OPTIMIZING GRID STABILITY: POWER SYSTEM STABILIZER TUNING WITH GENETIC ALGORITHMS

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الملخص

يعد ضمان استقرار نظام الطاقة الكهربائية أمرًا بالغ الأهمية لتشغيله الموثوق والفعال. تركز هذه الورقة على المهمة الحاسمة المتمثلة في ضبط متغيرات مثبت نظام الطاقة (PSS) للمولد داخل نظام الطاقة. الهدف الأساسي هو صياغة عملية الضبط هذه كمشكلة تحسين، مع الاستفادة من قدرات الخوارزميات الجينية (GA) باعتبارها طريقة التحسين المختارة. تهدف الدراسة إلى إثبات فعالية GA في اختيار المتغيرات المثلى لمثبت نظام الطاقة. وينصب التركيز على تخفيف التذبذبات في خط الطاقة، مع التأكيد بشكل خاص على فعاليتها في ظل ظروف الأعطال. من خلال عمليات المحاكاة واسعة النطاق، تؤكد النتائج على قدرة الخوارزميات الجينية على العمل كطريقة تحسين قوية، واختيار المتغيرات التي تعزز أداء مثبت نظام الطاقة بشكل فعال. وتساهم النتائج برؤى قيمة حول استخدام GA لتحسين متغيرات PSS، وإظهار قدرتها على تحسين استقرار الشبكة، خاصة في مواجهة التذبذبات وسيناريوهات الأخطاء.

ABSTRACT

Ensuring the stability of an electrical power system is paramount for its reliable and efficient operation. This paper focuses on the crucial task of tuning Power System Stabilizer (PSS) parameters for a generator within the power system. The primary objective is to formulate this tuning process as an optimization problem, leveraging the capabilities of Genetic Algorithms (GA) as the chosen optimization method. By presenting the paper as an optimization problem, the study aims to demonstrate the efficacy of GA in selecting optimal parameters for the power system stabilizer. The focus is on dampening oscillations in the power line, particularly emphasizing its effectiveness under fault conditions. Through extensive simulations, the results underscore the ability of Genetic Algorithms to serve as a robust optimization method, effectively choosing parameters that enhance the power system stabilizer's performance. The findings contribute valuable insights into utilizing GA for optimizing PSS parameters, showcasing its potential to improve grid stability, especially in the face of oscillations and fault scenarios.

KEYWORDS: Power System Stabilizer; Generator; Optimization; Genetic Algorithms.

INTRODUCTION

This historical overview highlights the evolution of power system stability concerns, starting with early challenges related to spontaneous low-frequency oscillations (LFOs). In the initial stages, the focus was on addressing these oscillations through solutions like damper windings on generator rotors and turbines [1]. This approach proved satisfactory, leading to a period where stability concerns were somewhat disregarded. However, as power systems approached their stability limits and synchronous torque weaknesses among generators became apparent, the industry recognized the need for renewed attention to stability problems. Although Automatic Voltage Regulators (AVRs) were introduced to enhance steady-state stability, the emphasis shifted towards addressing transient stability issues, particularly as power systems operated closer to their limits. The emergence of large, interconnected power systems introduced additional challenges, including the transfer of substantial power over extremely long transmission lines [2]. To mitigate the inhibiting effects of low-frequency oscillations, supplementary controllers were integrated into the control loop. One such advancement was the introduction of Power System Stabilizers (PSSs), working in tandem with AVRs on generators. This combination provided a means to effectively dampen low-frequency oscillations, ensuring improved power system stability, especially during transient conditions. As power systems continued to evolve and face new challenges, the integration of PSSs became a crucial component in maintaining the reliability and security of power grids.

Power System Stabilizer (PSS)

This description provides insights into the fundamental role of power system stabilizers (PSS) in mitigating electromechanical oscillations within power systems. By manipulating the generator's excitation system, PSS introduces a component of electrical torque proportional to speed change, effectively augmenting the damping torque. The success of a stabilizer hinges on its ability to generate damping torque across a broad spectrum of input frequencies. The effectiveness of a PSS is highlighted by its capability to produce damping torque over a wide frequency range [3]. This broad applicability is crucial, especially considering the dynamic nature of power systems where oscillatory modes can change due to alterations in the system's configuration. The distinction between local and inter-area modes underscores the complexity of the stabilizer's mechanism, tailored to address different modes of oscillation. An essential characteristic of PSS is its cost-effectiveness as an electromechanical damping control. The inherent power amplification within the generator obviates the need for additional external power sources, making PSS a practical and efficient solution. The widespread adoption of PSS in generators over the past two decades reflects its proven effectiveness in enhancing power system stability by providing consistent and adaptable damping control.

STABILITY ISSUES AND THE PSS

Traditionally, the excitation system plays a crucial role in regulating the generated voltage, maintaining system voltage stability. Automatic Voltage Regulators (AVRs) have been widely employed for effective voltage regulation through excitation control. However, the extensive use of AVRs has been associated with detrimental effects on dynamic stability, particularly in terms of low-frequency oscillations (typically in the range of 0.2 to 3 Hz). These persistent low-frequency oscillations can significantly impact the dynamic stability and steady-state stability of the power system, potentially affecting the system's power transfer capabilities over an extended period. To address this challenge, Power System Stabilizers (PSS) were developed as a means to enhance stability by dampening these oscillations through modulation of the excitation system. The fundamental role of PSS is to apply a signal to the excitation system, introducing damping torque that aligns with the rotor oscillations. This modulation of the excitation system provides an additional layer of control, supplementing stability to the power system. By strategically applying damping torque in phase with the rotor oscillations, PSS effectively counters the adverse effects of low-frequency oscillations, contributing to improved overall system stability and performance [4].

DESIGN CONSIDERATIONS

While the primary objective of Power System Stabilizers (PSS) is to dampen oscillations, careful consideration must be given to its potential impact on power system transient stability. The regulation of the generator field voltage by PSS to achieve oscillation damping can result in a swing of Volt-Ampere Reactive (VAR) output, introducing complexities that require thoughtful design considerations. One critical aspect is the careful selection of PSS gain to ensure an acceptable resultant gain margin for the Volt/VAR swing. To mitigate the swing of VAR output, adjustments to the time constant of the Wash-Out Filter can be made, allowing for frequency shaping of the input signal. This design consideration is vital in maintaining stability while achieving the intended damping effect. Additionally, special attention is needed during loading/unloading or in cases of loss of generation, where large fluctuations in frequency and speed may impact the system through the PSS, potentially driving the system towards instability. To address this, modified limit logic can be implemented, minimizing these limits while ensuring effective damping action of PSS for all other system events. Furthermore, the interaction of PSS with other controls, whether part of the excitation system or external systems such as High Voltage Direct Current (HVDC), Static Var Compensator (SVC), Thyristor-Controlled Series Capacitor (TCSC), and Flexible AC Transmission Systems (FACTS), needs thorough examination. This consideration ensures that the integration of PSS aligns harmoniously with other control mechanisms within the power system, avoiding conflicts and optimizing overall stability [5].

