ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 9, March 2020

A Review on Application of Computational Intelligent Techniques to Power System Stability

Omorogiuwa Eseosa, Egbunefu Allwell, Amanze
Electrical/Electronic Engineering, Faculty of Engineering, University of Port Harcourt, Nigeria

***Abstract*— Generally, computational Intelligence (CI)/Artificial Intelligence (AI) is a set of nature-inspired computational methodologies and approaches used to address complex real-world problems to which mathematical or traditional modelling can be very un-useful for a few reasons: the processes might be too complex for mathematical reasoning, it might contain some uncertainties during the process, or might simply be stochastic in nature. CI techniques have been widely applied to many challenging real-world problems in signal processing, control, communication, robotics, power system stability, control and protection to mention a few. Different CI/AI methods exist and some are reviewed in this work.**

***Index Terms*— Artificial intelligence, Computational intelligence, Differential Evolution, Optimization.**

I. INTRODUCTION

Differential Evolution (DE), a subfield of evolutionary computation is a technique that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Such methods are commonly known as Meta heuristics as they make few or no assumptions about the problems being optimized and can search very large spaces of candidate solutions. DE is used for multidimensional real-valued functions. It does not use the gradient of the problem being optimized, which means DE does not require the optimization problem to be differentiable, as it is required by classical optimization methods such as gradient descent and quasi-newton methods. DE can therefore be used on problems that are continuous as well as discrete, noisy and have dynamic optimums. DE optimizes a problem by maintaining a population of candidate solutions and creating new candidate solutions by combining existing ones according to its simple formulae, and then retaining which ever candidate solution has the best score or fitness on the optimization at hand.DE works with two entities, old generation and new generation of the same population [1]. The population size is adjusted by the parameter N_p and it is composed of dimensional vectors that are usually equal to the number of design parameters/control variables.

II. LITERATURE REVIEW

In 2018, [3] did a study on approximating the solution of swing equation using particle swarm optimization (PSO) technique.

Manuscript received: 25 February 2020
Manuscript received in revised form: 20 March 2020
Manuscript accepted: 08 April 2020
Manuscript Available online: 15 April 2020

The researchers in their studies highlighted the fact that in a large-scale power system, the transient period from the start of a large disturbance to the restoration of synchronism is governed by a nonlinear, second order, differential equation called the **swing equation**. Numerical techniques such as Runge-Kutta method, Modified Euler method, and Point by Point method had been used to find an approximate solution to the swing differential equation. Further investigations proved that these numerical methods have some limitations. It was from this point of view that transient stability of power system was investigated by solving the swing equation with the aid of PSO. The parameter investigation of swing equation was done in terms of angle stability under the assumption of normal conditions as well as under fault conditions. Single machine and multi machine models were used in the study. The outcomes show satisfactory approximate solutions for the swing equation. Also, the results obtained indicate that they were superior to those obtained by other traditional numerical methods. In 2018, [4] did a study on optimal tuning of Static Synchronous Series Capacitor (SSSC) based supplementary damping controller employing Real Coded Genetic Algorithm (RCGA). The focus of the study was on the improvement of transient stability of power system incorporating Flexible Alternating Current Transmission Systems FACTS device (SSSC) as the damping controller. The study involved a design problem which was formulated as an optimization problem. The solution to the problem which had to do with optimal parameter tuning was obtained through the use of RCGA. Remote and local signals were compared considering the time delays. The proposed controller was tested and its robustness was validated under different conditions for a single machine infinite bus. The outcomes from the simulation were presented and compared with PSO-based damping controller. In 2018, [5] did a study on micro grid stability improvement using fuzzy based PSS design for virtual synchronous generator. In their study, conventional synchronous generators were used for instant injection of energy during fault and post-fault conditions. In micro grids however, Inverter-Based Distributed Generation (IBDG) was used for this purpose. The use of IBDGs in micro grids presented two important issues; their synchronization with the grid for interconnection purposes and their performance during fault and post-fault conditions for stability improvement. To deal with the stability requirements of the grid, a virtual synchronous generator

(VSG) was used. It was against this background that Fuzzy Logic (FL) power system stabilizer was designed for virtual synchronous generator for the improvement of damping of electromechanical low frequency oscillation during system disturbances. A multi-objective genetic algorithm (GA) was used for the design and optimization of fuzzy inference system (FIS). The proposed FL-PSS used the rotor speed deviation as an input for the controller and generates a supplementary control signal based on Tagaki-Sugeno (T-S) technique. A micro grid comprising multiple VSGs was simulated and studied to validate the robustness of the proposed controller. When the proposed GA controller was compared with conventional controllers, the results demonstrated the effectiveness of the proposed controller under the influence of different system disturbances and fault scenarios. In 2018, [6] did a study on review of stability enhancement in single machine infinite bus system using AI techniques. In the paper presented, the researchers put forth that power system was highly complex and nonlinear and consequently, it was not possible to predict its behaviour at every point in time. It was found that modern power systems were operated close to their stability limits. The stability issues mainly encountered were related to low frequency oscillations (0.2-3 Hz) and this could lead to blackouts and outages in the power system. The paper revealed that to counteract the effects of some of this stability related problems, the use of FACTS device were an attractive option in modern times. It was further shown that FACTS devices had the potentials to operate efficiently if their parameters were optimally tuned. The focus of the paper was therefore on a survey of various AI techniques applied for the optimal tuning of various controller gains in a single machine infinite bus system. In 2018, [7] did a comparative study on intelligent control strategies of power system stabilizers (PSS). In the study, it was found out that power system stabilizers were devices if well designed could measure and enforce system stability in synchronous generators.

