AUTOMATIC VOLTAGE REGULATOR WITH COMMUNICATION TIME DELAYS UNDER WATER CYCLE ALGORITHM BASED IDDF CONTROLLER

Abstract

This paper investigates the optimal performance of the automatic voltage regulator under the control of integral double derivative plus filter (IDDF) based on the water cycle algorithm (WCA) subjected to the integral time square error (ITSE) index. However, to showcase the sovereignty of the WCA, the performance of the AVR is analysed with the IDDF controller based on the optimizations of gravitational search algorithm (GSA) and simulated annealing (SA). Moreover, the analysis of the AVR is carried out subjected to the practical constraints of without and with taking the communication time delays (CTDs) and their subsequent impact on the AVR performance is demonstrated. Further, the performance of IDDF controller efficacy is validated with the other widely accepted controllers in the literature. Simulation results reveal the effectiveness of the WCA based IDDF controller in maintaining the terminal voltage of the AVR.

Keywords: Automatic voltage regulator, communication time delays, IDDF controller, water cycle algorithm, Integral time square error.

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I. INTRODUCTION

The control of the AVR transient nature has been the challenging thing for the power system engineers especially at the event of rapid load fluctuations. The inductive nature of the generator field winding made the behaviour of the AVR more transient and its operation becomes too complex. Moreover, the overall stability of the power system also depends on the control of AVR action. Thus, the control of AVR has become the serious issue while assessing the electrical power network stability. The major intention of the AVR is to maintain the system voltage at the specified value irrespective of the load changes. Recently, the industrial experts are striving their efforts in control of the AVR to attain the constant voltage at any conditions.

Several control strategies for AVR analysis is put forwarded by the researchers and most of them are related to the conventional PID controllers. The design of PID is simple, but finding its best suitable parameters for the plant model is not an easy task. Various traditional tuning approaches such as Ziegler-Nicholas, Nelder-Mead, pole placement method, and Cohen-Coon are reported extensively. However, the primitive tuning methods are no more suitable for the plant models with non-linearity behaviour of the CTDs. Further, the research scholars adopted various soft computing optimization methods like frog search algorithm, sine-cosine algorithm [1], cat search technique, gradient based algorithm [2], moth flame optimizer, sea horse algorithm, generalized Hurwitz approach [3], symbiotic organisms search method, naked mole rate optimizer, squirrel search algorithm, COOOT algorithm, and RUN optimizer [4] etc. for parameter tuning of controllers to the AVR.

In addition to the above approaches, fuzzy logic control (FLC), and the control techniques evolved from the theory of fractional calculus and are termed as fractional order (FO) controllers have become the recent trends in AVR analysis. However, the optimal performance of FO and FLC also demand the soft computing optimization methods for parametric identification.Algorithms like JAYA optimizer [5], gravitational search algorithm, schooling fish method, slap swarm algorithm, bibliography algorithm, sooty tern optimizer, seagull algorithm, Harris Hawks algorithm, Equilibrium optimizer [6], atom search algorithm, teaching learning algorithm [7], heuristic ant colony optimizer [8], and sine-cosine algorithm [9]etc. are studied.

So many parameters in FO and complexity in the design of FLC made the authors to concentrate on the development of the modified conventional controller. IDDF controller efficacy is reported in the literature and this enlightens to adopt this controller in this work for AVR analysis. Moreover, the WCA is selected for the parametric tuning of IDDF controller in this study.

The contributions in this work are

- IDDF using WCA optimization is enacted for the AVR action.
- Efficacy of IDDF is validated with the PID, PIDD, and TID.
- Supremacy of WCA is demonstrated with the GSA and SA.
- Impact of CTDs on AVR performance is demonstrated.