THE CONNECTION OF PSS

The holistic representation of a generator or alternator within a power system involves the integration of Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) controllers, as depicted in Figure (1). This comprehensive structure encompasses essential control parameters that define the machine's behaviour and performance in the power system. Mechanical Torque (Cmech): Represents the mechanical input to the generator, influencing its rotational motion and power generation. Mechanical Power (Pmech): Signifies the power produced by the mechanical input to the generator, a crucial parameter in understanding the generator's energy conversion process. Speed (W): Reflects the rotational speed of the generator rotor, a pivotal factor in determining the frequency of the electrical output. Excitation Voltage (Uexc): Denotes the voltage applied to the generator's field winding by the excitation system, playing a vital role in controlling the generator's terminal voltage. Electrical Power (Pelec):

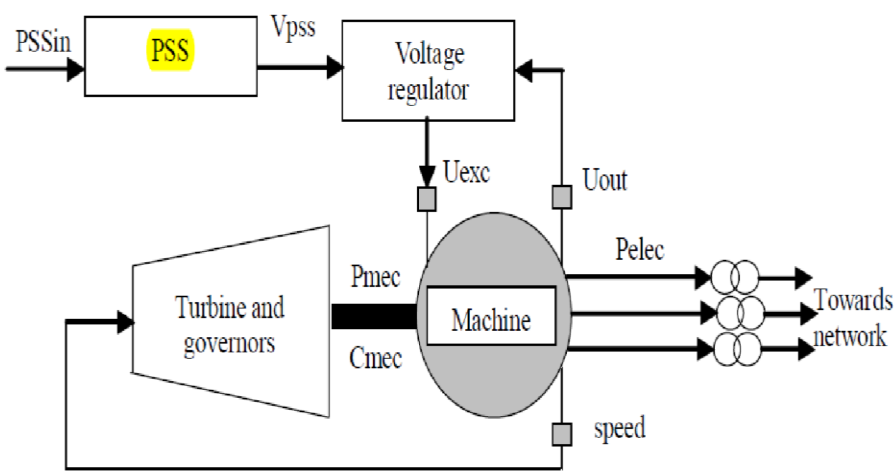

Figure 1: Overall structure of a machine connected to the network.

Represents the electrical power output of the generator, indicating the amount of power delivered to the electrical grid. Output Voltage (Uout): Signifies the voltage at the generator's terminals, a critical parameter in maintaining the stability and reliability of the connected power system. Figure (1) illustrates the interconnected relationships between the generator/alternator, AVR, and PSS controllers, emphasizing the collaborative influence of these components on the specified control parameters. Understanding and optimizing the connection of PSS within this intricate framework contribute to the effective control and stability of the power system, ensuring reliable and efficient operation. The coordination of these control parameters facilitates the seamless integration of generators into the larger electrical network.

THE BLOCK DIAGRAM OF PSS

The block diagram of the Power System Stabilizer (PSS) in Figure (2) is structured with five main blocks, each serving a specific function in enhancing the stability of the power system. The individual blocks and their roles are detailed as follows: Sensor: The sensor block captures relevant signals from the power system, providing input to the PSS. This could include speed or frequency signals that reflect the dynamic behaviour of the synchronous machine. PSS Gain (K): The PSS gain, denoted as 'K,' plays a pivotal role in determining the amount of damping introduced by the stabilizer. It influences the overall effectiveness of the PSS in responding to oscillations and stabilizing the power system. Washout Circuit: The washout circuit serves as a high-pass filter, eliminating low frequencies present in the signal. This ensures that the PSS responds primarily to speed changes, filtering out undesired low-frequency components. Compensator (Lag/Lead) Controller: The compensator block represents a simple lag/lead controller. It contributes to the phase compensation system, addressing phase lags between the excitation voltage and the electrical torque of the synchronous machine. This component helps optimize the overall response of the PSS. Limiter: The limiter block sets bound on the output signal, preventing it from exceeding certain predefined limits. This ensures that the PSS operates within specified constraints, enhancing its reliability and preventing undesirable system behaviour. The interaction and coordination of these blocks within the PSS block diagram illustrate a systematic approach to enhancing power system stability. Through the careful design and tuning of each block, the PSS can effectively dampen oscillations and contribute to the overall stability and reliability of the power system.

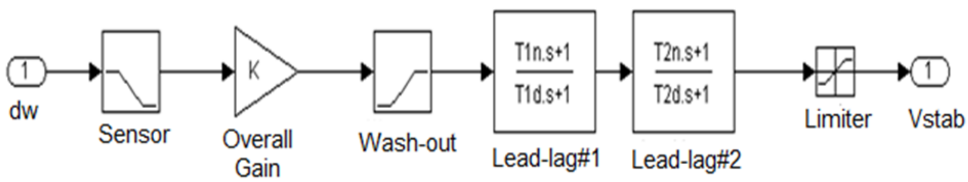

Figure 2: Block diagram of power system stabilizer.

GENETIC ALGORITHM (GA)

The Genetic Algorithm (GA) is a powerful optimization technique inspired by the process of natural selection and evolution. It has found applications in various fields, including engineering, computer science, finance, and biology. Here's a breakdown of the key components and characteristics of genetic algorithms. Population: The genetic algorithm begins with a population of potential solutions, represented as individuals or chromosomes. Each individual in the population corresponds to a potential solution to the optimization problem. Encoding: The solutions are encoded into a format that the algorithm can manipulate. This encoding could be binary, integer, or any other representation depending on the nature of the problem. Selection: Individuals from the current population are selected to act as parents for the next generation. The probability of selection is usually proportional to the individual's fitness, which is determined by the objective function. Crossover (Recombination): Crossover involves taking two parent solutions and combining their genetic information to create new offspring. This mimics the process of genetic recombination in biology. Mutation: Random changes are introduced to some individuals in the population to explore new regions of the solution space. This introduces diversity into the population and helps avoid convergence to local optima. Evaluation: The fitness of each individual in the population is evaluated based on the objective function of the optimization problem. The objective function is the function that you want to optimize (minimize or maximize). This function takes a candidate solution as input and produces a scalar evaluation of its fitness. Its guides the algorithm toward finding better solutions. Termination: The algorithm repeats the selection, crossover, mutation, and evaluation steps for multiple generations. Termination conditions, such as reaching a specified number of generations or achieving a satisfactory solution, determine when the algorithm stops. Applications in Optimization: Genetic algorithms are particularly well-suited for optimization problems with complex and nonlinear objective functions, discontinuities, or non-differentiability. They are versatile and have been successfully applied in various domains. Controller Tuning and power System Stability: In the context of controller tuning for different operating conditions or power system stability via Power System Stabilizers (PSS), genetic algorithms offer an effective approach. They can optimize parameters to enhance system performance. Independence of Performance Indices: Genetic algorithms are not dependent on the complexity of performance indices. They require only the specification of the objective function and bounds on the optimized parameters, making them applicable to a wide range of problems. Bounds are constraints on the possible values that the variables in the solution can take. These constraints define the search space for the GA [6]. In summary, genetic algorithms provide a flexible and robust approach to optimization, making them valuable for solving problems that may be challenging for traditional optimization algorithms. They have been successfully utilized in diverse fields, showcasing their adaptability and effectiveness in finding optimal solutions.

