Solution of Optimal Power Flow Using Genetic Algorithm with Facts Devices.

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Abstract - Optimal Power Flow (OPF) minimizes operational costs while ensuring power system stability. Incorporating Flexible AC Transmission System (FACTS) devices enhances efficiency by improving power transfer, reducing congestion, and enhancing voltage stability. These controllers provide dynamic compensation, minimizing infrastructure expansion needs.

This study proposes a Genetic Algorithm (GA)-based OPF approach for tuning system parameters.
Implemented on the IEEE 30-bus system, it minimizes fuel costs and the L-index (voltage stability metric).
Unlike deterministic methods, GA efficiently handles non-convex OPF constraints.

FACTS devices within the optimization framework improve voltage regulation and power flow control. Simulation results show that GA outperforms conventional techniques in cost-effectiveness, voltage stability, and computational efficiency. A comparative analysis highlights GA's advantages, proving bio-inspired algorithms offer scalable solutions for modern grids.

Key Words: Thyristor controlled series capacitor, optimal power flow, L-index.

1. INTRODUCTION

The primary aim of Power Flow Optimization (PFO) is to minimize electricity production expenses while ensuring the reliable operation of the power grid. Traditionally, the standard PFO problem has been formulated considering only conventional fossil-fuel-based power plants. However, the evolution of modern power networks has introduced significant challenges related to system reliability, dynamic stability, and energy quality. To tackle these issues, power-electronic-based Adaptive Transmission Control Systems (ATCS) have emerged as essential components. These devices help in mitigating various energy quality issues, alleviating transmission congestion, and enhancing power transfer capability. Most importantly, ATCS technologies provide an efficient alternative to extensive infrastructure expansion by maximizing the utilization of existing generation and transmission facilities. Instead of requiring large-scale upgrades, these devices enable real-time control and optimization of grid operations.

2. Proposed System Modelling

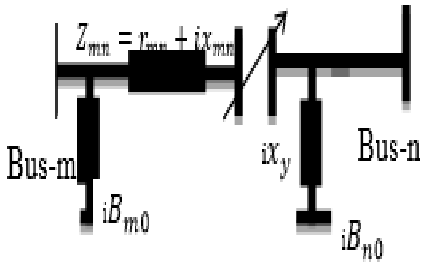

Fig. 1 illustrates the circuit representation of the Thyristor-Controlled Series Capacitor (TCSC).

Where it denotes the reactance introduced by the device, represents the resistance, and indicate the susceptance at buses and, respectively. The straightforward design of this compensator contributes to its high operational efficiency. Numerous studies have been conducted to determine the optimal placement of TCSC within a power system network to minimize its impact on the objective cost function.

This device functions by altering the effective reactance of the transmission line, thereby enhancing power flow control. The variation in impedance introduced by the TCSC can be mathematically expressed through the following equations, which highlight its influence on system performance.

REFERENCES	TECHNIQUES	OBJECTIVE FUNCTIONS	FACTS DEVICES
8	Newton method	minimization of fuel cost	TCSC, SVC
9	Sequential Quadratic Programming	Maximization of voltage security margin	TCSC, SVC
10	Min cut algorithm	minimization of fuel cost	TCSC
11	Adaptive clonal selection	reducing cost and L-index	UPFC, IPFC and GUPFC
12	Harmony search	reducing Severity index	TCSC
13	Krill herd	Minimization of cost, emission, power loss	TCPS

Table -1: Setting Word Margins

B. PROBLEM FORMULATION

In standard Optimal Power Flow (OPF) analysis, the primary objective is to minimize the overall generation cost while satisfying a set of operational and system constraints.

1. OPTIMIZATION OF TOTAL COST

$$OF1 = \sum_{i=1}^{N_g} (a_i + b_i P(G_i) + c_i P(G_i)^2)$$

where

PGi represents active power of the **i**th generator bus;

ai, bi, **c**i represents cost coefficients of the **th** generator bus**.**

2. MINIMIZATION OF L – INDEX

The minimization of L- index is given by minf = max(Lm**)**

$$Lm = \left| 1 - \sum_{n=1}^{NG} \frac{H_{mn} V_{mn}}{V_m} \right|$$

n = 1,2,..NL ; Hmn = - [inv (Ymn)]*[Ymn]

Where, Lm is the L- index of m^{th} bus.

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C. PROPOSED GENETIC ALGORITHM WITH THREE – PARENT CROSSOVER.

Over the past few decades, various Genetic Algorithm (GA) variants have been developed to solve a wide range of real-world numerical optimization problems. However, the effectiveness of these methods largely depends on the nature of the objective function. In certain cases, GA may not perform as efficiently as other optimization techniques. To enhance its performance, this study incorporates a three-parent crossover mechanism instead of the conventional two- point crossover, along with a diversity-preserving operator replacing standard mutation techniques.

1. SELECTION:

In this step, parent individuals are chosen to generate offspring. Various selection mechanisms exist in the literature; however, this study employs the roulette wheel selection method.

2. PROPOSED THREE – PARENT CROSSOVER:

Crossover plays a crucial role in the Genetic Algorithm (GA) framework. Unlike the traditional two-parent crossover approach, the proposed method adopts a randomized selection strategy. The detailed procedure is as follows:

1. Apply the roulette wheel selection technique to identify parent individuals.

2. If two selected individuals exhibit similarity, one is randomly replaced from the candidate pool.

3. Rank the three selected parents in descending order based on their fitness values.

4. Generate new offspring using Equation. $OF_1 = X_1 + \varepsilon(X_2 - X_3)$

$OF_2 = X_2 + \varepsilon (X_3 - X_1)$ $OF_3 = X_3 + \varepsilon (X_1 - X_2)$

3. **DIVERSITY OPERATOR**:

To improve the exploitation capability of individuals, a variability operator, is incorporated into the algorithm.

