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Simulation based of DC-DC Converter for AVR System and PID Controller with Tree Seed Algorithm based AVR System for Synchronous Generator

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Abstract: The voltage is supervised by AVR an automatic voltage regulator. It transforms the varying voltage into a constant voltage. The most prevalent cause of voltage fluctuation is changes in load on the supply system. An excitation system is a system that provides the necessary field current to the synchronous machine's rotor winding. The most important characteristics of an excitation system are dependability under all operating circumstances, ease of control, and ease of maintenance, stability, and quick transient response. In the literature, several control systems, such as in the literature, PID controllers, adaptive control methods, and intelligent control methods have all been suggested. On the one hand to get an accurate and quick generator terminal voltage control, the usage of a step down chopper in the exciter circuit is suggested in this study. DC-DC converters are also called as Choppers. The Step down chopper, It changes a given DC input voltage into a determined DC output voltage The input voltage source is tie up with governable solid state device that acts as a switch. Switches can be made using metal oxide semiconductor field effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBT). The field circuit of the generator is associated to the chopper and a Praportional-Intigral controller deviates the converter duty cycle to vary the generator's terminal voltage. to regulate the generator field voltage. On the other hand, Tree-Seed Algorithm (TSA) algorithm based PID controller is put forward for automatic voltage regulator system. The suggested approach calculates PID coefficients to the best of its ability. The execution of this TSA-based optimum PID controller is compared to that of various PID controllers produced in the literature utilizing different meta-hermetic optimization techniques. Comparative research in for the suggested schemes has a superior transient response and is more resistant to fluctuations in Generator load and DC input voltage.

Keywords: Automatic voltage regulator, DC−DC converter, PID controller, tree-seed algorithm, transient response, robustness, disturbance analysis.

I. INTRODUCTION

Electric networks are complex not linear systems with configuration and characteristics are varying over time, for example, as a result of deregulation of the energy market and collaboration among diverse energy generating methods. Furthermore, synchronous generators are extremely nonlinear and complicated equipment, which contribute significantly to their stability. The synchronous generators exhibits nonlinear behavior in response to changes in operating circumstances and disturbances, owing mostly to the synchronous generators' changing rotor speed and magnetic saturation of the synchronous generators magnetic circuit. Changes in the operating circumstances of a power system cause electromechanical oscillations to arise in that system. When oscillations of modest size and low frequency continue for extended periods of time, they can limit power transmission capability and decrease power system efficiency and stability. As a result, excitation controllers or exciters are widely employed for synchronous generator control [1]. Excitation management of synchronous alternators is among the most significant aspects in improving power system stability and power quality. The goal of excitation system is, to retain the amplitude of the terminal voltage of a alternator at its nominal value under typical operating conditions, the automatic voltage regulator is utilized in conjunction with the alternator to maintain the alternator's terminal voltage constant. As well as when the load changes the rated voltage level in an electrical power network must be consistent and stable. This is additionally one amongst the most management issues for an electric power system, as a result of all apparatus attached to this power network is intended to operate at a specific voltage level known as rated or nominal voltage. If the rated voltage level differs from that value, the performance of these equipment's degrades and their life expectancy degrades. Another important reason for this regulation is that both real and reactive power flow impact actual line losses. In reality, the reactive power flow is heavily influenced by the terminal voltages in the power system. However, by adjusting the nominal voltage level, real line problems can be mitigated. To address the aforementioned control issues, power production units employ an Automatic Voltage Regulator technology. The AVR system is a closed loop control system that ensures that the proper terminal voltage is maintained.