Model of two-machine transmission system with power system stabilizers (PSS) using Matlab: Circuit description:

A 1000 MW hydraulic generation plant (machine M1) is connected to a load centre of 500 kV through a long 700 km transmission line. The load centre is modelled by a 5000 MW resistive load as shown in Figure (3). The load is fed by the remote 1000 MW plant and a local generation of 5000 MW (machine M2) [7]. The system has been initialized so that the line carries 950 MW. The two machines are equipped with a Hydraulic Turbine and Governor (HTG), Excitation system and Power System Stabilizer (PSS). These blocks are located in the two 'Turbine and Regulator' subsystems.

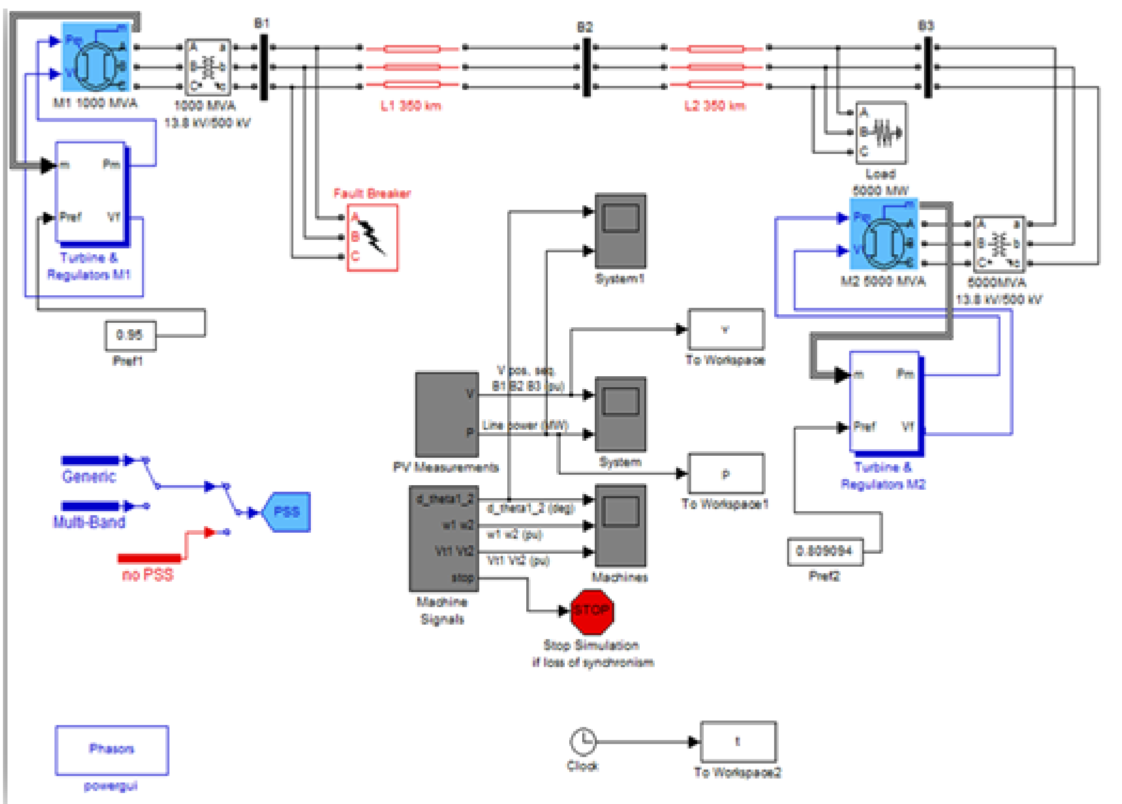

Figure 3: Two-machine transmission system with power system stabilizers (PSS)

Connection of PSS with excitation system: -

The Generic Power System Stabilizer (PSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. The output signal of the PSS is used as an additional input (vstab) to the excitation system block [8]. The PSS input signal its acceleration power (difference between the mechanical power and the electrical power, Pa=Pm-Peo) Figure (4) illustrates the connections between the PSS blocks and the corresponding Excitation System blocks for both machines in the two-machine transmission system. Adjust the parameters to fit your specific PSS and Excitation System models and simulate the behaviour of the system.

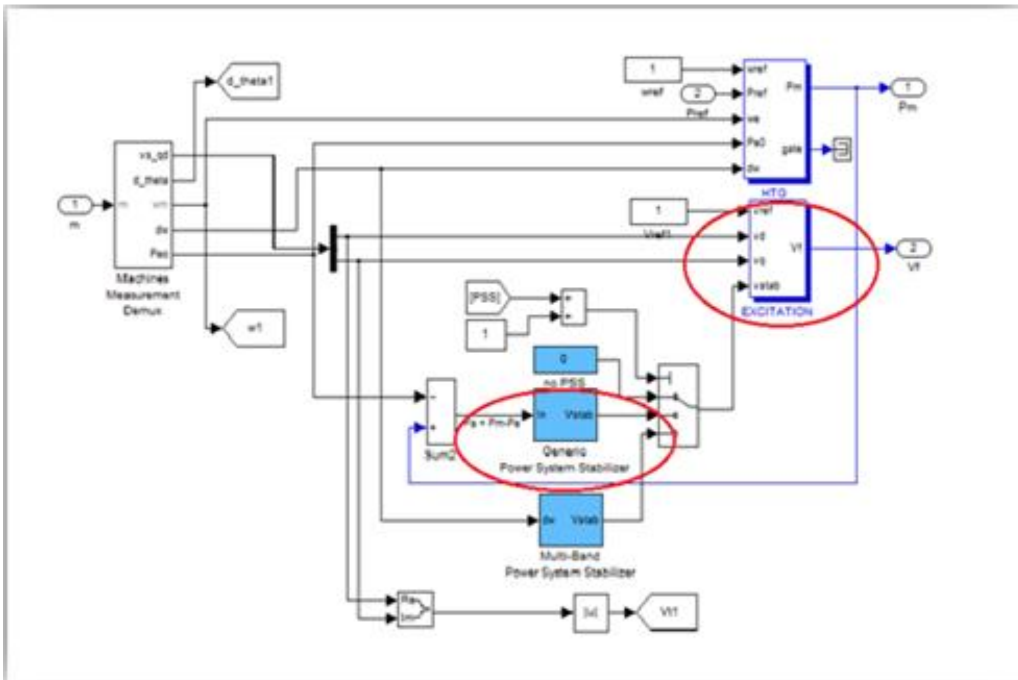

Figure 4: Power system stabilizer with excitation system.

