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Stability Enhancement of Power System with UPFC Using Hybrid TLBO Algorithm

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Power sector's complexity has been increasing due to rising demand—distributed generation and deregulation have greatly increased the complexity of the power system. Flexible Alternating Current Transmission System (FACTS) devices improve the quality of power by increasing the power transfer capability. This paper proposes an optimal power flow analysis using a Modified Teaching Learning Based Optimization (MTLBO) algorithm followed by an optimal placement of UPFC in the system. The proposed analysis has been validated and implemented on an IEEE 30 bus system.

Keywords: UPFC, stability Enhancement, FACTS, MTLBO, Power flow optimization

Introduction

Power systems are becoming more complex in nature due many factors like increasing demand for power, deregulation of electrical energy etc. The main objective of OPF is to optimize the operating condition of power system. This can be achieved by reducing transmission loss and by minimizing generation cost. Thus many conventional and novel optimization techniques have been introduced to solve this problem[1-3].But it is not enough for reallocation of power generation. In practice, shunt and series capacitors are implemented to reduce to the transmission line reactance and phase shifting transformers are utilized to control power flow in transmission line.

Optimal placement of the controller

Due to vast development in electronic field, controllers are introduced to afford controllability over transmission lines. The usage of FACTS devices in transmission line has been increased to enhance the system[4,5]. Hence, to conserve a security of a transmission lines, the FACTS devices should be located in optimal position[3]. Although various FACTS devices such as TCSC, STATCOM is utilized in transmissions lines, UPFC is the most advanced one. Because it can maintain the voltage magnitude, impedance and phase angle of the power network simultaneously. Hence, in this work, novel and an advanced technique Modified TLBO is tailored to identity the optimal location of UPFC. Finally, the performance of the proposed topology is compared with other techniques to confirm its efficiency.

Modelling of unified power flow controller

UPFC is a combination of series and shunt converters. It permits the bidirectional flow of real power between the shunt and series converters. The UPFC can be represented with two voltage sources, shown in Figure 1. The series converter provides both real / reactive power whereas the shunt converter implements the reactive power compensation. The mathematical model of a UPFC is displayed in Figure 2.

The voltage and phase angles of UPFC is controlled using coupling transformers. While implementing UPFC in a transmission line, it should be connected between to buses.

Problem statement

OPF is to optimization of real power generation cost. It should be designed to satisfy the nonlinear constraints within the operating limits of a system.

Minimize Fuel cost

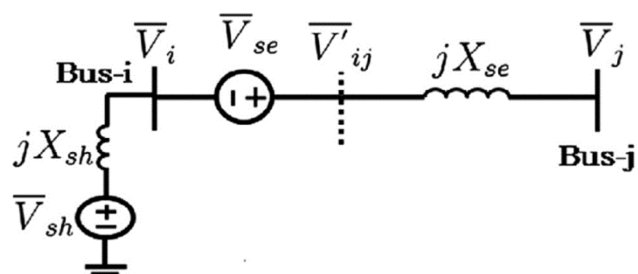

Fig. 1 — UPFC representation using voltage sources.

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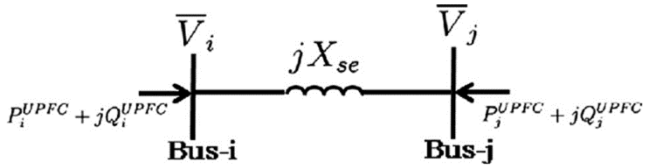

Fig. 2 — Mathematical model of UPFC

$$F_r = \sum_{i=1}^{ng} xP_{gi}^2 + y_i P_{gi} + z \quad \dots (1)$$

Subject to $g(z_1,a_1) = 0$ & $h(z_1,a_1) \leq 0$
Here, a_1 - control variable (Independent)
It can be defined as

$$a^T = [P_{g2,\dots}P_{geg,}V_{g2,\dots}V_{geg}] \quad \dots (2)$$

z_1 - state variable (Dependent)

$$z^T = [P_{g1,}V_{L1,} \dots V_{Lnlb,}Q_{g1,}S_{l1,\dots}S_{1nl}] \quad \dots (3)$$

