Impact of load variation on power system stability and performance of power system stabilizers: A case study of Peerdawd gas power station, Iraq

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ABSTRACT

Variable load on the station refers to the fluctuating load on a power plant due to erratic consumer demands. It is known to have an effect on the performance of power system stabilizers, particularly in damping inter-area oscillation. This paper examines how two power system stabilizer (PSS) models and various load conditions affect a power system's voltage and power stability. A dynamic model of the power system station, based on the real case study of the Peerdawd gas power station in north Iraq (PPGS), is utilized to investigate the response of both steady-state and transient-state models: the aggregated excitation control system (EX2100) and the power system stabilizer (PSS2B). The impact of load variation on voltage stability under normal situations and during disturbances is discussed. Furthermore, the effect of reactive power support from the power plant on the input of the two PSS models is analyzed and discussed. The paper employs a MATLABTM/Simulink-based simulation program, and the results contribute to understanding how load variation influences system damping based on PSS.

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1. INTRODUCTION

Recently, as the world has progressed, the structure of the electric power systems has expanded quickly. These systems now include many different components, including loads, transformers, transmission lines, generators, and controllers. The system is complicated by interference between these components [1]. Due to the necessity for the electrical energy, the rising demand for it poses a significant issue. Power exchanges between different zones of these systems lead to an increase in the complexity and size of power systems. Because the entire world depends on the electric network for daily living, the power networks are crucial to socioeconomic progress [2]. Consequently, a variety of protection and control mechanisms are required for the power systems to operate steadily. The term 'stability' for a power system is defined by the "ability of the system to retain its steady state when subjected to any disturbances is said to be power system stability" [3], [4]. The loads, generator outputs, topology, and other important operating factors of the power system are all constantly changing. This makes it a highly nonlinear system that functions in a dynamic environment. Two perspectives have been used to study the stability issue: steady-state stability and transient state stability. In order to analyze the power system and its generators under strictly steady-state conditions and make an effort to ascertain the maximum generator load that may be transmitted without endangering the synchronism of any other generator. Transient stability refers to the power system's capacity to maintain synchronism in the face of a sudden, significant disturbance (fault), such as a fault in the transmission infrastructure, the loss of a sizable load, or a loss of generation. When a disturbance (fault) occurs, the system's stability is influenced by both the type of disturbance and the starting operating conditions. When a fault occurs, it causes the generator to lose synchronism.

The essential condition for stable power system is synchronism [5], [6]. Three types of stability issues are rotor angle stability, frequency stability, and voltage stability. Rotor angle stability is necessary for the connected synchronous generators to operate synchronistical both during normal operation and following both a big and a small disruption [1], [7]. These tiny signal oscillations (SSOs) have low frequencies between (0.2 and 3.0 Hz) and low magnitudes. While most (SSOs) may be dampened down, some may continue for a while, increase gradually, and lead to system separation [8]–[10]. By using an autonomous voltage regulator in electrical power systems (EPS), stability can manage the generator's excitation (AVR). However, because the (EPS) is dynamically complex, it frequently deals with alterations in the operational environment and disruptions. A supplemental control signal in the excitation system to a generating unit can be utilized to improve dynamic performance, i.e., to provide quick damping to the power system. Power system stabilizers (PSSs) have been used extensively to reduce (SSOs) and enhance dynamic stability of electrical systems because they are affordable, straightforward, and quick to install (EPS). The most common (PSS) structure is a lead-lag type (phase compensator), whose gain and pole-zeros are established using linear control theory and a linearized dynamic model of (EPS) [10]–[12]. The power factor (PF) is one of the most important factors on the power system. PF and load are playing main role for effected on the control and stability power system. It is defined as the ratio of the actual power (active power in watts (W)) to the apparent power (in VA) flowing to the load in an (AC) system. Watts and (VA) are more frequently expressed in thousands as (KW and KVA). Low power factor results when (KW) is small in comparison to (KVA), that means the load absorb more reactive power (KVar) which occur at the inductive load. The ideal power factor is (unity PF), which occurs when the real and apparent powers are equal. Since the current and the voltage are in phase, there is no effective power, also known as reactive power, drawn into the circuit in this situation. But a low power factor results in a high current being drawn into the circuit. Therefore to keep the system in safety must be keep the power factor ($1 \geq PF \geq 0.8$) [13]–[15] have an innovative method for tuning a single machine infinite bus (SMIB) network's lead-lag (PSS), proportional-integral (PI), and proportional integral-derivative (PID) functions. In order to increase the stability of a multi-machine power system employing (PSS) in certain parameters, a unique design strategy is proposed in [16]. An improved technique for (PSS) tuning in multi-machine systems is proposed in [17]. This approach is based on the analysis of system participation factors and the pole placement method, while respecting the time domain behavior of the system following the application of a minor disturbance. In this paper was studied the main factors that reflectance on the response of steady-transient state as follows: section 2, showed the modeled of real case power system, Peerdawod gas power station which located in south of Iraq–Erbil (PPGS) as shown in block diagram model in Figure 1. The selection type inputs of (PSS) were proposed on section 3 with studied different situations of load conditions (light load at PF 60%, normal load at PF 80%, and heavy load at PF 95%). Section 4, discussed the simulation results.

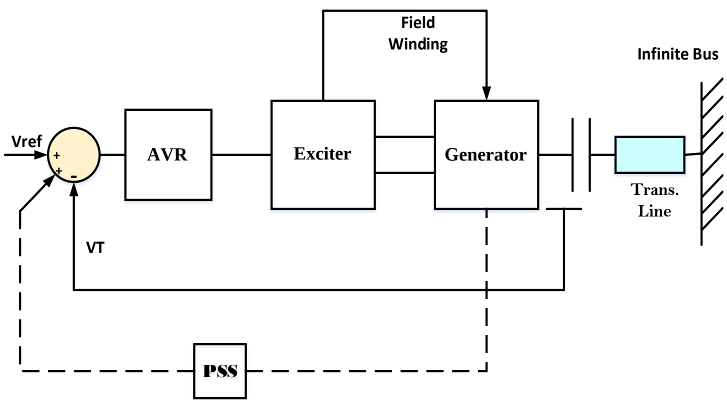

Figure 1. Power system model

2. POWER SYSTEM STATION

The Peerdawd gas power station (PPGS) is a real case study adopted in this paper. Located in the north of Iraq, the power station consists of ten units with a total power capacity of 1500 MW. Each unit is represented by a nonlinear machine model with a 2-axis representation (Xq and Xd) of the generator. The power station employs an excitation system of type EX2100, which includes a fully integrated digital lead/lag power system stabilizer (PSS2B). The PSS2B is based on the integral of accelerating power (P_{acc}) principle and is available for the EX2100 excitation system. The MATLAB/Simulink diagram in Figure 2 provides a visual representation of the system configuration.

