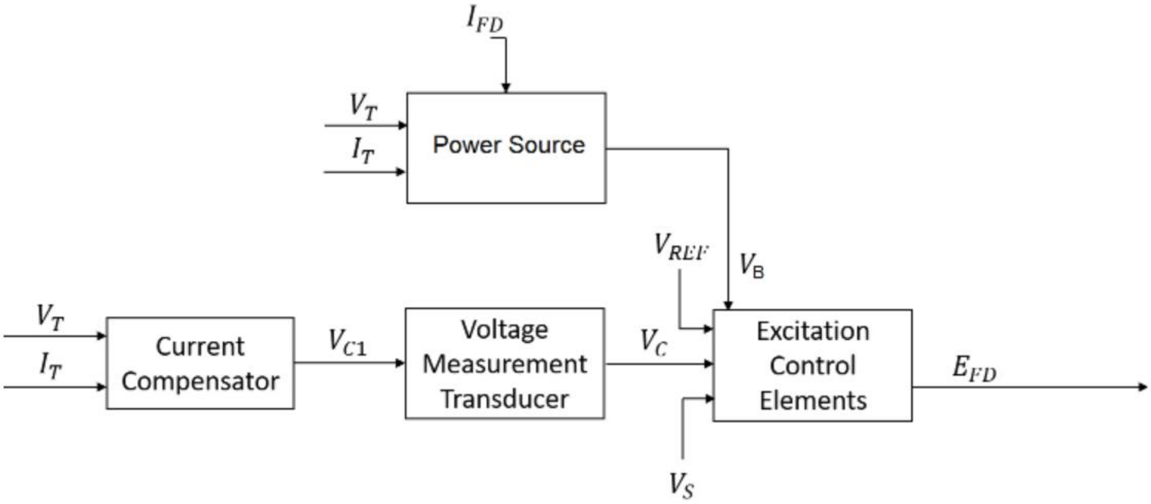
Automatic Voltage Regulator



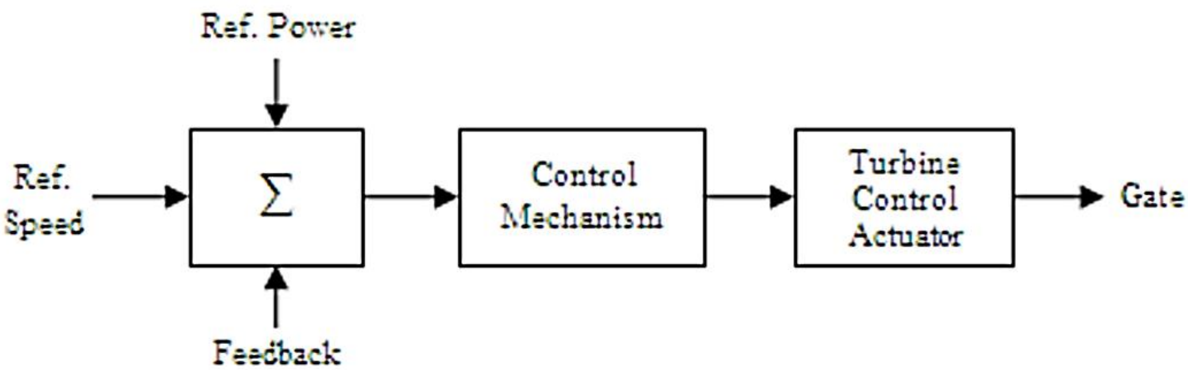
Power System Stabilizer



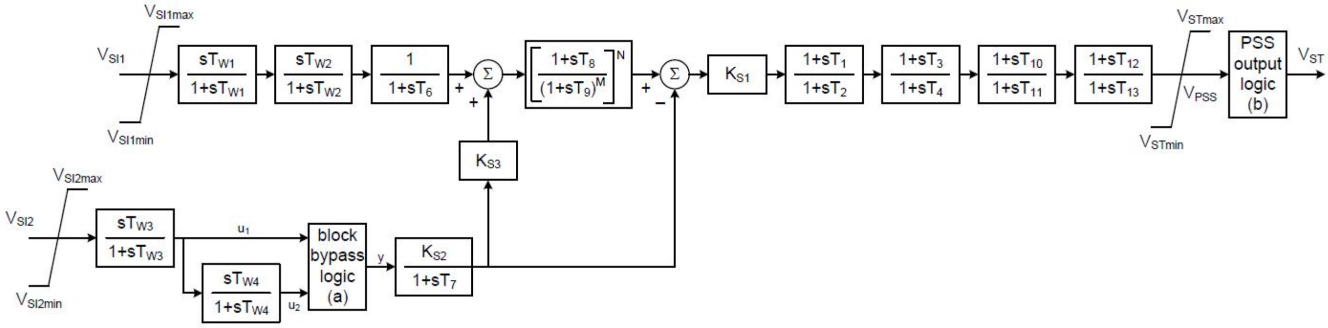
Excitation Control



Governor control



3.1 PSS tuning:



This stabilizer model PSS2C shown in Figure, is designed to represent a variety of dual-input stabilizers, which normally use combinations of power and speed (or frequency, or compensated frequency) to derive the stabilizing signal. For each input, two washouts can be represented (T_{W1} to T_{W4}) Filters out low-frequency components from the input signals (e.g., generator speed or power output), focusing on higher-frequency oscillations that need damping. Along with transducer or control lag time constants (T_6, T_7). Simulates the response delay of the system, ensuring the control model reflects real-world dynamics. (For example, The time constants T_6 and T_7 are used to represent the inherent delays in the power system due to physical components such as transducers, sensors, and controllers. These components do not respond instantaneously; they introduce a certain amount of delay in measuring signals and generating control actions.)