The study presented the performance comparison of optimally enhanced PSS using adaptive fuzzy control, artificial neural network (ANN), genetic algorithm (GA) and hybrid artificial intelligence, FL and PSO. The indices mainly studied in the performance comparison were simplicity of prototype, robustness and response speed, complexity of algorithm, flexibility in implementation and applicability to hybrid AVRs etc. The results from the comparative study indicated that intelligent techniques improve PSS performance in the sense that these techniques were more efficient in damping out low frequency oscillations by overcoming limitations that conventional control methodologies throw up. It was recommended that intelligent techniques could be considered in smart grid applications especially those deploying renewable energy resources and random high-power loads. In 2018, [8] did a study on small signal stability enhancement of power systems with GA optimized PD type PSS and AVR control. In the study, small signal oscillatory instability was quite common in power systems and to counteract its effects, sufficient damping torque for electromechanical modes of oscillation could be added. A power system stabilizer plus automatic voltage regulator in a synchronous generator could produce the required damping torque for the purpose of stabilizing the power system. The focus of the study is design of proportional plus derivative based PSS which supplemented the damping torque and reduced transient oscillation by reducing the settling time of constant damping ratio in system response. The control parameters were tuned using genetic algorithm (GA). The controller's effectiveness was verified using time domain analysis under the influence of different loading conditions. The study was done in MATLAB environment. In 2018, [9] did a study on voltage stability index and voltage deviation improvement using intelligent algorithms for capacitor sizing and placement. In the study it was revealed that voltage stability and deviation of voltage magnitude from tolerance limits were two of the most common and significant issues associated with present day distribution networks. The focus of the study is on identifying optimal location and sizing of capacitors to be used in a radial distribution network for mitigating voltage stability and deviation of voltage magnitude from tolerance limits.

In order to achieve this, an intelligent two stage methodology employing GA and ANN was used. By carrying out an analysis of load flow of the base case of load profile, voltage deviation and voltage stability indices were calculated for each node of the system. From the indices obtained, buses were identified for capacitor allocation in the first stage of the methodology. Then combinations of two AI algorithms were used to identify the ideal sizes of the capacitors for operation throughout the day. The methodology was implemented on a 33-bus radial distribution network. The outcomes from using these intelligent algorithms gave the ideal sizes of capacitors with optimal locations providing a stable system with a smooth voltage profile across the entire duration of the day. In 2018, [10] did a study on optimal allocation and size of appropriate compensation devices for voltage stability enhancement of power system. In the study, an efficient optimization technique called teaching-learning-based-optimization (TLBO) was used in determining optimal allocation, size, and suitable type of shunt compensation devices for voltage stability enhancement, voltage profile improvement, and power loss minimization of a power system. First of all, loss sensitivity analysis containing two loss sensitivity indices (LSIs) was used to determine the most suitable buses in need of shunt compensation devices. The analysis reduced the simulation time by reducing the search in all buses. The lower power loss objective function was adopted to be used in determining the validity of TLBO as it showed better voltage profile and greater voltage stability compared to other techniques such as GA and PSO. The method was tested on IEEE 14-bus and IEEE 30-bus test system. Simulation results revealed that the proposed method could be used in determining optimal location, size and type of shunt compensation to minimize power losses and improve voltage stability and voltage profile of power system. In 2018, [11] presented a paper on optimal phase measurement unit (PMU) placement for signal stability assessment using GA. In the study it was found that phase measurement unit (PMU) is a device which uses information from Global Positioning System (GPS) to synchronize measurements of voltage and current phasors.

PMUs are essential parts of wide area measurement systems and could provide real time monitoring of events and perturbations occurring in a power system. Data obtained from PMUs are useful for improving the performance of power systems monitoring, protection and control. It was from this viewpoint that the study proposed a multi-objective methodology for optimal placement of PMUs for small signal stability assessment of a power system. Through analysis of the voltage signals measured by the PMUs, two objectives are considered: optimum location with minimum number of PMUs and maximum signal to noise ratio. The principal focus of the study is to use a Multi-Objective Genetic Algorithm (MOGA) to obtain a good estimation of the eigenvalues (frequency and damping) of both local and inter-area electromechanical oscillations in a power system by finding the optimal number and location of PMUs full observability and maximum signal to noise ratio. The proposed algorithm was tested on an IEEE 39-bus system and the results were validated with modal analysis from PSAT toolbox. In 2018, [12] did a study on automatic generation control of two area reheat thermal power system using differential evolution-based controller. In the study it was found that the occurrence of sudden faults, different power demand requirements at different times, weather uncertainty amongst other factors directly affected the system frequency and power flow in tie-lines thereby putting the grids stability at risk. The researchers also posited that fluctuations in frequency and tie-line power flow deviations were the direct results of unanticipated imbalances between energy production and consumer's load demand. Furthermore the role of automatic generation control (AGC) to regulate the generator's output power within acceptable limits so as to maintain stable system frequency and power flow was analyzed.

The focus of the study was the performance analysis of a two area reheat thermal power system through incorporating Differential Evolution (DE) optimized proportional plus integral (PI) controller. DE was used in obtaining optimal sets of PI controller gain parameters $(k_p \text{ and } k_i)$ which depended on eigenvalues of the system matrix state space equation and objective function's minimum value. As the load on the system was varied in one or both of the areas, the controller's performance was determined by carrying out an analysis of the transient response of the system. The DE controller was compared with Genetic Algorithm (GA) controller. The DE controller outperformed the GA controller and was adjudged to be the superior controller. Simulation was done in MATLAB/Simulink environment. In 2018, [13] did a study on reactive reserve management-based voltage stability enhancement using GA. In the study it was posited that over the last few decades, severe voltage collapse conditions had been encountered in many large-scale power systems around the globe. Many of the reported cases had been attributed to voltage-VAR related problems. It was found out that the duty of the transmission system operator is to check the system's security margin before an increased set of loads was accepted. It was also the operator's duty to take preventive actions as soon as security margins were found to be insufficient. Furthermore the investigators revealed that over the years, several researchers had dealt with optimization techniques meant for preventive control of parameters having to do with voltage stability. Such techniques either dealt with minimizing stability margin (load power margin) or minimized an objective function related to voltage stability.