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By modulating the exciter voltage of the alternator, the exciter modulates the terminal voltage. The most renowned and well-known of them is the proportional integral derivative (PID) controller. Due to its durability and extensive stability margin, PID controllers have been used in a variety of control applications [2, 5]. The use of a chopper in the exciter circuit is proposed in this work to provide exact and rapid alternator terminal voltage regulation. The suggested system changes the duty cycle of the chopper to modify the field voltage consequently terminal voltage of the synchronous generator [3, 4]. This study describes a revolutionary intelligent optimizer for continuous optimization hinged on There is a correlation between trees and their seeds. The new method is heuristic and population based. The position of trees and seeds on an n-dimensional search space relates to a feasible solution to an optimization problem. The trees generate one or more seeds, and Trees take the place of the better seed places. The best solution or alternative tree location is examined with the tree location while producing new seed locations. This is accomplished by using a control parameter known as search tendency (ST), and the procedure is been repeated for a certain number of time. These methods allow the suggested approach's exploitation and exploration capabilities to be balanced [6].

II.METHEDOLOGY

A. AVR Model Integrated With A Standalone Synchronous Generator

1) *AVR Control System:* AVR rearrange the excitation voltage of a alternator to keep alternator's terminal voltage constant during load fluctuations. A DC-DC Buck Chopper regulates the field winding of the alternator, which requires DC power. The feedback circuit determines the duty ratio (D) of a buck chopper. It includes a Voltage capability that allows it to measure output voltage of alternator. A synchronous generators output voltage is converted to a direct current voltage via a rectifier. As stated in equation (1), the real voltage (V_{act}) is compared to the reference voltage (V_{ref}) and the voltage error (e(t).

$$e(t) = V_{ref} - V_{act} \qquad (1)$$

This voltage error (e(t)) is put into the PI controller in order to minimize the steady-state error. A PI controller in the forward path is used to regulate the system's response. The derivative term is not used for main field excited systems. The PI controller generates a duty cycle signal, reducing the error to zero. The proportional gain is denoted by '*Kp*,' integral gain by '*Ki*,' and the controller output is the duty cycle, denoted by 'D' .

$$D = K_p e(t) + \frac{K_p}{T_i}(\int e(t)dt \qquad (2)$$

The duty ratio (D) determines the output voltage (V_o) of the chopper in equation (3).

$$V_o = DV_{dc} \quad (3)$$

Where, V_o is output voltage (or) excitation voltage (V_f) V_{dc} Is supply voltage to chopper.

Alternator loading affects relationship in the middle of excitation voltage V_f and alternator terminal voltage *(V*). As can be seen in equation (4) Under NO-load conditions, the voltage at the alternator terminals is nearly equivalent to the internal electromotive force EMF (E).

$$V_f = \frac{\sqrt{2}}{X_f}(R_f E + L_f \frac{d}{dt}(E)) \quad (4)$$

The field current of a synchronous generator is controlled by adjusting duty ratio, which also controls the synchronous generator's terminal voltage.

2) *Design Of Dc-Dc Buck Chopper:* When a field voltage is applied to the synchronous generator field windings, synchronous generator is rotated by a prime mover, which generates AC voltage. The field winding of the generator is attached to the chopper, which is set up in a step-down arrangement. Variation of duty cycle of the converter allows for direct voltage control of the alternators terminal voltage, as illustrated in Figure 1.

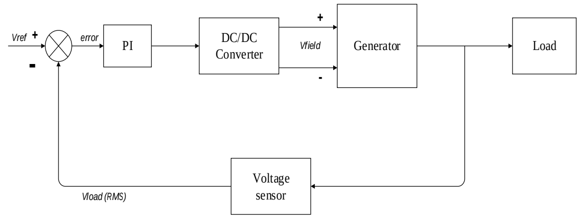

FIGURE 1 Automatic Voltage Regulator Block Diagram

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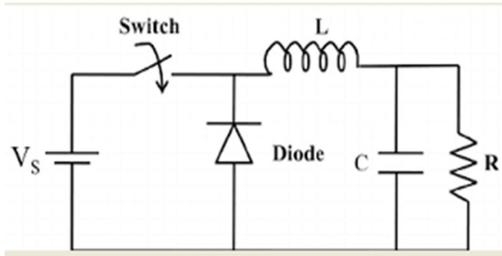


