Solution of OPF Using GA Variant With Inclusion of FACTS Devices

Priyanka D1*, Harish Pulluri2, and Dr. Venkateshwarlu S3

1Research Scholar, EEE Department, Anurag University, Hyderabad, TS.
2Associate Professor, EEE Department Anurag University, Hyderabad, TS.
3Professor, CVR college of engineering, Ibrahimpalnatham, Hyderabad, TS.

Abstract. Optimal power flow (OPF) is a tool used for minimization through that secured and cost-effective power systems is obtained with the inclusion of FACTS devices for existing power systems that enhance the power transfer ability of the power system, which reduces congestion. The current work proposed a solution to the OPF issue in power systems using genetic algorithm (GA). The proposed technique is implemented on an IEEE 30 bus system by considering the minimization of fuel cost and L-index functions. The results at the end of this paper present the efficacy of GA algorithm to solve OPF issues in power systems and FACTS devices while comparing it to other algorithms presented previous research.

Keywords: Thyristor controlled series capacitor; optimal power flow; L-index; power system security; genetic algorithm, three point crossover.

1 Preamble

The primary focus of OPF is to reducing the generation costs [1]. Traditionally, the classical OPF issue has been formulated exclusively with thermal power generators. However, the landscape of the power generation industry has evolved due to the modern electrical network faces challenges related to security, stability, and power quality [2]. To address these issues, electronically tuned flexible alternating current transmission system (FACTS) devices have emerged as valuable tools. These devices have the capability to mitigate a myriad of problems associated with power quality and network overload. Importantly, FACTS devices offer a means to circumvent the need for extensive upgrades to the generation and transmission capacities of the network. Instead, they facilitate the augmentation and efficient utilization of existing facilities. Given these considerations, it becomes imperative to conduct OPF studies that take into account not only conventional thermal power generators but also in-corporate renewable sources and FACTS devices. This comprehensive approach ensures a holistic examination of the electrical network, promoting a balanced integration of diverse energy resources while addressing contemporary challenges in power system operation and management [3].

* Corresponding author: harishee@anurag.edu.in

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
There are several techniques has implemented so far to solve the OPF issue with and without inclusion of FACTS devices. Namely gradient method [4] linear programming [5], quadratic method [6], interior point [7]. Nevertheless, Classical techniques excel in providing nearly optimal solutions for convex OPF problems. However, when faced with nonlinear and non-convex objective functions and constraints, implementing these traditional methods becomes challenging. To overcome these limitations and enhance the quest for optimal solutions, evolutionary methods have been developed introduced with inclusion of FACTS devices as depicted in Table 1.

### Table 1. Setting Word’s margins.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technique</th>
<th>Objective function</th>
<th>FACTS device</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Newton method</td>
<td>minimization of fuel cost</td>
<td>TCSC, SVC</td>
</tr>
<tr>
<td>9</td>
<td>Sequential Quadratic</td>
<td>Maximization of voltage security margin</td>
<td>TCSC, SVC</td>
</tr>
<tr>
<td>Programming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>min cut algorithm</td>
<td>minimization of fuel cost</td>
<td>TCSC</td>
</tr>
<tr>
<td>11</td>
<td>adaptive clonal selection</td>
<td>reducing cost and L-index</td>
<td>UPFC, IPFC and GUPFC</td>
</tr>
<tr>
<td>12</td>
<td>Harmony search</td>
<td>reducing Severity index</td>
<td>TCSC</td>
</tr>
<tr>
<td>13</td>
<td>Krill herd</td>
<td>Minimization of cost, emission, power loss</td>
<td>TCPS</td>
</tr>
</tbody>
</table>

The above Swarm intelligence-based techniques are highly effective and adaptable in addressing OPF inclusion of FACTS devices. Nevertheless, when the complexity of the problem is increased by introducing additional constraints, the solutions generated by these techniques may not be the most cost-effective. Therefore in the present work a new variant of GA is developed and applied to solve the above issue.