Phase compensation is provided by the four lead-lag blocks (parameters T1 to T4 and T10 to T13). (For example, each block is tuned to address specific aspects of the system's dynamics, and through repeated adjustments and testing, the PSS parameters converge to an optimal configuration that provides the necessary phase compensation across the entire frequency range.) A lead compensator can increase the stability or speed of response of a system; a lag compensator can reduce (but not eliminate) the steady-state error. For the integral of accelerating power PSS K_{S3} would normally be 1 and K_{S2} would be equal to $T_7/2H$ where H is the total shaft inertia of all mechanically connected rotating components of the unit Adjust the phase and gain characteristics of the signal to optimize the PSS2C's response. The lead component improves the phase margin, while the lag component ensures smooth system response.

Gain Blocks (Ks3 and Ks2) Scale the modified control signal to the appropriate level for the exciter. These gain blocks set the amplitude of the damping signal. In addition, typically $T_{W1} = T_{W3}$, $T_{W2} = T_7$, and $T_6 = 0$. The first input signal (V_{SI1}) would normally represent speed (or frequency, or compensated frequency) and the second input signal (V_{SI2}) would be the generator electrical power output signal, in per unit of the generator MVA rating.

The exponents M (magnitude of the response to frequency deviations) and N (timing of the response to frequency deviations of the damping effect) that allow a “ramp-tracking” or simpler filter characteristic to be represented. Typical values in use by several utilities are M = 5 and $N = 1$ or $M = 2$ and $N = 4$. Smooths out abrupt changes and noise from the input signal, providing a gradual and stable control signal. These threshold values are used to define a hysteresis, so typically $PPSS_{off}$ is defined as somewhat lower value than $PPSS_{on}$, between 5% and 10% of the generator capability.

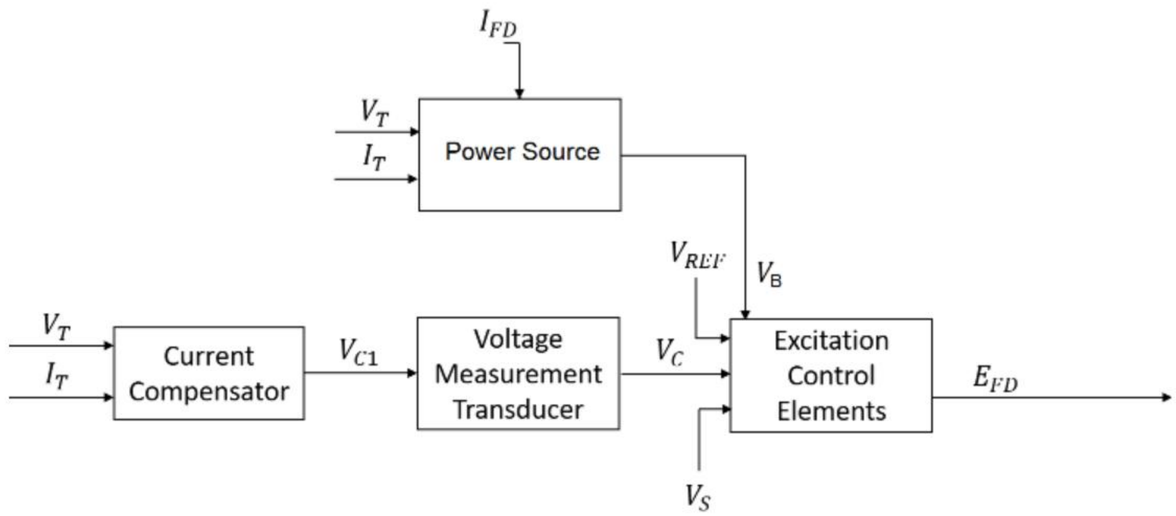
Damping Signal: The processed and scaled signal is sent to the exciter. This signal adjusts the excitation voltage of the generator, which in turn affects the generator's terminal voltage and reactive power output.

Note: Comparison with other PSS controller types,

- **PSS2C:** Widely used and well-suited for many standard industrial applications due to its reliability and cost-effectiveness.
- **PSS3C:** Chosen for more advanced systems requiring better performance and additional control.
- **PSS7C:** Used in high-complexity and critical systems where the highest level of stabilization and advanced features are necessary.

3.2 Type ST10C excitation system model

The static excitation model ST10C is shown in Figure 30. This model is a variation of the ST1C and ST5C models. In addition to ST5C model, this model offers alternatives for the application of the stabilizing signal VS coming from the PSS. It offers the option to apply the PSS signal at the AVR summing junction (voltage reference) and/or at the output of the gate structure, via separate but identical control elements.



In the diagram:

- V_T and I_T are the measured terminal voltage and current of the synchronous machine, respectively.
- V_{C1} is the current-compensated terminal voltage.
- V_C is the filtered, current-compensated terminal voltage.
- V_{REF} is the reference terminal voltage.
- V_S is the power system stabilizer voltage.
- V_B is the exciter field voltage.
- E_{FD} and I_{FD} are the field voltage and current, respectively.