It was against this background that the study was focused on determining the best control action with the purpose of restoring the system to voltage security margins with respect to load increase from present loading conditions. Consequently, the study carried out a single optimization aimed at the provision of improved margins and corresponding controls. A quadratic performance index which limited the reactive power excursions of generator buses from the mean value. This provided reactive power reserve in the upper as well as lower regions. Sufficient stability margin was maintained by selecting a threshold value of minimum eigenvalues of load flow Jacobian. Real coded genetic algorithm (REGA) was proposed to obtain the optimal setting of reactive power control variables. In 2018, [14] did a study on coordinated fuzzy logic controller for dynamic stability improvement in multi machine power systems. In the study, it was ascertained that due to the increased utilization of recent technologies like renewable sources and smart meters, complex and unexpected interactions were taking place in electric power systems and that in a power system, dynamic imbalance was as a result of mismatch between mechanical input and output power. For damping of resultant oscillations, power system stabilizers (PSS) and static synchronous compensators (STATCOMs) could be used. In the study, a unique fuzzy controller for dynamic stability of PSS and STATCOM in multi machine power system was designed. PSO and GA were used for fuzzy controller optimization. The proposed method was tested on IEEE 39-bus system under perturbations. The simulation results verified the efficiency of the proposed method for dynamic stability of power systems. In 2018, [15] did a study on static voltage stability analysis based on the combination of dynamic-continuous power flow (DCPF) and adaptive chaotic particle swarm optimization (ACPSO). In the study it was established that over the last few decades, severe incidents involving voltage collapse had occurred in many large electricity grids around the globe. Moreso, the economic losses and social dislocations these had caused were all too well known and it has become highly imperative for information on voltage stability of a system to be made available in real time to take effective measures to prevent voltage instability, to give an indicator that describe the system voltage stability. It was against this background that the study proposed a method based on the combination of DCPF and ACPSO for the analysis of static voltage stability of the system. Within the context of the ACPSO, the particles were regulating voltage and controlling variables, the system static voltage stability margin was the fitness value, and the maximal adaptation value was the objective function.

The problem was the deficiency in unbalanced power processing when continuous power flow calculates the particle's fitness value. The solution was the introduction of the dynamic power flow algorithm into the model for calculating fitness value. The chaos algorithm was introduced into the adaptive PSO to form the adaptive chaotic particle swarm optimization (ACPSO) which was used to search for the optimal particle and calculate the maximum fitness value. Through an analysis of particles and their fitness values, a way to enhance the system's static voltage stability margin was found. Examples were presented to verify the effectiveness of the algorithm. In 2017, [16] did a study on optimal tuning of power system stabilizer using genetic algorithm to improve power system stability. In the study they said over the last decade, it had come to be established that power system stabilizers played a very important role in power systems by ensuring the stability of the system. The principal focus of the study was on the optimization of PSS parameters using genetic algorithms. The performance of the proposed optimization method was determined by the application of a short circuit on single machine infinite bus system. Different results obtained showed that the genetic algorithm was able to find the optimal parameters of the PSS thereby ensuring stability. In 2017, [17] did a study on small signal stability improvement of large interconnected power systems using power system stabilizer. In the study, small signal stability analysis as an effective tool for the determination of system performance and system stability was presented and concluded that perturbations of small magnitude and low frequency oscillations were common and presented a major challenge in large scale power systems. It was also proved that power system stabilizers were used for the generation of auxiliary control signals to be used as input into the generator excitation system with the purpose of damping out low frequency oscillations. In the study, symbiotic organisms search (SOS) algorithm was applied to the optimal design of power system stabilizers for incorporation into a single machine infinite bus system and a multi machine power system. PSS parameters were tuned based on the objective function involving eigenvalues and damping ratios of the lightly damped electromechanical modes for a wide range of operating conditions. The results of the proposed method were compared with those obtained using GA and PSO. From this comparison, robustness of PSS under different operating conditions was established. In 2016, [18] did a study on PSO-based power system stabilizer for single machine infinite bus system. In the study, it was established that for the generation of auxiliary stabilizing signals, input to generator excitation systems so as to add damping to generator rotor oscillation (Low Frequency Oscillation), power system stabilizers (PSS) were normally used.

It was further highlighted that in the past, power system stabilizers had been designed based on classical control procedures. However, investigation revealed that this approach had some limitations. To overcome these limitations, numerous techniques had been proposed. Within the context of this study, a proportional integral plus derivative (PID) type PSS was considered for damping of electrical power system oscillations. The parameters of this PID type PSS were tuned based on PSO. The proposed PSS (PSO-PSS) was evaluated against a conventional PSS incorporated in a single machine infinite bus system considering system parametric uncertainties. The simulation results clearly indicate the effectiveness and validity of the proposed method. In 2016, [19] did a study on power system stabilizer parameters optimization using GA. In the study it was highlighted that with the ever-increasing load demand, and the slow growth of generation and transmission capacities, the operating constraints of modern power systems were increasing. This situation all too often led to low frequency oscillations which needed to be detected and eliminated quickly and efficiently as possible. The principal focus of the study was to check the stability of a high voltage power system when perturbed slightly. The paper presented an efficient approach to the optimal tuning of power system stabilizer parameters using GA with eigenvalue based objective function. The proposed approach was implemented and examined in a single machine infinite bus system. The outcome of this technique was verified by eigenvalue analysis and domain simulations. The results obtained were compared with the ones obtained using GA. Eigenvalue analysis of nonlinear system simulations demonstrated the effectiveness of the proposed approach in damping electromechanical oscillations and enhancing the system dynamic stability. In 2016, [20] did a study on improving voltage stability by optimal reactive power dispatch based on GA and linear programming method. In the study, it was put forth that minimization of voltage deviations and power loss could be controlled through optimal reactive power dispatch. The study presented GA approach for system parameter enhancement and optimal reactive power dispatch.