Genetic algorithm initially presented by John Holland in 1960 [14]. So far GA has been applied to solve various real world issues [15-22]. It is capable of reaching the global minimum search area in a quick period and takes longer to converge. One of the methods to tackle this issue is a hybrid strategy. Therefore, several variants of GA has been introduced to overcome the drawback trap in local optima [23]. In the pre-sent work one of the variant GA with three parent crossover has been applied to solve ED problem. This method introduced a diversity operator rather classical mutation which results maintain effective chromosomes. Two different test systems are considered to show the performance of GA-TPC. The reaming paper is organized as, section 2 gives modelling of TCSC; Section 3 mentions mathematical model, section 3 tells about formulation of GA-TPC, section 4 presents results and lastly conclusion explained in section 5.

### 2 Modelling of TCSC
Fig. 1 presents TCSC circuit, where $x_{mn}$ indicates the reactance offered, $r_{mn}$ is the resistance offered, $B_{mn}$ and $B_{no}$ are susceptances offered at buses $m$ and $n$ respectively [12]. The simplicity of this device adds to its efficient nature. Several research works have been carried out to find a best location for the placement of TCSC in a power system network in order for it to affect the cost function minimally. This device adds reactance to the line. This difference can be observed through the following equations:

$$
\begin{align*}
P_{mn} &= V_m^2 g_{mn} - V_m V_n g_{mn} \cos(\delta_m - \delta_n) - V_m V_n b_{mn} \sin(\delta_m - \delta_n) \\
Q_{mn} &= -V_m^2 b_{mn} - V_m V_n g_{mn} \sin(\delta_m - \delta_n) - V_m V_n b_{mn} \cos(\delta_m - \delta_n)
\end{align*}
$$

(1)

where;

$$
\begin{align*}
g_{mn} &= \frac{r_{mn}}{r_{mn}^2 + (x_{mn} - x_c)^2}; \\
b_{mn} &= \frac{x_{mn} - x_c}{r_{mn}^2 + (x_{mn} - x_c)^2}
\end{align*}
$$

(2)

Where $P_{mn}$ & $Q_{mn}$ indicates active and reactive power at $m^{th}$ & $n^{th}$ buses; $V_m$ and $V_n$ shows voltages at $m^{th}$ & $n^{th}$ buses; $g_{mn}$ & $b_{mn}$ indicates conductance and susceptance between $m^{th}$ & $n^{th}$ buses; $r_{mn}$ & $X_{mn}$ represents resistance and reactance between $m^{th}$ & $n^{th}$ buses.

### 3 Problem formulation

Regularly OPF is to minimize the total cost of all generators subjected to various constraints. The general formulation is taken from [11].

#### 3.1 Optimization of total cost (TC)

For each generating unit fuel cost is roughly represented as a quadratic function and is given below [11].

$$
\min f = \sum_{m=1}^{NG} a_m P_{Gm} + b_m P_{Gm}^2 + C_m P_{Gm}^2
$$

(3)

where $f$ denotes TC of all generators; $P_{Gm}$ indicates real power at $n^{th}$ generator.
3.2 Minimization of L-index

The minimization of L-index is given by

\[
\text{min} f = \max(L_m)
\]

(4)

\[
L_m = \left| 1 - \sum_{n=1}^{NG} H_{mn} V_{mn} \right|; m = 1, 2, \ldots, NL; H_{mn} = -[\text{inv}(Y_{mm})] \ast [Y_{mn}]
\]

(5)

Where, \( L_m \) is the L-index of \( m \)th bus.

The contraints in the current work are taken from [11].

4 Proposed Genetic Algorithm with three Parent Crossover

Over few decades, various GAs have been introduced to obtain solution for several real world numerical problems. Nevertheless, the efficacy of the different methods is merely based on characteristics of the objective. Nevertheless, in some cases GA not executed well as comparison to other algorithms [14]. Hence, GA accomplishment is enhanced by introducing three parent crossover in place of normal two point crossover and diversity operator is used rather regular mutation [14]. The present crossover utilizes three-parents to generate three new Childs, that helps the exploration capability and diversity operator is used for exploitation.

The procedure for the GA-TPC is as follows.

4.1 Selection

Here, initially, parent individuals are selected to create child individuals. In literature, various types’ of selection procedures are available. However, in the current research roulette wheel procedure is used [24].