Simulation model and Results

Case1

In this case tuning the (PSS) by controlling three of its parameters using genetic algorithm (GA) as shown in Figure (5), to obtain a short time constant that needed by the PSS to damp out oscillations that caused by a single line to ground fault that can have strong effect on power system transient stability.

The three parameters that we controlled are:

1) Sensor time constant [ST].
2) Gain [K].
3) Lead-lag #1 time constants: [T1n].

This case consists of three parts, the inertia constant (H) will be change in each part, as shown in Figure (6).

The machine load angle at which the fault is cleared depends mainly on the inertia constant. When the inertia constant increases, the load angle at which the fault cleared decreases. So, the higher the value of inertia constant the more stable the generator will be. It can be understood that the generator requires more acceleration energy to advance the rotor if the value of the inertia constant is small.

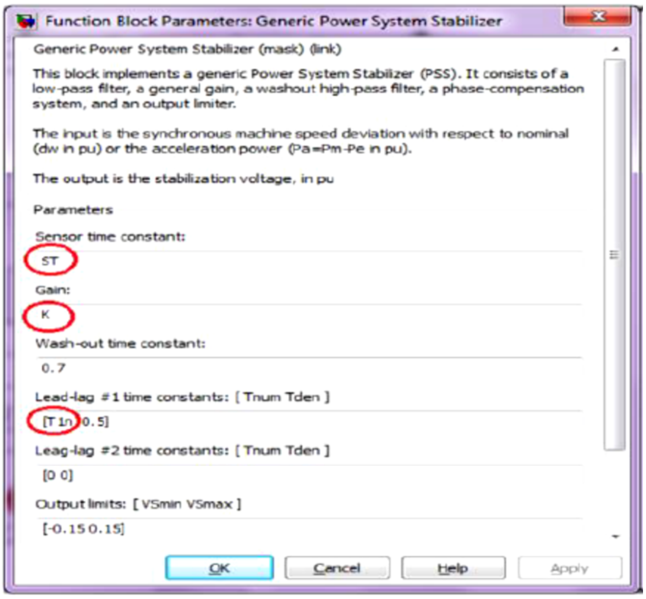

Figure 5: Function Block Parameters: Generic Power System Stabilizer

By implementing a genetic algorithm with careful consideration of the mentioned factors, you can effectively tune PSS parameters to enhance the transient stability of the power system under various operating conditions.

Part one

In this part the inertia constant (H) will be fix at 3, and will see the effect of the PSS on the oscillations of the power system, when changing its parameters with new one that has been tuned by using (GA).

When the time of fault = 100ms: -

Without using GA:

When we used the parameters that exists in the Matlab (S_T=15e-3), (K=2), (T_1n=60e-3), the results of the line power and delta 1-2 are shown in Figures (7 and 8). In Figure (7) the fault started at 5.1s and the oscillations were damped at 8s so the time constant is 2.9s.

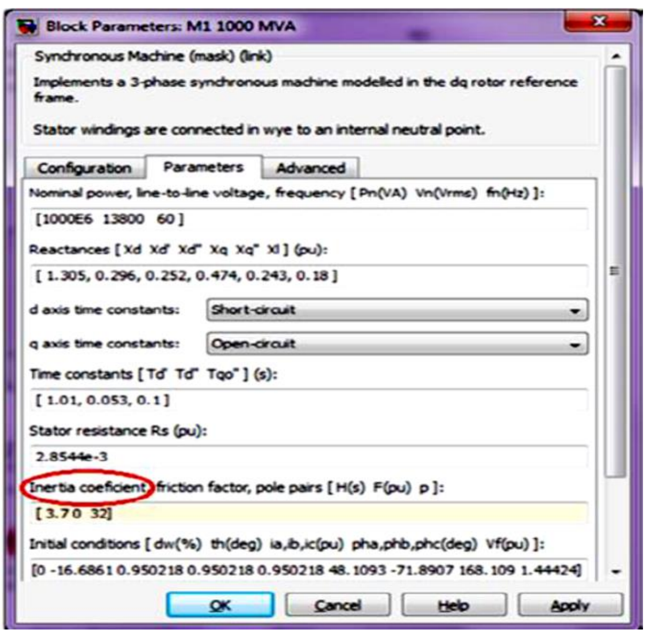

Figure 6: Block Parameters of machine M1

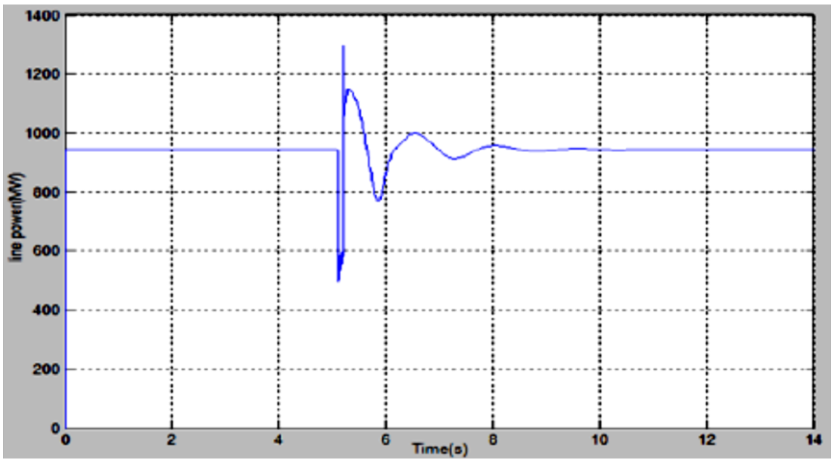

Figure 7: The line power (MW) verses time (s)