The tap changing transformer settings, generator excitation settings, and static-VAR compensation settings are used as control variables for system parameter improvement. The suggested approach permitted the use of optimization variables to be presented in their natural form in the genetic population. In the GA used, scattered crossover, constraint dependent mutation, double vector population operator which could directly deal with floating point numbers were considered. The performance of GA was compared with conventional linear programming and results were presented for the purpose of illustration. In

2016, [21] did a study on small signal stability enhancement of multi machine power system using bio-inspired algorithms.

The study was focused on improving the stability of a two area, four machine kundur power system stabilizer using cuckoo search algorithm (CSA), PSO and GA. In the study, the problem was formulated using an eigenvalue based multi-objective function that moved unstable and poorly damped modes to specific D-shaped region in the left half of the s-plane by controlling the damping ratio and damping factor. To demonstrate the effectiveness and superiority of the proposed CSA based PSS, nonlinear time domain simulations were compared with GA based PSS (GAPSS) and PSO based PSS (PSOPSS) for different line outages and different scenarios of severe disturbances. The robustness of the proposed CSAPSS was evaluated for wide range of loading conditions with severe faults. In 2016, [22] did a study on damping of power system oscillations using real coded genetic algorithm (RCGA) optimization based TCSC controller. In the study, it was affirmed that the ability of a power system to return to its normal operating state after having been subjected to perturbation was a fundamental focus of power system stability studies. These perturbations were of a major concern since it affects the power system's interconnections made up of numerous transmission lines and synchronous machines. Currently the trend was to incorporate FACTS devices with the existing systems for better power utilization and improved stability. The focus of the study was the design of a controller for a 9-bus multi machine power system. Real coded GA was used to search for the optimal controller parameters. In the simulation, different cases considered were power system under study with PSS only, with TCSC having no control, and with genetically optimized TCSC controller. After an exhaustive comparison, it was shown that the proposed TCSC controller with RCGA method greatly enhanced power system stability effectively under faulted conditions. In 2015, [23] did a study on power system stabilizer model based on fuzzy-PSO for improving power system stability. In the study, it was found that power system stabilizer was a device which could be used to enhance the damping of power systems during low frequency oscillations. It was posited that in multi machine power systems, tuning of power system stabilizer parameters was a complex Endeavour due to the presence of several poorly damped modes of oscillation. Moreso, this problem could be further complicated by continuous variations in power system operating conditions. In order to improve the performance of power system stabilizers, a combination of fuzzy logic and particle swarm optimization was used in the study. Simulations were carried out with the aid of several fault tests at transmission lines in a two-area multi machine power system. In the study, Delta w PSS and Delta Pa PSS were used for comparison with the fuzzy-PSO-PSS. The outcomes showed that power transfer response using fuzzy-PSO-PSS was more robust than Delta w PSS and Delta Pa PSS especially considering three phase and phase to ground faults. In 2015, [24] did a study on automatic generation control (AGC) of an interconnected hydrothermal system using chemical reaction optimization (CRO). In the study, CRO was used in tuning a proportional plus integral (PI) controller for AGC of a two-area hydro-thermal system. The parameter values obtained by CRO were compared with those obtained by Biogeography-Based Optimization (BBO), and Differential Evolution (DE) to illustrate the efficacy of the proposed technique in achieving improved system performance. From the simulation results, the objective function value kept on decreasing and at a faster rate and gave a better value compared to those obtained by other algorithms. This implied that the CRO gave a better dynamic performance and had better convergence characteristics when compared to GA, BBO, and DE, establishing the superiority of the proposed technique. In 2015, [25] did a study on particle swarm optimization based reactive power planning for line stability index. In the study, it was affirmed that transmission lines were currently being operated under very stressed conditions and as a result there was a very high risk of voltage instability. The focus of the study was particle swarm optimization method for solving optimal reactive power planning (ORPP) problem with the incorporation of thyristor-controlled series compensator (TCSC). The PSO used in the study was applied to the ORPP to enhance line stability of the system by minimizing the line stability index (Lmn), as well as minimizing the investment cost of the TCSC devices satisfying various constraints of the power flow equation, generator voltage limits, TCSC's reactance limits, transformer tap changer limits, and transmission line limits. The line stability indices were used to identify the lines under stress which were to receive the FACTS devices (TCSC). The proposed strategy was examined and tested on the 144-bus Algerian power grid and the results obtained were compared with those obtained through two other strategies such as GA and Interior Point Method (IPM). From the comparisons, the potentials of the proposed method was evident. The method also showed its effectiveness and robustness in solving ORPP problem. In 2014, [26] did a study on calculation of maximum power transfer capability between two interconnected areas by using particle swarm optimization. In the study, it was discovered that in transferring large amounts of power from the generators to the load centres, there was a tendency for the system stability margin to be reduced. It is because of this that there was a need for the evaluation of maximum power transfer capability. The study proposed the calculation of maximum power transfer capability which could satisfy N-1 contingency by re dispatching generation using particle swarm optimization.

The stability of the system was specified by PQVSI (a stability index). The proposed method was tested on a Thai 28-bus transmission system. The authors reported promising results. In 2014, [27] did a study on the impact of modified differential evolution (DE) strategy on reactive power dispatch (RPD) problem. In the study, it was established that reactive power planning was a nonlinear, mixed integer,

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 9, March 2020

optimization problem which could optimize grid congestion by minimization of real power losses, and voltage deviation for a fixed economic power dispatch. To solve the RPD problem an efficient technique based on DE was used. The researcher put forth that DE sometimes suffered from slow convergence. Consequently, modified DE was used. RPD optimizes power system losses by controlling reactive power control variables such as generator voltages, tap changing transformer tap settings, and/or VAR source settings. The modified DE improved the voltage profile, system security, power transfer capability, and overall system protection. The IEEE 118-bus system was used as a test system. Simulation results were compared to other evolutionary techniques. The results showed the effectiveness and robustness of the proposed approach to solve RPD problem. In 2013, [28] did a study on optimizing power system stabilizer parameters using hybridized differential evolution and particle swarm optimization. In the study, it was established that in large scale power systems, low frequency oscillation was a common phenomenon which also offered some challenges. Presently, the best way to mitigate the effects of low frequency oscillations was through the use of power system stabilizers.