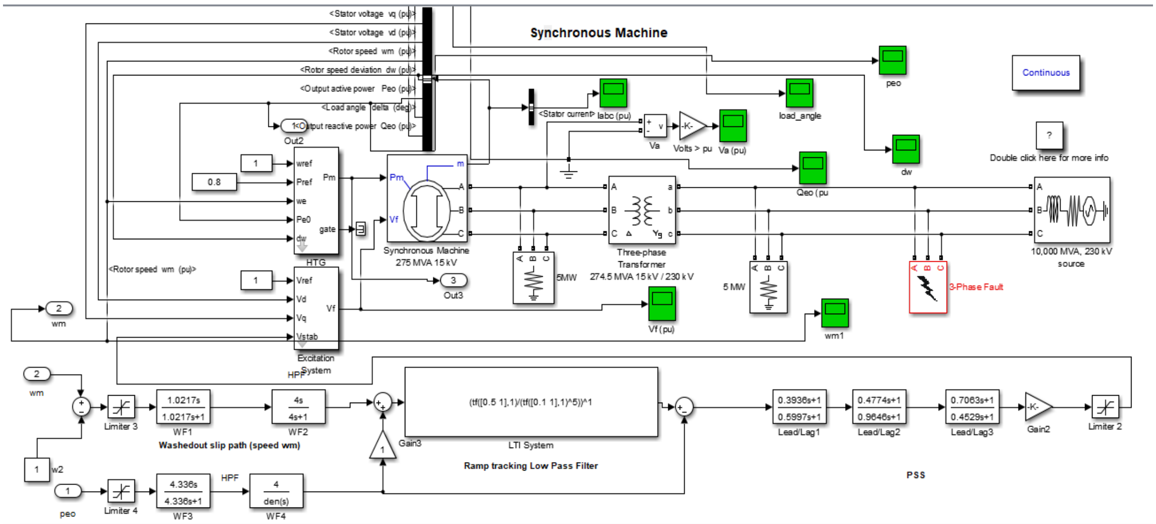

Figure 2. Model of a practical power system, generator, exciter, and PSS in MATLAB/Simulink

2.1. Synchronous generator model

The synchronous generator of Peerdawod gas power station (PPGS) is represented by sixth-order model [18], [19].

$$2H\Delta\dot{\omega} = P_m - P_e \tag{1}$$

$$\dot{\delta} = \Delta\omega \tag{2}$$

$$T'_{do}\dot{V}'_q = E_f - V'_q + I_d(X_d - X'_d) \tag{3}$$

$$T'_{qo}\dot{V}'_d = -V'_q + I_d(X_q - X'_q) \tag{4}$$

$$T''_{do}\dot{V}''_q = V'_q - V''_q + I_d(X'_d - X''_d) \tag{5}$$

$$T''_{qo}\dot{V}''_d = V'_d - V''_d + I_q(X'_q - X''_q) \tag{6}$$

2.2. The excitation system

The excitation system is one of the most crucial components of the synchronous generator's electric power system, because it is the source of electrical energy. Generators convert mechanical energy (typically from turbines) into electrical energy. Only when generator excitation exists is energy transformation possible. Generator output values such as voltage and reactive power are also determined by the generator's excitation. This means that controlling generator excitation also controls generator output energy, which affects the overall stability of the electric power system [20]. The terminal bus voltage (V_T) is measured by the excitation system, and it is compared to a desired reference voltage (V_{ref}). The automatic voltage regulator (AVR), which uses the error to drive a number of control circuits, determines the desired and actual signals by comparing them. The exciter, which could be a rotating alternator or a power-electronic rectifier, receives the output signal from the voltage regulator and supplies the field voltage to the rotor circuit of a synchronous generator. There are two main functions of an excitation system:

- In steady state, the voltage regulator sets a desirable value for the voltage at the generator bus terminals.

− The excitation control system supplies additional reactive power to the post-fault system in disturbance conditions (like short-circuit faults) to maintain the generator terminal voltage. This raises the synchronizing torque and enables the generator to keep synchronism, which increases the transient stability of the connected system [21].

The static excitation system in Peerdawod power gas station (EX2100) has high gain and fast response times, which aid to synchronizing torque stability and also reduce small signal stability (damping torque). The (PSS) provides a positive contribution to damping generator rotor angle swing, in range of the frequency of the power system. As shown in the linear block diagram of a signal machine connected to infinite bus power system. This diagram demonstrates the effect of excitation system on the damping of local mode machine oscillation. The generation is also provided by an automatic voltage regulator (AVR), as shown Figure 3 [22], [23].

$$G(s)_{Excitation} = \frac{1}{K}[G(s)_{PID} * G(s)_{Generator}] \tag{7}$$

$$G(s)_{Excitation} = \frac{1}{K}\left[\frac{K_D S^2 + K_P S + K_I}{S} * \frac{K_3}{T'_{do} K_3 S + 1}\right] \tag{8}$$

Where K and K3 are gains, T'_{do} is the time constants generator, and K_D, K_P, and K_i are the PID gains for the controller.

