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Optimum Placement of UPFC Using Evolutionary Algorithms

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Abstract

: Among the different FACTS devices the cost of Unified Power Flow Controller (UPFC) are more expensive, optimum location of these devices plays important role in power system. This paper proposes a multi-objective optimization problem work using Gray Wolf Optimizer- Cuckoo Search (GWO-CS) algorithm for UPFC to place optimally. The cost of generation is used as the objective function, by considering optimum power flow. The results of proposed algorithm are compared with Particle Swarm Optimization (PSO) and Cuckoo Search (CS) algorithms. Comprehensive study includes the proposed algorithms for placement of UPFC, cost of generation & voltage profile of IEEE 62 bus test system.

Keywords: GWO-CS Algorithm, CS-Algorithm, PSO-Algorithm, Optimum placement of UPFC.

1. Introduction

In the current situation, the rise in power demand increases the too much stress on the power system network.[1] As a result the transmission line of power system expansion constrained and causes overloading of transmission line. This may leads to verge of stability limits. So it has been a challenge for power system operators to maintain power stability with reliability[2]. FACTS devices helps to improve transient stability and enabling existing systems can be used closer to their thermal loading capacity [3-5]. The UPFC can also help to increase the stability of the power system by placing optimal in power system.

Literature survey reveals that some of the research has been carried out for optimum placement of UPFC using optimization techniques[6]. Different allocation methods are used to find optimum for UPFC such as analytical method, heuristic method and numerical method.[7-9] Usually, for complex and large system calculations heuristic methods are used because of robust and finds near optimum solutions [10]. Hybrid methods such as Artificial Bee Colony (ABC) and Gravitational Search (GS) algorithms [11], Imperialist Competitive algorithm and Pattern Search method [12] and PSO [13-18] are used for optimum placement.In this paper optimal location of UPFC is determined using the GWO[19] & CS[20-21] integrated as GWO-CS [22-24] algorithms on an IEEE 62 bus system

2. Optimum Location Of UPFC

2.1 Objective function

Choosing the best site is an optimization challenge, the goal of objective function is to keep the value of generating cost with satisfying operating conditions.

The equation1 represents the total power generation, transmission loss & cost of UPFC that must be minimized using optimum power flow. In equality constraint both voltage and power is considered in (2&3).

The main objective function is,[25]
Min.

$$F_{costi}(P_{gi})=a^*\sum(xP_{gi}^2+yP_{gi}+z)+b^*P_{loss}+c^*UPFC_{cost} \quad (1)$$

Where P_{gi} is generator output, x,y,z are cost coefficients and a,b,c are constant coefficients

The objective function is to minimise cost of generation with the following constraints,
Equation 2&3 gives the In-Equality Constraint, Voltage, and Power.

$$V_{i\,min} \leq V_i \leq V_{i\,max} \quad (2)$$

$$P_{load} + P_{loss} + \sum P_{gi} = 0 \quad (3)$$

2. 2 UPFC Model

The UPFC employs two converters namely DC-AC converter (VSC_1) & AC-DC converter (VSC_2) connected back to back with through a DC link as shown in Fig. 1.

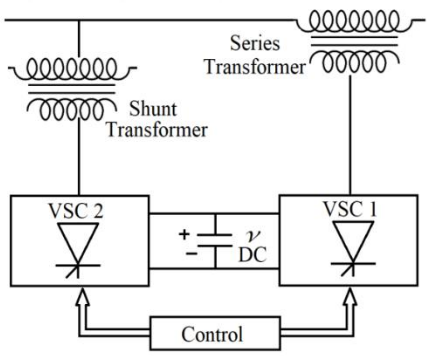

Fig.1. The basic structure of UPFC.

UPFC is made up of two FACTS devices: a Static-Var Compensator (SVC) and a Thyristor-Controlled Series Capacitor (TCSC).

The transmission line impedance & reactance is given by equation 4 & 5.

$$Z_{ij} = Z_L + jX_{TCSC} \quad (4)$$

$$X_{TCSC} = r_{TCSC} X_L \quad (5)$$

SVC will be operated in two different modes, inductive & capacitive by absorbing injecting reactive power.