From this viewpoint, in order to better optimize power system stabilizer parameters, differential evolution particle swarm optimization (DEPSO) algorithm was proposed. DEPSO algorithm had the capability to seek the global optimum through information exchange between PSO and DE populations so that the algorithm possessed a dynamic adaptation to skip local optimums. The outcomes of the simulation showed that PSS stability designed by DEPSO algorithm was greatly enhanced and the effect of DEPSO algorithm was superior to that of PSO. In 2013, [29] did a study on power system stability by reducing power losses using optimization techniques. In the study, it was established that even though there was no cost of production associated with reactive power generation, it contributed significantly to transmission losses. Moreso to minimize losses associated with the power system in general, real and imaginary power had to be controlled. It is against this background that their study compared optimization techniques such as particle swarm optimization (PSO) and modified particle swarm optimization (MPSO) in a standard 3-bus and 6-bus power system. In the study, the objective function was such that what had to be minimized were the active and reactive power so that the voltage drop could be minimized thereby enhancing the stability of the given power system. The study also compared optimization techniques and determined which was the better option in reducing power losses such that this better option was selected as that well suited to reducing power losses and maintaining power system stability.

In 2011, [30] did a study on power system voltage stability analysis using modified differential evolution. In the study, it was affirmed that problem of voltage stability was one of the main concerns of operating power systems, thus estimating voltage stability limit had been done through many approaches. One of the approaches was the determination of maximum loading point of the system. In the study what was to be determined was the margin from the current operating point to the maximum loading point. It was put forth that differential evolution (DE) algorithm had the main advantages of faster convergence simple, and required few control parameters. However, it needed a higher population size for faster convergence and sometimes got trapped in local optima. Modified DE eliminated the disadvantages of DE. The principal focus of the study was the use of DE for the determination of maximum load ability limit of a power system.

A sample 6-bus and an IEEE 30-bus were used as test systems. In 2009, [31] did a study on a genetic algorithm PSS and AVR controller for electrical power system stability. In the study, it was found out that the control of power systems required continuous balance between the electrical energy generated and a varying load demand while maintaining system frequency and voltage levels. Also the use of high performance excitation systems was investigated and found very essential for the maintenance of both steady state and transient state stability of modern synchronous generators and provide fast control of terminal voltage. A major drawback of the exciters was that they could significantly contribute to oscillatory instability in the power system. This instability was characterized by low frequency oscillation which could persist or even grow in magnitude. It is from this view point that GA was applied to PSS/AVR controllers for the purpose of improving transient stability as well as voltage regulation of a power system under the influence of a symmetrical three phase short circuit fault. Simulation was then carried out so as to make comparison between the proposed strategy and classical controllers such as manual control, AVR with no PSS, and AVR with PSS. A single machine infinite bus test system was used in the simulation. The outcomes demonstrated the effectiveness of the proposed approach. In 2008, [32] did a study on multi agent based particle swarm optimization (PSO) approach for power system stabilizer design in multi machine power system. In the study, optimum parameters of power system stabilizer were obtained by multi agent particle swarm optimization. Thereafter, the results were then compared with traditional PSO algorithm. Eigenvalue analysis was used for the comparison. The principal focus of the optimization problem was to shift the electromechanical modes of all machines to the left side of the S-plane as far away as possible from the origin thereby offering better stability. Simulation outcomes of a three-machine power system under different operating conditions were obtained. The results confirmed the focus of the study.

III.SOME STEPS ON RESOLVING STABILTY PROBLEMS USING AI TECHNIQUE

Three different terminologies of vectors are used in differential evolution (DE).These include donor vector, trial vector and target vector. Donor vector is created in the mutation stage. Trial vector is created in the crossover stage

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 9, March 2020

while target vector is the current vector of the population. In power engineering, it has been implemented intensively in generator modelling, tuning of static excitation systems, generation expansion planning, reactive power planning, state estimation and forecast, fault identification and removal optimal reactive power flow, electricity trading amongst many others [2]. The population is initialized randomly and is supposed to cover the entire search space. Each vector is represented by;

$x_{i,g}$ (1)

Where $i = 1, 2, 3\ldots,N_p$, g = generation number, New offspring in DE are generated in three operations namely; Mutation, Crossover, and Selection.

a) Mutation

In the mutation operation, a mutant vector also called the donor vector is created. The donor vector $V_{1,g}$ of the ith population member is calculated by adding the weighted difference of two vectors to the third vector.

$$v_{1,g} = x_{r1,g} + F(x_{r2,g} - x_{r3,g}) \quad (2)$$

Where $ri, r2, r3 \in \{1, 2, 3 \ldots N_p\}$ are randomly selected to be different from i and F is the mutation probability parameter.

b) Crossover

Crossover strategies control the number of inherited components from the mutant vector to form a target vector. Binomial and exponential crossover schemes are the main ones used. DE crossover rate parameter C_r influences perturbation size of the target vector to ensure the population diversity.

i) ***Binomial Crossover***

In the crossover operation of DE algorithm, a trial vector is formed. In the binomial crossover scheme, the trial vector $u_{1,g} = [u_{i,1,g}, u_{i,2,g}, u_{i,3,g}, \ldots u_{i,D,g}]$ is generated as shown in equation 3.0

$$u_{i,j,g} = \begin{cases} v_{i,j,g} & (rand_j \le C_r \text{ or } j = j_{rd}) \\ x_{i,j,g} & \text{Otherwise} \end{cases} \quad (3)$$

