Congestion Management in Power System by Optimal Location And Sizing of UPFC

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Abstract: This paper presents a particle swarm optimization (PSO) based algorithm to perform congestion management by proper placement and sizing of one unified power flow controller (UPFC). The proposed approach makes use of the PSO algorithm to allocate the near-optimal GenCos as well as the optimal location and size of UPFC whereas the Newton–Raphson solution minimizes the mismatch of the power flow equations. Simulation results (without/with the line flow constraints, before and after compensation) are used to analyze the impact of UPFC on the congestion levels of the 5-bus test system.

I. Introduction

Promising idea has been rapidly developing over the last two decades for controlling the power flow in transmission lines with the application of flexible AC transmission systems (FACTS) through the utilization of large power converters. Different approaches have been presented for optimal placement of FACTS devices[1] including sensitivity analysis[2], congestion management by interline power flow controller and unified power flow controller (UPFC) [3]. Application of artificial intelligent approaches for optimal congestion management is increasing in deregulated power systems. Recent approaches are mainly based on market models, particle swarm optimizations (PSOs) [4], genetic algorithms (GAs) and sensitivity analysis. Some studies have concentrated on maximizing social and individual welfare, as well as, social welfare considering reactive power and congestion management in deregulated environments. On the other hand, there have been a few studies on the UPFC application for congestion management. An artificial bee colony algorithm is proposed to minimize the generation fuel costs using UPFC unit[5].

This paper proposes a PSO-based algorithm for alleviating congestion in power systems by optimal placement and sizing of one UPFC. The cost of UPFC is also included as the location index of merit in the optimization process. Simulations are performed to investigate the impact of UPFC on congestion levels of the 5-bus test system.

II. Mathematical Model Of Upfc

In this paper, UPFC is selected to improve congestion management because of its flexibility and abilities in regulating the bus voltage and simultaneously controlling the active and reactive power flow.

2.1 Power injection model of UPFC

Newton–Raphson power flow formulation is used and UPFC is represented using the power injection model[6, 7]. UPFC consists of two back-to-back voltage-source converters connected to power system through series and parallel power transformers. Impacts of UPFC on the network is reflected by a series connected voltage source \( V_T \) and \( W_T \), shunt current sources \( I_T \) and \( I_q \), connected to the network through series and shunt transformers as shown in Fig. 1. Therefore UPFC includes three adjustable parameters: voltage magnitude and phase angle of the series transformer \( V_T \) and \( W_T \) and reactive current \( I_q \) of the shunt transformer. According to Fig. 1, UPFC can be modeled based on the following equations

\[
I_i = I_T + I_q + I_i' \quad (1)
\]

\[
I_T = \text{Re}[V_T \times I]' \quad (2)
\]

\[
V_i' = V_T + V_i \quad (3)
\]

The real and reactive power injections at buses i and j with a UPFC unit connected in lineij can be expressed as

\[
S_{ij} = P_{ij} + jQ_{ij} = V_i \times I_{ij}' = V_i \times (I_i + JV_iB/2)' \quad (4)
\]

\[
S_{ji} = P_{ji} + jQ_{ji} = V_j \times I_{ji}' = V_j \times (JViB/2 - I_j)' \quad (5)
\]
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\[
P_{is} = -g_{ij}V_i^2 - 2V_iV_Tg_{ij}\cos(\varphi_T - \delta_i) + V_jV_T\left[g_{ij}\cos(\varphi_T - \delta_i) + b_{ij}\sin(\varphi_T - \delta_i)\right] \\
P_{js} = V_jV_T\left[g_{ij}\cos(\varphi_T - \delta_i) + b_{ij}\sin(\varphi_T - \delta_i)\right] \\
Q_{is} = V_iV_q + V_iV_T\left[g_{ij}\sin(\varphi_T - \delta_i) + b_{ij}\cos(\varphi_T - \delta_i)\right] \\
Q_{js} = -V_jV_T\left[g_{ij}\sin(\varphi_T - \delta_i) + b_{ij}\cos(\varphi_T - \delta_i)\right]
\]

Where \(B, g_{ij}, b_{ij}, P_{is}, Q_{is}, P_{js}\) and \(Q_{js}\) are line charging admittance, conductance of line \(ij\), susceptance of line \(ij\), and active and reactive power injections at buses \(i\) and \(j\), respectively. Equations (6)–(9) are added to the Jacobian matrix in load flow formulations.

2.2 Cost of UPFC

For more practical optimal placement and sizing of FACTS devices, it is recommended to also consider their investment costs in the OF [8].

\[
C_{UPFC} = 0.0003S_{UPFC}^2 - 0.2691_{UPFC} + 188.22
\]

Where \(C_{UPFC}\) and \(S_{UPFC}\) are the total investment cost (in US$/kVar) and the size (in MVar) of UPFC, respectively.

III. Problem Formulation

3.1 Objective function

In the market-based power systems, the conventional objective of market operator is to minimize the total generation cost. In this paper, the costs associated with congestion and voltage profile improvement are also included in the OF. Therefore we are faced with a more complex multi-objective optimization problem that includes load flow equality and operational inequality constraints

\[
\min \left\{ \sum_{i=1}^{N_G} \left\{ \frac{TGC_i}{TGC_{base,i}} + \frac{VV_i}{VV_{base,i}} \right\} + n \cdot C_{UPFC,\text{Annual}} \right\}
\]

Where TGCi, and VVi are the total GenCos and voltage violation respectively.

