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Research Article

Optimal PID Controller Parameters Tuning via GOA and VSA for an AVR System

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Abstract

One of the very vital control scheme for power systems is automatic voltage regulator (AVR). Voltage instability may occur in the power systems when its cannot meet the reactive power demand. The reactive power balance in the power system is related to the terminal voltages of synchronous generators (SGs) in the system. The voltage stability for a synchronous generator can be provided with AVR. In this paper, proportional-integral-derivative (PID) controller has been used for controlled the AVR system. In order to determined optimal PID controller gains, two different optimization methods called Golf Optimization Algorithm (GOA) and Vortex Search Algorithm (VSA) have been chosen. The results have been analyzed with respect to maximum overshoot (MP), settling time (ST) for ±0.05 bandwidth and rising time (RT) from 0.1p.u to 0.9p.u. values. Moreover, the founded results have been compared with the Particle Swarm Optimization (PSO) algorithm in the literature. Also, robustness analyses have been performed for ±25% and ±50% changes of time constant parameters through the algorithm that gives better performance results. From the computed results, it has been observed that GOA has been capable to improved the performance outputs of AVR system and could tolerate changes in system time constant parameters.

Key Words

"Automatic voltage regulator, GOA, VSA, PID controller"

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1. Introduction

In electrical power systems, voltage stability is very vital factor for stability and reliability. The voltage stability of the system can be directly affected from the reactive power flow (Sharma, et al., 2021). At this point, voltage fluctuations can be observed in the system. These fluctuations may lead to breakdown of insulation and may even lead to unstable system (Chatterjee, et al., 2017). In order to prevent these, voltage outputs can be regulated at specific value (Saadat, 2004). This process is achieved through with automatic voltage controller (AVR). The primary task of automatic voltage regulator is kept the terminal voltage of the generators in specific limits and provide constant voltage (Chadar, et al., 2022).

In the AVR system, set of controller gains are very significant for determined the expected system outputs. For this purpose, many optimization techniques have been applied to find different controller parameters. Some of them summarized as follows: Gozde et al. proposed global neighborhood algorithm (GNA) for found optimal PID parameters in 2017 (Gozde, et al., 2017), Hekimoglu et al. selected grasshopper optimization algorithm (GrOA) for determined PID controller parameters in 2018 (Hekimoglu, et al., 2018), Can et all. proposed honey badger algorithm (HBA) for tuning of FOPID controller (Can, et al., 2022) in 2022, Eke proposed genetic algorithm (GA) for tuning of PID controller (Eke, 2022) in 2022, Zhang et all. proposed enhanced whale optimization (EWOA) algorithm for determined PID controller parameters (Zhang, et al, 2023) in 2023, Shukla et all. applied equilibrium optimizer (EO) for tuning of TID controller gains (Shukla, et al., 2023) in 2023, Türksoy et al. proposed sliding mode controller technique (Turksoy, et al, 2024) in 2024 and Jegatheesh et al. used seagull optimization algorithm (SOA) for found FOPID controller parameters (Jegatheesh et al, 2024) in 2024.

In this study, vortex search algorithm (VSA) and golf optimization algorithm (GOA) have been used in order to find optimal PID controller parameters for an AVR system. Calculated results have been compared with the literature results. The main contributions of this study summarized as follows:

- GOA and VSA techniques have been applied to an AVR system as comparatively,
- AVR system performances have been examined with respect to overshoot, rising time and settling time,
- Robustness analyzes have been performed via GOA,
- Founded performances illustrated as graphics.

The rest or the paper organized as follows: AVR was briefly mentioned and linear model is given in Section 2. GOA and VSA have been briefly reported in Section 3. In Section 4 computed results have been presented. Conclusions are given in Section 5.

