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Control Techniques for Enhancing the Performance of Automatic Voltage Regulator in Power System Stability

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Abstract— Voltage variations in electrical power system can result in voltage drop, spike or surge and thereby damaging electrical devices. The introduction of Automatic Voltage Regulator (AVR) as part of the power generating unit has brought relief in power system stability management. Implementing good and efficient controller as part of closed control system for AVR unit guarantees the running of generating sets at safe and stable conditions for normal operations and rapid response under different type of disturbances is very important in power system stability. This paper has carried out empirical survey of proposed and implemented control techniques for enhancing AVR system performance in power system stability management. The study showed that Proportional-Integral-Derivative (PID) controller is most commonly used control strategy such that majority of current research is geared towards optimizing the its gain parameters using bio inspired or intelligent algorithms such as particle swarm optimization (PSO), generic algorithm (GA), artificial bee colony (ABC), bacteria foraging optimization, teaching learning based optimization (TLBO) and their modified versions.

Keywords— AVR system, Control technique, Power system stability, Voltage variation.

1. INTRODUCTION

In electrical power systems and industrial applications, achieving stable and good regulation of different equipment has largely involved the use of Automatic Voltage Regulator (AVR). An AVR may be used as electromechanical system, active or passive electronic device.

Depending on the design, AVR can be employed to control alternating current (AC) or direct current (DC) voltage [1]. Maintaining specific voltage profile at the output terminal of a generator is important for satisfactory mains power supply.

Practically, the voltage levels should be sustained within certain limits. Given that the voltage profile is consistently varied by load fluctuations, therefore it should be permanently controlled by AVR. There is decrease in generator's terminal voltage as the reactive power increase. Compensating for the terminal voltage reduction requires some increments in the excitation current of the field winding of generating set.

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There are implications for terminal voltage of generator as changes in load, temperature, speed and other disturbances occur such that voltage regulating equipment is expected to keep specific voltage value and maintain continuous supply within acceptable quality. In power generation site, AVR system is employed to guarantee stability of generator's terminal voltage. Nevertheless, without any controller, the response of AVR system will be slow and may cause instability [2].

Thus, providing proper generator control by AVR system is very necessary to make sure that generators operate at safe and stable conditions for normal operations and rapid response under different types of disturbances.

It is necessary to develop a system that will provide minimum voltage deviation under certain load variations. In view of this, control technique to enhance the operation of automatic voltage regulator (AVR) system in which the concern is to ensure that the output (actual) voltage is kept near the desired or referenced level of voltage with minimal or zero error is desirable.

Automatic voltage regulator works on the concept that when the voltage at the output terminal of the generator gets disturbed due to the application of certain load then a change in the excitation of field can distort terminal voltage.

Leveraging on this concept, different control techniques designed and proposed to ensure that any deviation in terminal voltage arising due to changing load effect and any other disturbance is addressed by continuously coordinating the exciter system of synchronous generator.

This paper is an empirical survey of some of the most recent control techniques that have been proposed and implemented in literature. The surveyed literatures were obtained online from different journal sites and Google scholar. The study has considered recently published article not more than a decade (that is from 2010-2020).

II. TERMINAL VOLTAGE PROBLEM OF GENERATOR

An essential role is provided by AVR in power generating stations. Stabilizing the generator's voltage requires that the terminal voltage should be maintained at specific level all the time.

Manual regulation is difficult in a large connected system and as such it is necessary to generate and regulate voltage automatically. So maintaining a specific level of voltage at each generating station/synchronous generator, AVRs are used.

Generally, the voltage fluctuation is mainly due to either the variation in the load, speed, temperature and power factor, and if there is voltage variation then it can damage the equipment.

In fact, any deviation from these physical parameters can result in decrease in performance and lifetime of these synchronous machines.

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Therefore, it is necessary to stabilize the voltage, so AVR integrating a control algorithm is employed power systems to stabilize the voltage or regulate the voltage. A schematic diagram of a typical AVR system is shown in Fig.1.