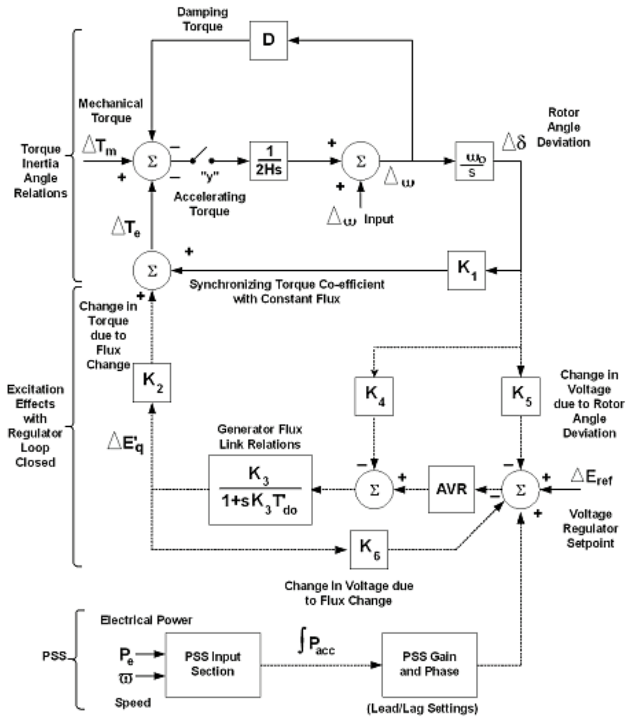

Figure 3. EX2100 excitation control power system stabilizer

2.3. Power system stabilizer

Rapid response excitation systems may destabilize power systems by introducing slightly attenuated electromechanical oscillation modes. To improve the damping of these modes, power system stabilizers (PSS) are used extensively. The purpose of a (PSS) is to add damping to the unit's characteristic electromechanical oscillations. This is achieved by modulating the excitation of the generator in such a way as to develop electrical torque components in phase with the rotor speed deviations. In this way, the (PSS) assists in improving the stability of small signals in power systems [24], [25]. The frequency range of interest for electromechanical oscillations typically falls within (0.1-3.0 Hz). The electromechanical oscillations might be further classified into three categories, namely, inter-area modes (0.1-0.8 Hz), local-machine modes (0.8-3.0 Hz), and inter-unit modes (1.5-3.0 Hz). The objective is to ensure that the (PSS) provides optimum improved damping for all electromechanical oscillations in the frequency range of interest. Two common oscillation patterns that can be readily solved using a (PSS) are: a) oscillation of a single generator or plant against rest of the power system, b) oscillation between a few generators close to each other as shown in Figure 4 [24], [26].

The paper focuses on the utilization of the modern power system stabilizer (PSS2B) which incorporates two input signals: electrical power and rotor speed. By combining these two signals, the PSS2B generates an equivalent speed signal that is directly proportional to the integral of accelerating power. Figure 5 provides a visual representation of this process. The PSS2B is a dual-input power system stabilizer that holds significant importance in improving the stability and performance of power systems. With its ability to utilize both electrical power and rotor speed signals, the PSS2B effectively monitors and controls the system's response to disturbances, ensuring stable operation [27].

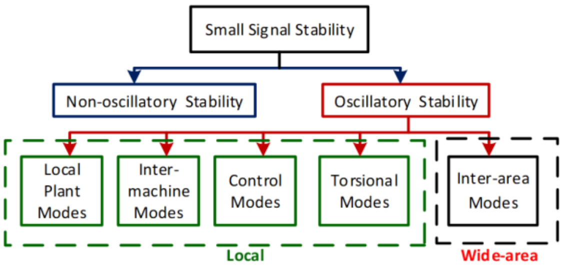

Figure 4. Electromechanical oscillations categories

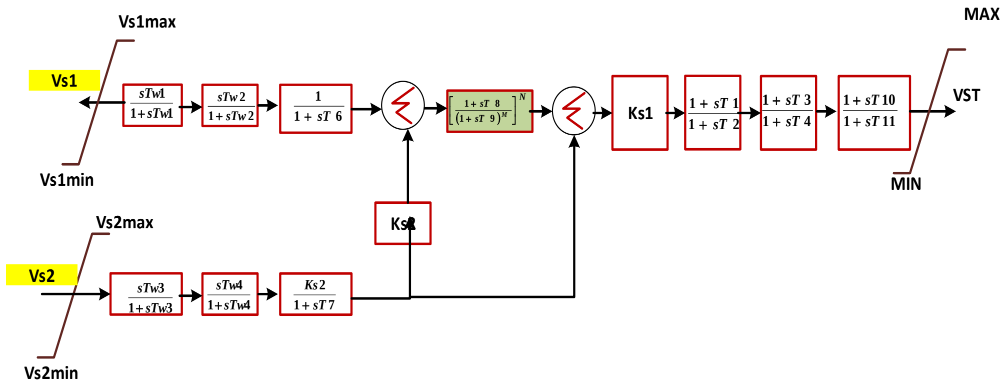

Figure 5. Power system stabilizer PSS2B model

The equivalent speed deviation is equal to the integral of accelerating power divided by inertia constant (M=2 H). Thus if the speed signal can be evaluated, a stabilizer can be formed based on it. In (PSS2B), mechanical power influences are regarded as really simple measurement from entirely electrical signals as shown in (9)-(17):

$$\Delta\omega_{eq} = \frac{1}{2H}\int(\Delta P_m - \Delta P_e)dt = \frac{1}{2H}\int P_{acc}\, dt \quad (9)$$

$$\Delta\omega_{eq} = \frac{1}{M}\int \Delta P_m dt - \int \Delta P_e\, dt = \frac{1}{M}\int P_{acc}\, dt \quad (10)$$

$$M\Delta\omega_{eq} = \int \Delta P_m dt - \int \Delta P_e\, dt = \int \Delta P_{acc}\, dt \quad (11)$$

from in (11),

$$M\Delta\omega_{eq} + \int \Delta P_e\, dt = \int \Delta P_m dt \quad (12)$$

substituting in (12) in (11) gives:

$$\int \Delta P_{acc}\, dt = -\int \Delta P_e dt + [M\Delta\omega_{eq} + \int \Delta P_e\, dt] \quad (13)$$

$$\frac{\Delta P_{acc}}{MS} = -\frac{\Delta P_e(s)}{MS} + G(s)[\frac{\Delta P_e(s)}{MS} + \Delta\omega_{eq}(s)] \quad (14)$$

