SINGLE OBJECTIVE POWER FLOW PROBLEM ANALYSIS USING HCSA WITH IPFC

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Abstract: *Optimal Power Flow (OPF) with Interline Power Flow Control (IPFC) device place an important role in power systems. In this the modeling of IPFC device and location of IPFC device are discussed in this paper. A proposed NDSHCSA algorithm for multi-objective optimal power flow problem with IPFC with different stated objective functions are discussed. In the proposed algorithm Fuzzy toll is used to find the best Pareto front solution. The results are showing better when compared to existing literature.*

Keywords: **Optimal power flow, IPFC, Hybrid cuckoo search algorithm, cost, loss and emission**

1. INTRODUCTION

Now a day's growing in demand for electricity, due to increase in utility of electrical energy in various modes that leads operation of power system become difficult task. A recent development in power electronic technology with FACTS device is described in [1-3]. The modeling of UPFC is described in [4-7]. Power flow control in single transmission line UPFC is used and for multiline power flow control IPFC is used. The voltage source converter is described in [8]. Further, on observation it is revealed that the PIM of FACTS devices are described in [9-10]. In [11], the IPFC is a successful power flow control of multi-line systems. In this reference explained the basic operation of IPFC. Modeling of IPFC and execution in Newton method is described in [12]. In [13] proposed OPF method with IPFC to solve load flow problem with minimizing generation fuel cost. Real power loss minimization in power system was developed by Jun Zhang and Akihiko Yokoyama [14]. In [15], describes a PIM of IPFC for power flow analysis by considering the transformer impedance and the line charging susceptance. In [16], the PSO, GA and SA optimization techniques are used to optimize the total power loss in the network with IPFC. A current based model of IPFC has developed by Vinkovic A and Mihalic R [17] In the above literature, reveals that all the FACTS devices incorporated for power flow management of single transmission line. But this chapter describes the performance of a multi-line FACTS device which is IPFC. Numerical analysis is carried out with sundered test systems on IEEE-14 bus.

2. POWER INJECTION MODEL OF IPFC

IPFC is the versatile member of FACTS controller used in power flow management of multiple transmission lines of a power system network. IPFC model consists of number of DC-AC converters. These converters provide series compensation for the lines. IPFC consists of number of SSSC's but for simplicity IPFC represents two back-to-back DC-AC converters in series with two transmission lines through coupling transformer. The basic diagram of IPFC is shown in Figure 1 In this way IPFC can be supply real power to DC link for its transmission line.

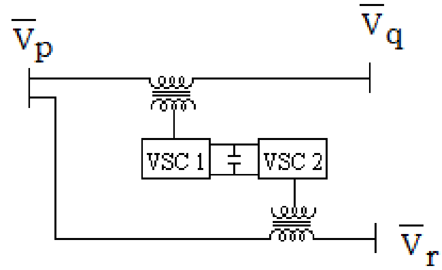

Figure 1. Basic Structure of IPFC

Impact of the IPFC device on power system is analyzed using PIM of IPFC can be incorporated in NR power flow method. Under steady state condition VSC can be represented as series voltage source whose magnitude and angle can be controlled. The simple basic diagram of IPFC is shown in Figure 2.

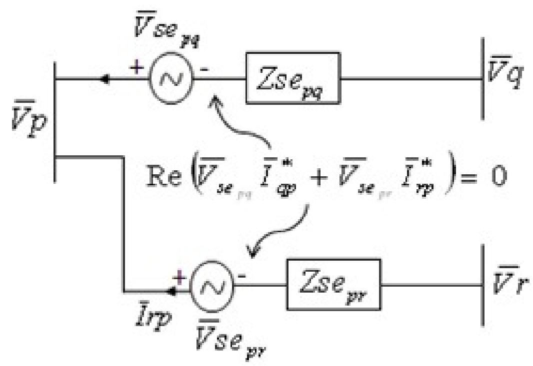

Figure 2. Equivalent circuit of two converters IPFC

The active and reactive power injections at p^{th} bus are

$$P_p^{'} = \mathrm{Re}\left(\overline{S}_p^{'}\right) = \sum_{m=q,r} |V_p| |V_{ser_{pm}}| |b_{ser_{pm}}| \sin\left(\delta_p - \theta_{ser_{pm}}\right) \quad (1)$$

$$Q_p^{'} = \mathrm{Im}\left(\overline{S}_p^{'}\right) = \sum_{m=q,r} |V_p| |V_{ser_{pm}}| |b_{ser_{pm}}| \cos\left(\delta_p - \theta_{ser_{pm}}\right) \quad (2)$$