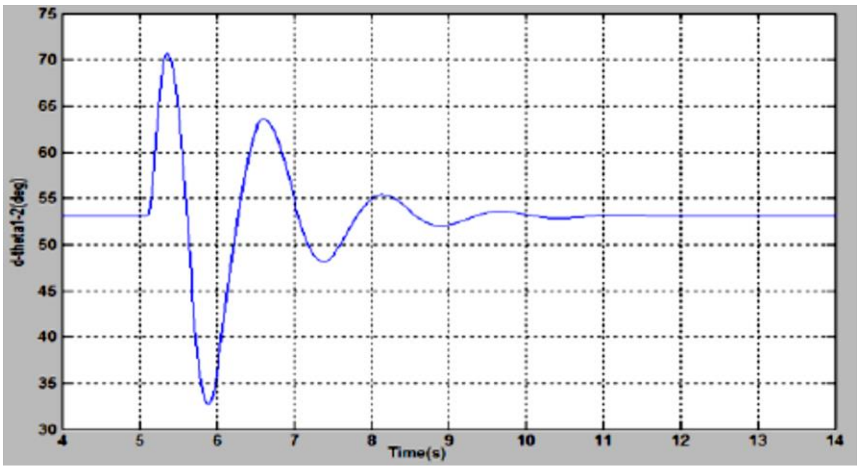

Figure 8: Delta 1-2 (degree) verses time (s)

With using GA:

When we used the parameters that the GA found (S_T=0.867e-2), (K=2.93), (T_1n=0.233e-1), the results of the line power and delta 1-2 (degree) are shown in Figure (9) and Figure (10). In Figure (9) the fault started at 5.1s and the oscillations were damped at 7.1s so the time constant is 2s. Compared the results noted that the oscillations and the time constant reduced when the PSS tuned by using (GA) as shown in Figure (11) and Figure (12).

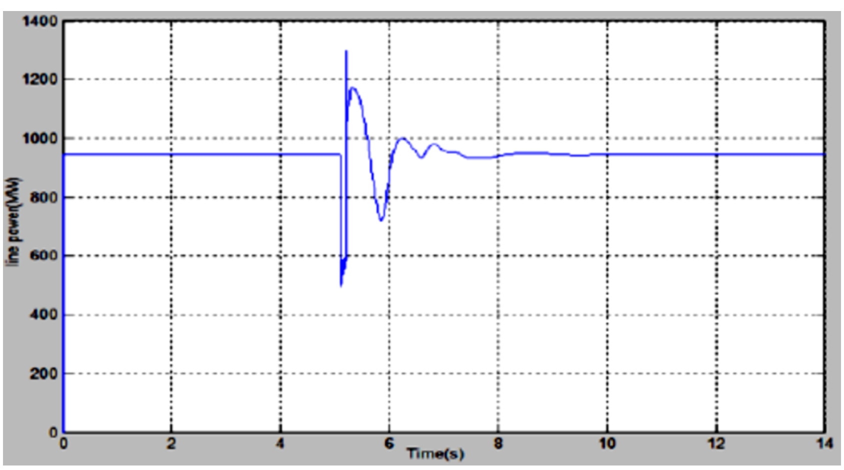

Figure 9: The line power (MW) verses time(s)

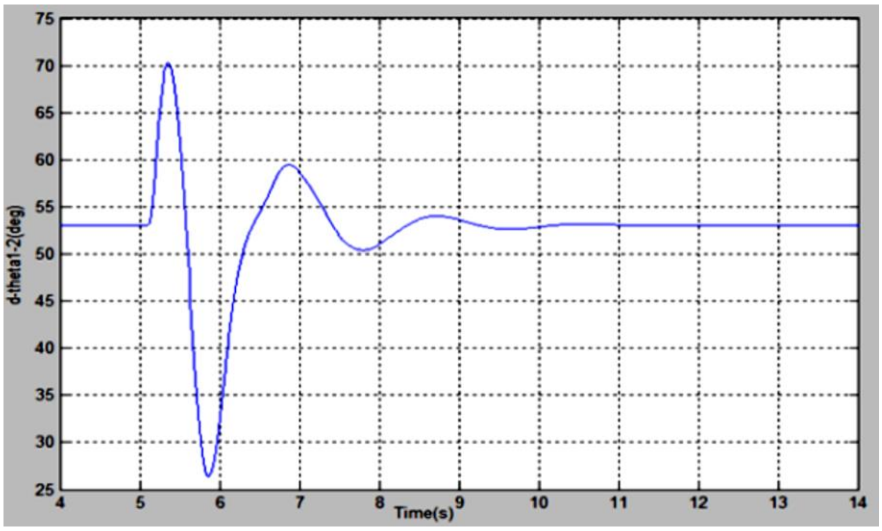

Figure 10: Delta 1-2 (degree) verses time (s)

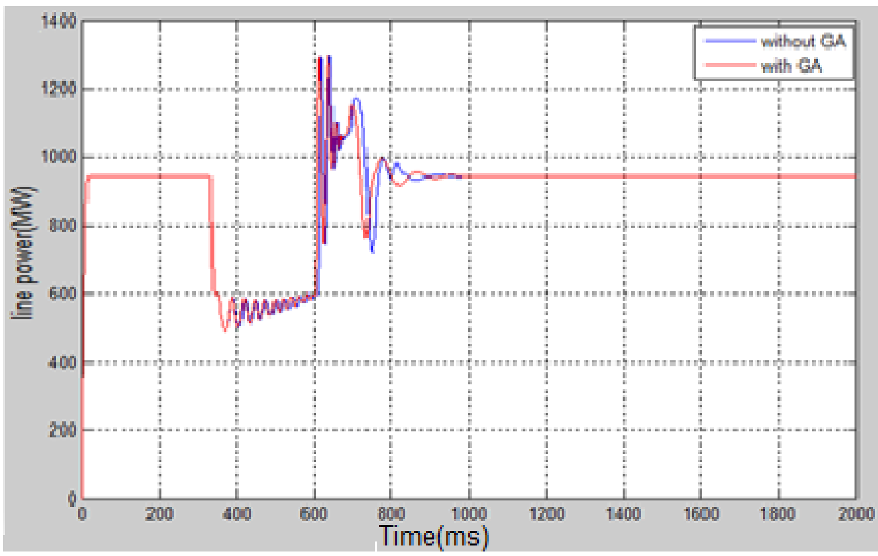

Figure 11: Comparing the line power with and without GA

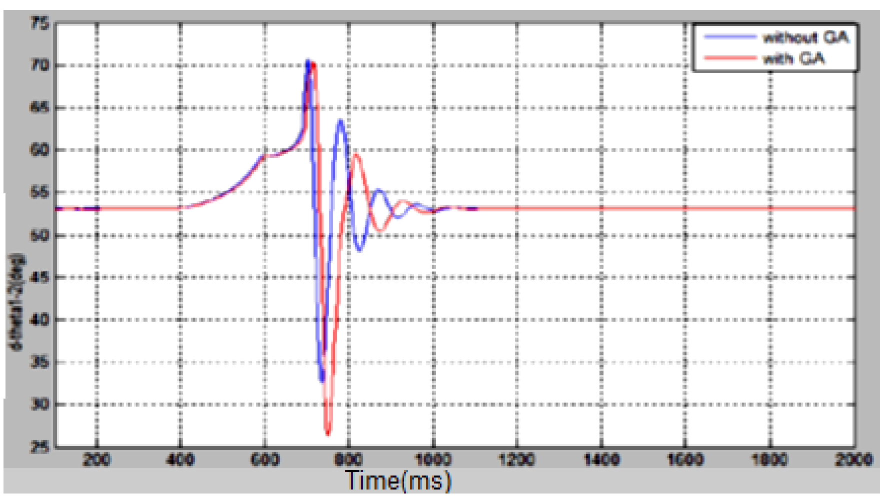

Figure 12: Comparing delta 1-2 with and without GA

When the time of fault = 120ms: -

Without using GA

When we used the parameters that exists in the Matlab (S_T=15e-3), (K=2), (T_1n=60e-3), the results of the line power and delta 1-2 are shown in Figures (13 and 14). In Figure (13) the fault started at 5.1s and the oscillations were damped at 8.1s so the time constant is 3s.