where (P_m, P_e, and P_{acc}) are the mechanical, electrical, and accelerating powers of the generator respectively in per-unit, (M and H) are the inertia constant both in second, (ω_{eq}) is the equivalent angular speed in per-unit and (G(s)) is the transfer function of the low-pass filter. Thus, The integral of mechanical power is related to shaft speed and electrical power. There are two main parts on the (PSS2B): the filters (washing filter is the high pass filter at the input path "electrical power change (ΔP_e) and speed rotor deviation (Δw)" and mechanical power change passed through a low-pass filter to remove shaft torsional components), and stabilizing parts contain lead lag compensation, as shown in Figure 5 [24], [26]. The integral of the input accelerating power (P_{acc}) is the input to the stabilizing parts which contain two or three lead lag phase compensation, (PSS) gain (Ks1), and output limit function (VSTMAX and VSTMIN) as shown in Figure 6 [24].

$$G(s)_{PSS} = Kpss\left[\frac{1+sT1}{1+sT2} * \frac{1+sT3}{1+sT4} * \frac{1+sT10}{1+sT11}\right] \tag{15}$$

$$VST = G(s)_{PSS} * \frac{\Delta P_{acc}}{MS} \tag{16}$$

$$VST = Kpss\left[\frac{1+sT1}{1+sT2} * \frac{1+sT3}{1+sT4} * \frac{1+sT10}{1+sT11}\right] * \frac{\Delta P_{acc}}{MS} \tag{17}$$

Where, Kpss is the (PSS) gain in (pu), T1 is the first lead time constant in (sec), T2 is the First lag time constant in (sec), T3 is the Second lead time constant in (sec), T4 is the second lag time constant in (sec), T10 is the third lead time constant in (sec), T11 is the third lag time constant in (sec) and VST is the (PSS) output in (pu). 0.02≤T1, T2, T3≤2 and 0.02≤T4≤6.

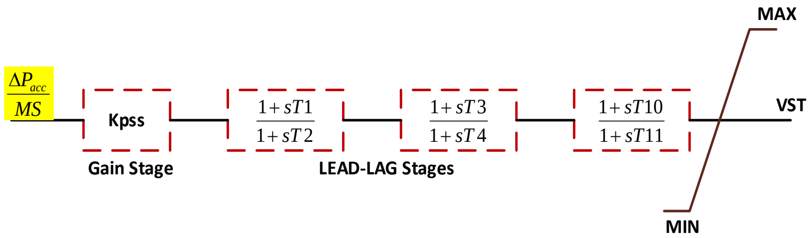

Figure 6. Stabilizing parts of PSS of PSS2B model

3. STEADY-TRANSIENT STATE RESPONSES

MATLAB/Simulink has been used to run the modelled of the real case study, during three situations of loads, (light load at p.f 60%, normal load at p.f 80% and heavy load at p.f 95%). Within these cases, will suggest three options: i) Without (PSS) on the system (NO PSS), ii) With conventional PSS (CPSS), which has only one input the active power, and iii) The modern PSS (PSS2B), which has two inputs the active power input (P_e) and the rotor speed deviation input (dw).

Then noted the effected of the load case to the (PSS) performance through the response of the four power system parameters (voltage terminal (vf), rotor speed deviation (dw), output active power (P_{eo}), and reactive power (Q_{eo}) in pu). Modelled of power station was evaluated with free disturbance and under fault (three phase fault 2 s) as shown Figures 7 to 30.

3.1. Performance of PPGS (NO fault and fault) at light load

Figures 7 to 14 demonstrate the response of various parameters at Peerdawd gas power station (PPGS) under light load conditions with a power factor of 60%. The figures depict the behavior of voltage terminal (Vf), rotor speed deviation (dw), output active power (P_{eo}), and reactive power (Q_{eo}) in per unit (pu) during both fault and no-fault scenarios. These figures provide insights into the dynamic response of the power system under different conditions, helping to analyze the performance and stability of the PPGS during light load operation with a power factor of 60%.

Based on the provided information, Figures 7-14 illustrate the variations of different parameters (Vf, dw, P_{eo}, and Q_{eo}) in the power system under normal and faulty conditions at light load, with a power factor of 60%. The analysis reveals that the presence of the power system stabilizer (PSS) has a detrimental effect on the power system parameters during both steady state and transient state. In these scenarios, the system takes longer to return to stability when the PSS is active compared to when it is not present. This indicates that the PSS does not have a positive influence on the system's behavior, especially under light load conditions where the predominant load is inductive. The inductive load results in the power system absorbing more reactive power during transient periods. Based on these findings, it can be concluded that the PSS does not offer significant benefits in improving the behavior or stability of the power system during light load conditions.

3.2. Performance of PPGS (NO fault and fault) at normal load

When the normal case occur, Based on the information you provided, it seems that the refers to a specific type of power system stabilizer (PSS2B), which is a device used in power systems to enhance stability and dampen oscillations. It is mentioned that the (PSS2B) performs better during fault conditions compared to normal cases. During a fault, the (PSS2B) is able to detect the fault directly and quickly restore the system to stability within a short period of time. It also helps in smoothing out oscillations during the transient duration before and after the fault. The (PSS2B) is more active during fault conditions than during steady-state conditions and the transient duration before the fault. It is also mentioned that the power system relies solely on the excitation control system, which means that the power system stabilizer (PSS) has more activity during disturbances. Figures 15 to 22 likely illustrate the behavior and performance of the (PSS2B) and its activity during different operating conditions, including fault conditions. Overall, the (PSS2B) appears to be an effective device for detecting faults, restoring stability, and dampening oscillations in power systems.