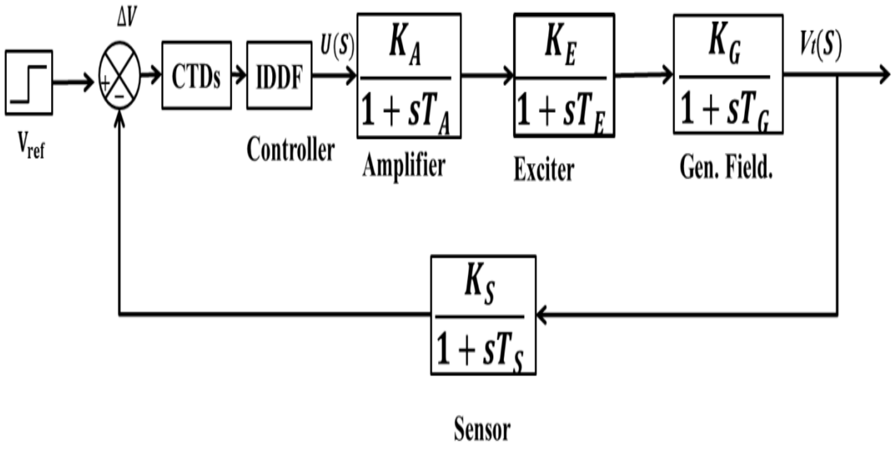

Figure 1: Transfer function model of AVR

II. AUTOMATIC VOLTAGE REGULATOR

The AVR plays a vital role in the power system in maintain the system terminal voltage. The AVR consists of various units such as amplifier (G_A), exciter (G_E), and generator filed (G_G), and the sensor (G_S). The transfer function modelling of AVR is shown in Fig.1 and the mathematical modelling is as follows:

$$G_A = \frac{K_A}{1+sT_A} \tag{1}$$

$$G_E = \frac{K_E}{1+sT_E} \tag{2}$$

$$G_G = \frac{K_G}{1+sT_G} \tag{3}$$

$$G_S = \frac{K_S}{1+sT_S} \tag{4}$$

Every time, the sensory unit senses the terminal voltage and compares with the reference signal to generate the error. Depending up on the error, the controller makes the control actions to regulate the voltage. The signal delivered by the controller is amplified and then fed to the exciter to change the generator field excitation. However, the transmitting of signals is possible through the communication peripherals and these have the inherit property of the CTDs. The CTDs are given least priority in the literature and to investigate the analysis near to the real time environment, this work considers the CTDs as modelled in Equation (5).

$$e^{-s\tau_d} = \frac{1-\frac{\tau_d}{2}s}{1+\frac{\tau_d}{2}s} \tag{5}$$

III. CONTROLLER AND OBJECTIVE FUNCTION (IDDF-ITSE)

The integral knob in the IDDF can made the continuous effort in avoiding the gap between the process variable and the set point. The double derivative knob helps to dampen the deviations more effectively and the filter in the IDDF can eliminate the disturbances in the error as well as in the control signal. Thus, considering the aforementioned advantages the IDDF controller is enacted for the AVR in this work and the parameters are found with the WCA optimization subjected to ITSE index given in Equation (6). The IDDF controller structure is shown in Fig.2.

$$J_{ITSE} = \int_{0}^{T_{Sim}} (V^2)*T\,dt \qquad (6)$$

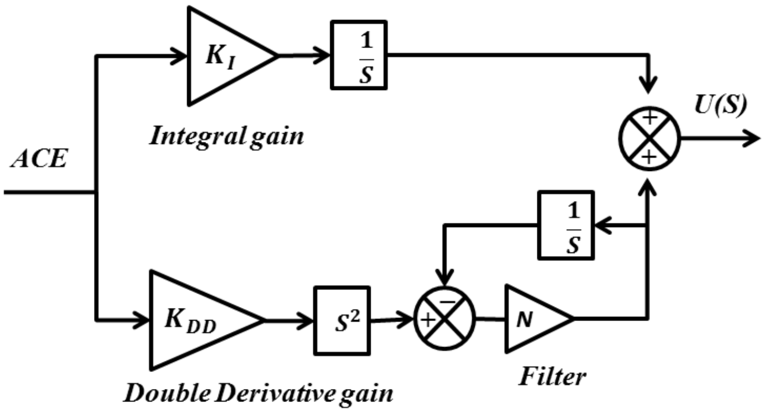

Figure 2: Structure of IDDF controller.