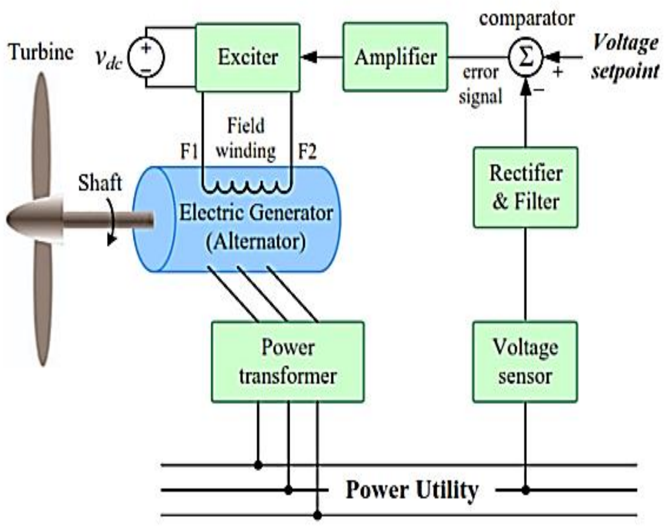

Fig. 1 Illustration of AVR system [3]

III. CONCEPT OF AVR SYSTEM AND COMPONENT DESCRIPTION

The demand for AVR becomes very necessary because the supply voltage from generating set is expected to be kept at steady profile otherwise the performance of motors, lights and other loads will be affected. The voltage of an alternating current (AC) generator can vary 30% or more from no-load to full load [4]. Closed loop control of generator voltage is achievable only by automatically regulating the voltage by means of an AVR device. A typical AVR assisted synchronous generator is shown in Fig. 2.

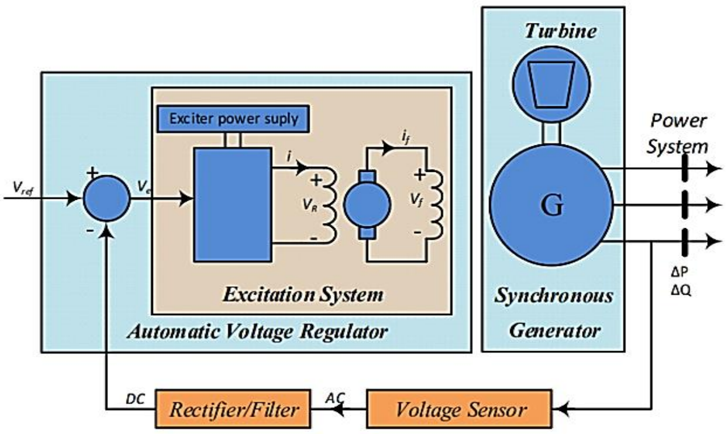

Fig. 2 AVR assisted synchronous generator [5]

In view of AVR system in synchronous generator, consider Fig. 2 such that any change generator's output voltage will change the terminal voltage. The value of the voltage measured by a voltage sensor is

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transmitted to AVR. The terminal voltage of the excitation system is then altered by the AVR to keep the generator's terminal voltage at a preset or desired voltage level. The generator's field current changes by this way, and this also results in changes in the generated electromotive force (EMF) [4]. The power generation of the generator is adjusted to a new stable point and the terminal voltage is sustained at the expected value [2][5][6].

A. Exciter System

The exciter system is used in power system to provide field current to rotor winding of synchronous machine. The basic requirement of excitation system is reliability under all condition and simplicity of control. The amount of excitation required is a function of the load power factor (p.f.), load current and machine speed. The excitation is more when load current of the system is high, p.f. is lagging and machine speed is less [4].

In the transient study of power system analysis, excitation control system is one of the important factors [7]. It controls the generated EMF of the generator and therefore not only the output voltage is controlled but also the p.f. and the magnitude of the current as well. A typical relationship between the excitation control system and the generator is shown in Fig. 3.