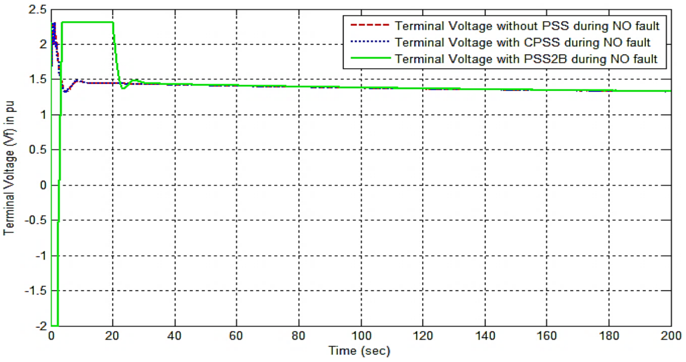

Figure 7. The (Vf) in pu during NO fault at light load

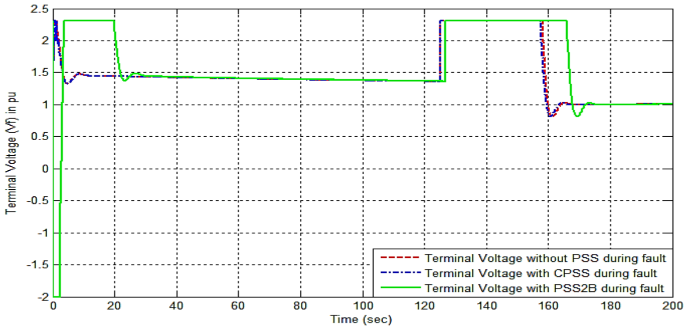

Figure 8. The (Vf) in pu during fault at light load

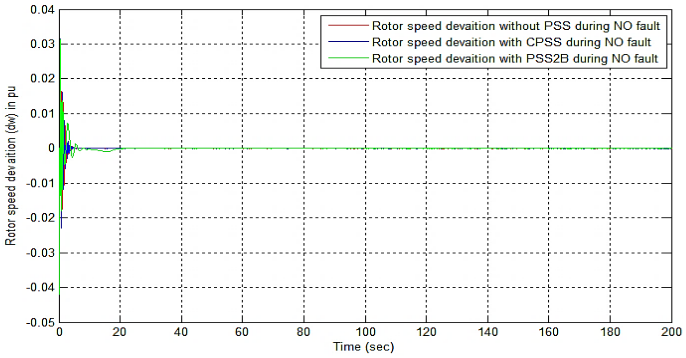

Figure 9. The (dw) in pu during NO fault at light load

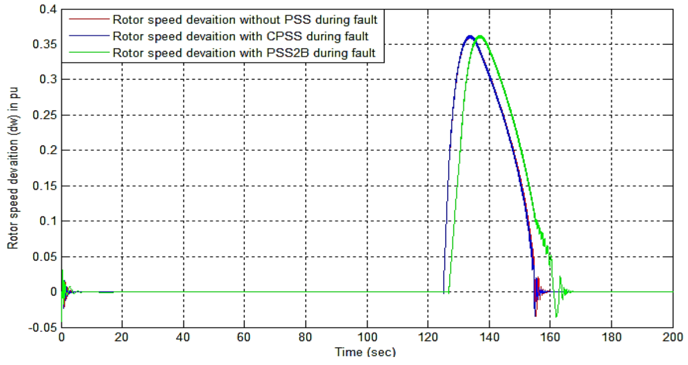

Figure 10. The (dw) in pu during fault at light load

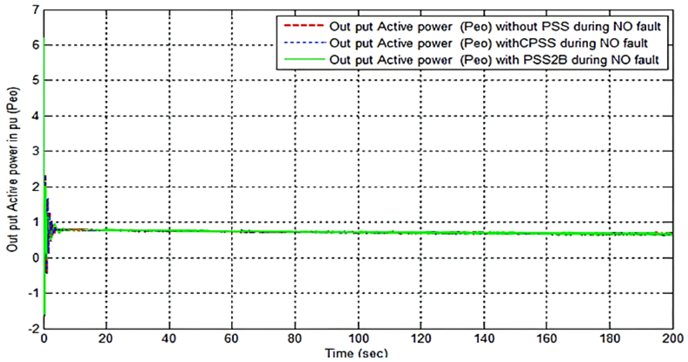

Figure 11. The (P_{eo}) in pu during NO fault at light load

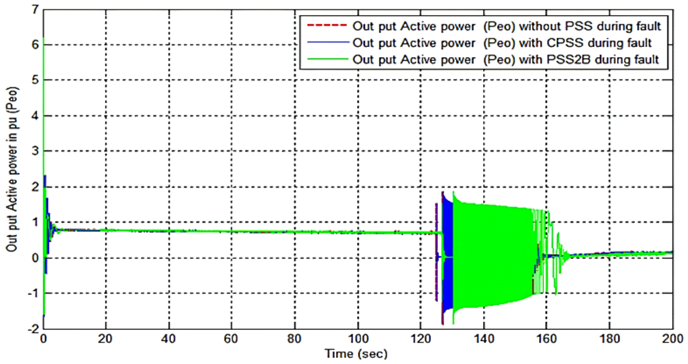

Figure 12. The (P_{eo}) in pu during fault at light load

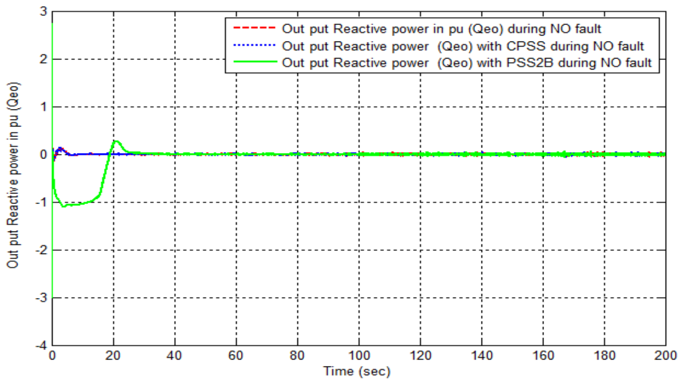

Figure 13. The (Q_{eo}) in pu during NO fault at light load

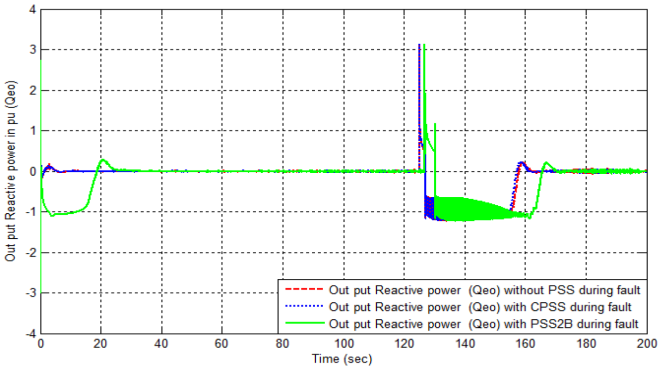

Figure 14. The (Q_{eo}) in pu during fault at light load

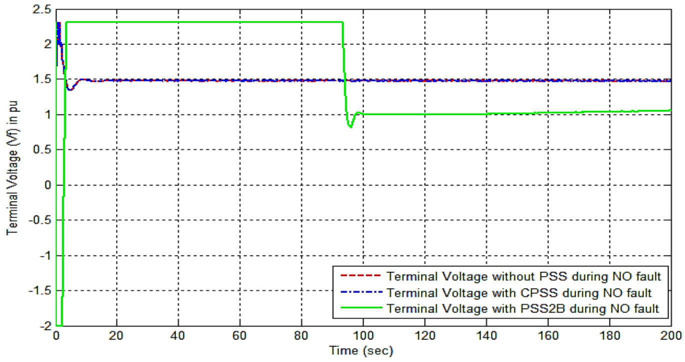

Figure 15. The (Vf) in pu during NO fault at normal load

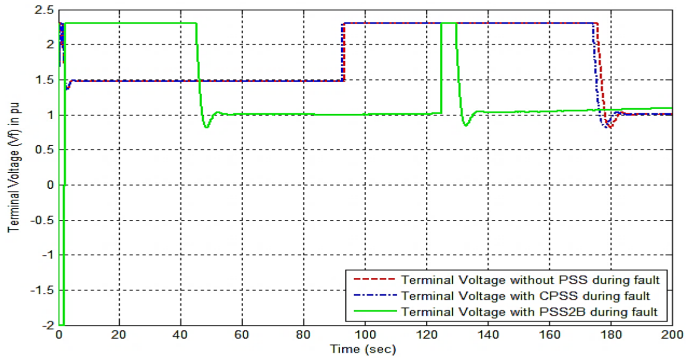

Figure 16. The (Vf) in pu during fault at normal load

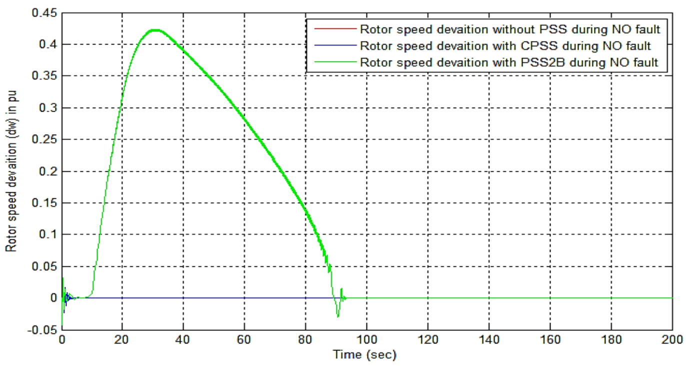

Figure 17. The (dw) in pu during NO fault at normal load

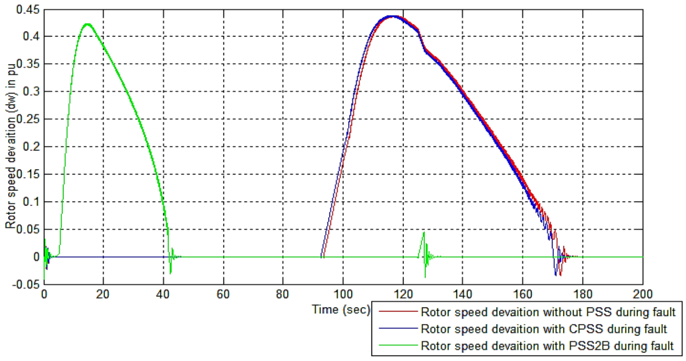