Where
P_g / P_{gi} - Active power of PV buses / slack bus
V_g / V_L - Voltage across PV buses / (PQ / load buses)
n_g / n_{lb} - No. of generators/load buses
Q_g - Reactive power
S_l - Transmission line loading
$g(z_1,a_1)$ - Equality constraints
$h(z_1,a_1)$ - Inequality constraints

Optimization using MTLBO (TLBO-PSO)

A hybrid population-based optimization algorithm is formulated to perform power flow optimization of the considered system. The algorithm is a combination of TLBO and PSO. PSO is a meta-heuristic algorithm which is based on the characteristics of flocks of birds and schools of fishes. Unlike other optimization algorithms like evolutionary or genetic algorithm, PSO has minimal intermediary variables. This greatly reduces the computation time[6]. TLBO, on the other hand, is a population-based optimization algorithm based on the teaching-learning process in class. Unlike all the other optimization algorithms including PSO, TLBO doesn’t include any pre-defined optimization variables. PSO arrives at the optimal solution by updating the position and velocity of each particle of the population[7]. This updation is done by assessing the personal and social behaviour of each particle. The particle with the best position (solution) in the entire swarm is computed as the global best and the best position (solution) obtained by each particle is computed as personal best. The velocity of each particle is updated based on p_{best} and g_{best} values. The position (decision variables) of each particle is then updated based on the updated velocity[8]. TLBO is stimulated version of teaching process which continues practically in classroom environment. The teacher put efforts to divulge knowledge to the learners aiming at increasing the knowledge level of the whole class. Apart from gaining knowledge from the teacher, the learners also acquire knowledge through the other students to improvise their grades. A group of students (called population) learn in two stages namely the teacher-phase and learner-phase. The best of the group is selected as a teacher, and the rest of the students learn from the teacher in the teacher-phase, i.e., their knowledge is updated based on the difference between the teacher’s knowledge and the mean knowledge of the students. In the learner-phase, the students update their knowledge from fellow-students, i.e., the knowledge of a learner is renewed based on the difference in knowledge between the considered learner and any randomly selected individual from the class. The proposed hybrid optimization algorithm combines the best features of both PSO and TLBO. Two sets of updated population are computed using PSO and TLBO. The best half of each updated population is combined to form the new updated population. This population is further updated through the learner-phase of the TLBO optimization. Convergence of the optimization algorithm is checked by analysing the difference in function values. This procedure of PSO-TLBO is repeated till the convergence criterion is satisfied.

Algorithm

Step 1: Set the maximum and minimum limits of each decision variable (Y), the size of the population and optimization parameters such as r_1,r_2 etc.,

Thus, the initial population can be formulated as Population = $Y_{min} + r * (Y_{max} – Y_{min})$,

Where, r – Random number whose value ranges between [0,1].

Step 2: Calculate objective function value for each individual of the population.

Step 3: PSO: Update the position and velocity of each individual according to:

3a: Compute the personal best (p_{best}) of each particle

3b: Compute the global best (g_{best}) of entire population

3c: Update the velocity of each particle based on p_{best} and g_{best}

3d: Update the position (decision variable) of each particle based on updated velocity

Step 4: TLBO: Select the best individual as the Teacher $X_{teacher}$

Step 5: TLBO: Compute the mean knowledge of the entire class X_{gmean}

Step 6: TLBO – Teacher-Phase: Update each individual's knowledge according to:

6a: Compute the difference between teacher's knowledge and mean knowledge of class

6b: Assign random Teaching Factors (TF) for each individual

6c: Update knowledge of each learner by adding the product of diff mean and TF

Step 7: Update Population: Form a new population according to:

7a: Sort the population updated according to PSO

7b: Sort the population according to their updated knowledge after teacher phase

7c: Combined population: best half from *step 7a* and best half from *step 7b*

Step 8: TLBO – Learner-Phase: Update each individual's knowledge according to:

8a: Select a random learner, for each individual, from the updated population

8b: Compute the difference in knowledge

8c: Update the knowledge of the individual based on this difference in knowledge.