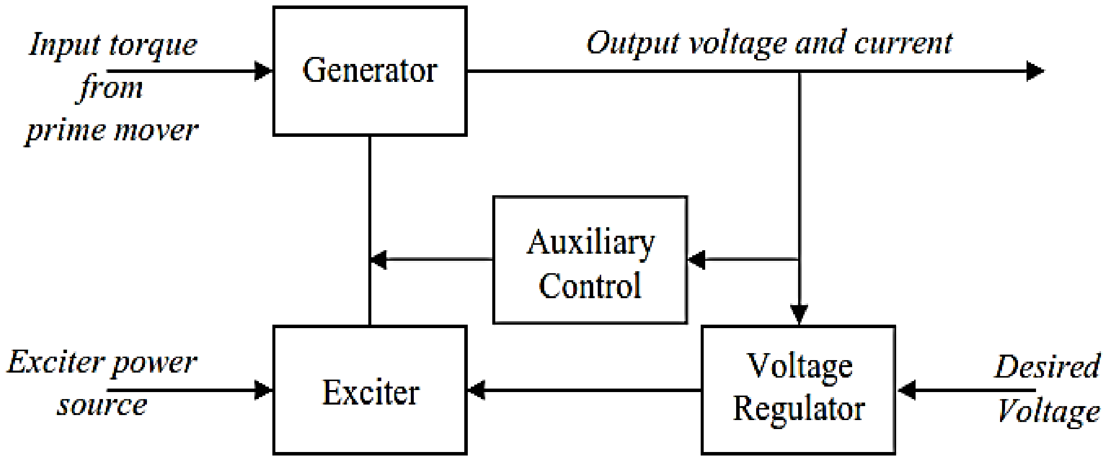

Fig. 3 Typical structure of excitation components [8]

B. Operation of Generating Set

In generating set, both active (P) and reactive (Q) powers are supplied by generator. Active power is the power required for purely resistive loads such as an ideal heater. A purely resistive load is one in which no phase shift between the voltage and the current. It is necessary to produce the same amount of the active power as it is consumed. Otherwise the frequency starts increasing or decreasing.

On the other hand, the power oscillating between the load and the generator is called the reactive power. An inductive reactive power is needed for creating say, a magnetic field for electric motor. Voltage leads current by 90^0 in inductive reactive power. The reactive power can also be capacitive in which case the voltage lags behind the current by 90^0. The capacitive reactive power is required in long power transmission lines which form a huge capacitor with the earth. Also, reactive power generation must meet the consumption (load variation). Otherwise the voltage increases or decreases. Hence, the reason why the need for AVR system to achieve steady voltage for power generation and transmission in the operation of synchronous generator is increasingly being demanded in power sector.

C. Description of AVR system Components

The components of a conventional AVR system are the amplifier, the exciter, the generator, and the output voltage measurement sensor. The excitation system amplifier may be a magnetic amplifier, rotating amplifier, or contemporary electronic [9]. The model of the amplifier is expressed in transfer function given by:

$$G(s) = \frac{K_a}{1 + \tau_a s} \qquad (1)$$

where K_a is the amplifier gain, τ_a is the time constant of the amplifier.

Although different types of excitation system are common, contemporary ones employ AC power source through solid state rectifiers such as silicon control rectifier (SCR) [9]. The output voltage of the exciter is a nonlinear function of the field voltage as a result of the saturation effect of the field voltage. Nevertheless, in modern exciter, a linearized model is established that considers the time constant while ignoring the saturation or other nonlinearity [10]. Exciter model is given by:

$$G(s) = \frac{K_e}{1 + \tau_e s} \qquad (2)$$

where K_e is the exciter gain, τ_e is the time constant of the exciter.

The generated EMF of synchronous generator is a function of the machine magnetization curve. The model of the generator is a transfer function of terminal voltage to exciter field voltage is given by:

$$G(s) = \frac{K_g}{1 + \tau_g s} \qquad (3)$$

where K_g is the generator gain, τ_g is the time constant of the generator.