3.2.1 Current Compensator and Voltage Measurement Transducer

The block models the **current compensator** by using this equation:

$$V_{C1}=V_T+I_T\sqrt{R^2_C+X^2_C},$$

Where, R_C is the load compensation resistance and X_C is the load compensation reactance.

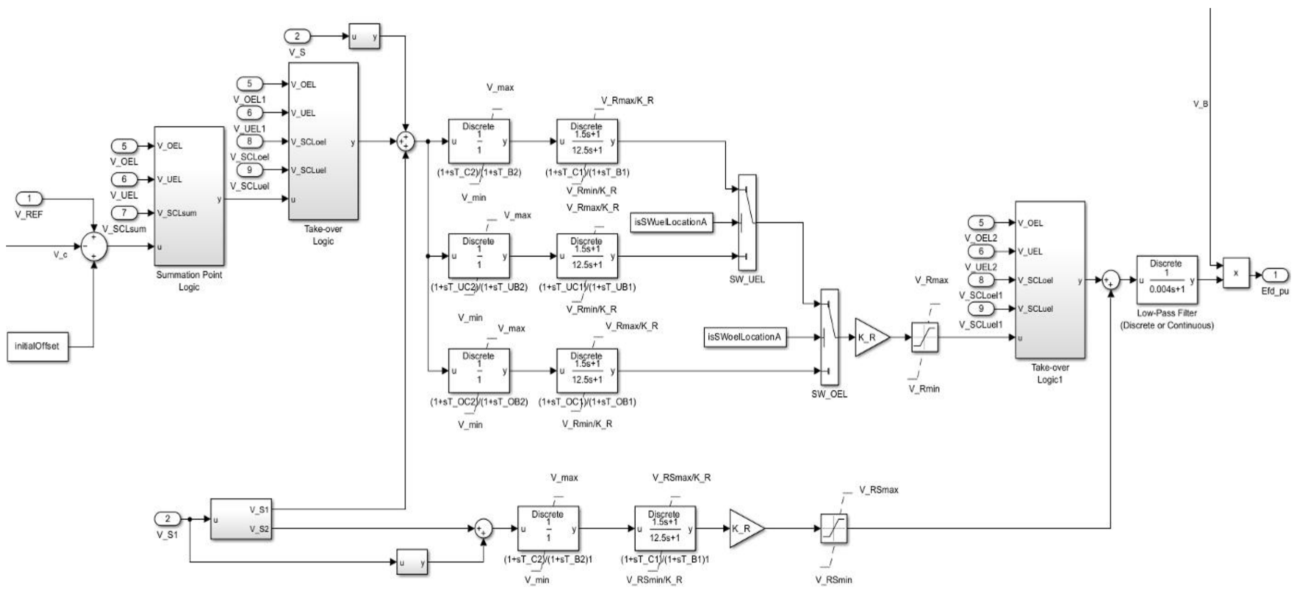
Consider a scenario where the terminal voltage is experiencing a drop due to a high load current I_t . The compensator calculates the required adjustment based on the impedance and adds this adjustment to the terminal voltage to generate V_{c1} . This adjusted voltage helps to counteract the voltage drop caused by the load and impedance, maintaining the desired voltage level. The block implements the voltage measurement transducer as a Low-Pass Filter block with the time constant T_R.

In a power system, suppose the terminal voltage Vt has high-frequency noise due to switching actions or other disturbances. The Voltage Measurement Transducer with a low-pass filter will:

1. Receive the noisy V_t signal.
2. Filter the signal to remove high-frequency noise using the low-pass filter with time constant T_R .
3. Output a smoother voltage signal V_c that is less affected by noise and provides a more accurate measurement for control and monitoring purposes.

3.2.2 Excitation Control Elements

This diagram shows the structure of the excitation control elements:



- The Summation Point Logic subsystem models the summation point input location for the overexcitation limiter (OEL), under excitation limiter (UEL), and stator current limiter (SCL).
- There are two Take-over Logic subsystems. They model the take-over point input location for the OEL, UEL and SCL voltages.
- A parallel configuration of Lead-Lag (Discrete or Continuous) blocks offer independent control settings when a limiter is active. The model offers a common gain factor K_R and two Lead-Lag (Discrete or Continuous) blocks for the AVR and for

the under excitation and overexcitation limiters. The SW_UEL and SW_OEL Switch blocks activate the appropriate control path when the V_{UEL} and/or V_{OEL} signals are connected to their respective alternate positions. The SW_UEL and SW_OEL Switch blocks are on position B when the Alternate UEL input locations (V_UEL) and Alternate OEL input locations (V_OEL) parameters to Take-over at voltage error.

- The two Lead-Lag blocks in each control path model additional dynamics associated with the voltage regulator and with the under excitation and overexcitation limiters. The first Lead-Lag block in each respective path represents a transient gain reduction, where T_{C2} (or T_{UC2} and T_{OC2}) is the lead time constant and T_{B2} (or T_{UB2} and T_{OB2}) is the lag time constant. The second Lead-Lag block allows the possibility of representing a transient gain increase, where T_{C1} (or T_{UC1} and T_{OC1}) is the lead time constant and T_{B1} (or T_{UB1} and T_{OB1}) is the lag time constant.
- The SM ST10C block also offers the option to apply the PSS signal at the AVR summing junction after the first Take-over Logic subsystem or at the output of the gate structure, through a separate path (the bottom path in the model). This separate path comprises the same control elements as the main summing junction path.