3.2 The GenCos cost functions

To allocate the best network settings that minimize the overall generation cost function while imposing all network constraints. In this paper, the overall generation cost function is modeled by a quadratic function as follows

\[
TGC = \sum_{i=1}^{N_G} \left( a_{\varphi} + b_{\varphi} P_{\varphi} + c_{\varphi} P_{\varphi}^2 \right)
\]

3.3 The Voltage Violation

Voltage violation is to allocate the best network settings that minimise the overall voltage violation while imposing all network constraints. In this paper, the overall voltage violation function is presented by the following quadratic function

\[
VV = \sum_{i=1}^{NB} PF \times (V_i - I)^2
\]

Where \(V_i\) is the voltage magnitude of bus \(i\), \(NB\) is the number of buses in the test system and \(PF\) is the voltage penalty factor.

3.4 The UPFC cost function

In this paper, one UPFC unit is used to minimize the total system cost (including the total GenCos and congestion costs) and improve the voltage profile.
3.5 Constraints

In this paper, the OF (11) is subjected to the following constraints:

1. Power injection: The net injections of real and reactive power at each bus are set to zero.
2. Generation limits: The limits on the maximum and minimum active (PG) and reactive (QG) power generation of the generators are included as

\[
P_{G}^{\text{min}} \leq P_{G} \leq P_{G}^{\text{max}} , \quad Q_{G}^{\text{min}} \leq Q_{G} \leq Q_{G}^{\text{max}}
\]

\[i = 1, 2, \ldots, G
\]

Where \(P_{G}\) and \(Q_{G}\) are the active and reactive power generation vectors at bus \(G_i\), respectively.

Compensation limit: The maximum and minimum values of UPFC parameters are included as

\[
V_{T}^{\text{min}} \leq V_{T} \leq V_{T}^{\text{max}}
\]

\[
\phi_{T}^{\text{min}} \leq \phi_{T} \leq \phi_{T}^{\text{max}}
\]

\[
l_{q}^{\text{min}} \leq l_{q} \leq l_{q}^{\text{max}}
\]

IV. Development Of Proposed Pso

One of the most difficult parts encountered in practical engineering design optimizations is handling constraints. Real-world limitations frequently introduce multiple, nonlinear and non-trivial constraints in the engineering design problems. Constraintsoften limit the feasible solution to a small subset of the design space. A general engineering optimization problem can be defined as follows:

4.1 PSO Based OPF

Though a wide variety of optimization techniques have been applied for solving the single objective OPF problem, as mentioned earlier, but the results obtained by using PSO methods are much more promising and better than those compared to other techniques [13]. Many advantages of PSO over the other techniques include:-

- It can deal with non-differentiable objective functions.
- It is more flexible and robust.
- No problem of premature convergence.
- Solution quality independent of the initial population.

4.2 PSO Algorithm for OPF problem

The various steps involved in the implementation of PSO to the OPF problem are

**Step 1:** Input parameters of system, and specify the lower and upper boundaries of each variable.

**Step 2:** Initialize randomly the particles of the population. These initial particles must be feasible candidates solutions that satisfy the practical operation constraints.

**Step 3:** To each particle of the population, employ the Newton-Raphson method to calculate power flow and transmission loss.

**Step 4:** Calculate the evaluation value of each particle, in the population using the evaluation function.

**Step 5:** Compare each particle’s evaluation value with the gBest. The best evaluation value among the gBestis denoted as gBest.

**Step 6:** Update the time counter t = t + 1
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**Step7:** Update the inertia weight given by

\[ W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \]  

(15)

**Step8:** Modify the velocity of each particle according to the mentioned equation.

\[ V(k, j, i + 1) = w \times V(k, j, i) + C1 \times \text{rand} \times (pbest - x(k, j, i)) + C2 \times \text{rand} \times (gbest - x(k, j, i)) \]

(15)

**Step9:** Modify the position of each particle according to the mentioned equation. If a particle violates the position limit in any dimension, set its position at the proper limit.

\[ x(k, j, i + 1) = x(k, j - 1, i) + v(k, j, i) \]

(16)

**Step10:** Each particle is evaluated according to its updated position. If the evaluation value of each particle is better than the previous pBest, the current value is set to be pBest. If the best pBest is better than gBest, the value is set to be gBest.

**Step11:** If none of the stopping criteria is satisfied, then go to Step 12. Otherwise, go to Step 6.

**Step12:** The particle that generates the latest gBest is the optimal value.

The parameters that must be selected carefully for the efficiency of the PSO algorithm are:-

a. Both acceleration factors C1 & C2.

b. Number of particles.

c. The inertia factor.

d. The search will terminate if one of the following scenarios is encountered:

1. \(|g_{best} - g_{best}| < 0.0001\) for 50 iterations

2. Maximum number of iteration reached (500 iterations)

e. Number of intervals N, which determines the maximum velocity

\[ v_{max} \]

V. Results and Discussion

Matlab programming codes for PSO and modified power flow algorithm to include UPFC are developed and incorporated together for the simulation purposes in this work. The suggested algorithm is applied to the 5-bus test system.

![Figure 2.5 Bus test System](www.iosrjournals.org)


Table -1 UPFC rating

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<th>Parameter</th>
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<tr>
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Table-2 comparative result of Without UPFC and With UPFC

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VI. Conclusion

In this paper, the effectiveness of the optimal location of UPFC for enhancing the security of power systems by alleviating the congestion under single line contingencies has been investigated. A PSO technique has been successfully applied to the problem under consideration. Alleviation of congestion is considered as the optimization criterion.

References