For $i = 1,2, \ldots, N_p$ and $j = 1,2, \ldots D$

Where j_{rd} is a randomly chosen integer in the range [1, D] and $rand_j$ is a random number in [0, 1]. $v_{1,g}$ is donor vector and $C_r \in [0, 1]$ is crossover control parameter. Due to the range of $rand_j u_{1,g}$ is always different from $x_{1,g}$.

ii) ***Exponential Crossover***

In the exponential crossover scheme, the trial vector is usually $u_{1,g} = [u_{i,1,g}, u_{i,2,g}, u_{i,3,g}, \ldots u_{i,D,g}]$ and it is created as shown in equation 4.0

$$u_{i,j,g} = \begin{cases} v_{i,j,g} \text{ if } j \in \{l, (l+1)_D, \ldots (l+L-1)_D\} \text{and } (rand_j \le C_r) \\ x_{i,j,g} \\ \text{Otherwise} \end{cases} \quad (4)$$

For $i = 1, 2, \ldots, N_p$ and $j = 1, 2, \ldots D$ where $(.)_D$ denotes the modulo function with modulus R. The starting index l is chosen at random from [1, D] and L is also a randomly generated number from [1, D].The parameters l and L are regenerated for each trial vector.

c) Selection

In DE, new population members are formed using the selection operation. The selection operator uses the greedy approach by comparing the fitness of trial vector $u_{1,g}$ with the fitness of the target vector $x_{1,g}$. The vector having the best fitness is selected as a member of the new population

$$x_{i+1,g} = \begin{cases} u_{i,g}, & \text{fitness}(u_{i,g}) < \text{fitness}(x_{i,g}) \\ x_{i,g} & \text{Otherwise} \end{cases} \quad (5)$$

Where the fitness function calculates the fitness value of the objective function.

A. Particle Swarm Optimization (PSO)

PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regards to a given measure of quality. It solves a problem by having a population of candidate solution called particles moved around in a search space according to simple mathematical formulae over the particles position and velocity. Each particle's movement is influenced by its local best-known position. It is also guided towards the best-known position in the search space, which are updated as better positions are found by other particles. This is expected to move the swarm towards the best solution. Individuals in a particle swarm follow a very simple behavior: to emulate the success of neighboring individuals and their own successes. The collective behavior that emerges from this simple behavior is that of discovering optimal regions of a high dimensional search space.

A PSO algorithm maintains a swarm of particles where each particle represents a potential solution. In analogy with evolutionary computation paradigms, a swarm is similar to a population while a particle is similar to an individual. In simple terms, the particles are flown through a multidimensional search space where the position of each particle is adjusted according to its own experience and that of its neighbors. Let $x_i(t)$ denote the position of the particle I in the search space at time t where t denotes discrete time steps unless otherwise stated. The position of the particle is changed by adding a velocity $v_i(t)$ to the current position as shown in equation 6.0.

$$x_i(t+1) = x_i(t) + v_i(t) \quad (6)$$

$$x_i(0) \sim [x_{min}, x_{max}] \quad (7)$$

Originally, two PSO algorithms were developed which differed in the size of their neighborhood. These two algorithms are called gbset PSO and lbest PSO. For gbest PSO, the velocity of the particle is calculated as shown in equation 8.0

$$v_{ij}(t+1) = v_{ij}(t) + c_1 r_{1j}(t)[y_{ij}(t) - x_{ij}(t)] + c_2 r_{2j}(t)[\hat{y}_j(t) - x_{ij}(t)] \quad (8)$$

Where

$\hat{y}_j(t)$ is the best position found by the swarm.

$v_{ij}(t)$ is the velocity of particle I in dimension j =1, 2, … n_x at time step t. $x_{ij}(t)$ is the position of particle I in dimension

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 9, March 2020

j at time step t. c_1 and c_2 are positive acceleration constants used to scale the contributions of the cognitive and social components respectively.r_{1j} and $r_{2j} \sim [0,1]$ are random values in the range (0,1) sampled from a uniform distribution . These random values introduce a stochastic element to the algorithm. For lbest PSO, the velocity is calculated as shown in equation 9.0

$$v_{ij}(t+1) = v_{ij}(t) + c_1 r_{1j}(t)[y_{ij}(t) - x_{ij}(t)] + c_2 r_{2j}(t)[\widehat{y_{ij}}(t) - x_{ij}(t)] \quad (9)$$

Where $\widehat{y_{ij}}(t)$ is the best position, found by the neighborhood of particle I in dimension j.

B. Genetic Algorithm (GA)

GA is a search heuristic that is inspired by Charles Darwin's theory of natural evolution. The algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring in the next generation. The process of natural selection starts with the selection of the fittest individuals from a population and produce offspring which inherit the characteristics of the parents and will be added to the next generation. If parents have better fitness, their offspring will be better than the parents and have a better chance at survival. This process keeps on iterating, and at the end, a generation with fittest individuals will be found. This notion can be applied to a search problem. Five phases are considered in a genetic algorithm;

a) Initialization
b) Fitness Function
c) Selection
d) Crossover
e) Mutation

1. Initialization

An initial population is a set of individuals where each individual is a solution to the problem. Each individual is characterized by a set of parameters (variables) known as genes. Genes are joined into a string to form a chromosome (solution). In a genetic algorithm, the set of genes of an individual is represented using a string in terms of an alphabet. Usually binary values are used (stings of 1s and 0s). Genes are usually encoded in a chromosome.

2. Fitness Function

The fitness function determines how fit an individual is. This demonstrates the ability of an individual to compete with other individuals? It gives a fitness score to each individual. The probability that an individual will be selected for reproduction is dependent on the fitness score.

3. Selection

The idea behind the selection process is to select the fittest individuals and let them pass their genes to the next generation. Two pairs of individuals (parents) are selected based on their fitness scores. Individuals with high fitness have more chance to be selected for reproduction.