Figure 18. The (dw) in pu during fault at normal load

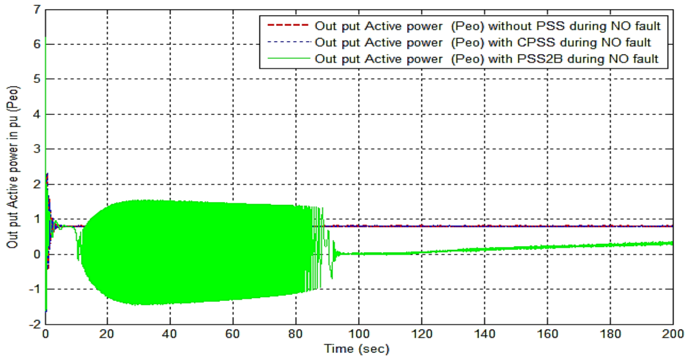

Figure 19. The (P_{eo}) in pu during NO fault at normal load

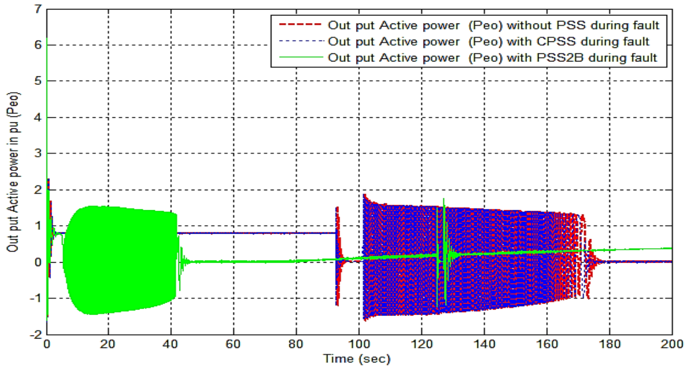

Figure 20. The (P_{eo}) in pu during fault at normal load

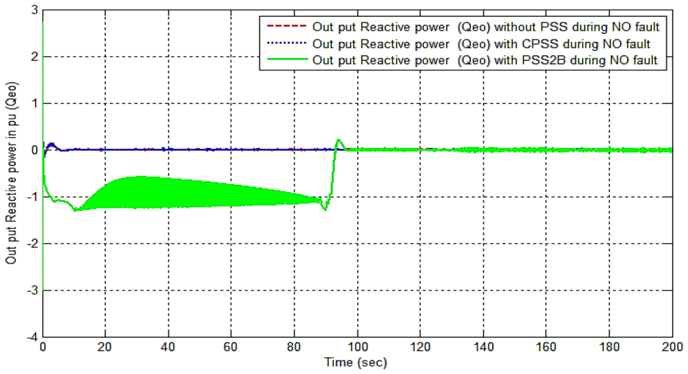

Figure 21. The (Q_{eo}) in pu during NO fault at normal load

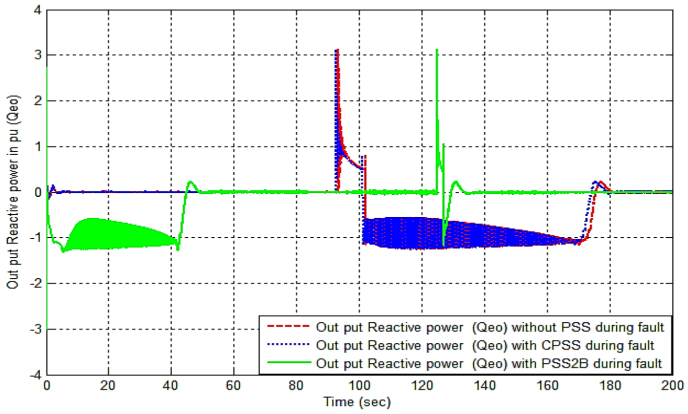

Figure 22. The (Q_{eo}) in pu during fault at normal load

3.3. Performance of PPGS (NO fault and fault) at heavy load

At heavy load conditions, the presence of the power system stabilizer (PSS2B) leads to an overcompensation of the active power system (P_{eo}), resulting in increased oscillations during the transient period before a fault occurs. However, the PSS2B effectively reduces the drop in reactive power during the fault. During the fault condition, the PSS2B helps to smooth out the oscillations, as demonstrated in Figures 23-30. These figures provide a visual representation of the system's response and highlight the role of the PSS2B in mitigating oscillations and maintaining stability, particularly during heavy load conditions.