The sensor measures or detects the terminal voltage of the generator and feeds it back to a comparator circuit of the exciter amplifier. The sensor model is given by:

$$G(s) = \frac{K_s}{1 + \tau_s s} \qquad (4)$$

where K_s is the exciter gain, τ_s is the time constant of the exciter.

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This section has presented the concept of AVR and the description of its components including the mathematical models.

IV. CONTROL TECHNIQUE IMPLEMENTATION

This section presents a thorough but concise reassessment of various control strategies that have been done in this area of research in control system design and implementation in power stability management. The review focuses on recent studies related to this work not more than a decade.

Muoghalu et al. [10] studied performance response improvement of automatic voltage regulator (AVR) using linear quadratic Gaussian tuned controller (LQGTC). The objective of the study was to minimize deviation from the desired terminal voltage using linear quadratic Gaussian (LQG) method to design a control algorithm that would offer robust performance for different value range of operational parameters of AVR system. Using the Control and Estimation Tools Manager (CETM) LQG controller design technique of the automatic tuning of the MATLAB/Simulink, the proposed LQGTC controller was designed. The performance of the system was evaluated in terms of time domain parameters namely, rise time, time to peak, percentage overshoot, and settling time. The results from the first scenario indicated that the AVR system achieved rise time of 0.25 second, time to peak of 0.61 second, overshoot of 4.50%, and settling tome of 1.01 seconds. For the second case, the AVR system achieved 0.28 second in rise time, 0.72 second in time to peak, 23.76% overshoot, and 1.97 seconds respectively. The study further validated the effectiveness of the proposed system by considering different desired voltage values and the results obtained were the same as those from unit step input voltage. The effect of load variation or disturbance was not considered in the study.

Govindan [11] studied evolutionary algorithms-based tuning of PID controller for an AVR system. Particle swarm optimization (PSO) and cuckoo search (CS) algorithms were proposed in the study with a new objective function to tune the gains of PID controller for the control of AVR system. The PID was tuned using Ziegler-Nichol (ZN), PSO, and CS methods. The proposed method found the optimal gains of the PID controller by solving the optimization problem for minimizing the objective function consisting of integral absolute error (IAE), rise time, settling time and peak overshoot. Simulation results showed that ZN tuned PID controller offered rise time of 0.2128 second, peak time of 0.5535 seconds, peak overshoot of 31.4216%, and settling time of 1.074 seconds. For PSO with IAE and PSO combined, rise times were 0.1689 second and 0.3271 second, peak times were 0.355 second and 2.3326 seconds, peak overshoots were 13.872% and 0.4532%, and settling times were 0.8982 second and 1.1375 seconds. Then for CS with IAE and CS combined, the time domain performance in terms of rise time, peak time, peak overshoot, and settling time were 0.1847 second and 0.344 second, 0.5733 second and 0.6581 second, 4.4346 % and 0.0853%, and 0.7423 second and 0.5299 second respectively. The CS algorithm was found to have offered the most effective performance in terms of the time domain characteristic performance criteria. However, the study did not consider the effect of load variation or other form of perturbation such as rise in temperature on the system.

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Micev et al. [12] used hybrid simulated annealing-manta ray foraging optimization (SA-MRFO) algorithm in AVR control system. Four different types of PID controllers for an AVR system were optimally tuned by a hybrid metaheuristic method. The approach was based on manta ray foraging model which was combined with simulated annealing algorithm. The study further proposed a novel objective functions for the optimization of the controller's parameters. The proposed SA-MRFO method was considered for ideal PID, real PID, fractional order PID (FOPID), and second order derivative PID ($PIDD^2$). The results obtained by optimizing the performance of the various PID controllers with SA-MRFO algorithm were presented in terms of time domain parameters. For conventional PID, the rise time was 0.2540 second, settling time was 0.3802 second, and overshoot was 1.7999%. Then for the real PID and FOPID, the rise times, settling times, and overshoots were 0.2576 second and 0.1309 second, 0.3871 second and 0.1909 second, and 1.7283% and 1.9765%. Finally, with the SA-MRFO algorithm applied to $PIDD^2$ the results showed rise time of 0.0535 seconds, settling time of 0.0798, and overshoot of 0.7562%.