2. Automatic Voltage Regulator

AVR is one of the very vital control mechanism in power systems. The stability of the terminal voltages of the synchronous generator is provided with AVR. Main goal of AVR is maintain constant and stabile terminal voltage within acceptable limits (Chadar, et al., 2022). An uncontrolled AVR model mainly formed as four main components: amplifier, exciter, generator and sensor. A linear model of AVR system having PID controller can be illustrated in Figure 1 (Yavarian, et al., 2014):

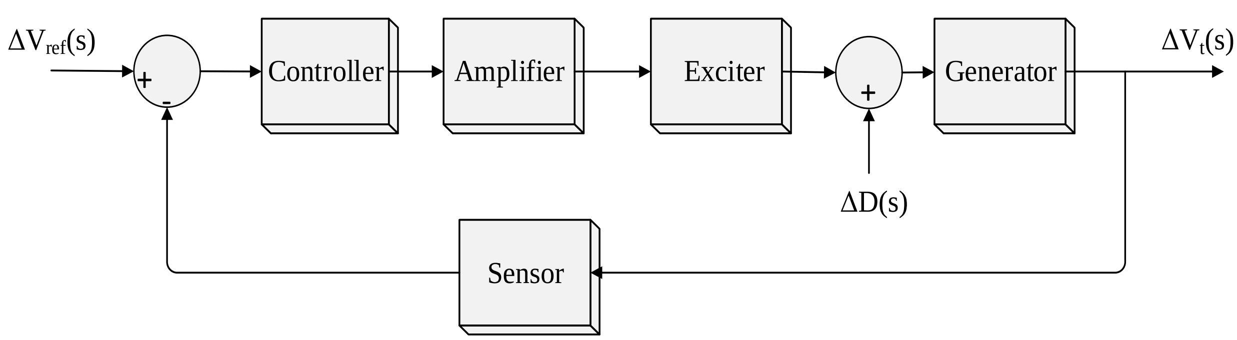

Figure 1. Linear AVR model

The amplifier model can be given in following equation (Celik, et al., 2018):

$$G_a = \frac{K_a}{1+sT_a} \tag{1}$$

The exciter model can be expressed as follows (Celik, et al., 2018):

$$G_e = \frac{K_e}{1+sT_e} \tag{2}$$

The generator model can be identified as following equation (Celik, et al., 2018):

$$G_g = \frac{K_g}{1+sT_g} \quad (3)$$

The sensor model can be expressed as follows (Celik, et al., 2018):

$$G_s = \frac{K_s}{1+sT_s} \quad (4)$$

The definitions and values of these model parameters given in Table 1 (Bhullar, et al., 2020):

Table 1. AVR system parameters and definitions

Parameter	Definition	Value
K_a	Gain of amplifier	10
T_a	Time constant of amplifier	0.1
K_e	Gain of exciter	1
T_e	Time constant of exciter	0.4
K_g	Gain of generator	1
T_g	Time constant of generator	1
K_s	Gain of sensor	1
T_s	Time constant of sensor	0.01

3. Methods

In this section, vortex search algorithm and golf optimization algorithm has been explained briefly.

3.1. Golf Optimization Algorithm

GOA is game based metaheuristic method and it was developed by Montazeri et all. in 2023 (Montazer, et al., 2023). This algorithm was formed by taking into account the strategic dynamics and player behavior in golf. GOA has two main phase namely exploration and exploitation. Candidate solutions have been search the search space in exploration phase. In this phase, the hole is considered as best member position.

Players try to make the strongest shot in the direction of the hole an calculation of new positions of each GOA member modelled as following Eq 5 (Montazer, et al., 2023). In this way, a significant amount of scanning of the area is achieved.

$$S_m^{K1}: s_{m,e}^{K1} = s_{m,e} + r * C_e - I * s_{m,e} \quad (5)$$

In here, S_m^{K1} new position of the mth GOA member in exploration phase, $s_{m,e}^{K1}$ is its eth dimension, r is random coefficient between 0-1, C is best solution is GOA and C_e is its eth dimension and I random coefficient between 1-2.

In the exploitation phase of GOA, players make more precise shots to get the golf ball into the hole. This allows the ball to effectively scan the area around the hole without moving away from the hole. The update of the GOA members is based on mathematical modeling of a player's low-powered shots to the ball and is represented by the Eq 6 (Montazer, et al., 2023):

$$S_m^{K2}: s_{m,e}^{K2} = s_{m,e} + (1-2r) + \frac{lb_e + r*(ub_e - lb_e)}{t} \quad (6)$$

In here, S_m^{K2} new position of the mth GOA member in exploitation phase, $s_{m,e}^{K1}$ is its eth dimension, t is iteration number, lb and ub are lower and upper limits.