4.2 Proposed three parent crossover

The crossover procedure holds significant within the GA framework. In contrast to the conventional two-parent crossover, the current method relies on a random procedure. The specific steps are outlined [24].

1. Utilize the roulette wheel technique to choose parent individuals,
2. In the event of resemblance between two individuals, one is exchanged arbitrarily from the assortment pool.
3. Organize these three entities based on their fitness values, from highest to lowest.
4. New off springs are generated using eq. (6)

\[
\begin{align*}
\text{OF}_1 &= x_1 + \varepsilon (x_2 - x_3) \\
\text{OF}_2 &= x_2 + \varepsilon (x_3 - x_1) \\
\text{OF}_3 &= x_3 + \varepsilon (x_1 - x_2)
\end{align*}
\]

(6)
4.3 Diversity Operator

For enhancing the individuals' exploitation capacity, the diversity operator, as referred in [24], is taken into account here.

4.4 The steps of GA-TPC for OPF with FACTS

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

\[
X_k = [P_{G_{m,1}}, \ldots, P_{G_{m,NG}}, V_{G_{m,1}}, \ldots, V_{G_{m,NG}}, t_{m,1}, t_{m,NT}, Q_{C_{m,1}}, \ldots, Q_{C_{m,NC}}]
\]

**Step 2:** Calculate fitness using eq. 8.

\[
|F| = f + w_p \left( |P_{G_{k}} - P_{G_{k}^{\text{lim}}}| \right)^2 + \sum_{k=1}^{NL} w_V \left( |V_{L_{k}} - V_{L_{k}^{\text{lim}}}| \right)^2 + \sum_{k=1}^{NG} w_Q \left( |Q_{L_{k}} - Q_{L_{k}^{\text{lim}}}| \right)^2 + \sum_{k=1}^{NT} w_S \left( |S_{L_{k}} - S_{L_{k}^{\text{lim}}}| \right)^2
\]

where, \( w_p, w_V, w_Q, w_S \) indicates penalty values.

**Step 3:** 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 move to step 2.

5 Simulation results

The quality of GA-TPC is examined by considering two different objectives of OPF problem.

5.1 30-bus system

It has six generators and load is 283 MW. Complete data for this system is considered from [25]. Comparison of obtained results with this system with GA-TPC compared with initialized DE (IDE) [25], differential search algorithm [26] and results are depicted in Table 2 and it is identified that current technique provided optimum objective function values as compared to others. The Table 2 also shows the L-index value of the with and without TCSC also and it is decided that inclusion of FACTS devices in the system enhanced security by decreasing congestion on the transmission line. Table 3 provides the optimum control variables obtained with the proposed method in the three cases. Convergence graph emerged with GA-TPC for L-index with TCSC is given Fig. 1, and is understood that it is very smooth and drops quickly, signifying that exploitation contributes most in GA-TPC along with exploration.

Table 2. Comparison of 30-bus system with different methods

<table>
<thead>
<tr>
<th>Objective function</th>
<th>Method</th>
<th>Minimum ($/h)</th>
<th>L-index</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>OF1</td>
<td>IDE [25]</td>
<td>800.41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>DSA [26]</td>
<td>799.0943</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>GA-TPC</td>
<td>799.0317</td>
<td>0.3661</td>
<td>2.40</td>
</tr>
<tr>
<td>OF 2 (without FACTS)</td>
<td>IDE [25]</td>
<td>-</td>
<td>0.1246</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DSA [26]</td>
<td>-</td>
<td>0.1244</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GA-TPC</td>
<td>839.074</td>
<td>0.1243</td>
<td>1.02</td>
</tr>
<tr>
<td>OF 2 (with FACTS)</td>
<td>GA-TPC</td>
<td>845.2423</td>
<td>0.1120</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Table 3. Optimal variables of all the objectives