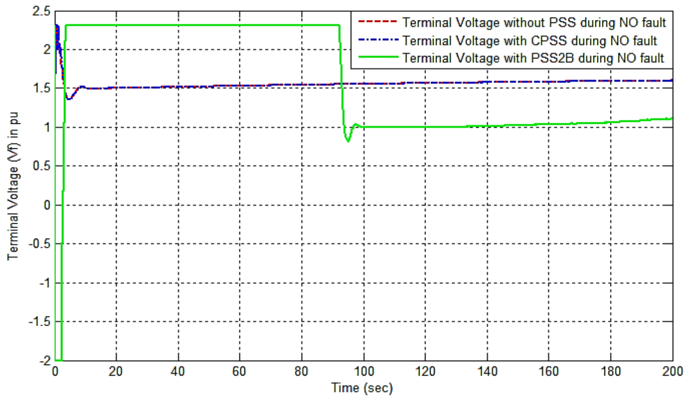

Figure 23. The (Vf) in pu during NO fault at heavy load

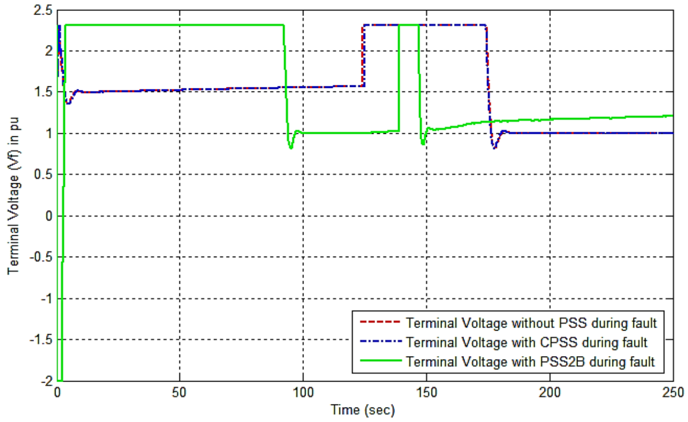

Figure 24. The (Vf) in pu during fault at heavy load

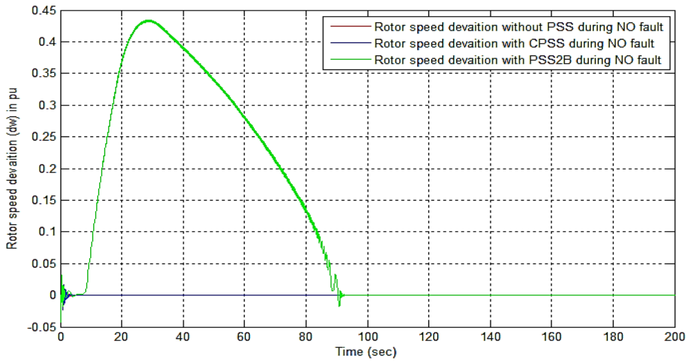

Figure 25. The (dw) in pu during NO fault at heavy load

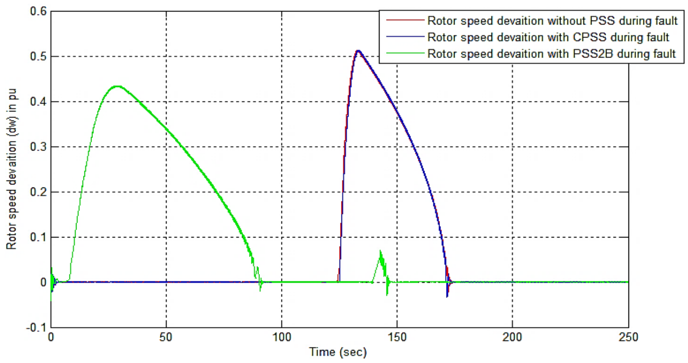

Figure 26. The (dw) in pu during fault at heavy load

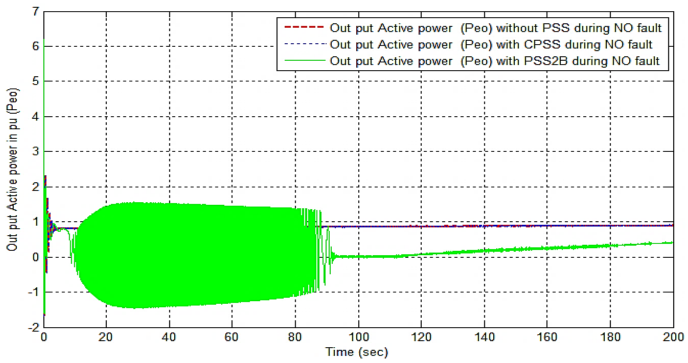

Figure 27. The (P_{eo}) in pu during NO fault at heavy load

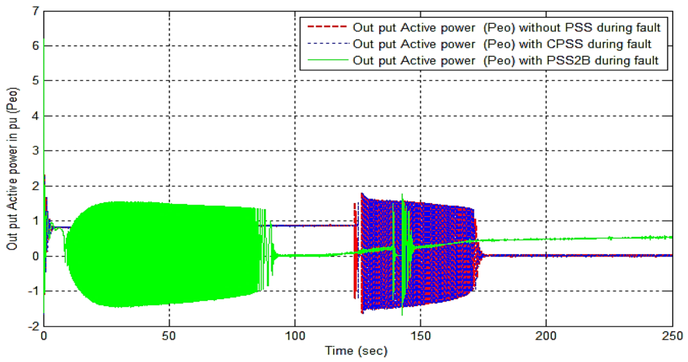

Figure 28. The (P_{eo}) in pu during fault at heavy load

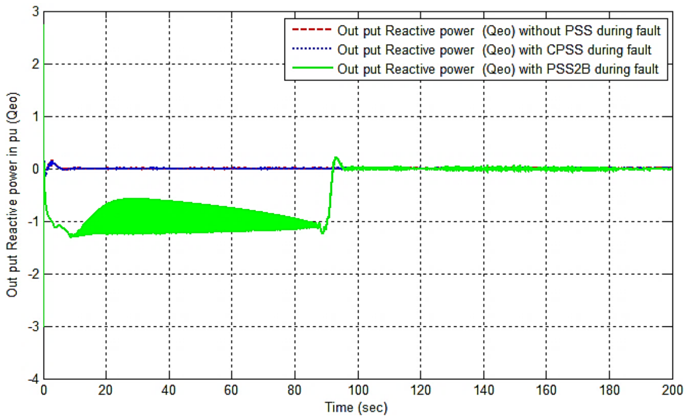

Figure 29. The (Q_{eo}) in pu during NO fault at heavy load

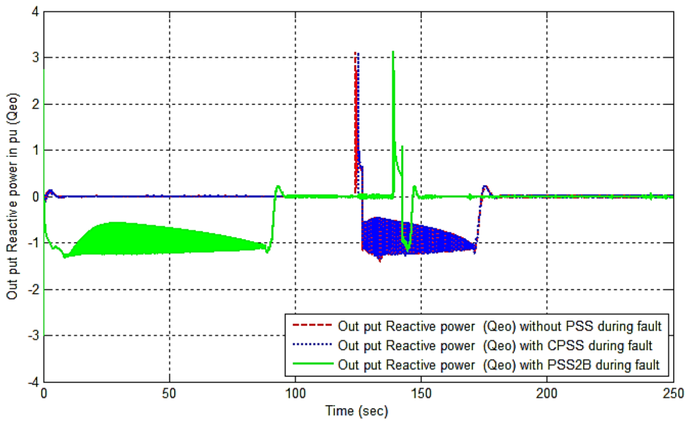

Figure 30. The (Q_{eo}) in pu during fault at heavy load

4. CONCLUSION

The real case study conducted on the Peerdawod Gas Power Station yielded significant findings in both steady state and transient state conditions. Firstly, it was observed that the power system stabilizer (PSS) with two inputs, namely active power (Peo), and rotor speed deviation (dw), known as PSS2B, outperformed the PSS with only one input, Peo (referred to as CPSS). Secondly, while the PSS is essential during high disturbances, it can have adverse effects during steady state conditions, normal load fluctuations, and the initial transient period. In such cases, relying solely on the excitation control system proves to be sufficient.

