Transient Stability Improvement of an IEEE 9 Bus Power System Using FACTS Devices with ABC Optimization Technique

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Abstract—This paper examines the Unified Power Flow Controller (UPFC) technology for managing active and reactive power in electrical networks, with the aim of improving overall system performance and achieving optimal operational efficiency. The contributions of this research include the formulation, derivation, coding, and implementation of network equations to incorporate both steady-state and dynamic models of UPFC in power systems. Furthermore, Genetic Algorithm (GA) applications are applied to a real-world sub-transmission network to address practical operational challenges. An enhanced GA technique is proposed, which optimizes the objective function and enhances the selection process by considering population diversity and adjusting selection probabilities. Simulation results confirm the advantages of the proposed method in achieving superior system performance.

Index Terms— ABC, FACTS, IEEE 9 Bus, Unified Power Flow Controller (UPFC)

I. INTRODUCTION

The primary focus of this research is to enhance the steady-state and dynamic performance of power grids using Flexible AC Transmission Systems (FACTS) based on computational intelligence. Effective control of electric power systems can be achieved through the design of FACTS controllers, where emerging trends in Artificial Intelligence can significantly improve controller performance characteristics.

The proposed technique will address real-world challenges in a Finnish power grid, utilizing data up to the year 2020. The FACTS device employed in this study is the Unified Power Flow Controller (UPFC), recognized as one of the most promising solutions.

This research aims to optimize the type, location, and size of power and control elements associated with UPFC to maximize system performance. It establishes criteria for the optimal installation of UPFCs in ideal locations with the best parameters and subsequently designs an AI-based damping controller to enhance the dynamic performance of the power system. Genetic Algorithms (GA) will be employed to search for controller parameters at various operating points, recognizing that the parameters for each operating point differ. Adaptive Neuro-Fuzzy Inference Systems (ANFIS) will be used to identify appropriate parameters for each specific operating condition.

Voltage support is critical in minimizing voltage fluctuations along transmission paths. Reactive power support in transmission networks enhances stability by maximizing the active power that can be transmitted. It helps maintain a well-regulated voltage profile across all sections of power transfer, improves the performance of High Voltage Direct Current (HVDC) systems, increases transmission efficiency, stabilizes normal bus voltages, prevents over voltages, and mitigates the risk of severe blackouts.

Both series and shunt VAR compensators can modify the performance characteristics of electrical networks. Series compensators adjust the parameters of transmission grids or distribution systems, while shunt compensators alter the impedance at connected terminals. In both cases, the management of reactive power can significantly enhance the overall performance of the power system.

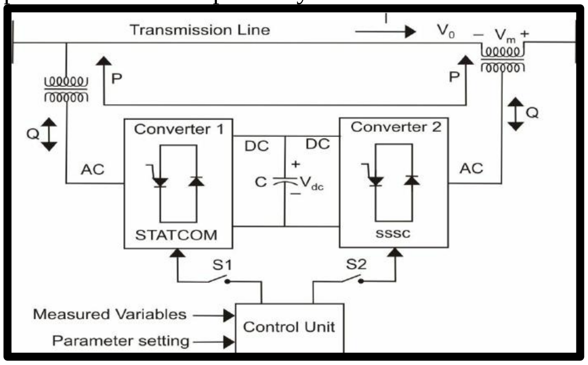

Figure1. 1 Schematic Diagram of UPFC

The UPFC (Unified Power Flow Controller) enhances power system performance through its two converters: the parallel converter and the series converter. The parallel converter absorbs controlled current, with a portion being reactive, while the series converter injects voltage and phase angle into the transmission line to influence power flow.

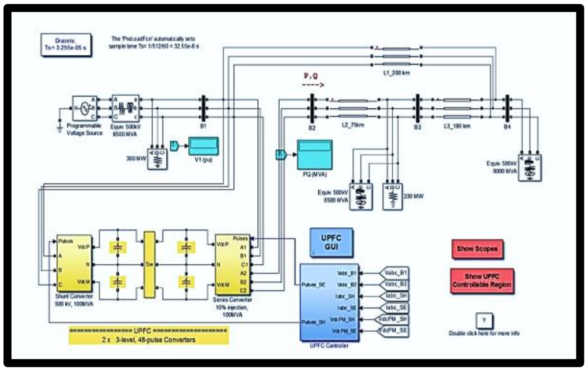

Figure1. 2 UPFC Connection to The Network

It operates in various modes, including direct voltage injection, phase shift emulation, and line impedance emulation, ensuring stable power flow while avoiding negative resistance or capacitance effects. Additionally, it utilizes automatic power flow control to maintain steady active and reactive power transfers.

