AN OPTIMAL POWER FLOW ON GRID CONNECTED POWER SYSTEM USING FACTS DEVICES

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Abstract: The optimized genetic algorithm (OGA) for the solution of the optimal power flow (OPF) with use of controllable FACTS devices is studied. Two types of FACTS devices, thyristor-controlled series compensators (TCSC) and thyristor-controlled phase shifters (TCPS) are considered in this method. This method can provide an enhanced economic solution with the use of controllable FACTS devices. The probabilities of crossover and mutation are varied by adaptive genetic algorithm. Advanced and problem-specific operators are introduced in order to enhance the algorithm’s efficiency and accuracy. IEEE standard 30-bus system is taken and results are presented to show the feasibility of the system.

Key words— FACTS, grid control, TCPS, TCSC, Optimum control strategy.

1. Introduction

The Flexible AC Transmission System (FACTS) devices become more commonly used as the power market becomes more competitive. They may be used to improve the transient responses of power system and can also control the power flow (both active and reactive power) [13, 14]. The main advantages of FACTS are the ability in enhancing system flexibility and increasing the load ability. In this work, the conventional OPF problem is solved with simple GA (SGA) and optimized GA (OGA) approaches along with two powers flow constraints [1]. The probabilities of crossover and mutation are varied by adaptive genetic algorithm [2]. In addition to the basic genetic operators of the SGA used in [3] and the advanced ones used in [4] problem-specific operators, inspired by the nature of the OPF problem. The approach minimize total cost as well as iteratively evaluates the control settings of TCSC and TCPS that are needed to maintain specified line flows. The sensitivity analysis is carried to position the TCSC and TCPS in test system [5]. The results obtained shows that OGA is superior in convergence compared to SGA. Here OGA is used to obtain economic dispatch of generators such that these generations give minimum cost as well as does not result in line flow violation. In order to increase the GA search speed at smooth areas of the search space a hill-climbing operator is introduced, which perturbs a randomly selected control variable [6,7]. The modified chromosome is accepted if there is an increase in FF value; otherwise, the old chromosome remains unchanged [8]. If the modified chromosome proves to have better fitness, it replaces the original one in the new population [13]. Otherwise, the original chromosome is retained in the new population. All problem-specific operators are applied with a probability of 0.2. Step by step algorithm for optimized genetic algorithm is shown is Fig. 1.

Three cases have been studied; Case 1 is the conventional OPF without FACTS devices and (N-I) security constraints using SGA [14]. Case 2 is the conventional OPF with FACTS devices using SGA. Case 3 is the conventional OPF with FACTS devices using EGA. The main optimization results are listed in Table 1.

Table 1 IEEE 30-bus system case study results

<table>
<thead>
<tr>
<th>Pi (MW)</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 (MW)</td>
<td>182.1800</td>
<td>190.5400</td>
<td>187.8200</td>
</tr>
<tr>
<td>P2 (MW)</td>
<td>42.9700</td>
<td>46.6200</td>
<td>45.4100</td>
</tr>
<tr>
<td>P3 (MW)</td>
<td>19.4400</td>
<td>17.5200</td>
<td>22.6200</td>
</tr>
<tr>
<td>P4 (MW)</td>
<td>24.6200</td>
<td>14.7500</td>
<td>15.5800</td>
</tr>
<tr>
<td>P6 (MW)</td>
<td>12.0000</td>
<td>12.1100</td>
<td>12.2100</td>
</tr>
<tr>
<td>∑Pd(MW)</td>
<td>293.6400</td>
<td>294.7400</td>
<td>294.3500</td>
</tr>
<tr>
<td>∑cost($/hr)</td>
<td>804.0132</td>
<td>804.3227</td>
<td>802.3789</td>
</tr>
</tbody>
</table>

Without FACTS devices the cost of OPF is 804.0132 and cost of OPF with FACTS using SGA and OGA is 803.4227 and 802.3789 respectively. The results show that the generation cost increase
with FACTS device since the parameter constraint of TCSC and TCPS are included. However, FACTS can change the power distribution effectively and reduce the system losses.