Figure 2. Buck Chopper

Figure 2 illustrates the buck chopper used in AVR. During the ON state, the inductor is charged and the diode is reverse biased. During the OFF state, the diode is in forward bias, and the inductor is drained. The armature current (I_a) of a DC motor and the load current (I_L) of chopper are the same.

$$\text{Armature current } (I_a) = \frac{P_o}{V_t}$$

The average current of the inductor in a Buck chopper is equal to the current of the load (I_L). The current ripple in the inductor is expected to be 5% of the load current (I_L). The frequency of switching is 20 kHz. Equation (5) is used to design the inductance (L) and capacitance (C) values (6). The capacitor's voltage ripple is 1%.

$$L = \frac{(V_s - V_t)D}{\Delta I_{L1} f} \qquad (5)$$

$$C = \frac{(1-D)V_t}{8L\Delta L_t f^2} \qquad (6)$$

The chopper for AVR is meant to manage alternator's field current.

$$\text{Field current of generator } (I_f) = \frac{V_t}{R_a}$$

According to the buck chopper's power balancing equation (I_{L1}avg), the alternator's field current is equal to the inductor's average current.

B. AVR system with a Tree Seed Algorithm-based PID Controller.

We employ a PID controller for the automatic voltage regulator based on the tree-seed algorithm (TSA) system in this work. The suggested approach determines the values of PID coefficients in the most efficient way possible. TSA is a swarm intelligence-based metaheuristic algorithm that is both resilient and strong. The algorithm's convergence speed is also superior to that of its contemporaries in the literature. As a result, it has become increasingly popular in recent years for engineering design issues and numerical optimization computations. This algorithm is built on the habitual phenomenon of trees and their seeds as its fundamental underpinning concept. The TSA method is developed in this work to compute the PID controller's coefficients in the AVR system as efficiently as possible.

The following is a list of contributions:

- The tree seed algorithm is utilized for the first time to regulate AVR voltage.
- The suggested technique is quantitatively compared to current work in order to highlight realized improvements using a variety of evaluation criteria.
- Traditional objective functions are used to assess the compatibility and adaptability of the proposed method in various circumstances.
- To assure the suggested algorithm's real-time operation in an AVR system, many analytical approaches are employed.

The pile of this section is as follows. Part 2.1 presents the PID controller idea briefly, part 2.2 describes a basic AVR design with its key components for control design, and part 2.3 shows the tree seed algorithm.

1) *PID Controller:* In industrial sector, these controllers are the most often employed. This is attributable to the fact that it has a simple structure and excellent performance qualities. The PID controller is used to enhance dynamic responsiveness while also lowering or eliminating steady state error. By including a finite zero in the open loop plant transfer function, Transient sensibility is improved by using a derivative controller. By increasing a pole at the first place, the integral controller elevates the system's order by one and decreases the steady state error due to a step function to zero. This is evident by the fact that it has a straightforward structure and has high performance characteristics. Figure 1 depicts the PID controller's schematic design. K_p Stands for proportional gain coefficient, K_i for integral gain coefficient, and K_d for derivative gain coefficient. The transfer function of a controller is shown. (3)[7].

$$G_{PID}(s) = \frac{u(s)}{e(s)} = K_P + \frac{K_i}{s} + K_d s \qquad (1)$$

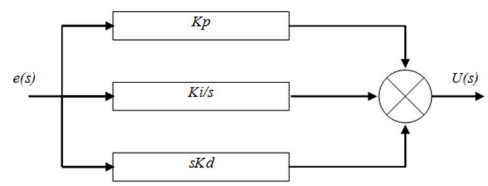


Figure 3. Schematic Diagram of a PID Controller

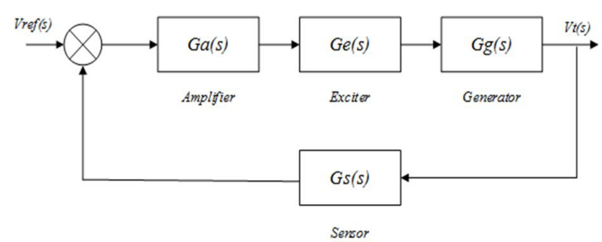
2) *AVR System Modeling:* An AVR's objective is to maintain a synchronous generator's terminal voltage magnitude at a predetermined level. The four fundamental components of a simple AVR structure are amplifier, exciter, generator, and sensor. The four components must be linearized for mathematical modeling and transfer function, which overlooks saturation and other nonlinearities in favour of the fundamental time constant. The appropriate transfer function of these fundamental components may be expressed in the following way [7].