IV. WATER CYCLE ALGORITHM

```
Initialize population  # Create an initial set of candidate solutions
Evaluate fitness for each solution in the population  # Calculate the quality of each
solution

Repeat until termination condition is met:
   Evaporation phase:
      Reduce the fitness of each solution in the population
      Update fitness values for the solutions
   Precipitation phase:
      Generate new solutions based on the fitness of the current population
      Evaluate the fitness of the new solutions
   Flow phase:
      Replace some solutions in the population with the newly generated solutions
      Maintain diversity while favoring better-performing solutions
   Update termination condition  # Check if termination criterion is met (e.g., maximum
iterations)
End loop
Select the best solution found in the population as the optimal solution
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Figure 3: Pseudo code of WCA.

Getting inspired from the phenomena of water cycle in the environment, the authors in [10] proposed the WCA for global optimization problems. This algorithm mimics the process of raining, precipitation and evaporation in its searching strategy. The pseudo code of the WCA is shown in Fig.3 and the detail mathematic modelling is available in reference [11]. The flow chart of WCA is depicted in Fig.4.

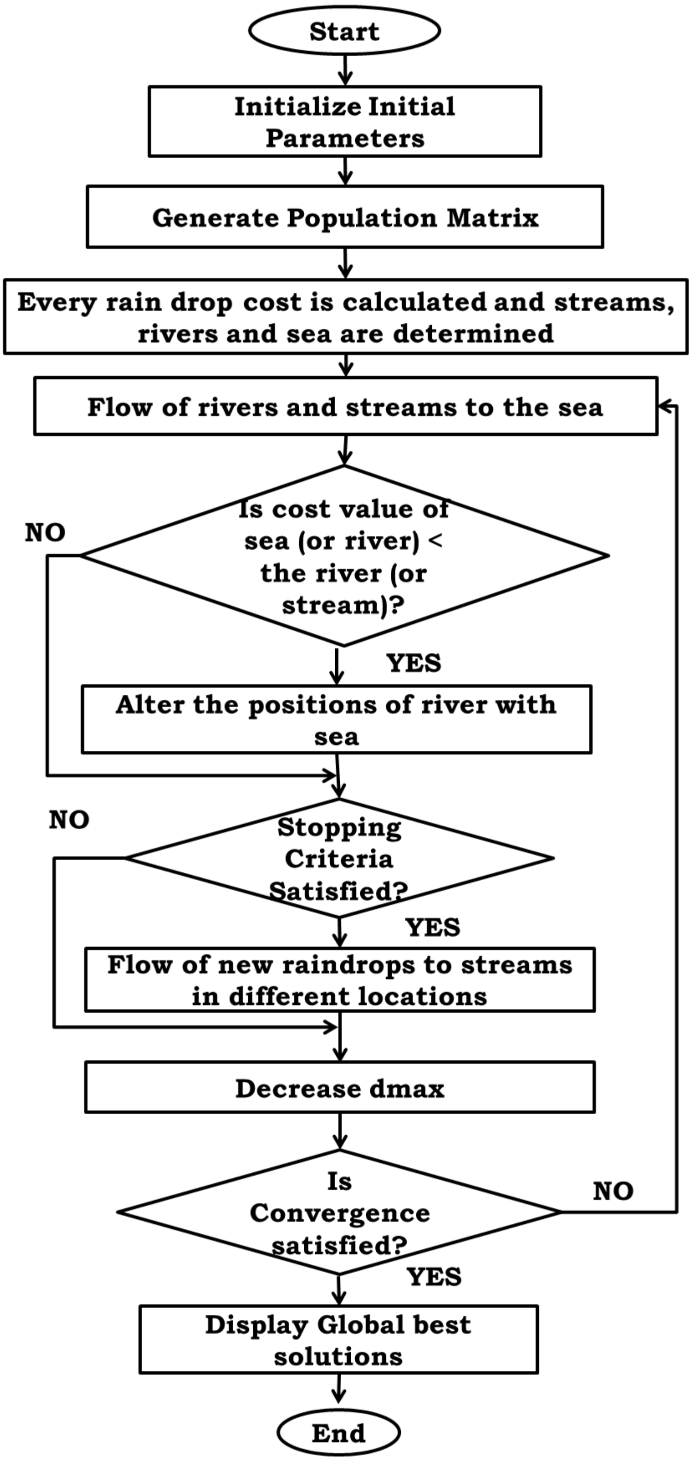

Figure 4: WCA flowchart.

V. SIMULATION RESULTS

1. **Scenario-1:** Analysis of AVR without CTDs under IDDF controller based on various algorithms.In this scenario, the AVR performance without CTDs is assessed under the control of IDDF based on optimizations like WCA, GSA, and SA individually. The dynamic responses of AVR under IDDF based on the above said algorithms are shown in Fig.5. Noticing the Fig.5, it is observed that the performance of the IDDF seems to be more efficacious with the optimization of WCA in compared to that of GSA and GA. The WCA tuned IDDF delivers good performance in terms of the AVR terminal voltage in attaining the 1P.u terminal voltage in less time as given in Table 1. Moreover, the ITSE index is regulated finely with WCA and is enhanced by 60.92% and 49.97% with SA and GSA.