Çelik and Durgut [3] used modified cost function and symbiotic organisms search (SOS) algorithm to enhance the performance of AVR system. The study attempted to address the problem of efficient design of PID controller used in a famous AVR system by introducing SOS algorithm. The SOS algorithm was used as an optimization scheme to tune the parameters of the PID controller so as to achieve minimum cost function. The performance of the proposed scheme was analyzed in terms of transient response, bode plots, and root locus in both time and frequency domains. The results obtained from the simulations conducted indicated that the addition of the developed cost function and SOS scheme improved the trade-off between the dynamic response and the stability margin of the AVR system. Simulation results also indicated that the system was capable to provide the desired response when subject to parameter variations and external disturbance. The robustness of the proposed SOS-PID was ascertained by varying the time constants of the various components of the AVR system such that the average deviation of peak overshoot, settling time and rise time were 4.2%, 115.2% and 22% and this was approximately below 0.5 for all the ranges of total deviations considered. However, one limitation of SOS scheme is that the transient response time characteristics such as rise time and settling are degraded by increasing the third weighting factor of the algorithm.

Yu and Zaw [13] examined the performance of AVR system controlled by stabilizer and PID controller. The proposed scheme was implemented on AVR controller simulation model developed in power system based on real data from Baluchaung number two (No. 2) Hydro Power Plant (Myanmar) to study the effectiveness of the stabilizer and PID controller. A linear block model and control techniques in MATLAB/Simulink environment was used to study the characteristics of the AVR system. Simulation results showed that the stabilizer and PID controller yielded better performance characteristics in terms of settling time and overshoot. The study did not consider the effect of disturbance and as such nonlinearity effect that can be caused by unanticipated perturbation entering the system will affect the performance of PID controller.

Özdemir and Çelik [5] carried out stability analysis of automatic voltage regulation system with proportional integral (PI) controller. The objective was to compute the stable parameter space of controller gains when AVR system is controlled by a PI controller. Stability boundary locus method, which is a graphical-based technique, was used to determine the stable parameters of Proportional-Integral (PI) controller. Closed region stability was calculated on parameter space obtained from the root of the characteristic equation of AVR system. The problem with this technique is that PI controller is prone to integral wind up due to error accumulation overtime.

Ibrahim et al. [2] studied modelling and simulation of AVR system. The objective of the study was to consider a generator AVR system without PID controller and with PID controller. The PID controller was tuned with a view of improving the response of the system and compared the frequency deviation step response and the tuned PID controller block performance using linear block model and control technique implemented in MATLAB/Simulink environment. The settling time of the AVR with PID controller was 1.44 seconds and it was better than that without PID which was 5.54 seconds. Using PID alone will not be effective enough in the presence of nonlinearity.

Eswaramma and Kalyan [9] presented an automatic voltage regulator system control using a proportional integral derivative (PID) plus second order derivative (PIDD) controller. The study proposed an AVR control system using double derivative PID controller (PIDD) to provide dead-beat response but generally make the response faster with reduced rise and settling times than conventional PID controller. However, the PIDD can produce high peak overshoots in the transient part such that a pre-filter was added to the loop to address this effect. Simulations were conducted for AVR closed loop without PIDD, with PIDD, and with PIDD plus pre-filter. The results obtained indicated that for AVR without PIDD, the rise time was 0.322 seconds, overshoot was 50.2 seconds, and settling time was 4.89 seconds. For AVR with PIDD, the values obtained were 0.00099 second rise time, 95.5% overshoot, and 0.282 second settling time. Finally, for PIDD plus pre-filter, the rise time, overshoot, and settling time were 0.066 seconds, 1.27 %, and 0.129 seconds respectively. The effectiveness of the PIDD control system in the presence of perturbation such as load variation was not tested.