3.2.3 Field Current Limiters

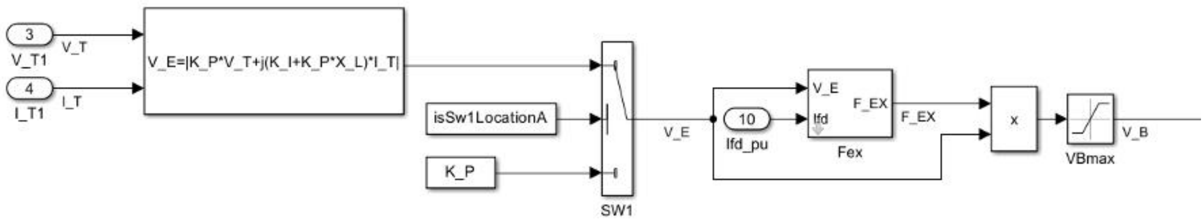
Different types of field current limiter to modify the output of the voltage regulator under unsafe operating conditions:

- Use an overexcitation limiter to prevent overheating of the field winding due to excessive field current demand.
- Use an under excitation limiter to boost field excitation when it is too low, which risks desynchronization.
- Use a stator current limiter to prevent overheating of the stator windings due to excessive current.

The stator current limiter at the summation point, use the input V_{SCLsum}. If the stator current limiter at the take-over point, use the overexcitation input V_{SCLoel}, and the under excitation input V_{SCLuel}.

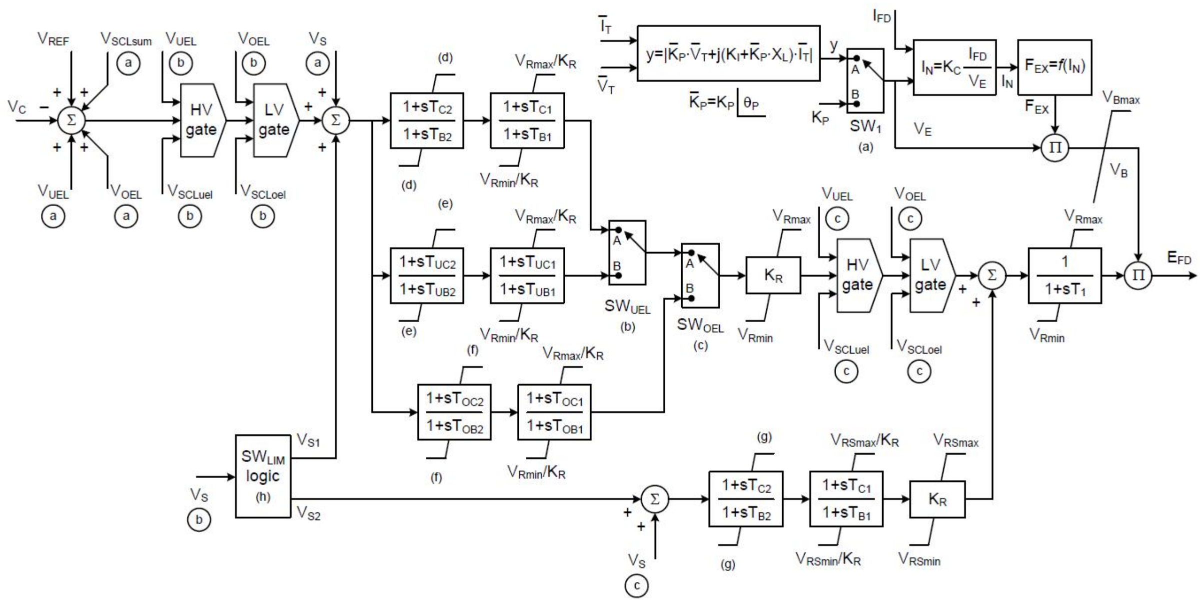
3.2.4 Power Source

Different power source representations for the controlled rectifier by setting the **Power source selector** parameter value. To derive the power source for the controlled rectifier from the terminal voltage, set the **Power source selector** parameter to Position A: power source derived from generator terminal voltage. To specify that the power source is independent of the terminal voltage, set the **Power source selector** parameter to Position B: power source independent of generator terminal conditions. This diagram shows a model of the exciter power source utilizing a phasor combination of the terminal voltage V_T and terminal current I_T:



The Power source selector parameter controls the origin of the power source for the controlled rectifier. The subsystem multiplies the voltage regulator command signal V_R by the exciter field voltage V_B. If the terminal voltage V_t drops below the desired level due to increased load, the excitation system will increase the field current I_{fd} by adjusting V_B. This compensates for the voltage drop and helps to maintain stable operation of the generator.

Overall Excitation Model:

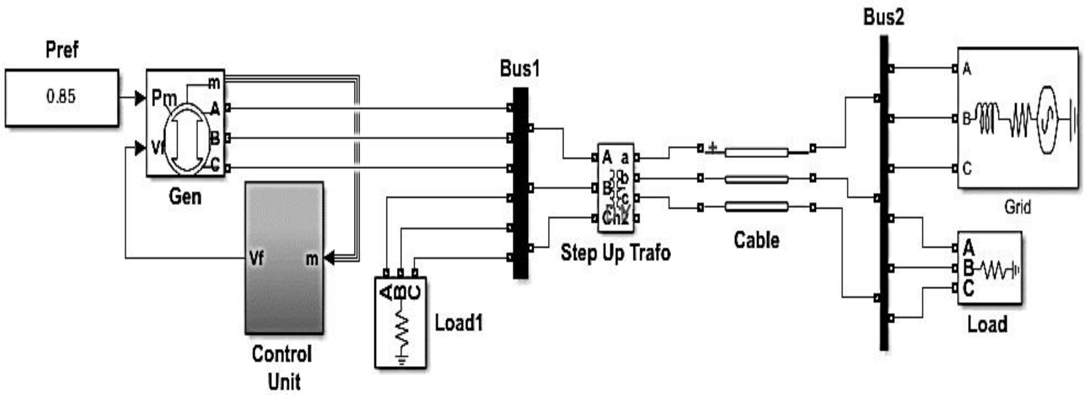


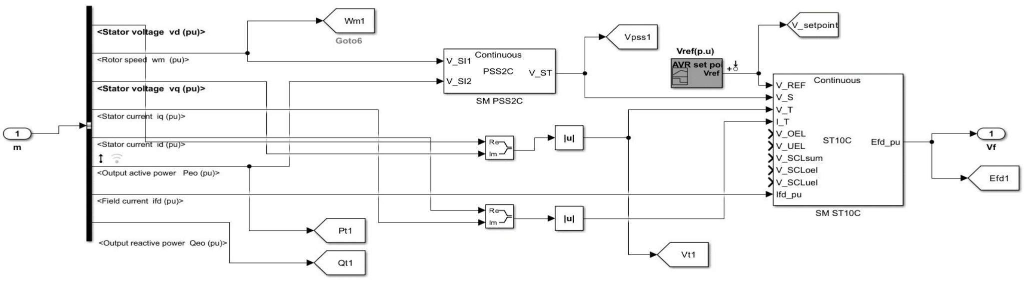
- Terminal Voltage Equation: $V_t = E_f - jX_sI_a$
- Reactive Power Output: $Q = \frac{V_t^2 - E_f^2}{X_s}$
- Voltage Regulation: $\text{Voltage Regulation}(\%) = \frac{V_{t,\text{no-load}} - V_{t,\text{full-load}}}{V_{t,\text{full-load}}} \times 100$
- Power Factor: $\text{PF} = \cos(\theta)$
- Excitation Voltage Relationship: $E_f = k \cdot I_f$
- AVR Control: $\Delta E_f = K_{\text{AVR}}(V_t^* - V_t)$

3.3 PSS Tuning Using MATLAB /SIMULINK

The following methodology is used for the tuning of the PSS:

1. Set basic parameter calculated from excitation system manufacturer as listed in above tables.
2. Load initial operation conditions of full load considering highest given positive sequence network impedance.
3. Tune PSS lead lag filters in order to obtain optimum phase compensation in the frequency range between 0.2 and 2.0 Hz for the open loop frequency response. The ideal damping will be obtained when the output of the transfer function is practically in phase with the rotor angular speed. Since the input signal of the transfer function is the power signal, that lags the speed by 90, the target compensation shall be 90°±30°.
4. For closed loop frequency response, in order to have satisfactory reduction of amplitude signal within the frequency range of 0.2 to 2.0 Hz.
5. Verify the PSS performance by means of simulations for different operation points and conditions.





The synchronous generator produces electrical power from mechanical input, with the excitation system maintaining the desired voltage level. The PSS and AVR work together to ensure system stability by damping oscillations and regulating voltage. The step-up transformer increases the voltage to transmission levels for efficient long-distance power delivery. High-voltage power is transmitted through cables and buses to the grid, ensuring reliability. The power is integrated into the grid, where it is distributed to meet consumer demand while maintaining stability and efficiency. The overall objective is to ensure that electrical power is generated, transmitted, and distributed reliably and efficiently, maintaining stability and quality across the system. Each component and control system works together to achieve these goals, addressing various operational challenges and dynamic conditions.

Table H.24—Sample data for PSS2C stabilizer (for ST1C model in Table H.23)

Description	Symbol	Type	Value	Units
Power system stabilizer gain	K_{S1}	A	20	pu
Power system stabilizer gain	K_{S2}	E/A	[a]	pu
Power system stabilizer gain	K_{S3}	E	1	pu
PSS transducer time constant	T_6	E	0.0	s
PSS transducer time constant[b]	T_7	A	10	s
PSS washout time constant	T_{w1}	A	10	s
PSS washout time constant	T_{w2}	A	10	s
PSS washout time constant	T_{w3}	A	10	s
PSS washout time constant	T_{w4}	A	[c]	s
PSS transducer time constant	T_8	A	0.30	s
PSS washout time constant	T_9	A	0.15	s
PSS transducer time constant	M	A	2	
PSS washout time constant	N	A	4	
PSS numerator (lead) compensating time constant	T_1	A	0.16	s
PSS denominator (lag) compensating time constant	T_2	A	0.02	s
PSS numerator (lead) compensating time constant	T_3	A	0.16	s
PSS denominator (lag) compensating time constant	T_4	A	0.02	s
PSS numerator (lead) compensating time constant	T_{10}	A	[d]	s
PSS denominator (lag) compensating time constant	T_{11}	A	[d]	s
Maximum PSS output	V_{STmax}	A	0.20	pu
Minimum PSS output	V_{STmin}	A	–0.066	pu
Input signal #1 maximum limit	V_{SI1max}	A	2	pu
Input signal #1 minimum limit	V_{SI1min}	A	–2	pu
Input signal #2 maximum limit	V_{SI2max}	A	2	pu
Input signal #2 minimum limit	V_{SI2min}	A	–2	pu
Generator MW threshold for PSS activation	P_{PSSon}	A	0	pu
Generator MW threshold for PSS de-activation	P_{PSSoff}	A	0	pu
NOTE—PSS settings depend not only on the excitation system model and parameters, but also on the generator model. These PSS parameters might not work properly for different generator models, even if the excitation system model remains the same.				