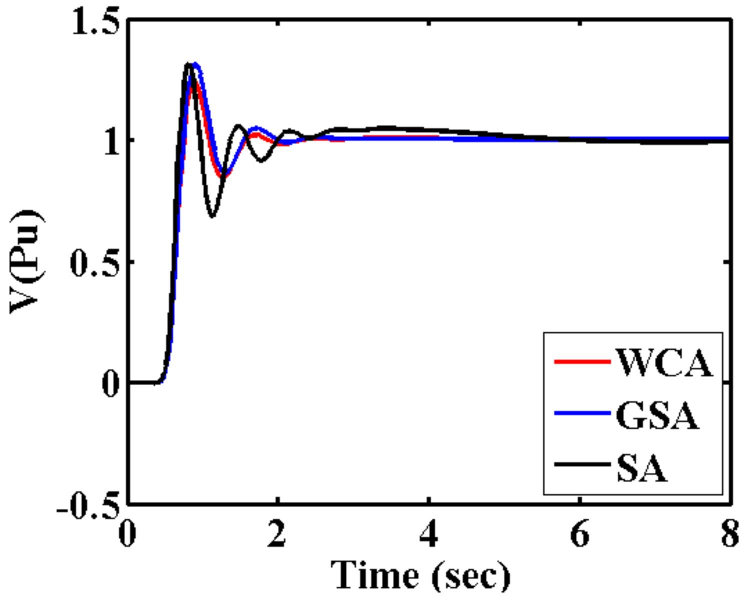

Figure 5: Scenario-1 responses.

2. **Scenario-2:** Analysis of AVR with CTDs under IDDF controller based on various algorithms In this scenario, the AVR performance is analysed by considering the CTDs with the time delay parameter of 0.25seconds. The WCA, GSA, and SA optimizations are implemented individually on the IDDF controller and the IDDF is placed with the AVR. The dynamic responses of AVR with CTDs are shown in Fig.6 and are clear that the efficacy of the WCA algorithm is showcased one more time. The peak over shoots (POS) of the AVR terminal voltage is predominantly regulated by the WCA tuned IDDF controller compared to the other algorithms. Further, even the CTDs are considered with the AVR, the WCA exhibits the dominance in minimizing the ITSE and is improved by 64.13% and 74.51% with GSA and SA as given in Table 1. From this, it is concluded that the WCA can perform well with the linearized and the non-linearized plant models in regulating the dynamical behaviour.

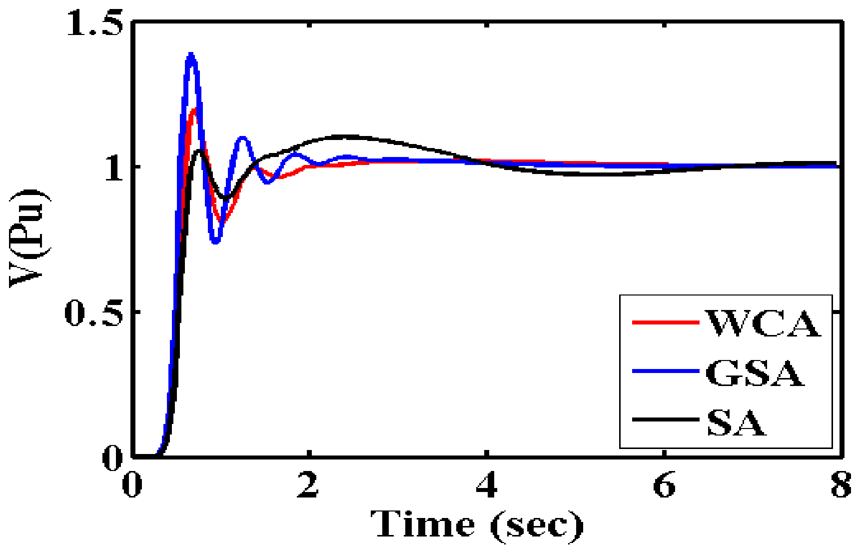

Figure 6: Scenario-2 responses.

Table 1: Responses settling time and controller optimal gains

Parameters	**Scenario 1**			**Scenario 2**		
	SA	GSA	WCA	SA	GSA	WCA
K_I	2.167	1.854	1.734	2.276	1.746	1.644
K_{DD}	3.287	2.198	2.117	2.978	2.166	2.771
N	201.32	211.45	224.17	221.89	238.65	239.18
Settling time (Seconds)	7.71	6.43	4.17	13.67	7.11	6.49
$ITSE*10^{-3}$	22.16	17.31	8.66	76.38	54.29	19.47

3. **Scenario-3:** Revealing the effect of CTDs on AVR performance: The dominance of CTDs on the working of the AVR is intended to demonstrate in this subsection under the control of WCA tuned IDDF regulator as it proved as the best in the above scenarios. The dynamic behaviour of AVR with and without CTDs is shown in Fig.7, and it has been observed that the AVR behaviour is slightly more disturbed while considering the CTDs. It happens because of the delay in signal received by the controller