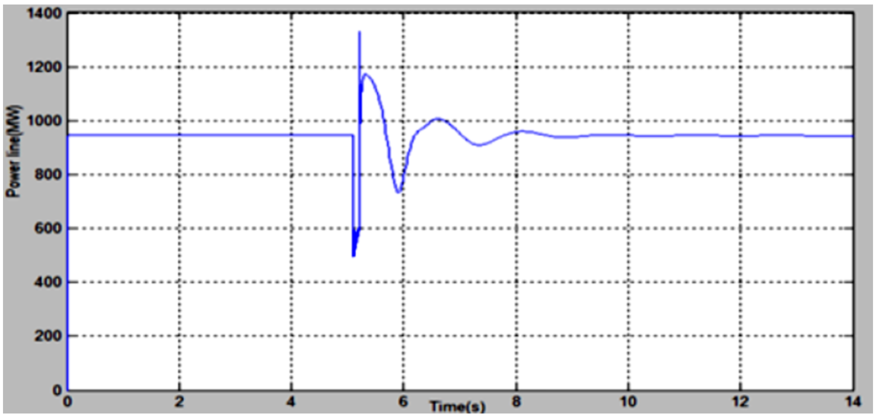

Figure 13: The line power (MW) verses time (s)

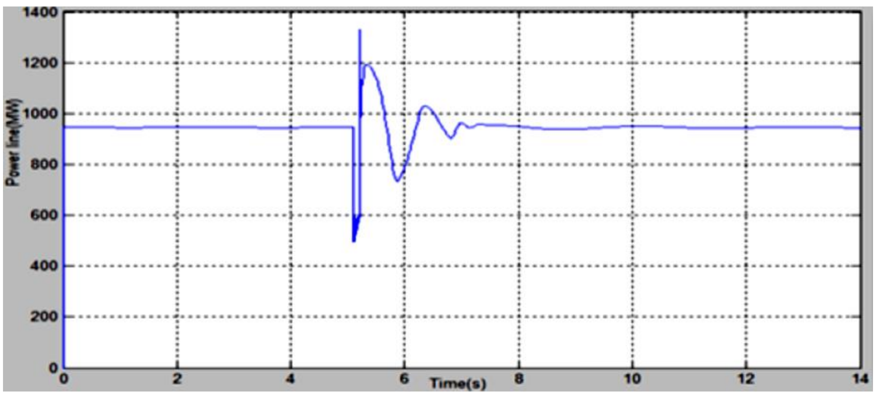

Figure 14: Delta 1-2 (degree) verses time (s)

With using GA

When we used the parameters that the GA found (S_T=0.559e-2), (K=7.65), (T_1n=0.343e-1), the results of the line power and delta 1-2 are shown in Figure (15) and Figure (16). In Figure (15) the fault started at 5.1s and the oscillations were damped at 7.1s so the time constant is 2s. Compared the results, noted that the oscillations and the time constant reduced when the PSS tuned by using (GA) as shown in Figures (17 and18).

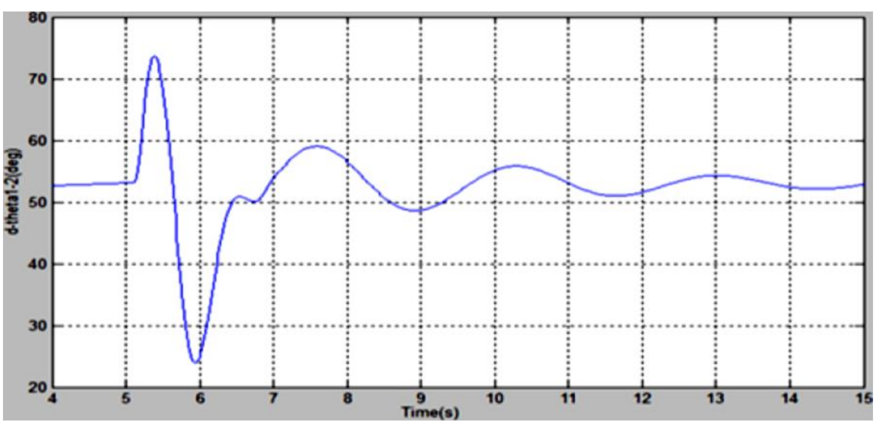

Figure 15: The line power (MW) verses time (s)

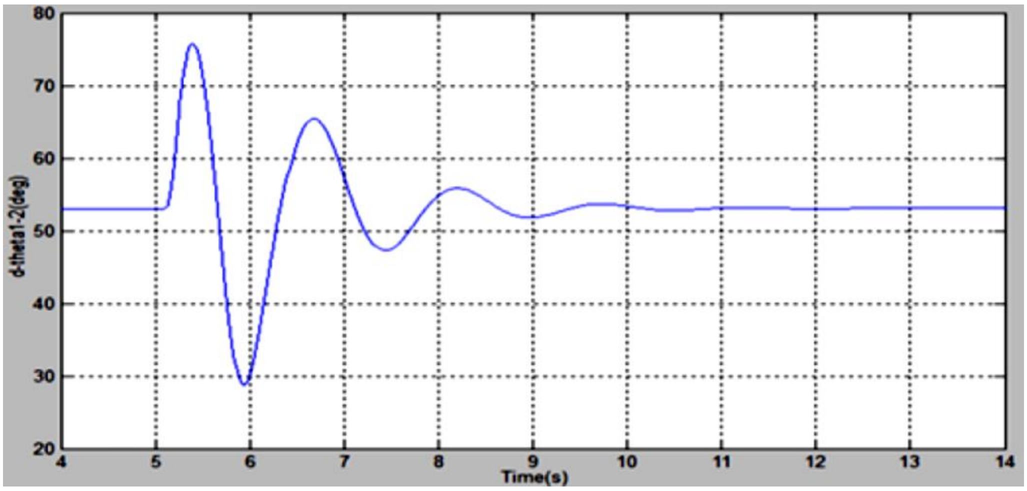

Figure 16: Delta 1-2 (degree) verses time (s)