The injected reactive power at bus i^{th} is

$\Delta Q_{is} = Q_{svc}$

Q_{SVC}: Reactive power injected by SVC (MVAR)

$Q_{svc} = Q_{Min} \sim Q_{Max}$

UPFC limit for reactance and reactive power are,

$X_{TCSC} = -0.8X_L$ to $0.8X_L$

$Q_{SVC} = -100$ MVAR to 100 MVAR

By varying magnitude & angle of series injected voltage of UPFC power flow in a transmission can be controlled. The capacitive & inductive control strategies are stated in equitation 6 & 7.

Capacitive mode

$$|V_{Se}| = 0.09,\ \alpha = -90^0,\ I_S = 0.9 \quad (6)$$

Inductive mode

$$|V_{Se}| = 0.09,\ \alpha = +90^0,\ I_S = 0.1 \quad (7)$$

2.3 Gray Wolf Optimizer (GWO) Algorithm

The GWO concept is introduced by Seyedali Mirjalili *et al [19]*. GWO algorithm is inspired by leadership, hunting, and hierarchy mechanism of gray wolves in nature.

2.3.1 Mathematical equations

The four types of gray wolves are α (Alpha), β (Beta), δ (Delta), and ω (Omega) are employed. The encircling pray equation given by,

$$D = \left|C \cdot X_p(t) - X(t)\right| \quad (8)$$

$$X(t+1) = \left|X_p(t) - A \cdot D\right| \quad (9)$$

Where A & D coefficient vectors and t is current iteration. X and X_p are position vector of gray wolf and pray respectively. Value of A & C calculated as,

$$A = 2 \cdot a \cdot r_1 - a \quad (10)$$

$$C = 2 \cdot r_2 \quad (11)$$

2.3.2 Hunting

The following formulas are used update the gray wolves[21].

$$D_\alpha = |C_1 \cdot X_\alpha - X|, D_\beta = \left|C_2 \cdot X_\beta - X\right|, D_\delta = |C_3 \cdot X_\delta - X| \quad (12)$$

$$X_1 = X_\alpha - A_1 \cdot D_\alpha, X_2 = X_\beta - A_2 \cdot D_\beta, X_3 = X_\delta - A_3 \cdot D_\delta \quad (13)$$

$$X(t+1) = \frac{X_1 + X_2 + X_3}{3} \quad (14)$$

2.4 Cuckoo Search (CS) Algorithm

The CS algorithm is inspired by a bird called by “cuckoo” and character of Lévy flights[20]. The cuckoo nest are updated by following equitation,

$$x_i^{t+1} = x_i^t + \alpha \oplus \text{lévy}(\lambda) \quad (15)$$

Where α is the step size (α > 1) and levy is given by

$$\text{lévy} \sim u = t^{-\lambda}, (1 \le \lambda \le 3) \quad (16)$$

2.5 Hybrid Gray Wolf Optimizer (GWO) - Cuckoo Search (CS) Algorithm

The integration GWO with CS is proposed as GWO-CS algorithm. The flow chart used for optimum location of UPFC shown in Fig. 2.