from the sensor. Sensor usually senses the terminal voltage continuously and sends to the regulator through the communication peripherals for appropriate actions. The communication peripherals have the time delay nature by inheritance. Hence, more deviations in the responses in terms of attaining the 1P.u after longer durations and more POS are identified in the AVR performance with CTDs. Even though, more deviations are noticed in the AVR performance with CTDs, this work recommending considering them for conducting the investigation near to the real time environment.

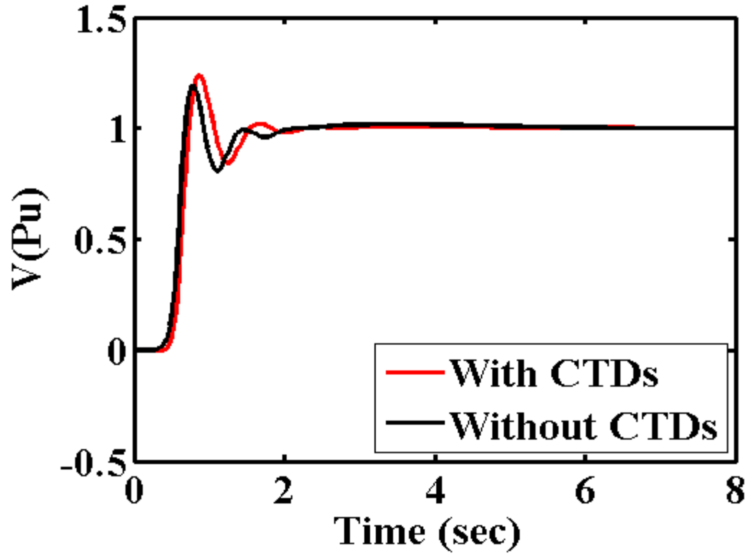

Figure 7: Scenario-3 responses.

4. **Scenario-4:** Analysis of AVR with CTDs under various controllers optimized with WCA. It is required to showcase the efficacy of the IDDF controller and hence the AVR performance with CTDs is analysed under various controllers like PID, PIDD, TID, and IDDF based on WCA optimization in this scenario. These controllers are enacted with the AVR independently and optimized with WCA in unique conditions of 100 populations and iterations, and the corresponding responses are shown in Fig.8. After analysing the Fig.8 responses it is concluded that the IDDF is more superior to the other controllers of PID, PIDD, and TID in regulating the AVR performance.

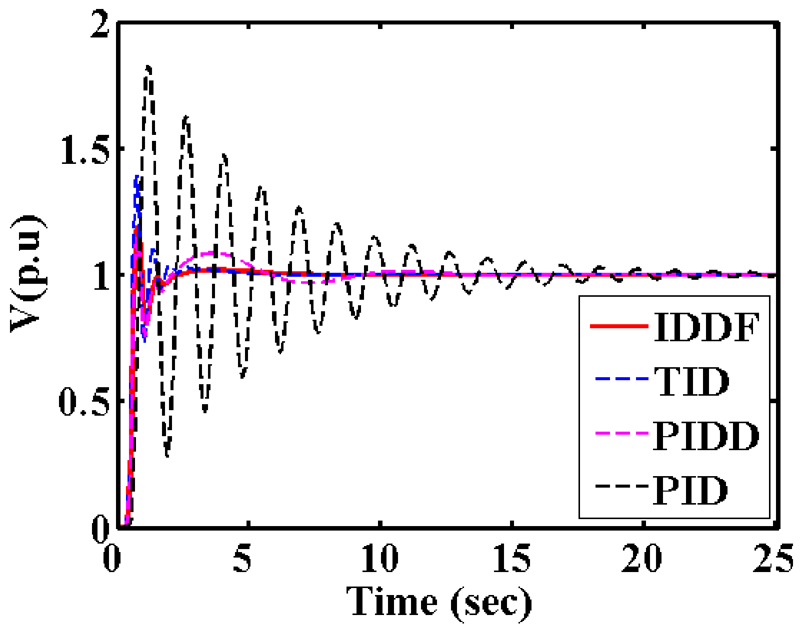

Figure 8: Scenario-4 responses.

VI. CONCLUSION

This paper developed the IDDF controller for the automatic voltage regulation using the optimization of WCA. However, for getting the investigation study near to the real time environment, the AVR analysis is performed without and with CTDs consideration. Further, the subsequent impact of CTDs on AVR performance is revealed and justified. The optimal tuning of IDDF is performed with WCA subjected to the objective function of ITSE index. The efficacy of the WCA is validated with the optimizations of GSA and SA. Further, the sovereignty of the IDDF controller performance is demonstrated with those of PID, PIDD and TID controllers.

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