Fig. 1 Optimized genetic algorithm

Two set of test runs are performed, the first (SGA) one is with only the basic GA operators and the second (OGA) one is with all operators, including advanced and problem-specific operators. The FF evolution of the best of these runs is shown in Fig. 2. The operating costs of the SGA and OGA solutions are 804.4227 $/h and 803.3789 $/h, respectively.

The operating cost of all OGA-OPF solutions is slightly less than the SGA. Fig. 2 demonstrates the improvement achieved with the inclusion of the advanced and problem-specific operators. It is found that the real power flows in lines are within the rating limit. Along with the conventional OPF, the power through line numbers 6 and 28 has been taken as additional constraints.

![Fitness value](image1)

**Fig. 2** FF comparison for IEEE 30-bus system

The specified values of power are to be achieved by placing TCSC in line 6 and TCPS in line 28. Now the next step is to find the value of TCSC reactivity and TCPS phase shift that are needed to maintain the specified power flow. These values are found by SGA and OGA method, with their convergence is shown in Fig. 3 through Fig. 4. The corresponding power flows found iteratively for SGA and OGA have been shown on Fig. 5 and Fig. 6 respectively.

![TCSC reactance](image2)

**Fig. 3** Modified IEEE 30 bus system with TCSC value in case 2

![Fitness value](image3)

**Fig. 4** Modified IEEE 30 bus system with TCSC value in case 3
With the SGA being optimization method used, the power flow through line 6 converge to the required value of 0.33 p.u approximately after 11 iterations, where as the power flow through line 28 converge to the required value of 0.18 p.u approximately after 8 iterations. With the OGA being optimization method used, the power in the line 6 and 28 are converged very fast than SGA and the results show that the proposed approach is effective. This improvement is achieved with the inclusion of the advanced and problem specific operators. If the power flow control constraints are not some specified values but some ranges, it is possible to use appropriate convergent threshold to achieve this. For example, suppose the power flow control value of one branch is between 0.5 and 0.6 p.u, it can be set the specified branch flow at 0.55 and set the convergent threshold at 0.05 p.u. Thus, when the problem converges, this branch power flow is between 0.5 and 0.6 p.u using this method, and fulfills different power flow control needs.

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In order to transfer sinusoidal grid current $i_g$ into the 30 bus grid system, DG current should include the harmonic components that can compensate the load current harmonics. Therefore, it is important to design an effective and low-cost current controller that can generate the specific harmonic components to compensate the grid current harmonics. Generally, traditional current controllers, such as the PI or PR controllers, cannot realize this demand because they lack the capability to regulate harmonic components. So we designed the proposed current controller in d-q reference frame.

In the fig 9 shows the proposed control strategy proposed control strategy is the combination of Current reference generation, Phased locked loop, and Current controller. Constant DC Voltage fed to inverter that can convert the DC to AC, Converted AC are not purely sinusoidal that DG current passes through LC filter which eliminate the harmonic part come from DG set after that current passes to local load, that may be balanced linear nonlinear or unbalanced load.abc and dq0 transformation are used to convert the three phase component to two phase component that help in controlling process. Phase Locked loop are used to detect the grid frequency variation.
To enhance grid current quality, an advanced current control strategy, as shown in Fig. 9, is introduced. Although there are several approaches to avoid the grid voltage sensors and a phase-locked loop (PLL), Fig. 10 contains the grid voltage sensor and a PLL for simple and effective implementing of the proposed algorithm, which is developed in the d-q reference frame. The phase locked loop, current reference generation, and current controller are three main blocks in proposed control strategy. That strategy operates without the local load current measurement and harmonic voltage analysis on the grid voltage. It can simultaneously adjusting nonlinear local load and distorted grid voltage on the grid current quality.

2. Current Reference Generation

In Fig. 10 Current reference of current controller can be generated in the d-q reference frame based on the desired power and grid voltage.

\[
\begin{align*}
    i_{gd}^* &= \frac{2}{3} \frac{P^*}{V_{gd}} \\
    i_{gq}^* &= -\frac{2}{3} \frac{Q^*}{V_{gd}}
\end{align*}
\]  

(1)

Where \(P^*\) and \(Q^*\) are the reference active and reactive power, respectively; \(V_{gd}\) represents the instantaneous grid voltage in the d-q frame; and \(i_{gd}\) and \(i_{gq}\) denote the direct and quadrature components of the grid current, respectively.