a) Amplifier Model.

The amplifier representation is given by a amplifier gain K_a and a time constant T_a whereas the transfer function is

$$G_a(s) = \frac{K_a}{1+sT_a} = \frac{10}{1+0.1s} \qquad (2)$$

Usually K_a values often in the 10 to 400 range. The T_a of the amplifier is quite short, ranging from 0.02 to 0.1 s.



b) Exciter Model.

An exciter gain K_e and a single time constant T_e can be used to describe the transfer function of a recent exciter.

$$G_e(s) = \frac{k_E}{1+sT_e} = \frac{1}{1+0.4s} \qquad (3)$$

Usually K_e values often in the 10 to 400 range. T_e ranges from 0.5 to 1.0 second.

c) Generator Model.

The generator gain K_g and the time constant T_e in the linearized model may be used to express the transfer function that connects the generator's terminal and field voltages.

$$G_g(s) = \frac{K_g}{1+sT_g} = \frac{1}{1+1s} \qquad (4)$$

Usually K_g values often in the 0.7 to 0.1 range. T_e is a time constant that ranges from 1.0 to 2.0 second.

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d) Sensor model.

The sensor transfer function given by below equation.

$$G_s(s) = \frac{K_s}{1+sT_s} = \frac{1}{1+0.01s} \qquad (5)$$

T_s is extremely minor, ranging from 0.001 to 0.06 seconds. We compute the AVR system's closed-loop transfer function using (2), (3), (4), and (5), resulting: (6)

$$G_{AVR}(s) = \frac{V_t(s)}{V_{ref}(s)} = \frac{G_a(s)G_e(s)G_g(s)}{1 + G_s(s)G_a(s)G_e(s)G_g(s)}$$

$$\frac{0.1s + 10}{0.0004s^4 + 0.045s^3 + 0.555s^2 + 1.51s + 11} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

Figure 4. Closed loop AVR Model Diagram.

Ranges of the gain and time	Selected gains and time constant
$10 \le K_a \le 40$	$K_a = 10$
$1.0 \le K_e \le 10$	$K_e = 1.0$
$0.7 \le K_g \le 1.0$	$K_g = 1.0$
$K_s = 1.0$	$K_s = 1.0$
$0.02 \le T_a \le 0.1$	$T_a = 0.1$
$0.5 \le T_e \le 1.0$	$T_e = 0.4$
$1.0 \le T_g \le 2.0$	$T_g = 1.0$
$0.001 \le T_s \le 0.06$	$T_s = 0.01$

Table 1. Avr System Parameters

The AVR system comes without a controller. A unit step response can be used to observe the system's dynamic behavior. Figure 4 shows a Simulink model that is used for this. Furthermore, when the terminal voltage changes, Figure 14 depicts response of an AVR system without a controller. The terminal voltage is represented as a per unit (p.u.) quantity system. The steady-state error should be decreased to zero, and the output voltage of the generator and its transient state behavior should be improved. A high geared controller must be included to the system in order to accomplish this which is, to get the system to a state where it will display adequate behavior. The PID controller is used to regulate the AVR system. The closed loop control topology of the excitation system with a PID controller is shown in Figure 5. The closed loop PID controlled AVR system's transfer function is shown in (7)