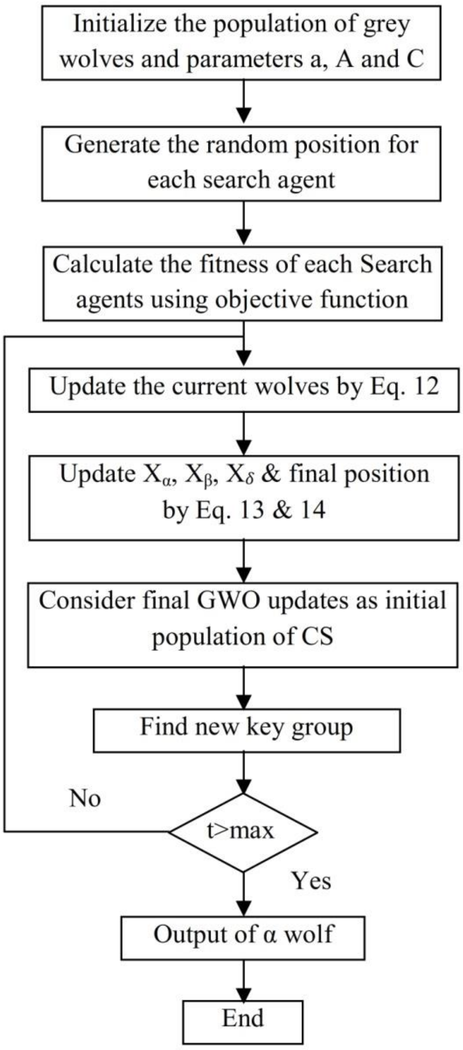

Fig. 2: Flowchart of GWO-CS algorithm

3. Results And Analysis

The proposed method is applied to minimize the generation cost, results are compared with PSO and CS algorithms. Paper [25] discusses the steps involved in PSO & CS algorithms. In this system, the total variables are 21, out of that 1-19 are generators and 20 & 21 are MVAR of UPFC and reactance of TCSC respectively. Hence in this paper, hybrid GWO-CS algorithm is evaluated on an IEEE 62 bus systems with and without UPFC. The bus voltage of IEEE 62 bus system with and without UPFC is shown Fig. 3, 4, and 5 respectively. The voltage profile was improved by using all three algorithms after placing UPFC in the system (IEEE 62) at optimum location compared to without UPFC in the same system.

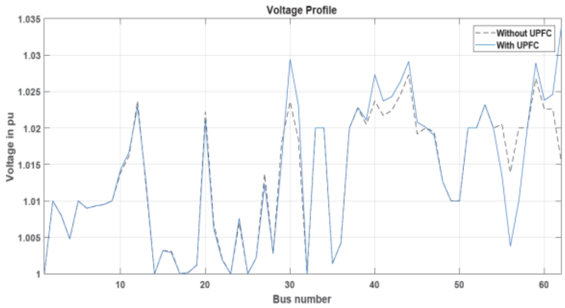

Fig.3. Bus voltage of IEEE 62 system by PSOA

UPFC is located at bus number 2 using the PSO algorithm. UPFC is far away from bus number 57, leading to a lower bus voltage than without UPFC. In the CS algorithm, the UPFC is placed at bus number 6, and all buses' voltages are higher than without the without UPFC bus profile as shown in Fig. 3. Using GWO-CS algorithm has optimum location as bus number as 29, at this location UPFC is managed to maintain the voltage level above the level compared to without UPFC as shown in Fig. 4

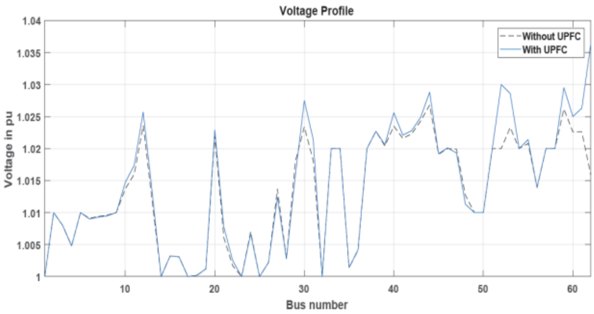

Fig.4. Bus voltage of IEEE 62 system by CSA

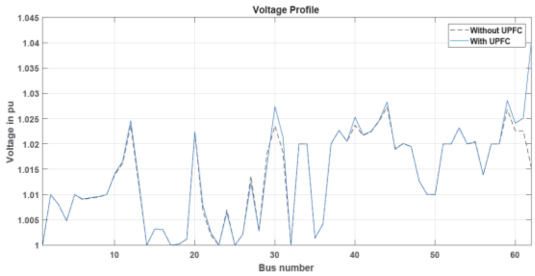

Fig.5. Bus voltage of IEEE 62 system by GWO-CSA

The power generation achieved from the GWO-CS algorithm is compared PSO and CS algorithm in table 3. In comparison to PSO and CS algorithms, the application of UPFC from GWO-CS results in optimal power generation. When compared to the PSO algorithm, the simulation results of GWO-CS transmission loss and total generation are higher, because GWO-CS has minimized the generation of generators where fuel costs are higher.

The objective function of the GWO-CS algorithm is to minimize generation cost, which has been reduced when compared to the PSO and CS algorithms. Table 4 summarizes the optimal placement location for UPFC.

Table 3: Generation in MW by PSO, CS & GWO-CS algorithms.