II. RELATED WORK

In [9] C. H. Liang et al., a presentation is made on Parallel Optimal Reactive Power Flow Based on Cooperative Co-Evolutionary Differential Evolution and Power System Decomposition. Differential Evolution (DE) is an effective evolutionary technique for solving optimal reactive power flow problems, but it primarily requires a large population to prevent convergence in a suitable timeframe.

In [10] W. Yan et al., a hybrid genetic algorithm–interior point method for optimal reactive power flow is presented. This research combines a Genetic Algorithm (GA) with a non-linear Interior Point Method (IPM), introducing a new hybrid technique for Optimal Reactive Power Flow (ORPF) applications. The proposed technique can essentially be divided into two sections. A dynamic updating strategy is also introduced to enable the GA and IPM to complement each other, thereby improving the efficiency of the hybrid method. The GA is utilized to solve the discrete optimization while keeping the continuous variables fixed, whereas the IPM addresses continuous optimization with constant discrete variables.

In [11] W. Yan et al., a new optimal reactive power flow (ORPF) model in rectangular form is proposed, where the load tap changing (LTC) transformer element is treated as an ideal transformer, and the series impedance is represented as a dummy point positioned between them. The terminal voltages of the ideal transformer winding are used to exchange the turn ratio of the LTC, making the ORPF model quadratic. Two separate modules for the new and traditional methods are developed in MATLAB to compare their performances. However, a limitation of this method is that, in some cases, it requires the same number of iterations as the conventional method to reach a solution.

In [12] L. A. Zarate et al., an easy, rapid, and powerful method is presented for calculating the maximum loading point (MLP) and the voltage stability security limit of electric power networks. The proposed technique relies on nonlinear programming methods. The MLP is accurately determined after several demand change steps. The computational procedure incorporates two types of power changes: primary load increases toward the MLP, applied to reduce a fitness function based on sensitivities.

In [13] Kumar B. V. et al., the maximum loading margin (MLM) method is introduced to determine generation directions for maximizing the static voltage stability margin. The MLM is calculated at different possible generation points in the generation space. A simple formula linking the generation direction and the loading margin (LM) is employed to identify the MLM point. The proposed technique is tested on the modified IEEE 14-bus system and applied to the Thailand power network. The loading margins of the system with varying generation steps are compared across different generator combinations.

In [14] Taher S. A. et al., Tellegen's theorem and adjoint networks are utilized to derive a novel local voltage-stability index. This new technique allows for the calculation of Thevenin's values using a method different from adaptive curve-fitting techniques, based on two consecutive phasor measurements. The new index is verified on various test systems, with results obtained from a static two-bus test system and a dynamic Belgian–French 32-bus test system, which contains complete dynamic models of all power system components essential for voltage instability analysis.

III. METHODOLOGY

Various methods have been proposed to model the intelligent swarm behavior of bees, which have been applied to solve complex problems. One such approach, the Artificial Bee Colony Algorithm (ABC), was introduced by Karaboga in 2005. In this algorithm, each food source corresponds to an employed bee. The population of employed bees is equal to the number of food sources around the hive. When an employed bee's food source is exhausted, it becomes a scout bee. Initially, the algorithm starts with random initialization, where food positions are chosen randomly, and their nectar values are determined. Once the bees return to the hive, the nectar information from each food source is shared with the bees waiting at the dance area inside the hive.

$$x_{ij} = x_{minj} + rand[0,1] \times \left(x_{maxj} - x_{minj}\right) \qquad (1)$$

In equation (1), x_{ij} is the j-th optimization variable from the i-th possible optimization solution, X_{min} is the lower bound of the j-th variable, X_{max} is the upper bound of the j-th variable. Equation (1) states that random numbers are generated in the permitted range of variations for each optimization variable. Equation (2) is used to initialize the ABC algorithm to determine the objective function of the possible results.