Under ideal conditions, the magnitude of \(V_{gd}\) has a constant value in the d-q reference frame because the grid voltage is pure sinusoidal. However, if the grid voltage is distorted, the magnitude of \(V_{gd}\) no longer can be a constant value. As a consequence, reference current \(i_{gd}\) and \(i_{gq}\) cannot be constant in (1). To overcome this problem, a low-pass filter (LPF) is used to obtain the average value of \(V_{gd}\), and the d-q reference currents are modified as follows:

\[
\begin{align*}
    i_{gd} &= \frac{2}{3} \frac{P^*}{V_{gd}} \\
    i_{gq} &= -\frac{2}{3} \frac{Q^*}{V_{gd}}
\end{align*}
\]  

(2)

3. Current Controller

Proposed current controller is design using a PI and RC in the d-q reference frame. The block diagram of current controller is shown in Fig 9. The open loop transfer function of the PI-RC in a discrete time domain is respectively given by:

\[
G_{PI}(z) = K_p + \frac{K_i z}{z-1}
\]

(3)

\[
G_{RC}(z) = \frac{K_p z^{N/6}}{1-Q(z)z^{-6}}
\]

(4)

Where, 
\(K_p\)=Proportional Gain and \(K_i\)=Integral Gain of PI Controller
\(Z^{-N/6}\)= Time delay unit, \(zk\)=phase lead term,
\(Q(z)\)= filter transfer function, \(Kr\)= RC gain.

The RC is used to eliminate the harmonic components in the grid current caused by the unbalanced nonlinear local load and/or distorted grid voltage. Meanwhile, the role of the PI controller is to enhance the dynamic response of the grid current and to stabilize the whole control system. In this analysis here the proposed current controller is basically designed to compensate both the current harmonic and the grid frequency variation, simultaneously. When the grid frequency varies, the grid frequency (fs) is quickly detected by the PLL, and the frequency variation is compensated directly by adjusting the number of delay samples, i.e., \(N/6 = \) fsample/ (6fs), inside the RC in Fig. 10 Simulation done in MALAB software to verify the effectiveness of the proposed control Method.

Three phase programmable voltage source are used as the grid where we can apply the voltage is 110V connected with the three phase line with photovoltaic source as distributed generation PV cell are connected with DC source and universal bridge to forming a distributed generation.
Low pass filter are used to filter out the current and voltage harmonic in the circuit as well as it give the average value of Vd0. Diode rectifier used as nonlinear load. Current passes through load is measured by voltage measurement parameter iabc. To eliminate the effect of nonlinear load current controller are designed that is proportional–integral proportional-resonant controllers are designed.

To eliminate the effect of nonlinear load and voltage distortion we designed the proposed current controller. Fig. 12 is the subsystem block are connected to the three phase line as a programmable voltage source, where the five sine wave block are connected to the adder with Gains that give the result distorted grid voltage at the end.

Simulation work carried out in MATLAB assuming grid voltage as distorted and unbalanced nonlinear load. This case provide the distorted grid voltage is given with the harmonic components 3.5%. In this simulation works used the constant voltage as a input connected to bus connected grid system, and developed current compensator for grid connected DG when the grid connected bus voltage distortion present and unbalanced nonlinear load condition. Three phase breaker are connected before inverter which helps to see result before controller and after controller.

4. CONCLUSION

An optimized genetic algorithm method was presented to solve the optimal power flow problem of power system with FACTS devices. The proposed method introduces the injected power model of FACTS devices into a conventional AC optimal power flow problem to exploit the new characteristic of FACTS devices. Case studies on modified IEEE test system show the potential for application of OGA to determine the control parameter of the power flow controls with FACTS. In this method, OGA effectively finds the optimal setting of the control parameters using the conventional OPF method. It also shows that the OGA was suitable to deal with non-smooth, non-continuous, non-differentiable and non-convex problem, such as the optimal power flow problem with FACTS devices.

Fig. 11. Simulation when grid voltage is distorted and unbalanced nonlinear load are connected

Fig. 12. Subsystem block for provide grid voltage distortion

Fig. 13. Simulation result of grid voltage distortion and unbalanced nonlinear load condition
Reference