<table>
<thead>
<tr>
<th>Control variables</th>
<th>OF 1</th>
<th>OF 2 (with out FACTS)</th>
<th>OF 2 (with FACTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG1</td>
<td>1.770574</td>
<td>1.440466</td>
<td>1.350146</td>
</tr>
<tr>
<td>PG2</td>
<td>0.485605</td>
<td>0.265903</td>
<td>0.394154</td>
</tr>
<tr>
<td>PG5</td>
<td>0.213607</td>
<td>0.244746</td>
<td>0.318248</td>
</tr>
<tr>
<td>PG8</td>
<td>0.211772</td>
<td>0.350000</td>
<td>0.141726</td>
</tr>
<tr>
<td>PG11</td>
<td>0.119112</td>
<td>0.195955</td>
<td>0.300000</td>
</tr>
<tr>
<td>PG13</td>
<td>0.120000</td>
<td>0.400000</td>
<td>0.390612</td>
</tr>
<tr>
<td>VG1</td>
<td>1.1000</td>
<td>1.0994</td>
<td>1.1000</td>
</tr>
<tr>
<td>VG2</td>
<td>1.0876</td>
<td>1.0879</td>
<td>1.0988</td>
</tr>
<tr>
<td>VG5</td>
<td>1.0613</td>
<td>1.0550</td>
<td>1.1000</td>
</tr>
<tr>
<td>VG8</td>
<td>1.0693</td>
<td>1.0828</td>
<td>1.0998</td>
</tr>
<tr>
<td>VG11</td>
<td>1.1000</td>
<td>1.0990</td>
<td>1.0998</td>
</tr>
<tr>
<td>VG13</td>
<td>1.1000</td>
<td>1.0999</td>
<td>1.1000</td>
</tr>
<tr>
<td>t6-9</td>
<td>1.0478</td>
<td>0.9713</td>
<td>1.0312</td>
</tr>
<tr>
<td>t6-10</td>
<td>0.9000</td>
<td>0.9000</td>
<td>0.9781</td>
</tr>
<tr>
<td>t4-12</td>
<td>0.9804</td>
<td>0.9874</td>
<td>1.0416</td>
</tr>
<tr>
<td>t28-27</td>
<td>0.9630</td>
<td>0.9456</td>
<td>0.9773</td>
</tr>
<tr>
<td>BC10</td>
<td>0.0498</td>
<td>0.0089</td>
<td>0.0038</td>
</tr>
<tr>
<td>BC12</td>
<td>0.0500</td>
<td>0.0327</td>
<td>0.0500</td>
</tr>
<tr>
<td>BC15</td>
<td>0.0493</td>
<td>0.0155</td>
<td>0.0448</td>
</tr>
<tr>
<td>BC17</td>
<td>0.0434</td>
<td>0.0307</td>
<td>0.0300</td>
</tr>
<tr>
<td>BC20</td>
<td>0.0500</td>
<td>0.0152</td>
<td>0.0401</td>
</tr>
<tr>
<td>BC21</td>
<td>0.0290</td>
<td>0.0378</td>
<td>0.0500</td>
</tr>
<tr>
<td>BC23</td>
<td>0.0278</td>
<td>0.0241</td>
<td>0.0339</td>
</tr>
<tr>
<td>BC24</td>
<td>0.0500</td>
<td>0.0072</td>
<td>0.0500</td>
</tr>
<tr>
<td>BC29</td>
<td>0.0228</td>
<td>0.0206</td>
<td>0.0500</td>
</tr>
<tr>
<td>TPC ($/h)</td>
<td>799.0317</td>
<td>839.0748</td>
<td>345.2423</td>
</tr>
<tr>
<td>L-index</td>
<td>0.1267</td>
<td>0.1243</td>
<td>0.1120</td>
</tr>
</tbody>
</table>

*All values are in pu

Fig. 2. Convergence characteristics obtained with 30 bus system for L-index with TCSC

6 Conclusion

Here, a variant of GA known as GA with three point crossover (GA-TPC) is evolved with incorporation of three point crossover and diversity operator in classical GA to solve OPF
with FACTS problem. With inclusion of TPC and diversity operator, exploration and exploitation capability has been enhanced. The quality and efficiency of the GA-TPC is tested by considering two objective function and acquired results confirms that the suggested method is superior as compared to different techniques mentioned in the survey.

References

5. D.W. Wells, Method for economic secure loading of a power system, Proceedings of IEE 115 (8), 1190–1194 (1968)