$$fiti = \begin{cases} \dfrac{1}{1+fi} & => if \rightarrow fi \geq 0 \\ 1 + +|fi| & => if \rightarrow fi < 0 \end{cases}$$

where f_i is the possible solution cost of x_i and f_{iti} represents the fitness of this solution. Any onlooker bees or employed bees can make changes to the existing food source (feasible solution) in its memory and calculate its objective function. If the new result is greater than its previous version, the new result will be chosen and the old result will be dismissed; otherwise, the previous result will be held in its memory. In the algorithm, the production of a new solution from the previous solution is based on Equation (3):

$$V_{ij} = x_{ij} + \Phi_{ij} (x_{ij} - x_{kj}) \qquad (3)$$

In the above equation, Φ_{ij} is a random variable that controls the production of food sources beside x_{ij}, denoting an eye comparison of the sources. According to equation (3), as the difference between x_{ij} and x_{kj} reduces, the deviation from the x_{ij} position will also reduce. In equation (3), it is attempted to select a dimension from one of the food sources, and considering 8, motion is defined in the direction or the reverse way. If the parameters produced by equation (3) violate their bounds, their amounts are adjusted by an acceptable amount in a way that if they violate the upper bound, the upper bound will be used, and if they violate the lower bound, the lower bound will be used. This possibility can be calculated by several methods, which are presented in equation (4) and equation (5).

$$Pi = \frac{fiti}{\sum_{n=1}^{sn} fitn} \qquad (4)$$

$$Pi = \frac{A \times fiti}{\max(fit) + B} \qquad (5)$$

In equation (5), $\max(f_{it})$ is the highest objective function value in the possible results. Also, the parameter A and the parameter B are constant. By the explanation of this section, it may be said that the number of food sources (SN) is equal to the number of employed and onlooker bees. The bee colony algorithm for the placement of compensators in the power system is in the form of Fig. 3.1, illustrating the procedure for optimal placement of the FACTS devices in the power system. To increase the accuracy of the ABC algorithm, its parameters have been determined by repeated simulations and trial-and-error methods.

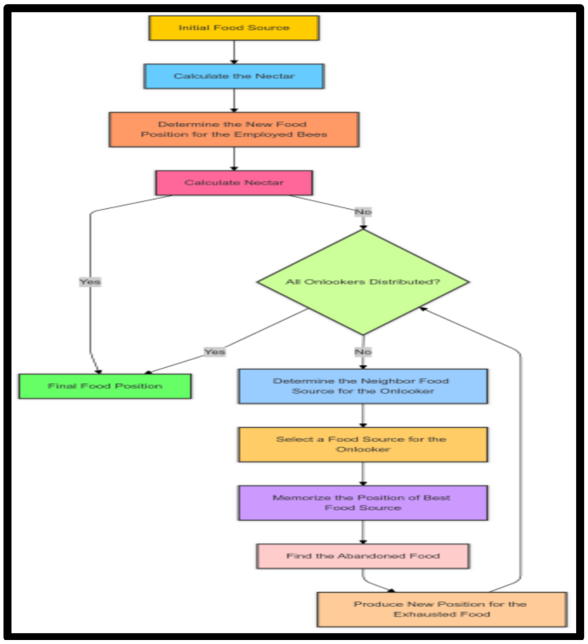

Figure 3.1 Flowchart of artificial bee colony algorithm based on [15]

This flowchart represents the process of finding an optimal food source in a colony of bees, likely inspired by the Artificial Bee Colony (ABC) algorithm. It starts with selecting an initial food source, followed by calculating the nectar amount. The employed bees then determine new food positions, and the nectar is recalculated. Onlooker bees are assigned to food sources based on the nectar quality. Once all onlookers are distributed, the best food source is memorized, and exhausted food sources are replaced. The process concludes when the final optimal food position is found.

IV. RESULTS AND DISCUSSIONS

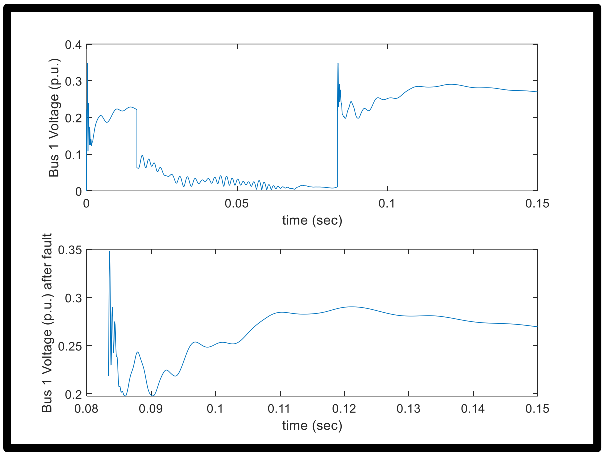

Figure 4.1 Bus 1 Voltage (p.u.) with respect to time (sec) (above) and Bus 1 Voltage (p.u.) after fault with respect to time (sec) (below)