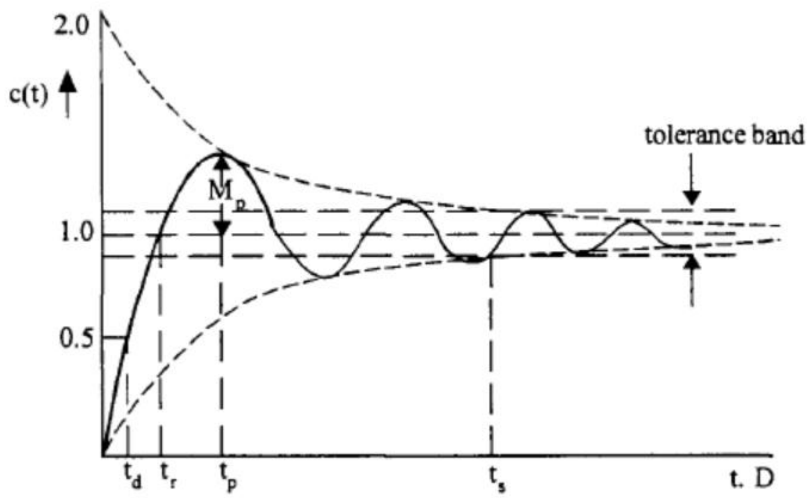
[a] The gain K_{S2} should be calculated as $T_7/2H$, where H is the inertia constant of the generator.
[b] The time constant T_7 should be equal to T_{W2}.
[c] The washout block with time constant T_{w4} should be bypassed. Set T_{w4} as necessary to bypass this block, based on the documentation of the software being used.
[d] The third lead-lag block is not used in this example. Set $T_{10} = T_{11}$ or follow the instructions in the documentation of the software being used.

Table H.38—Sample data for Type ST10C excitation system model

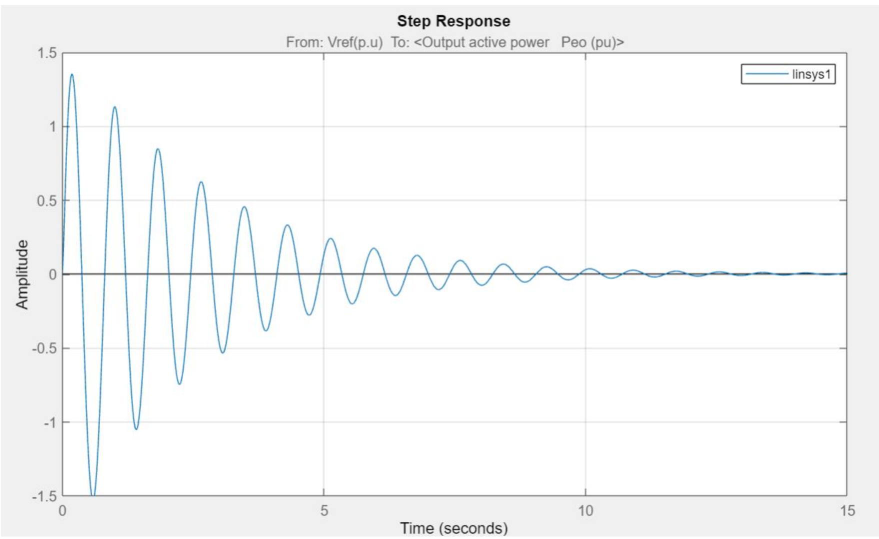
Description	Symbol	Type	Value	Units
Resistive component of load compensation	R_C	A	0	pu
Reactance component of load compensation	X_C	A	0	pu
Regulator input filter time constant	T_R	E	0.01	s
Regulator gain	K_R	A	500	pu
Voltage regulator denominator (lag) time constant 1	T_{B1}	A	12.5	s
Voltage regulator numerator (lead) time constant 1	T_{C1}	A	1.5	s
Voltage regulator denominator (lag) time constant 2	T_{B2}	A	0.1	s
Voltage regulator numerator (lead) time constant 2	T_{C2}	A	0.1	s
UEL regulator denominator (lag) time constant 1	T_{UB1}	A	12.5	s
UEL regulator numerator (lead) time constant 1	T_{UC1}	A	1.5	s
UEL regulator denominator (lag) time constant 2	T_{UB2}	A	0.1	s
UEL regulator numerator (lead) time constant 2	T_{UC2}	A	0.1	s
OEL regulator denominator (lag) time constant 1	T_{OB1}	A	12.5	s
OEL regulator numerator (lead) time constant 1	T_{OC1}	A	1.5	s
OEL regulator denominator (lag) time constant 2	T_{OB2}	A	0.1	s
OEL regulator numerator (lead) time constant 2	T_{OC2}	A	0.1	s
Maximum PSS regulator output	V_{RSmax}	A/E	5	pu
Minimum PSS regulator output	V_{RSmin}	A/E	–5	pu
Maximum regulator output	V_{Rmax}	A/E	10	pu
Minimum regulator output	V_{Rmin}	A/E	–8.7	pu
Rectifier loading factor proportional to commutating reactance	K_C	E	0.01	pu
Equivalent time constant for rectifier bridge	T_1	E	0.004	s
Power source selector	SW_1	E	pos. A	
Potential circuit (voltage) gain coefficient	K_P	E	1	pu
Potential circuit (current) gain coefficient	K_I	E	0	pu
Reactance associated with potential source	X_L	E	0	pu
Potential circuit phase angle (degrees)	θ_P	E	0	degrees
Maximum available exciter voltage	V_{Bmax}	A/E	1.5	pu

NOTE—The PSS signal V_S should be connected using alternate option "C," while the other input signals (OEL signal V_{OEL}, UEL signal V_{UEL}, and SCL signal V_{SCL}) should be set to option "B."