If these updated members are not into the limits of the problem, they shifted into the problem limits with using Eq 7 (Montazer, et al., 2023):

$$s_{m,e}^{K(1-2)} = \begin{cases} ub_e \ , & s_{m,e}^{K(1-2)} > ub_e \\ lb_e \ , & s_{m,e}^{K(1-2)} < lb_e \\ s_{m,e}^{K(1-2)} \ , & lb_e \leq s_{m,e}^{K(1-2)} \leq ub_e \end{cases} \quad (7)$$

After than, GOA members are evaluated for an objective function and better of them (bestval) is determined. If bestval is better than best solution found so far (gbestval), bestval value is assigned as gbestval value. These iterative process are continued to termination criteria(s) met. Detail information and mathematical expression of GOA can be found in reference (Montazer, et al., 2023).

A pseudo code of GOA for an AVR system is given in Algorithm 1:

```
Start
    Define GOA parameters
    Define VSA parameters
    Formed initial population
        While iteration<maximum iteration
            Update the best candidate solution according to the AVR performances
                For i=1:k
                    Determine new positions according to the exploration phase of GOA and
                    update them
                    Determine new positions according to the exploitation phase of GOA and
                    update them
                End
            Keep the best solution in memory
        end
    Checked termination criteria(s)
Finish
```

Algorithm 1. Pseduo code for GOA

3.2. Vortex Search Algorithm

VSA was developed by B. Dogan and T. Olmez in 2015 (Dogan, et al., 2015). Behavior of mixed liquids is inspired to this algorithm. VSA can be thought as intertwined circles. The radius of biggest circle is computed as following Eq 8 (Dogan, et al., 2015):

$$\sigma_0 = \frac{maximum_{upperlimit} - minimum_{lowerlimit}}{2} \tag{8}$$

The center of the biggest circle is determined as following Eq 9 (Dogan, et al., 2015):

$$\mu_0 = \frac{upperlimit + lowerlimit}{2} \tag{9}$$

After from these definitions, candidate solutions have been formed within the circle(s). If candidate solutions are not satisfied the problem boundaries, they must be shifted into the boundaries by using following Eq 10 (Dogan, et al., 2015):

$$s_m^k = \begin{cases} s_m^k & ; \quad lowerlimit^k \le s_m^k \le upperlimit^k \\ r * (upperlimit^k - lowerlimit^k) + lowerlimit^k & ; \quad else \end{cases} \tag{10}$$

In here r is uniformly distributed random number, k=1, 2, 3, … d and m=1, 2, 3, … n. All randomly generated solutions are tried every iteration for an objective function. The best of them is chosen as itrBest and compared with the best candidate solution found so far (globalBest). If itrBest is lower than globalBest, itrBest is assigned as new globalBest value. For all other cases, the global best value continues to be kept in memory. After the end of every iteration, the radius of the circle is decreased by using following Eq 11 (Dogan, et al., 2015):

$$r_0 = \sigma_0 * \left(\frac{1}{x}\right) * gammaincinv(x, a_0) \tag{11}$$

In here, gammaincinv is inverse gamma function. After this step, center of the next circle is chosen as globalBest. This iteration process is continued to the termination criteria(s) are met. Detail information and mathematical expression of VSA can be found in reference (Dogan, et al., 2015).

A pseudo code of VSA for an AVR system is given in Algorithm 2:

```
Start
    Define VSA parameters
    Define AVR system parameters
        While iteration<maximum iteration
            Formed population
            Checked limits of population
```

Implement the candidate solutions into the AVR system
Evaluate the solutions
Keep best solution in the memory
Reduce the radius
End
Checked the termination criteria(s)
Finish

Algorithm 2. Pseduo code for VSA

4. Results and Discussion

In this section, AVR system performances have been computed for PID controller via golf optimization algorithm and vortex search algorithm. In addition, founded results compared with each other and literature PSO results (Gozde, et al., 2010). Moreover, robustness analyses have been performed for ±%25 and ±%50 deviations of time constant parameters. The objective function has been selected as integral time square error (ITSE) for tuning of PID parameters in GOA an VSA. ITSE function can be given in following equation (Burnaz, et al., 2020):

$$ITSE = \int_0^{tsim} time.* (error.* error).dt \quad (12)$$

Founded AVR performance with these algorithms results have been compared according to maximum overshoot, rise time (from 0.1 p.u. to 0.9 p.u.) and settling time (for ±0.05 bandwidth level).