4. **The Steps of GA- TPC for OPF with FACTS**

STEP 1: Initialize GA-TPC variables, max generations (G_{max}) and create initial population as follows.

$$X_K= [P_{Gm,2}, PGm_{, NG}, VGm_{,1}\ldots, VGm_{,NG}, t_{m,1}, t_{m,NT}, Q_{Cm,1}, Q_{Cm,NC}]$$

STEP 2: Calculate fitness using equation.

STEP3: Implement the choice suggested recombination, diversity operator, and generate a new generation.

STEP 4: Conclude the procedure if the last iterations is reached, selecting the optimal outcome from the preceding iteration as the best one or else to move to step 2.

RESULT AND ANALYSIS

The effectiveness of the GA-TPC approach is evaluated by analyzing two distinct optimization objectives within the OPF problem.

1. **30 BUS SYSTEM**

The system comprises six generators with a total load demand of 283 MW. The complete dataset for this system is sourced from. The performance of the proposed GA-TPC approach is compared with Initialized Differential Evolution (IDE) and the Differential Search Algorithm. The results, presented in Table 2, indicate that the proposed method achieves superior optimization outcomes compared to other techniques.

Additionally, Table 2 also illustrates the L-index values with and without the incorporation of a Thyristor-Controlled Series Capacitor (TCSC). The findings confirm that integrating FACTS devices enhances system security by mitigating transmission line congestion. Table 3 outlines the optimal control parameters derived from the proposed approach across three different scenarios.

OBJECTIVE FUNCTION	Method	Minimum(S/h)	L-index
OF_1	IDE [25]	800.41	-
	DSA[26]	799.0943	-
	GA-TPC	**799.0317**	**0.3661**
OF_2	IDE [25]	-	0.1246
(without	DSA[26]	-	0.1244
Facts)	**GA-TPC**	**839.074**	**0.1243**
OF_3 (With facts)	**GA-TPC**	**845.2423**	**0.1120**

Table 2: Comparison of 30 Bus – System with different methods.

Control variables	OF_1	OF_2(With out FACTS)	OF_3(With FACTS)
P_{G1}	1.77	1.44	1.35
P_{G2}	0.48	0.26	0.39
P_{G5}	0.21	0.24	0.31
P_{G8}	0.21	0.35	0.14
P_{G1}	0.11	0.19	0.30
P_{G1}	0.12	0.40	0.39
V_{G1}	1.10	1.09	1.10
V_{G2}	1.08	1.08	1.09
V_{G5}	1.06	1.05	1.10
V_{G8}	1.06	1.08	1.09
V_{G11}	1.10	1.09	1.09
V_{G11}	1.10	1.09	1.10
t_{6-9}	1.04	0.97	1.03
t_{6-10}	0.90	0.90	0.97
t_{4-12}	0.98	0.98	1.04
t_{28-27}	0.96	0.94	0.97
bc_{10}	0.04	0.08	0.03
bc_{12}	0.50	0.03	0.05
bc_{15}	0.04	0.01	0.04
bc_{17}	0.04	0.03	0.03
bc_{20}	0.05	0.01	0.04
bc_{21}	0.02	0.03	0.05
bc_{23}	0.02	0.02	0.03
bc_{24}	0.05	0.07	0.05
bc_{29}	0.02	0.02	0.05
TPC(s/h)	799.0317	839.0748	345.2423
L-index	0.1267	0.1243	0.1120

Table 3 : Outlines the optimal control parameters derived from the proposed approach across three different scenarios.

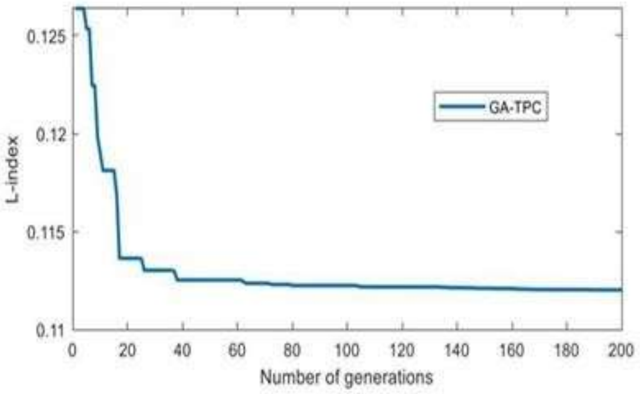

Fig 2: Convergence Characteristics obtained with 30 Bus System for L-index with TCSC.

3. CONCLUSIONS: In this study, an enhanced variant of the Genetic Algorithm, termed GA with Three-Point Crossover (GA-TPC), has been developed by integrating a three-point crossover mechanism and a diversity operator into the conventional GA framework to address the OPF problem with FACTS device integration. The incorporation of these modifications has significantly improved the algorithm's exploration and exploitation capabilities.

The effectiveness and efficiency of GA-TPC were evaluated using two objective functions, and the obtained results validate the superiority of the proposed approach compared to other methodologies discussed in the literature. The findings confirm that GA-TPC provides a more optimized and reliable solution for OPF while enhancing system performance and stability.

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