The type of load was found to have a substantial impact on the performance of the PSS in both steady state and transient states. Specifically, for heavy loads with a power factor (PF) of 95%, the PSS2B caused overvoltage after a fault. On the other hand, during light loads with a P.F of 60%, voltage drops were observed during the transient period before and during the fault. However, during normal loads with a power factor of (PF 75-80%), the PSS2B demonstrated excellent performance by swiftly restoring system stability during high fault conditions, preventing system collapse within a short timeframe.

The parameters of the PSS in the Peerdawod gas power station (PPGS) are specifically set for normal loads (PF 75-80%) during high disturbance faults. It is essential to use an intelligent program to select the desired parameter values for the PSS based on the variation of load cases. Tuning the parameters of the PSS is crucial and should be done considering the load type and other relevant circumstances within the power system.

At PPGS, the parameter values (T1, T2, T3, T4, T10, T11) of the PSS2B are established for normal load conditions (PF 75-80%) during high disturbance faults. Notably, the PSS2B remains inactive during light load cases, leading to the system absorbing more reactive power before and during faults. Therefore, it is necessary to fine-tune these parameters based on the prevailing power system conditions. In conclusion, the case study highlights the importance of selecting an appropriate PSS configuration, considering load variations, and tuning the parameters accordingly. These factors play a vital role in ensuring optimal performance and system stability, as observed in the scenario of the Peerdawod gas power station.

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