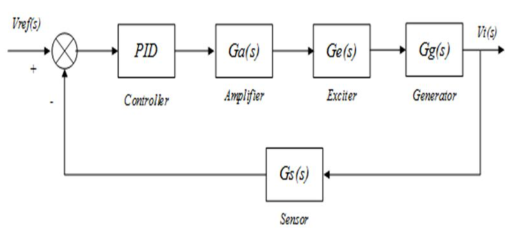

Figure 5. Structure of a Closed Loop AVR System with PID

$$G_{AVR}(s) = \frac{V_t(s)}{V_{ref}(s)} = \frac{G_{PID}(s)G_a(s)G_e(s)G_g(s)}{1 + G_{PID}(s)G_s(s)G_a(s)G_e(s)G_g(s)}$$

$$= \frac{0.1K_d s^3 + (0.1K_p + 10K_d)s^2 + (0.1K_i + 10K_p)s + 10K_i}{0.0004s^5 + 0.0454s^4 + 0.555s^3 + (1.51 + 10K_d)s^2 + (1 + 10K_P)S + 10k_i} \quad (7)$$

3) *Tree Seed Algorithm:* The motivation for the tree-seed algorithm (TSA) came from the connection in the middle of trees and their seeds. In environment, trees disperse their seeds. These seeds will be grown throughout time, and new trees will emerge from the aforementioned seeds. The position of trees and seeds might be the answers if the surface was supposed to be an adequate search space. Achieving the position of a seed produced from a tree is crucial for the improvement problem, since this procedure includes the search's core. Eqs. 8 and 9 are supposed for this procedure. Equation 8 improves the capacity of the given algorithm's local search or intensification. In addition, Eq. 9 uses two dissimilar tree sites to create a fresh seed for the tree.

$$S_{kj} = T_{ij} + \alpha_{ij} x\left(B_j - T_{rj}\right) \quad (8)$$
$$S_{kj} = T_{ij} + \alpha_{ij} x(T_{ij} - T_{rj}) \quad (9)$$

where $S_{k,j}$ denotes the j^{th} dimensional parameter of the K^{th} seed generated by the i^{th} tree, and B_j is the j^{th} dimensional parameter for the elite tree placement thus far, $T_{r,j}$ is thej^{th} dimensional parameter for the r^{th} tree, society which is picked at random, and $\alpha_{i,j}$ is the scaling factor generated at random in [-1,1]. The most important factor to consider is the equation for determining the placement of a fresh seed. This selection would be controlled by a control parameter called search tendency (ST) on a scale of [0, 1]. The higher the ST value, the more powerful the local search and the faster the convergence; the lower the ST value, the more powerful the global search and the slower the convergence. The first tree positions are built applying Eq. 10, since they represent possible answer to the optimization problem, at the start of the search.

$$T_{i,j} = L_{j,min} + r_{i,j}(H_{j,max} - L_{j,min}) \quad (10)$$

Where $L_{j,min}$ denotes the search space's lower bound and $H_{j,max}$ denotes the search space's upper bound, for each dimension and location, $r_{i,j}$ is a arbitrary number in the range [0, 1]. There is the chance that there will be more than one seed, as a tree's new seed sites are being established and this quantity is determined by the population size. The amount of seed produced in TSA is random. The best solution from the population is chosen for minimization using Eq. (11)

$$B = \min\{f(\overline{T}_i)\} \; i = 1,2, \dots, N \quad (11)$$

where N is the population's total number of trees.

III. SIMULATION RESULTS

A. AVR Model Integrated With A Standalone Synchronous Generator

1) Proposed AVR design without PID

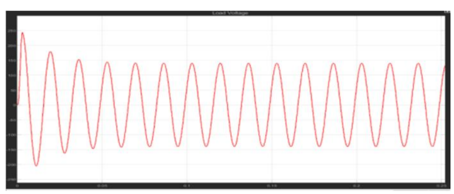

Figure 6. Peak Load Voltage (Voltage Vs Time)

The suggested system is developed in MATLAB and runs on the Simulink platform. The system is simulated without PID controller for variable voltage levels. The voltage response of a standalone synchronous generator with AVR in fig (6). This is peak load (Line to line) voltage at 100V for 45% pulse width.