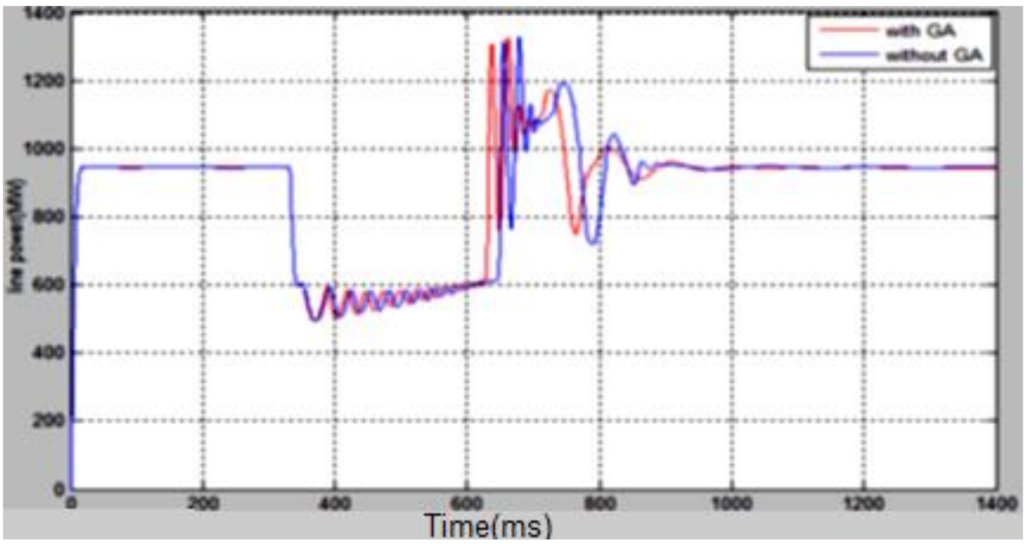

Figure 17: Comparing the line power with and without GA

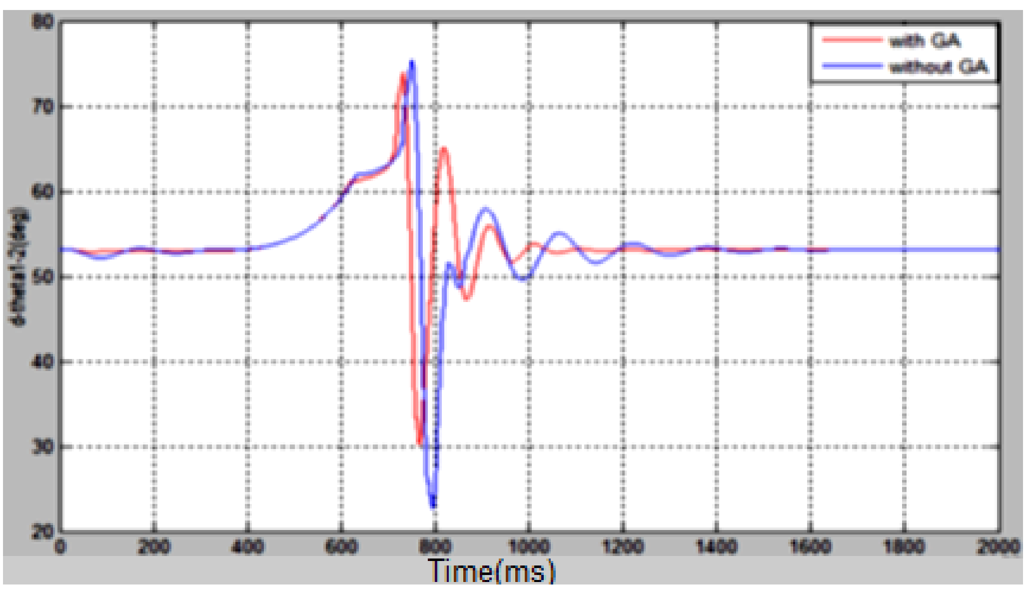

Figure 18: Comparing delta 1-2 with and without GA

Part two

In this part, the inertia constant (H) is fixed at 4, and the focus is on observing the impact of Power System Stabilizer (PSS) parameters on the oscillations of the power system. The PSS parameters have been tuned using a Genetic Algorithm (GA).

Part three

The inertia constant (H) is a crucial parameter in power systems, representing the ability of a machine to resist changes in speed. Keeping it fixed at 5 while examining the impact of PSS, when changing its parameters with new one that has been tuned by using (GA).

When comparing the results of tuned parameters using Genetic Algorithms (GA) for different inertia constants (H = 3, 4 and 5) at a fault time of 100ms, there's a trade-off between the amplitude of oscillations (delta 1-2) and the time constant required by the Power System Stabilizer (PSS) to damp out these oscillations. as shown in Figures (19 and 20).

When comparing the results of the parameters that have been tuned by using (GA) for (H = 3, 4 and 5) at fault time of 120ms, noted that the higher the value of inertia constant the small oscillations will be in delta 1-2, but the time constant that needed by the PSS to damp out oscillations will be higher, as shown in Figures (21 and 22).

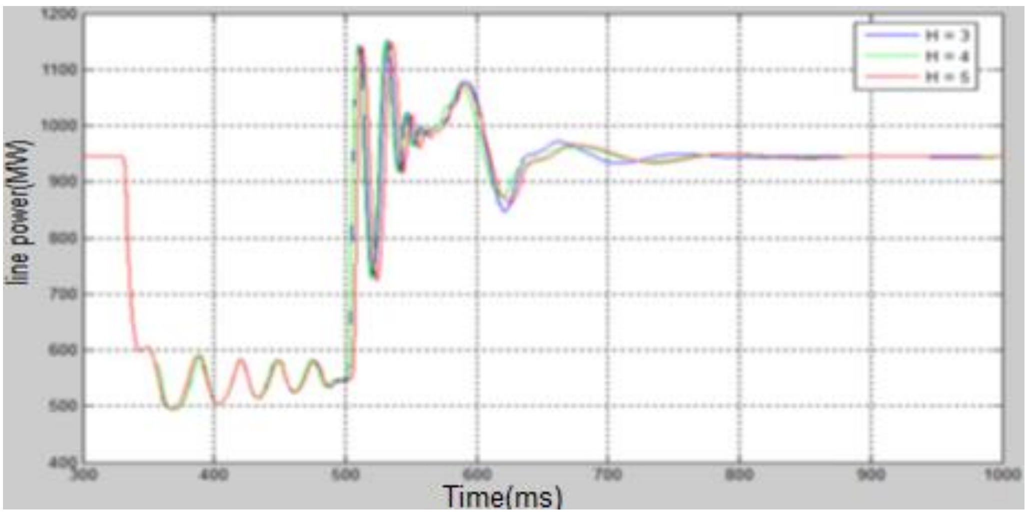

Figure 19: Comparing the line power with using (GA) with (H=3, 4 and 5)