4. Crossover

Crossover points are usually chosen at random from within the genes.

5. Mutation

In certain new offspring formed, some of their genes can be subjected to a mutation with a low random probability. This implies that some of the bits in the bit string can be flipped. Mutation occurs to maintain diversity within the population and prevent premature convergence.

6. Termination

The algorithm terminates if the population has converged (does not produce offspring which are significantly different from the previous generation. Then it can be inferred that the genetic algorithm has provided a set of solutions to the given problem.

IV. CONCLUSION

This work involves review on optimization of the fundamental equation of power system stability known as the swing equation under normal and fault conditions using artificial intelligent techniques for single as well as multi machine system. Review of various numerical techniques such as runge-kutta, modified Euler and point by point method in finding the approximate solution were also reviewed. Moreso design and modeling of Flexible Alternating Current Transmission systems devices for optimal tuning to serve as damp controllers with the overall aim of improving transient stability for mini, micro and large grid network was reviewed. Comparative studies on intelligent control strategies for power systems stabilizers using fuzzy logic, adaptive fuzzy logic, genetic algorithms, artificial neural network, particle swarm optimization and hybrid artificial intelligence in terms of robustness, performance, simplicity, flexibility, response to faults etc including their limitations were reviewed. Optimal location, type and sizing of capacitors for radial distribution network and optimal phase measurement unit placement for signal stability assessment was also reviewed.

ACKNOWLEDGEMENT

The authors would like to acknowledge the management and staff of eseogietec engineering company limited (www.eseogietec.com) for all their support academically, materially and financially towards the completion of this task. Their facilities were indeed very useful for this task and the researchers would like to recommend them to other fellow researchers.

REFERENCES

[1] V. Jyothi and P.B. Kumar, "Tuning of controller parameters and load frequency control of multiarea, multisource power systems by particle swarm optimization", International research journal of engineering and technology, Vol. 2, Issue 8, pp. 863-870, 2015.

[2] A. Qing, "Differential Evolution: Fundamentals and Applications in Electrical Engineering", John Wiley and Sons, 2009.

[3] A. Zaidi and Q. Cheng, "An approximate solution of the swing equation using particle swarm optimization", Proceedings at the 2018 IEEE conference on technologies for sustainability, DOI: 10.1109/SusTech.2018.8671355, 2018.

[4] A.H.A. Mohamed, L. Maaraba, A.M.A. Elagap, "Optimal tuning of SSSC based supplementary damping controller employing real coded genetic algorithm", Proceedings at the 2018 international conference on computer, control, electrical, and electronics, DOI: 10.1109/ICCE.2018.8515790, 2018.

[5] M.M. Esfahani, H.F. Habib, O.A. Mohammed, "Micro grid stability improvement using a fuzzy based PSS design for virtual synchronous generator", Proceedings at Southeast on, DOI:10.1109/SECON.2018.8478982, 2018.

[6] S.R. Paital, P.K.Ray, and A. Mohanty, "Review on stability enhancement in SMIB system using artificial intelligence techniques", Proceedings at 2018 IEEMA Engineer Infinite Conference, DOI: 10.1109/ETECHNXT.2018.8385324, 2018.

[7] M. Kashif, Y. Peng, W. Sun, "Comparison study on intelligent control strategies of power system stabilizers", Proceedings at the 2018 international conference on power system technology, DOI:10.1109/POWERCON.2018.8602085, 2018.

[8] B. Rout, B.B. Pati, and A. Pattnaik, "Small signal stability enhancement of power systems with GA optimized PD type PSS and AVR control", Proceedings at the 2018 recent advances on engineering, technology, and computational sciences, DOI: 10.1109/RAETCS.2018.8443890, 2018.

[9] Y.H. Bhatt, D.V. Bhatt, and V.H. Pakka, "Voltage stability index and voltage deviation improvement using intelligent algorithms for capacitor sizing and placement", Proceedings at the PES Asia-Pacific Power and energy engineering conference, DOI: 10.1109/APPEEC.2018.8566319, 2018.

[10] H. Youssef, S. Kamel, and M.M. Aly, "Optimal allocation and size of appropriate compensation devices for voltage stability enhancement of power system", Proceedings at the 2018 international conference on innovative trends in computer engineering, DOI: 10.1109/ITCE.2018.8316642, 2018.

[11] T. Tarif, A.A. Ladjici, and Y. Chabane, "Optimal PMU placement for signal stability assessment using genetic algorithm", Proceedings at the 2018 international conference on electrical science ad technologies in Maghreb, DOI: 10.1109/CISTEM.2018.8613597, 2018.

[12] M.A. Zamee, M.M. Hossain, K.R. Zafreen, and K.K. Islam, "Automatic generation control of two area reheat thermal power system using differential evolution-based controller", Proceedings at the 2018 international conference on innovations in science, engineering, and technology, DOI: 10.1109/NPSC.2018.8745639, 2018.

[13] A. Varma, N.K. Sharma, and S.K. Gawre, "Reactive reserve management-based voltage stability enhancement using genetic algorithm" Proceedings at the 2018 IEEE international students conference on electrical, electronics, and computer science, DOI: 10.1109/SCEECS.2018.8546919, 2018.

[14] M. Deghani, W. Han, and H. Karimipour, "Coordinated Fuzzy controller for dynamic stability improvement in multimachine power system", Proceedings at 2018 IEEE international conference on smart energy grid engineering, DOI: 10.1109/SEGE.2018.8499474, 2018.

[15] B. Cao, M. Bo, J. Pan, and Y. Liu, "Static voltage stability analysis based on the combination of dynamic continuous power flow and adaptive chaotic particle swarm optimization", Proceedings at the 2018 IEEE 3rd advanced information technology, electronic, and automation control conference, DOI: 10.1109/IAEAC.2018.8577520, 2018.