Figure 7. RMS Load Voltage (Voltage Vs Time)

In the second figure, the 100V RMS voltage, the system is open loop system due to this the proposed AVR system is not accurate and reliable. Internal disruptions provide inaccurate findings when parameter changes occur. The above graph states that, cannot obtain 100V RMS voltage. For quality and accuracy, this suggested AVR System without PID controller recalibration is necessary from time to time.

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2) Proposed AVR design with PID Controller

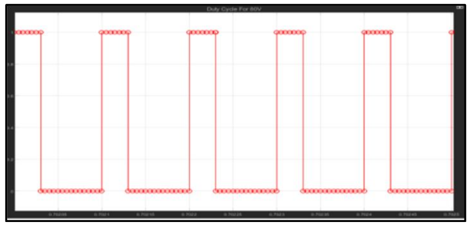

Figure 8. Duty cycle for 80 V

Figure (8) is a waveform of duty cycle for 80V. Duty ratio (D) is nothing but the ratio of ON time to total time.

$$D = \frac{T_{on}}{T} \times 100$$

Duty ratio varies between 0 and 1 or 0 to 100%. Here pulse width is 30%. For this pulse width output voltage is obtain 80V.

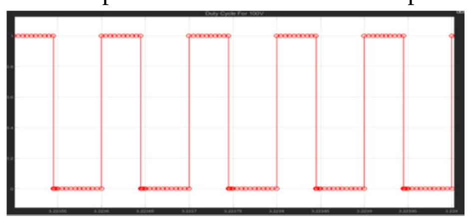

Figure 9. Duty cycle for 100 V

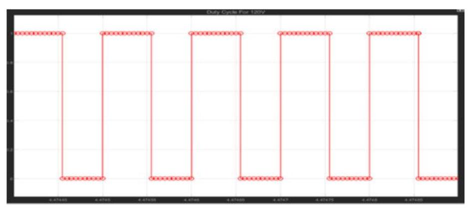

Figure 10. Duty cycle for 120V

Similarly for 100V the pulse width is 45% and for the duty cycles for 120V the pulse width is 55%. By regulating (D) values, To manage the terminal voltage to the alternator, the field current of the alternator is adjusted.

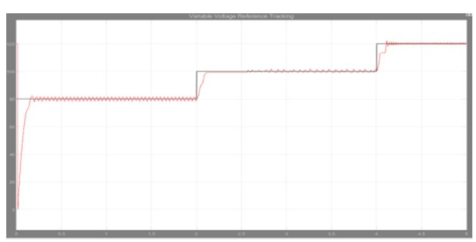

Figure 11. Variable voltage reference tracking (voltage Vs Time)

The suggested AVR has been simulated in MATLAB/simulink, and the results have been provided here. The above figure is a graph of variable voltage reference tracking performance. In this example, the suggested AVR's tracking ability is assessed by varying the terminal voltage reference from 80V to 100V and then 100 to 120V. The suggested AVR modifies the duty-cycle of the buck converter to remain generator's terminal voltage at the proper reference level. The generator terminal potential difference varies as the reference voltage is substituted from 100 to 120 Volt. The field voltage (V_{field}) and field current (I_{field}) rise as the duty cycle increases. The black line is reference voltage level line and red line is tracking voltage level line.

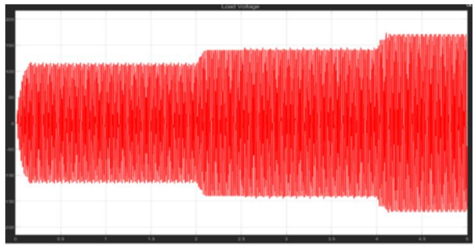

Figure 12. Peak Load Voltage (Voltage Vs Time)

This is generator field voltage for input supply voltage. By using stair generator block supply input voltage is applied for different time intervals different amplitude applied. In figure 7 at period 0 to 2 its voltage is 80V and for 2 to 4 interval of time voltage is 100V and 4 and beyond that its 120V.