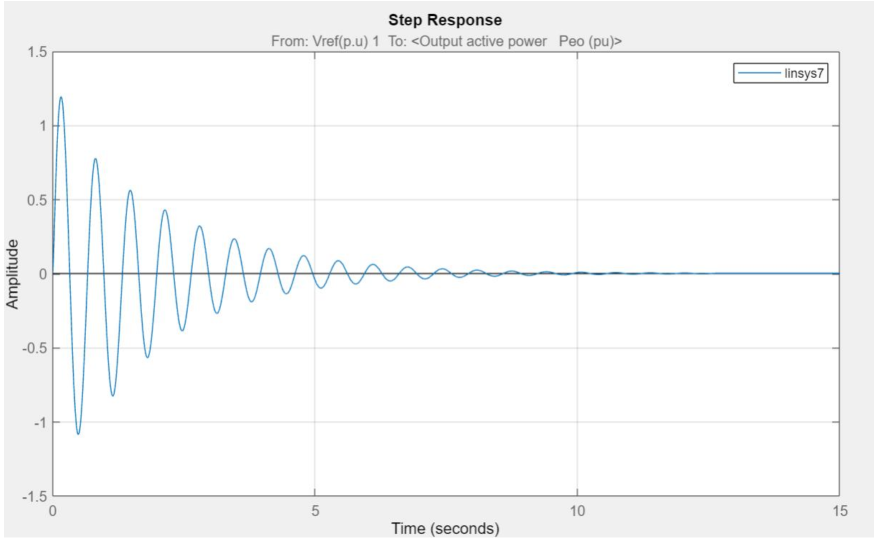
After entering all these values in PSS and excitor block, we need to check the stability of the system. For that first, the simulation done without using PSS block (open loop) and corresponding step plot is analysed. Let's see the general step response definitions,



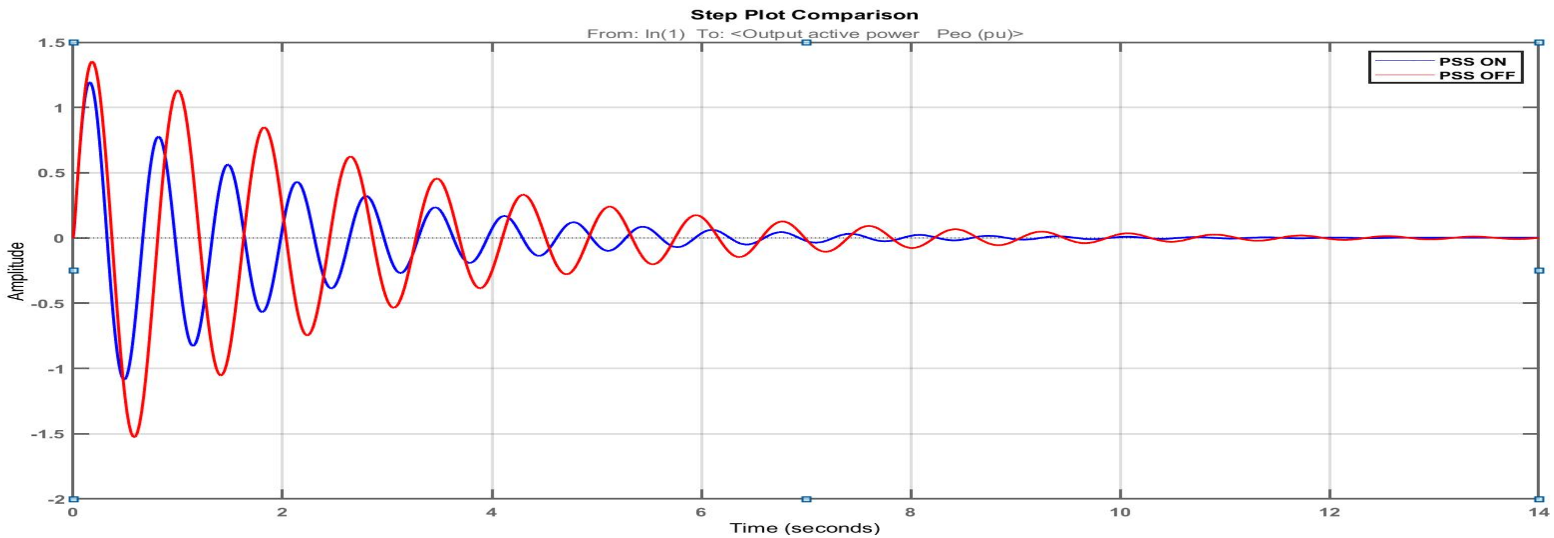
Whereas the same system is analysed using PSS with proper tuning using MATLAB coding, the results obtained as follows from reference voltage to real power variation,