Mittal and Rai [14] carried out performance analysis of conventional controllers for AVR. The primary purpose of study was to evaluate performance of different traditional control schemes in AVR system. The model of PID controller, cascade controller and internal model controller (IMC) were presented and added separately in AVR closed loop system. Simulations were conducted with respect to the various controllers. The results obtained with each controller in AVR closed loop were presented in time domain. For PID controller designed based on Ziegler-Nichol method, the rise time was 0.236 seconds, overshoot was 44%, and the settling time was 3.31 seconds. For PID controller designed using trial-error method, the rise time was 0.606 seconds, the overshoot was 0.446%, and the settling time was 1.00 seconds. Then, for the cascade controller, the response performance in terms of rise time, percentage overshoot, and settling time were 0.368 seconds, 0.41%, and 0.606 second respectively. Finally, the IMC provided 0.86 second in rise time, 0% in overshoot, and 1.49 seconds settling time. The authors maintained that IMC based model provided a better response performance than conventional PID. The capacity of the IMC control to handle load variation was not considered.

Gunadin et al. [15] designed a control system for AVR to improve voltage stability at Senkang power plant, South Sulawesi, Indonesia. Routh-Hurwitz equation was used to determine the gain of AVR. A PID controller was designed via MATLAB simulation to determine the gain constants, and applied to improve the output response of the AVR. Simulation showed that the system achieved maximum voltage of 1 per unit and the settling time is 10.15 seconds.

Pan and Das [16] designed a fractional order (FO) PID to address the various contradictory objective functions of AVR system. An evolutionary Non-dominated Sorting Generic Algorithm (NSGA II) that was improved with a chaotic map for greater effectiveness was employed for multi-objective optimization problem. The proposed a multi-objective optimization was use as a framework for comparing PID and FOPID controller for AVR system. It was from the simulations carried out that none of the controllers was superior to each other for all the designed specifications. However, for opposing objectives of setpoint tracking and load disturbance rejection, FOPID controller outperformed the PID.

Odili et al. [17] attempted to tune the parameters of a PID controller for effective AVR control using a metaheuristic tuning method called the African Buffalo Optimization (ABO) algorithm. The ABO scheme was used to solve the problem of the system's gain overshoot and steady state errors. The performance results of the proposed scheme were compared with that of Genetic Algorithm PID (GA-PID), Particle-Swam Optimization PID (PSO-PID), Ant Colony Optimization PID (ACO-PID), Bacteria-Foraging Optimization PID (BFO-PID), Linear Quadratic Regulator PID (LQR-PID), and others. It was observed that ABO-PID provided superior tuning capability of PID parameters of AVR system for effective time domain performance indices.

Al-awad [18] presented different reduced order models of AVR system and their corresponding time domain characteristics. The study showed that the considered various reduced order models yielded time responses that emulate or look similar to that of original system characteristics. Modeling and simulations were conducted in MATLAB/Simulink environment. It was observed that among the reduced order models, Deadbeat of first order outperformed all the three followed by Kalman controller and then lastly by internal model controller (IMC).

Chauhan and Patra [19] studied optimum design of Particle Swam Optimization (PSO) based tuning using PID controller for AVR system. In the study, the parameters of PID controller were optimized for a viable AVR. With the application of the proposed scheme, the transient response analysis showed that the maximum peak, settling time, rise time, and peak time of the system were considerably reduced.

Sajnekar et al. [20] presented an approach to tune PID controller to address the problems of digital excitation control system (DECS) that are responsible for deviating the terminal voltage from the rated

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value and at the same time make the power system unstable. The developed PID controller improved the performance of the excitation control system by reducing the overshoot from 75% to 16%.