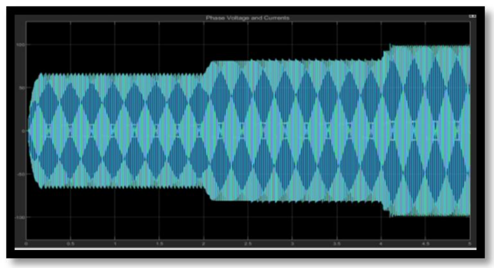

Figure 13. Phase Voltage and Current

The suggested AVR scheme's disturbance rejection property is evaluated the outcomes are then shown. The alternators terminal voltage is set to 120 V, and the load is added and withdrawn as needed. By changing the duty cycle, the suggested method is capable to successfully deny the disruption and restore the voltage at terminal to the target reference.

3) Voltage Current Frequency Observation for load Variations

Load	Voltage (V)	Frequency (F)	Current (A)
No Load (1 KW)	120	49.99	0.003323
¼ Load (4 KW)	120	49.99	2.9994
½ Load (8KW)	120	49.99	5.9988
¾ Load (12KW)	120	49.99	8.9982
Full load (16 KW)	120	49.98	11.9976

Due to load fluctuations, the system operates at no load for 2 seconds before applying a step load of 4 KW every 4 seconds. Without changing the terminal voltage, the load current varies from no load to full load. AVR compensates for the voltage loss. The table tabulates the detailed observations of current, voltage, and frequency at each step in the load shift.

B. AVR system with a PID controller based on the Tree Seed Algorithm.

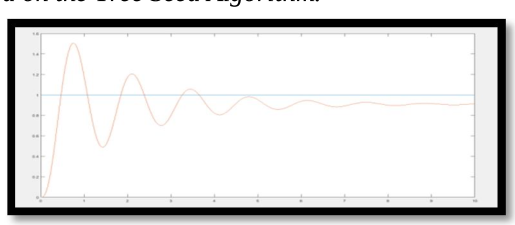

Figure 14. The AVR system's terminal output voltage change without PID controller
(Terminal Voltage (p.u.) Vs Time (s))

As seen in Figure 14, the output voltage does not match the intended reference, necessitating the use of a controller to reduce the steady-state inaccuracy while also minimizing the settling time. Table 2 shows theM_p, t_s, t_r, and E_{ss} open-loop system parameters of the AVR system. The excitation systems poles and zero are shown in Table 3. The stability response of the AVR system may also be shown by looking at the poles of the transfer function. The system's zero-poles are listed in Table 3. There are two conjugate poles in the system. The system's damped oscillation is caused by these conjugated poles.

Table 2. Behavior of the AVR system

Criteria	Response values
M_p	65.4272%
	(Peak value=1.5039 p.u.)
t_s	6.9711s($\pm$2%)
t_r	0.2607s
t_p	0.7547s
E_{ss}	0.0907

Table 3. Zero and Poles of AVR system

Zeros-Poles	Values
Two real poles	$s_1 = -98.8170 + 0i$
	$s_2 = -12.46261 + 0i$
Two complex pole	$s_3 = -0.5285 - 4.6649i$
	$s_4 = -0.5285 - 4.6649i$
One Zero	Z=-100+0i

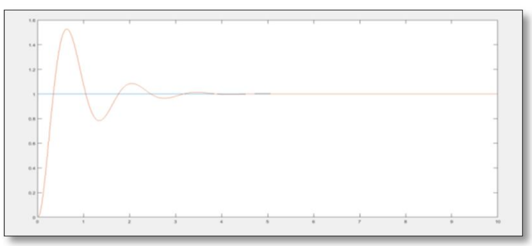

Figure 15. The AVR system's terminal output voltage change with PID controller (Terminal Voltage (p.u.) Vs Time (s))

The synchronous generator's transient response must be improved, and its steady state error must be eliminated. For this, a high performance controller should be including in the system. The closed loop control topology of the AVR system with a PID controller is shown in Figure 15.