Steady state time = 0.146468802900899 sec, Max. overshoot = 29.0997%, Peak time = 0.083541 sec, Location = 0.9 meters, Fitness value = 11.47836

Table 4.1: Optimal Location of UPFC using Ant Bee colony optimization

Location (m)	Steady state time (s)	% peak over shoot	Peak time(sec)	Fitness value
7	0.146962571530411	31.8705626836189	0.083541248133896	11.8011205566221
5	0.146773882350638	30.5345878574485	0.083555125577458	11.5894725111775
2.1	0.14671829166787	30.0269060975062	0.083552240465334	11.5839812347807
1.3	0.146595541912831	29.839749778773	0.083549386048586	11.5621968590314
3	0.146561538045913	29.7075458365709	0.083553313318051	11.5481263681382
1.7	0.146546721683671	29.616311556441	0.083552879163897	11.5386325310692
1.9	0.146600503849866	29.7648126245796	0.083554956004381	11.5281605253713
0.7	0.146587075989634	29.4990222684502	0.083553152502769	11.5212457932525
2.3	0.146508010102396	29.4302132445804	0.083556561762182	11.5190549103513
2.5	0.146533241646127	29.3059324205095	0.083556700947974	11.4939242832041
0.9	0.146468802900899	29.09978837798	0.083541917008459	11.4783655769871
1.1	0.146542918828987	29.168280404623	0.08355975398154	11.4737343445203
1.5	0.146554574869393	29.1146608779167	0.083556611595752	11.4686637928598

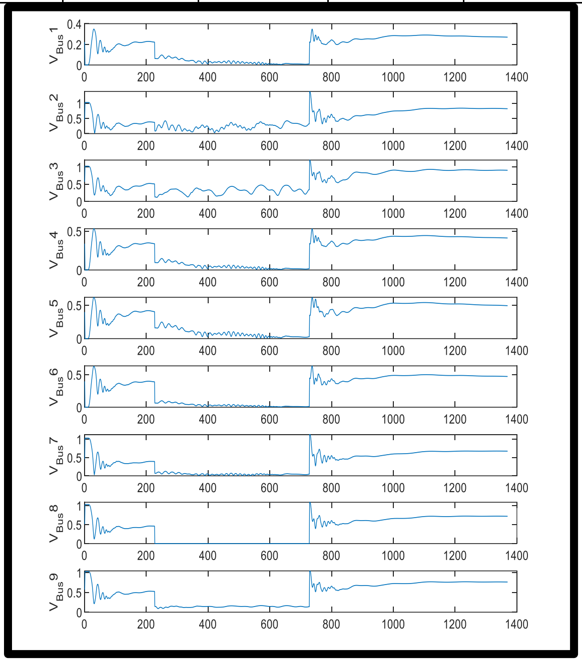

Figure 4.2 V Bus 9, V Bus 8, V Bus 7, V Bus 6, V Bus 5, V Bus 4, V Bus 3, V Bus 2, V Bus 1

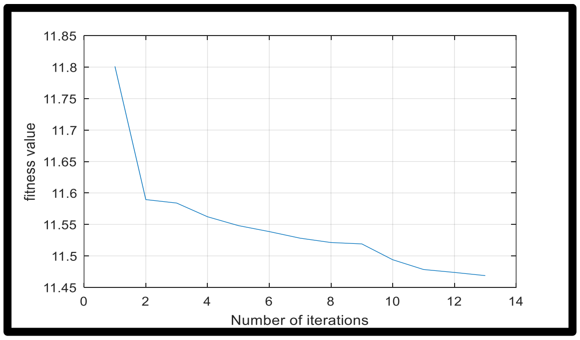

Figure 4.3 Fitness Value with respect to Numbers of iterations

V. CONCLUSION

In conclusion, this project demonstrates that the Unified Power Flow Controller (UPFC) with ABC algorithm significantly enhances transient stability and power quality in electrical power systems. Through simulations on the IEEE 9-bus system, the UPFC shows balanced improvements in voltage stability, power flow control, and transient response. Its ability to minimize both peak overshoot and settling time makes it an essential tool for reducing system losses and improving overall grid resilience. The UPFC proves to be a versatile and effective solution for optimizing modern power grids.

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