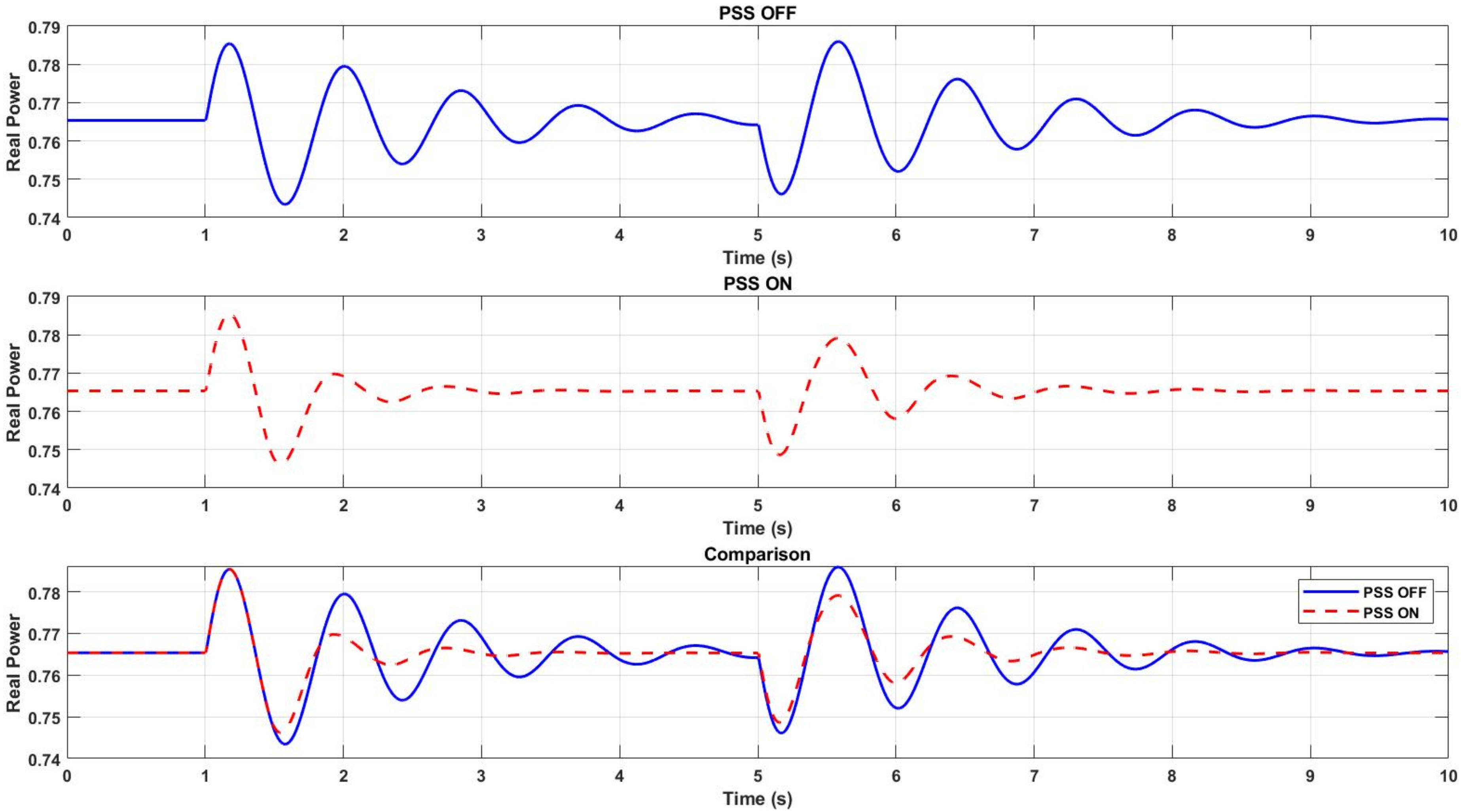
a. Step response when PSS OFF



b. Step response when PSS ON



The corresponding real power tracking by PSS is shown below for change in reference voltage,



t_d: It is the time required for the response to reach half of its final value from the zero instant.

t_r: It is the time required for the response to rise from 0% to 100% of its final value. This is applicable for the under-damped systems.

t_p:It is the time required for the response to reach the peak value for the first time.

Peak overshoot Mp is defined as the deviation of the response at peak time from the final value of response. It is also called the maximum overshoot.

t_s: It is the time required for the response to reach the steady state and stay within the specified tolerance bands around the final value. In general, the tolerance bands are 2% and 5%.

From the above results, it is observed that the response of the system is clearly indicates that there is a minimum overshoot and less settling time using PSS ON.

4. Conclusion:

The Power System Stabilizer (PSS) is a critical component in modern power systems, designed to enhance the stability and reliability of the electrical grid. The analysis helps to evaluate the system's response to sudden changes, showing how well the PSS can stabilize the system and return it to equilibrium after disturbances with less overshoot and settling time. In conclusion, the effective design and implementation of a PSS involve careful consideration to achieve optimal damping and system response. By focusing on the frequency range of 0.2 to 2 Hz, PSS tuning addresses the key low-frequency oscillations that can impact system stability, ensuring that the power system remains robust and responsive to disturbances. Through systematic analysis and targeted adjustment, PSS tuning enhances the power system’s ability to withstand and recover from disturbances, contributing to a stable and efficient electrical grid.

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