[16] S. Keskes, N. Bouchiba, S. Sallem, and L. Chirfi-Alaoui, "Optimal tuning of power system stabilizer using genetic algorithm to improve power system stability", Proceedings at the 2017 international conference on green energy conversion systems, DOI: 10.1109/GECS.2017.8066200, 2017.

[17] P. Dey, A. Bhattacharya, J. Datta, and P. Das, "Small signal stability improvement of large interconnected power system using power system stabilizer", Proceedings at the 2017 2nd international conference for convergence in technology, DOI: 10.1109/ICCT.2017.8226229, 2017.

[18] P. Jagadeesh and M.S. Veerraju, "Particle swarm optimization-based power system stabilizer for single machine infinite bus system", Proceedings at the 2016 international conference on emerging trends in engineering, technology, and science, DOI: 10.1109/ICETETS.2016.7603084, 2016.

[19] M. Jebali, O. Khahouli, and H.H. Abdallah, "Power system stabilizer parameter optimization using genetic algorithm", Proceedings at the 2016 5th international conference on systems and controls, DOI: 10.1109/ICOSC.2016.7507031, 2016.

[20] K. Rayudu, G. Yesuratnam, and A. Jayalaxmi, "Improving voltage stability by optimal reactive power dispatch based on genetic algorithm and linear programming technique", Proceedings at the 2016 international conference on electrical, electronics, and optimization techniques, DOI: 10.1109/ICEEOT.2016.7754904, 2016.

[21] D. Chitara, K.R. Niazi, A. Swarnkar, and N. Gupta, "Small signal stability enhancement of multimachine power system using bioinspired algorithm", Proceedings at the 2016 National Power Systems Conference, DOI: 10.1109/NPSC.2016.7858962, 2016.

[22] S.H. Qurratulain, A. Iqbal, K. Hasan, and N. Ahmad, "Damping of power system oscillations using RCGA optimization based TCSC controller", Proceedings at 2016 IEEE 7th Power India International Conference, DOI: 10.1109/POWERI.2016.8077168, 2016.

[23] R. Syahputra and I Soesanti, "Power system stabilizer model based on Fuzzy-PSO for improving power system stability", Proceedings at the 2015 international conference on advanced mechatronics, intelligent manufacture and industrial automation", DOI: 10.1109/ICAMIMIA.2015.7508015, 2015.

[24] L.P. Das, S. Paul, and P.K. Roy, "Automatic generation control of an interconnected hydrothermal system using chemical reaction optimization", Proceedings from the Michael Faraday IET international summit 2105, DOI: 10.1049/CP.2015.1673, 2015.

[25] Y. Amrane, M. Boudour, and A.A. Ladjici, "Particle swarm optimization based reactive power planning for line stability index", Proceedings at the 2015 3rd international conference on control engineering and information technology, DOI: 10.1109/CEIT.2015.7233063, 2015.

[26] S. Patchanee, S. Chaitusaney, and B. Eua-arpon, "Calculation of maximum power transfer capability between two interconnected areas by using particle swarm optimization", Proceedings at 2014 11th international conference on electrical, computer, telecommunications, and information technology, DOI: 10.1109/ECTICON.2014.6839889, 2014.

[27] S. Biswas, K.K. Mandal, and N. Chakraborty, "Impact of differential evolution strategy on reactive power dispatch

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 9, March 2020

problem", Proceedings at 2014 annual IEEE India conference, DOI: 10.1109/INDICON.2014.7030534, 2014.

[28] Z. Qing, W. Huang, and S. Jiao, "Optimizing power system stabilizer parameters using hybridized differential evolution and particle swarm optimization", Proceedings at 2013 9th international conference on natural computation, DOI: 10.1109/ICNC.2013.6818036, 2013.

[29] S.N. Deepa and J. Rizwan, "Power system stability by reducing power losses using optimization techniques", Proceedings from the 2013 IEEE international conference on computational intelligence and computing research, DOI: 10.1109/ICCIC.2013.6724152, 2013.

[30] C. Selvi and K. Gnanambal, "Power system voltage stability and analysis using modified differential evolution", Proceedings at the 2011 international conference on computer, communication, and electrical technology, DOI: 10.1109/ICCCET.2011.5762505, 2011.

[31] A. Kahouli, T. Guesmi, H.H. Abdullah, and A. Ouali, "Genetic algorithm PSS and AVR controller for electrical power system stability", Proceedings at 2009 6th international multiconference on systems, signals, and devices, DOI: 10.1109/SSD.2009.4956736, 2009.

[32] H.K. Kargar, R. Aghmasheh, A. Safari, and G.R.Z. Govar, "Multiagent based particle swarm optimization approach for power system stabilizer design in multimachine power system", Proceedings at 2008 IEEE 2nd international power and energy conference, DOI: 10.1109/PECON.2008.4762448, 2008.

AUTHOR BIOGRAPHY

Engr.Dr Eseosa.Omorogiuwa is a Lecturer in the Department of Electrical/Electronic Engineering, Faculty of Engineering, and University of Port Harcourt, Nigeria. He holds Ph.D degree in power systems and electric machines, Master degree (M.Eng) in power systems and electric machines Bachelor of engineering degree (B.Eng) and diploma in computer engineering from university of Benin, Nigeria.. He has published well over 60 international articles in highly refereed journals. His interest is on renewable energy resources, electricity economics/marketing and power system optimization, reliability and electric machines management .He is a fellow in world global engineering research institute, registered engineer with council for the regulation of engineers (COREN) and member of Nigeria society of engineers, Nigeria.

Engr Egbunefu Allwell, Amanze holds a bachelor of Engineering Degree (B.Eng) and currently doing his masters degree programme (M.Eng) in power and machines from University of Port Harcourt, Rivers State Nigeria. His interest is on renewable energy resources, electricity economics/marketing and power system optimization.