4.1. AVR Performances

In this part, AVR performance results founded with GOA and VSA and the results were compared with PSO [15]. Determined optimal controller parameters given in Table 2:

Table 2. Controller gains of PID

	Kp	Ki	Kd
GOA	2.5264	0.3988	0.4635
VSA	2.1045	0.4954	0.3849
PSO (Gozde, et al., 2010)	1.7774	0.3827	0.3184

Obtained AVR system performances have been illustrated in Figure 2:

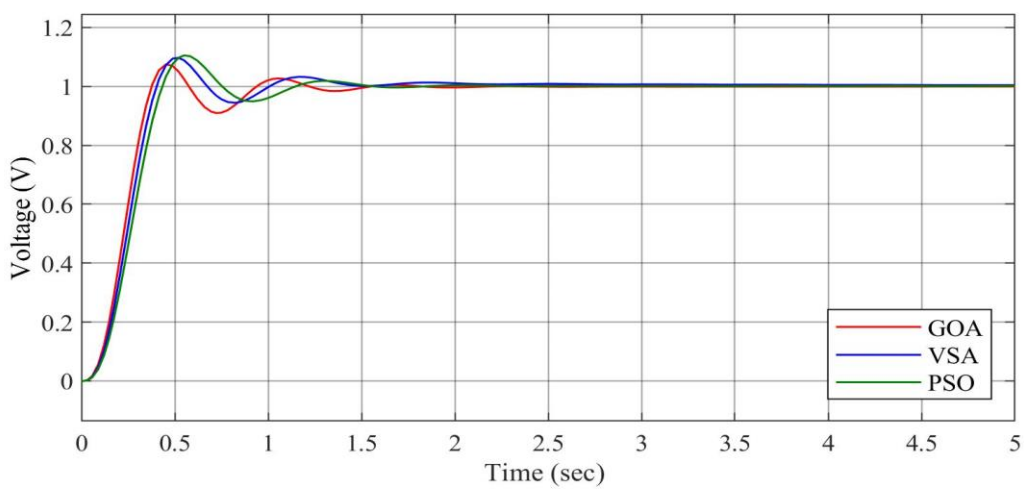

Figure 2. Obtained output results

Figure 2 clearly showed that obtained output signal with GOA quickly rising than PSO and VSA. Moreover, GOA gave lower settling time value for considered AVR system. On the other hand, PSO (Gozde, et al., 2010) has bigger overshoot level than VSA and GOA. The numerical performance results have been given in Table 3:

Table 3. Performance Results

	MP	RT(0.1 p.u to 0.9 p.u)	ST(±0.05 BW)
GOA	1.0748	0.2240	0.8471

Table 3. Performance Results (continuing)

VSA	1.0967	0.2401	0.8656
PSO (Gozde, et al., 2010)	1.1048	0.2597	0.9286

It can be clearly seen from Table 3 that lower MP value, settling time and rising time has been calculated via GOA. Moreover, these results have been illustrated as bar graphic in Figure 3 to clearly shown superior effect of GOA for AVR system.