Rajinikanth and Satapathy [21] designed a controller for AVR using teaching learning based optimization. The study proposed one degree of freedom (1DOF) and two degree of freedom (2DOF) PID control schemes and implemented the schemes on an AVR system using traditional teaching learning based optimization (TLBO) algorithm. The use of the TLBO algorithm to ensure that the process converged with an optimal solution was directed by minimization of a multi-objective function. Simulation was carried out to evaluate the performance of the proposed TLBO assisted 1DOF and 2DOF controller in an AVR closed loop control system. The results of the proposed system with 1DOF provided 1.6015 seconds in settling time and 0.0126% overshoot. For the various 2DOF PID controller namely, prefilter PID (FPID), feed-forward PID (FFPID), and feedback PID (FBPID), which are code name 2DOF (FPID), 2DOF (FF), and 2DOF (FB). The results showed that 2DOF (FPID) offered 1.7382 seconds and 0.0216% overshoot, 2DOF (FF) provided 1.7243 seconds and 0.0236% overshoot, and 2DOF (FB) 1.7252 seconds and 0.0241% overshoot. The authors stated that the FFPID and FBPID designed with traditional TLBO provided better performance than the 2DOF PID controller designed using particle swarm optimization (PSO), bacteria foraging optimization (BFO) and firefly algorithm (FA). The effectiveness of the proposed scheme notwithstanding, the rise as an essential parameter of transient response time characteristics of control system was not reported in the study.

Sahib [22] presented a novel optimal PID plus second order derivative controller for AVR system. The study proposed a new four term structure PID plus second order derivative (PIDD^2) whose four gains were tuned and optimized by PSO algorithm with integral time absolute error (ITAE) performance criterion. The performance of the AVR with PIDD^2 was compared with other PID controllers tuned using modern heuristic optimization algorithms such as many optimization liaison (MOL), genetic algorithm (GA), artificial bee colony (ABC), differential evolution algorithm (DEA), and local unimodal sampling (LUS). Further comparison of the proposed algorithm was done with fractional order PID controller tuned with chaotic ant swarm (CAS) algorithm. In the first comparison of the proposed PIDD^2 tuned PSO with ITAE (PIDD^2-PSO-ITAE) with other heuristic optimization techniques with either ITAE, integral time square error or f-function such as PID-PSO-ITAE, PID-MOL-ITAE, PID-GA-f, PID-PSO-f, PID-ABC-ITSE, PID-DEA-ITSE, and PID-LUS, the proposed algorithm provided the best time domain performance response in terms of rise time, peak time, peak overshoot, and settling time. It offered a rise time of 0.0929 seconds, peak time of 0.3200 seconds, overshoot of 0%, and settling time of 0.1635 seconds. Also when compared with CAS-PID, CAS-FOPID, PSO-PID, and PSO-FOPID, the PSO tuned PIDD^2 outperformed all of them yielding a rise time of 0.0929 second, overshoot of 0%, settling time of 0.1635, and steady state error of 1.06×10^{-8}. In addition, the study revealed that the frequency response, zero-pole, and robustness analysis carried out on PIDD^2 controller indicated better stability and improved performance characteristics than the PID and FOPID controllers. The problem with the PIDD^2 controller is that its output will show a large spike when there is sudden variation in the AVR system output due to load disturbance.

Ibraheem [7] used linear quadratic regulator (LQR) controller for a digital-based optimal AVR design of synchronous generator exciter. The study proposed a novel configuration for the AVR of power system exciter using digital-based LQR. Two weighting factors R and Q, which are the state and control matrices, were used to produce an optimal regulator that was used to generate the feedback control mechanism. Performance of the proposed AVR control system was evaluated on Single machine Infinite Bus-bar (SMIB) system and compared with conventional AVR system. Simulations were carried out to compare the performances of both the conventional AVR and the proposed digital-based AVR (DAVR). The results of the evaluation indicated that DAVR performed better than conventional AVR. The author uses linear quadratic regulator (LQR) controller. The LQR method assumes that all states are measurable, and find the control matrix (control law) before a control law can be applied. This required long computational process, which can be attributed to the difficulty in determining the right weighting matrices.

Fernaza and Laksono [23] studied linear quadratic regulator (LQR) control technique and its application to AVR system. The study focused on the use of LQR method to keep the terminal voltage level of a generator steady. Two matrices Q and R called weight matrix were used to achieve the optimal control signal from feedback state to raise AVR performance in maintaining stability of the system. Simulation results showed that the AVR closed loop response without LQR has a time domain characteristic performance of 0.2534 second, 82.7892%, and 19.0812 seconds in terms of rise time, percentage overshoot, and settling time. For the AVR system with LQR, the rise time was 0.4639 second, percentage overshoot of 3.5506%, and settling time of 1.2353 seconds.