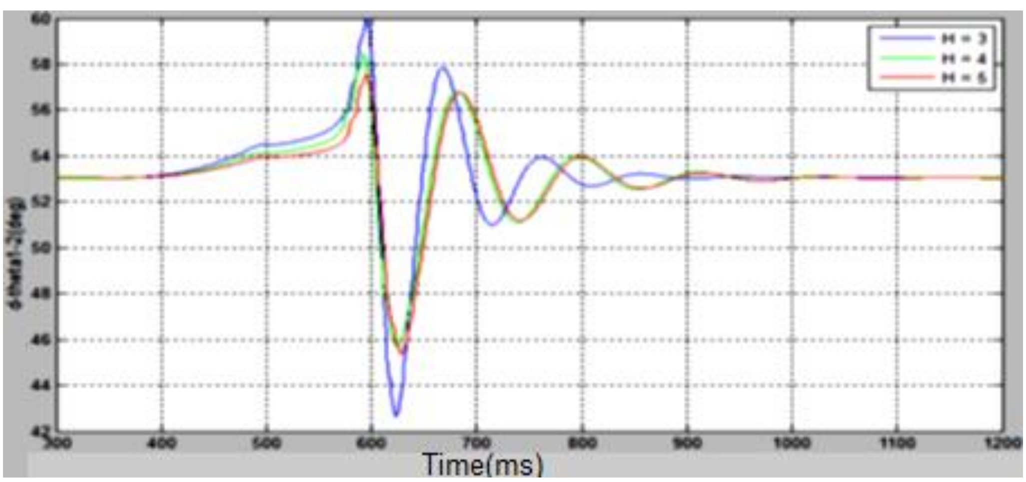

Figure 20: Comparing delta 1-2 with using (GA) with (H=3, 4 and 5)

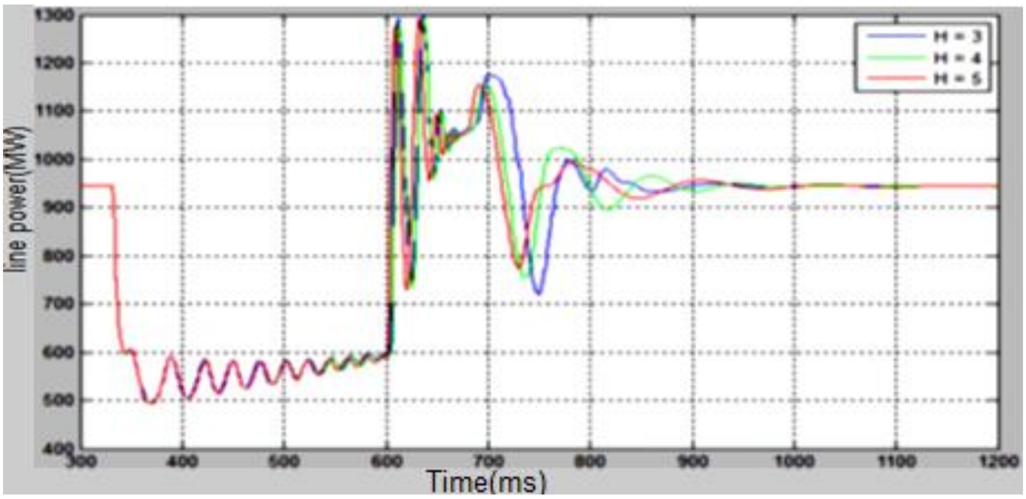

Figure 21: Comparing the line power with using (GA) with (H=3, 4 and 5)

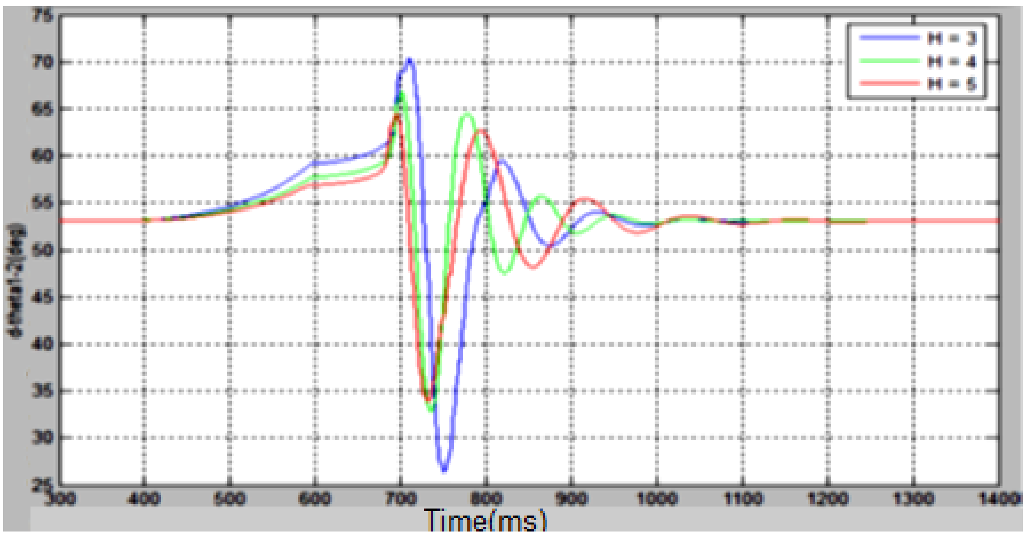

Figure 22: Comparing delta 1-2 with using (GA) with (H=3, 4 and 5)

CONCLUSIONS

The Power System Stabilizer (PSS) with parameters tuned using Genetic Algorithms (GA) demonstrated superior performance compared to the default PSS parameters provided by Matlab. Specifically, the tuned GA PSS was more effective in damping out oscillations, indicating an improvement in dynamic response and stability. When comparing results for different inertia constants (H=3, 4, and 5) with the PSS tuned using GA. Higher inertia constants (H=4 and H=5) resulted in smaller oscillations in delta 1-2 during fault conditions. However, there was an associated increase in the time constant required for the tuned PSS to damp out oscillations. The observations suggest a trade-off between the amplitude of oscillations and the time required for the PSS to stabilize the system. Higher inertia constants contribute to reduced oscillation amplitudes but require a longer time constant for PSS to dampen out these oscillations. The findings emphasize the importance of carefully selecting and tuning PSS parameters, taking into account the inertia constant and system response requirements. System designers should consider the trade-offs and balance between stability and response time when configuring PSS parameters.

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