Step 9: Check for convergence: Go to *step 2* and repeat till convergence is reached.

Step 10**:** Display the optimal power flow solutions.

Simulation results

A standard IEEE 30 bus system has been considered to validate accuracy and efficiency of the developed MTLBO algorithm based OPF solution with and without UPFC. This system has 30 buses, 6 generating units and 41 transmission lines, with a 189.2 MW of load power. By simulating the modified IEEE 30 bus system using various algorithm (NR, PSO, TLBO and MTLBO) and their corresponding results are tabulated in Table 1 and Table 2. From the load flow analysis, it is witnessed that magnitude of the voltage at bus 26 is about 0.9076 p.u. It is comparatively less when compared with other buses. Hence to improve the voltage profile at bus. No:26, UPFC is placed bus no. 25 and 26. Thus fuel cost and total loss obtained by this system under these topology are as follows, Conventional (NR) method (772.536 ($/h) and 17.528 MW), PSO topology (801.8436 ($/h) and 9.377 MW) and for TLBO methodology (801.8256 ($/h) and 9.352 MW). Similarly, for the proposed MTLBO topology, fuel cost and loss are about 801.7951($/h) and 9.348 MW without UPFC and 800.6812($/h) and 9.214 MW in the presence of UPFC. Hence, it is concluded that MTLBO is superior to other algorithms. From the figure 3, it can be observed that the proposed MTLBO algorithm with

Table — 1 OPF results of proposed system using various optimization techniques

Variables	Bus Number	NR	PSO	TLBO
Generator Real power Output (MW)	1	200	176.7267	175.825
	2	40	48.8049	48.4185
	5	50	21.4781	21.4126
	8	35	21.7292	21.6051
	11	16.25	12.0357	12.4025
	13	10.47	12.0000	12.0166
Generator Voltage (pu)	1	1.06	1.0600	1.0600
	2	1.0430	1.0430	1.0430
	5	1.0100	1.0100	1.0100
	8	1.0100	1.0100	1.0100
	11	1.0820	1.0820	1.0820
	13	1.0710	1.0710	1.0710

Table — 2 OPF results of proposed system with and without UPFC

Variables	Bus Number	MTLBO (Without UPFC)	MTLBO (With UPFC)
Generator Real power Output (MW)	1	175.0514	169.3123
	2	48.3256	49.542
	5	21.3027	21.8425
	8	21.5236	23.5142
	11	12.0652	13.2145
	13	12.0010	12.5213
Generator Voltage (pu)	1	1.0600	1.0600
	2	1.0430	1.0398
	5	1.0100	1.0100
	8	1.0100	1.0099
	11	1.0820	1.0721
	13	1.0710	1.0671

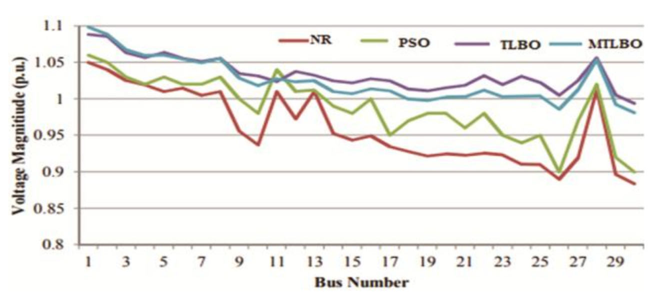

Fig. 3 — Voltage profile improvement with FACTS devices

UPFC proved to be an effective solution to the OPF problem. It can also be inferred that the developed algorithm has better convergence characteristics and robustness in effectively solving the OPF problem.

Conclusion

This paper has proposed a hybrid MTLBO algorithm to solve OPF problem. The developed OPF solution was then used to identify the optimal location for UPFC. The effectiveness is measured by comparing the OPF results after optimally placing the UPFC with the base case OPF results. The codes developed for this solution procedure was executed for a modified IEEE 30 bus system. UPFC was placed between bus no. 25 and 26 and OPF solution was again computed. From the results, it was observed that the active power flow has significantly increased. Thus, it is concluded that the proposed OPF based MTLBO algorithm with UPFC has improved the power flow capability of the considered network.

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