Generators	Power generation in (MW)		
	With PSO	With CSA	With Hybrid GW- CSA
G1	41.846	71.2944	19.432
G2	306.317	258.75	222.67
G5	51.5794	279.048	229.52
G9	150	148.655	148.21
G14	218.184	288.767	179.02
G17	299.089	213.463	239.94
G23	50	152.405	62
G25	120.151	95.2779	67.933
G32	68.5641	41.9765	204.3
G33	40.7653	99.9828	99.129
G34	150	127.328	148.78
G37	100	36.1276	97.032
G49	299.952	290.418	286.62
G50	150	143.963	148.35
G51	267.46	266.78	156.41
G52	150	144.314	141.22
G54	100	96.4704	99.272
G57	300	204.429	295.74

G58	100	107.917	128.39
Total	2963.91	3067.37	2973.97

Table 4: Comparison of PSO, CS & GWO-CS algorithms for IEEE 62 bus.

Parameters	With PSO	With CSA	With GWO-CSA
Total Generation(MW)	2963.908	3067.367	2973.968
Transmission loss (MW)	16.1083	19.1618	16.176
Generation Cost($)	13385	13768	13111
Placement of UPFC (Bus No.)	2	6	29

Table 5: Comparison of PSO, CS & GWO-CS algorithms for IEEE 30 bus.

Parameters	With PSO	With CSA	With GWO-CSA
Total Generation(MW)	280.04	269.3404	267.457
Transmission loss (MW)	6.6381	6.5157	3.9382
Generation Cost($)	792.12	791.95	756.11
Placement of UPFC (Bus No.)	5	5	5

In addition, Comparison of PSO, CS & GWO-CS algorithms for IEEE 30 bus system is shown in table 5. The results of the CS are superior to those of the PSO because the CS algorithm has a better search path for fewer variables. However, GWO-CS has the best search ability, and as a result, it has produced better results when compared to the PSO and CS algorithms. Analytical results of both system shows that the GWO-CS algorithm surpasses the PSO and CS algorithms.

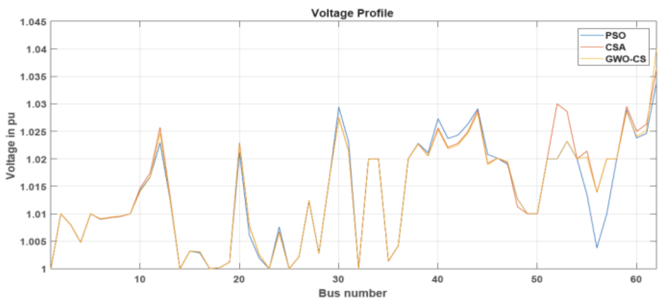

Fig.6. Bus voltage of IEEE 62 system by PSO, CS and GWO-CSA

Voltage profile of IEEE 62 bus test system shown in Fig. 6 and Voltage profile of IEEE 30 bus test system shown in Fig. 7. In comparison to the PSO and CS algorithms, the GWO-CS algorithm kept a lower voltage profile for both systems while staying within the voltage limit.

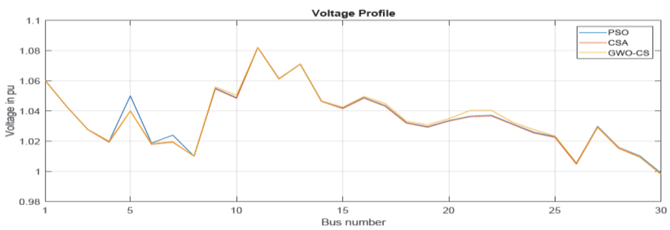

Fig.7. Bus voltage of IEEE 30 system by PSO, CS and GWO-CSA

4. Conclusion

The optimum location of UPFC is proposed using a multi-objective function and optimal power flow in this paper. Transmission loss, power generation, generation cost, and UPFC placement are all taken into account at the same time. The proposed algorithms improved the voltage profile when UPFC is inserted in the test system. The PSO algorithm produces better results for complex systems, while the CS algorithm produces better results for systems with fewer variables. The results revels GWO-CS algorithm outperforms the PSO and CS algorithms on the IEEE 62 and 30 bus systems.

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