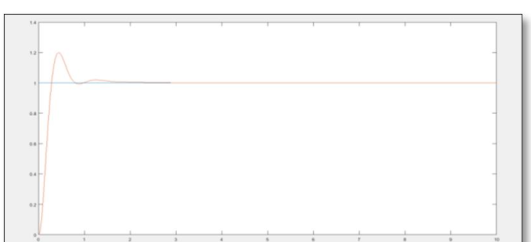

Figure 16. AVR system terminal voltage curve for TSA algorithm. (Terminal Voltage (p.u.) Vs Time (s))

Figure 16 appear the response of the AVR system for TSA algorithm. This achieved result illustrates In terms of transient steady state responsiveness, the suggested AVR structure with TSA PID controller performs. Table 4 shows the M_p, t_s, t_r, and E_{ss} system parameters of the excitation system.

Table 3. Parameter of AVR system for different topology

Parameter	Without PID	With PID	Tree Seed Algorithm
Rise Time	0.2282	0.2631	0.1889
Settling Time	2.9825	7.0190	0.7370
Settling Min	0.7836	0.4882	0.9608
Settling Max	1.5281	1.5061	1.2004
Overshoot	52.8082	65.1660	20.0437
Peak	1.5281	1.5061	1.2004
Peak Time	0.6360	0.7614	0.4394

1) *Reference Voltage and Disturbance rejection of AVR System:* Disturbances can be used to simulate load variations in synchronous generators. It is essential that controllers have robustness and transient response characteristics while dealing with these disruptions. Figure 17 in the MATLAB/Simulink environment depicts this structure.

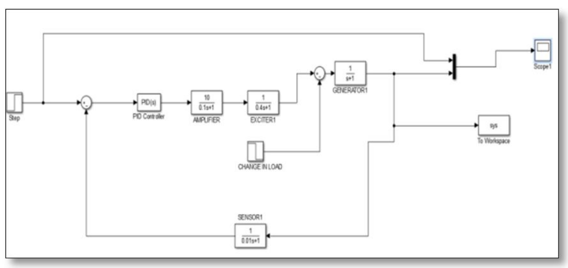

Figure 17. AVR system disturbance model in Simulink.

The system is subjected to disturbance signals that correspond with the reference at the rate of ± 10% at different time intervals. Figure 18 depicts the AVR system's reactions utilizing a TSA-based PID controller, as well as a comparison to the literature.

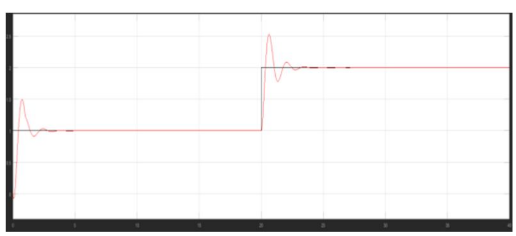

Figure 18. Disturbance responses of the AVR system.

The TSA method outperforms other algorithms in terms of steady state errors and disturbance.

IV. CONCLUSIONS

This paper presented a new AVR that use a step-down MOSFET-based DC-DC converter. The suggested methodology has strong disturbance rejection characteristics and can monitor the reference voltage, it is simple to implement. And is resilient under input DC voltage fluctuations, according to simulation findings. The TSA-based PID control method is suggested in this work for optimum AVR control. The algorithm (TSA) is based on tree-seed relationships. TSA is used to determine the best values of K_a, K_i, and K_d PID controller coefficients.

The results demonstrate that the suggested AVR system with TSA recuperated PID controller outperforms current AVR methods with regards of transient and steady state behavior of voltage tracking performance. In terms of steady-state errors and disturbances, the TSA technique beats other methods. The obtained findings show that in synchronous generator AVR systems, the TSA recuperated PID controller recommended for the AVR system is impervious to system parameter uncertainties.

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