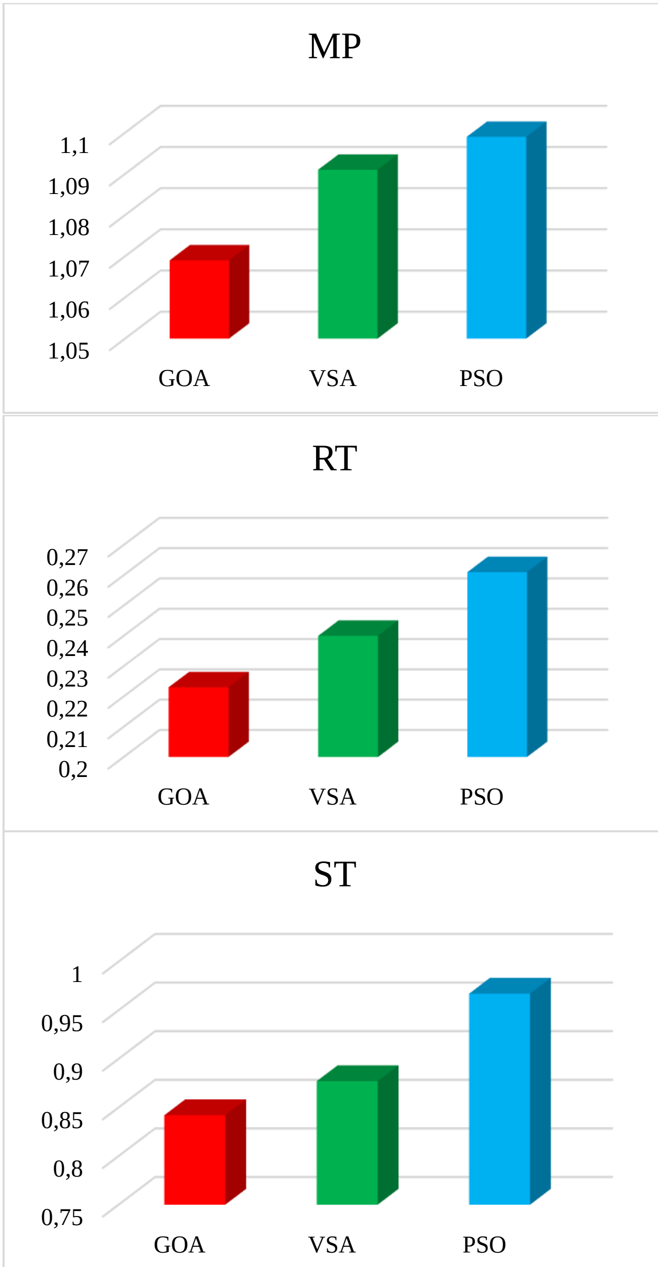

Figure 3. Bar graphic illustration of MP, RT and ST as AVR performances

It can be easily understood from Figure 3 that better system performances found with golf optimization algorithm.

4.2. Robustness Analyzes

It can be easily seen from the previous part that GOA gave better AVR performance results. For this reason, robustness analyzes of AVR system is performed via GOA in this part.

Determined controller parameters via GOA are given Table 4:

Table 4. Founded controller gains

	Kp	Ki	Kd
+50% Amplifier	2.4071	0.3235	0.5452
+25% Amplifier	1.9224	0.3403	0.4007
-25% Amplifier	2.1386	0.4205	3.3473
-50% Amplifier	2.0433	0.4788	0.3007
+50% Exciter	2.6502	0.3532	0.5563
+25% Exciter	2.8092	0.3810	0.5525
-25% Exciter	2.5779	0.5307	0.4258
-50% Exciter	2.0424	0.5446	0.2957
+50% Generator	2.8196	0.3156	0.5588
+25% Generator	2.0912	0.3375	0.4085
-25% Generator	2.4545	0.4753	0.4414
-50% Generator	1.8884	0.5240	0.3115
+50% Sensor	2.1161	0.4138	0.4002
+25% Sensor	2.3481	0.4378	0.4342
-25% Sensor	1.8443	0.3510	0.3522
-50% Sensor	2.6533	0.4154	0.4565

AVR performances for time constant deviations have been presented in between Figure 4 and Figure 7:

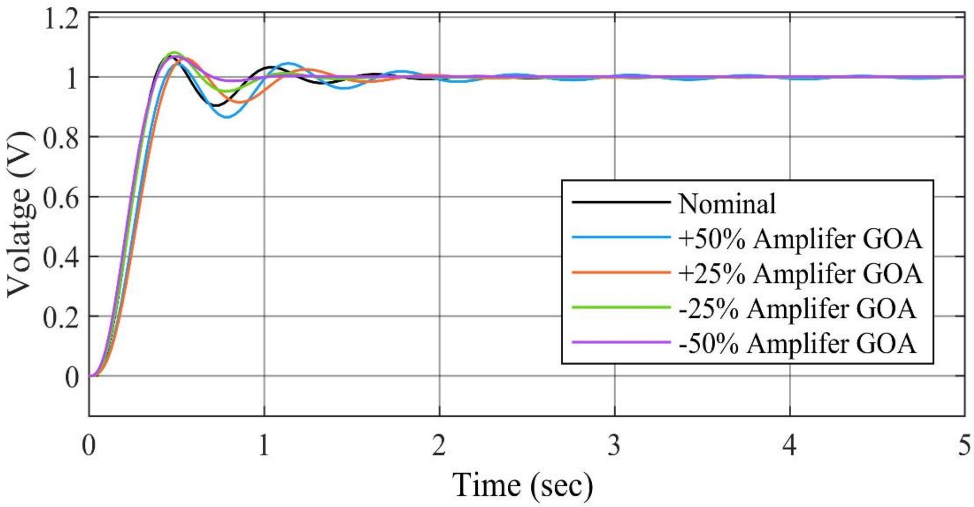

Figure 4. Amplifier time constant variations results via GOA

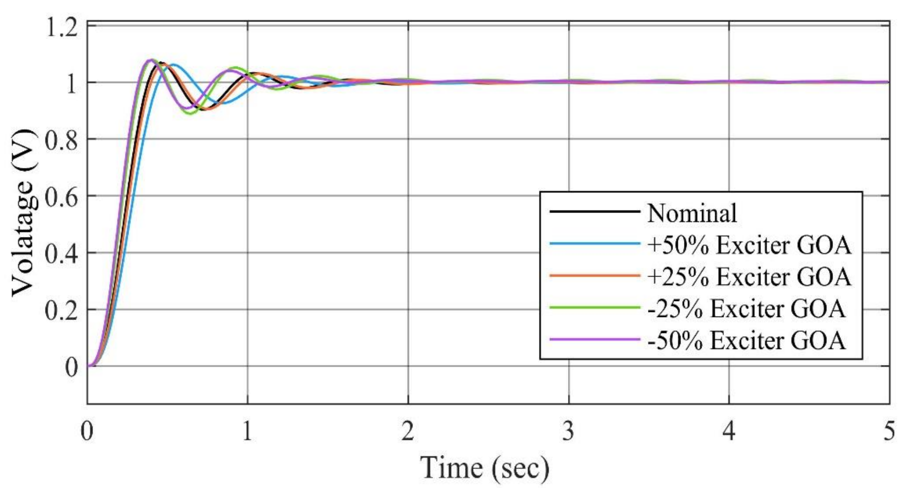

Figure 5. Exciter time constant variations results via GOA

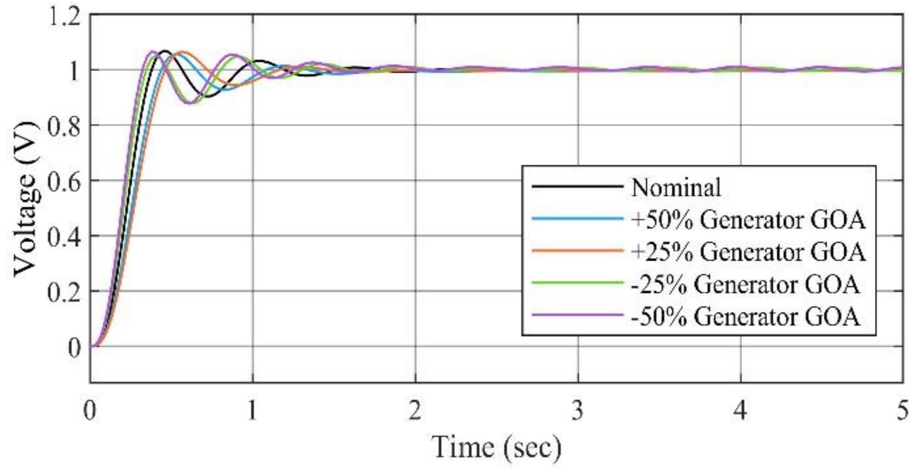

Figure 6. Generator time constant variations results via GOA

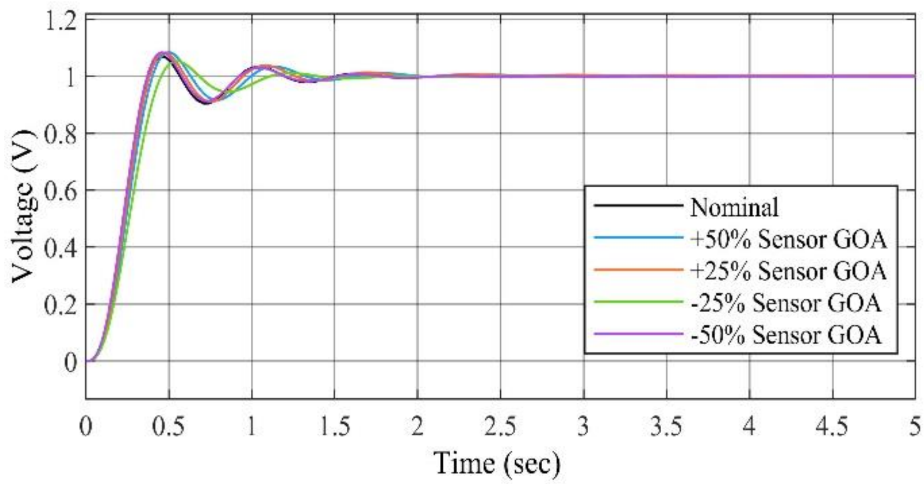

Figure 7. Sensor time constant variations results via GOA

When examined the ±%25 and ±%50 deviations graphics of the amplifier, exciter, generator and sensor time constant parameters determined by GOA, it is understood that the results are close to the nominal result.

The numerical outputs for the robustness analyzes have been given in Table 5:

Table 5. Performance results for robustness analyzes

	MP	RT(0.1 p.u to 0.9 p.u)	ST(±0.05 BW)
Nominal	1,069	0,223	0,842
+50% Amplifier	1,045	0,254	0,945
+25% Amplifier	1,061	0,268	0,989
-25% Amplifier	1,082	0,231	0,568
-50% Amplifier	1,068	0,235	0,571
+50% Exciter	1,062	0,261	0,947
+25% Exciter	1,063	0,234	0,872
-25% Exciter	1,080	0,196	0,942
-50% Exciter	1,077	0,189	0,713
+50% Generator	1,057	0,260	0,936
+25% Generator	1,065	0,275	0,954
-25% Generator	1,050	0,203	0,749
-50% Generator	1,065	0,189	0,911
+50% Sensor	1,083	0,238	0,901
+25% Sensor	1,083	0,228	0,865
-25% Sensor	1,052	0,269	0,910
-50% Sensor	1,083	0,219	0,837

It can be clearly seen from the Table 5 that computed results are near to the nominal output results. From the results here, it is seen that GOA exhibits quite capable performance when the system time constants parameters deviations for AVR system.

Calculated results have been presented as a bar graphic in Figure 8 and Figure 9:

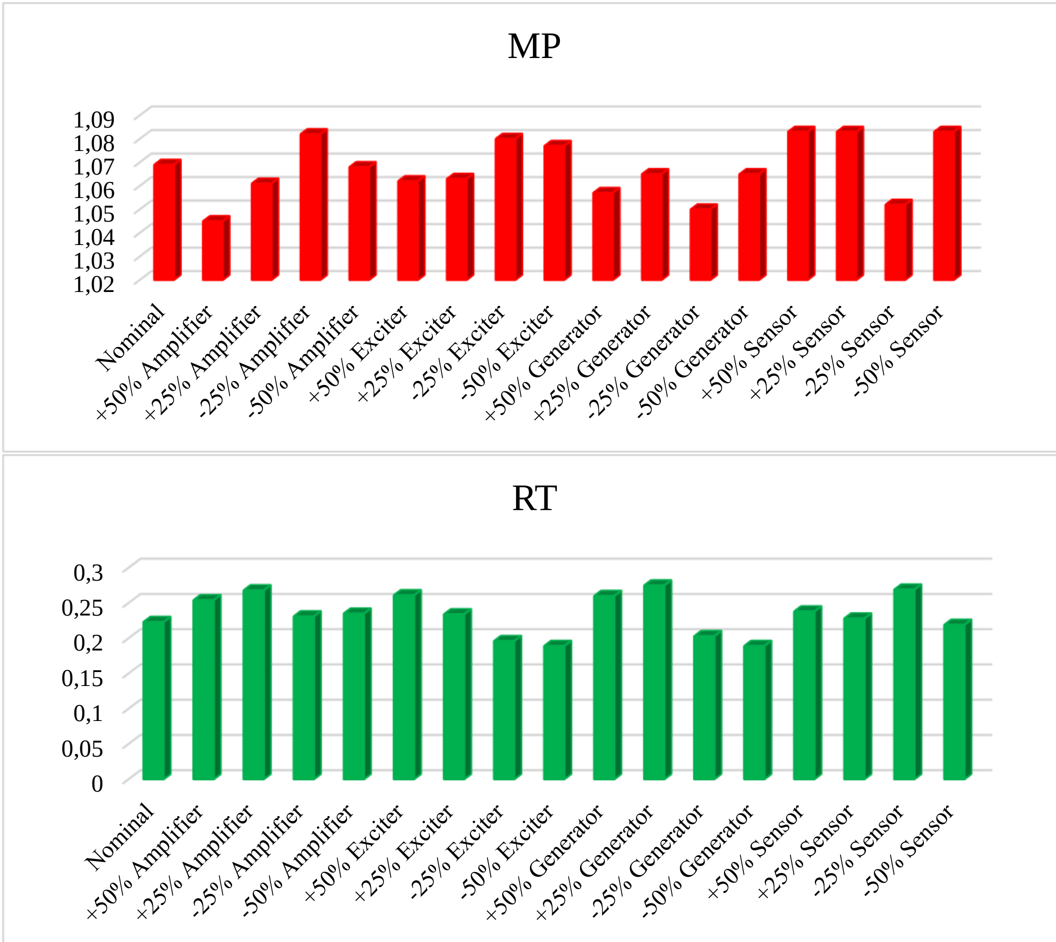

Figure 8. Bar graphic illustration of MP and RT as robustness analyzes performances

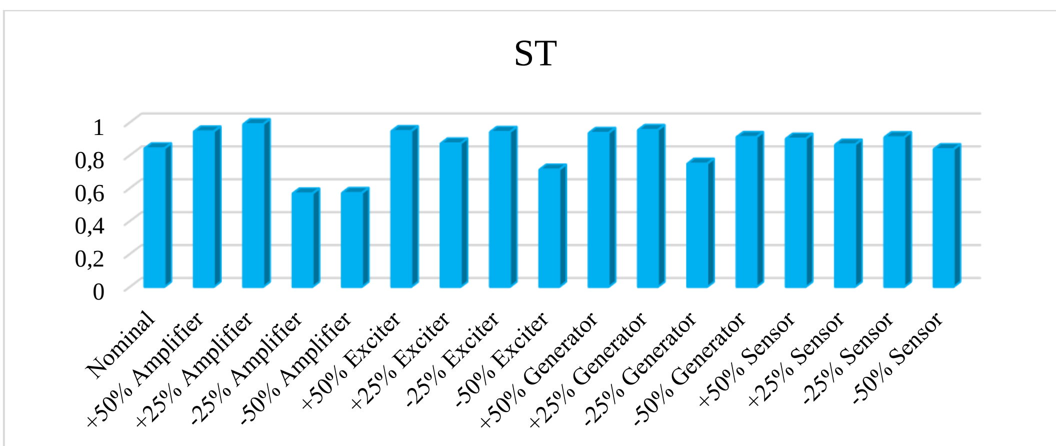

Figure 9. Bar graphic illustration of ST as robustness analyzes performances

5.Conclusions

In this paper, in order to improve the AVR system performances golf optimization algorithm and vortex search algorithm has been selected. PID controller parameters have been determined with using of these techniques for the AVR system. Objective function has been selected as integral time square error for GOA and VSA algorithms. System performances have been analyzed with respect to MP values, rising times (from 0.1 p.u. to 0.1 p.u) and settling times (±0.05 bandwidth). The results with GOA and VSA have been compared with particle swarm optimization result [15]. It can be clearly seen from the obtained results that recently developed GOA gives better system outputs than PSO [15] and VSA. For this reason, robustness analyzed have been performed via GOA for ±25% and ±50% deviations of time constant parameter. The results obtained with GOA have been found to be close to the nominal results.

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