Dixit et al. [24] surveyed PID optimization for automatic voltage regulator (AVR). The study investigated the use of PSO-PID and other optimization methods in solving the problem of AVR system. The review presented some AVR control systems that have employed evolutionary inspired algorithms to optimize PID controller such as chaotic optimization based on Lozi map (COLM), teaching learning based optimization (TLBO) method, bacterial foraging optimization (BFO) techniques, chaotic PSO and others.

Shayeghi and Dadashpour [25] studied anarchic society optimization based PID control of AVR system. The study aimed to apply a robust method for optimal PID control of AVR system to reduce terminal voltage fluctuation due to disturbances in power systems. Social grouping inspired anarchic society optimization (ASO) algorithm in which the members behave in anarchic manner to improve their state was used for the optimization. An optimization problem whose objective function is in time domain was formulated by considering the tuning of the PID gains as an optimal problem to control AVR system against uncertainties in parameters. The ASO algorithm which possessed a strong ability to determine the most optimistic results to minimize control system effort and obtain optimal design was able to address the optimal tuning problem of the PID gains. Multiple operation conditions were considered while performing the

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optimization to achieve the desired terminal voltage profile regulation. Investigation was carried out to ascertain the effectiveness of the ASO algorithm optimized PID controller under varying system parameter and was compared with PID controller optimized with craziness based particle swarm optimization (CRPSO) method and vector evaluated PSO (VEPSO) method respectively. Simulation results showed that ASO based PID control AVR system was effective and offered good terminal voltage instability reduction capacity. In addition, the ASO-PID outperformed the CRPSO-PID and VEPSO-PID methods in terms of accuracy, convergence and computational effort. Despite the fact that the graphical results of the study revealed the effectiveness of ASO-PID, no numerical figures were presented to sustain the report.

Shewtahul et al. [26] optimized the parameters of AVR in a multi-machine power system using PSO. The purpose of the study was to apply PSO method aimed at determining the optimal values of the gains and time constants of PID controller of an AVR system installed on generators of a multi-machine power system. The study proposed two artificial intelligent (AI) techniques namely, PSO and genetic algorithm (GA). The effectiveness of the AI algorithms was examined by analyzing the time domain characteristic of the AVR system considering different disturbances. The AI schemes: PSO and GA offered a great deal of simplified way of addressing nonlinear problem compared with classical control techniques.

Bhatt and Bhongade [27] designed a PID controller by applying particle swam optimization (PSO) technique to tune the gains. The PSO tuned PID controller was applied to AVR system. Simulation was carried out in MATLAB environment. The PSO-PID controller was observed to provide more efficient and robust in improving the step response of AVR system.

Sitthidet et al. [28] provided robust control of fluctuation in voltage as a result of reactive loads variations in an isolated wind-diesel hybrid power system using Static Var Compensator (SVC). A normalized co-prime factorization was applied to represent potential uncertainties that were not structured in power system or perturbation such as system parametric variation in generating and loading modelling of the system conditions. An optimization problem based on h-infinity (H_∞) loop shaping was formulated in terms of the performance and robust stability conditions. The optimization problem was solved using genetic algorithm (GA) and this ensure effective use of parameters of Proportional-Integral (PI) controller to control parameters of SVC and AVR at same time.

V. CONCLUSION

The Excitation control of generators is a very important topic in the field of power systems. There are various control strategies that have been proposed and implemental for AVR system in theory and in practice. The simulation results of the various implemented control techniques reviewed in this paper showed that good excitation control can effectively support and provide stabilized voltage while enhancing transient stability and damps oscillations in power system. This paper has surveyed various control strategies that have been recently implemented by researchers to augment the performance of AVR system in power system stability design.

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