The active and reactive power injections at m^{th} bus are

$$P_m^{'} = \mathrm{Re}\left(\overline{S}_m^{'}\right) = |V_m| |V_{ser_{pm}}| |b_{ser_{pm}}| \sin\left(\delta_m - \theta_{ser_{pm}}\right) \quad (3)$$

$$Q_m^{'} = \mathrm{Im}\left(\overline{S}_m^{'}\right) = |V_m| |V_{ser_{pm}}| |b_{ser_{pm}}| \cos\left(\delta_m - \theta_{ser_{pm}}\right) \quad (4)$$

3. INSTALLATION COST OF IPFC DEVICE

The Installation Cost (IC) [18] of IPFC is

$$IC_{IPFC} = \frac{C_{IPFC} \times S_{IPFC} \times 1000}{n \times 8760} \quad \$/h \quad (5)$$

Cost of IPFC is

$$C_{IPFC\,A} = 0.00015\, S_A^2 - 0.01345\, S_A + 94.11 \quad \$/kVAr \quad (6)$$

$$C_{IPFC\,B} = 0.00015\, S_B^2 - 0.01345\, S_B + 94.11 \quad \$/kVAr \quad (7)$$

$$C_{IPFC} = C_{IPFC\,A} + C_{IPFC\,\mathbf{B}} \quad (8)$$

$S_A = |Q_{A2}| - |Q_{A1}|$, $S_B = |Q_{B2}| - |Q_{B1}|$, $S_{IPFC} = S_A + S_B$

Q_{A1}, Q_{B1} and Q_{A2}, Q_{B2} are reactive power flows in lines, $k-m$ and $k-n$ before and after installing IPFC, n is the life time of IPFC in years

4. HYBRID CUCKOO SEARCH ALGORITHM (HCSA)

This algorithm [19] is population based computational technique. The main steps are as follows

a. Initialization

$$x_{pq} = x_q^{\min} + rand(0,1) \times \left(x_q^{\max} - x_q^{\min}\right) \tag{9}$$

b. Levy flights

The cuckoo randomly chooses the nest position to lay egg is given in equations (10) and (11). For i^{th} cuckoo, while generating new solutions levy flight is performed [11]

$$x_i(t+1) = x_i(t) + S_{pq} \times \alpha \oplus Levy(\lambda) \tag{10}$$

Where, α is generated randomly between -1 and 1;

Hence step size is calculated by $S_{pq} = x_{pq}^t - x_{fq}^t$

Levy flights in which the step lengths are distributed according to heavy tailed probability distribution mathematically.

$$Levy(\lambda) = \left| \frac{\Gamma(1+\lambda) \times \sin\left(\frac{\pi \times \lambda}{2}\right)}{\Gamma\left(\frac{1+\lambda}{2}\right) \times \lambda \times 2^{\left(\frac{\lambda-1}{2}\right)}} \right|^{1/\lambda}; \qquad 1 < \lambda \le 3 \tag{11}$$

c. Cross over

Once population of random set of points is created, a reproduction operator can be used to select good population. Recently new efficient crossover operators have been designed for searching process.

$$x_{pq}^{new} = (1-\lambda) \times x_{1q}^{ref} + \lambda \times x_{pq}^{old} \tag{12}$$

Where 'λ' is random number between 0 and 1

d. Selection

After sorting and ranking processes based on fitness values, the lowest fitness value and its corresponding population value are treated as best, and best population vector is considered for the next generation until the stopping criteria is reached.

e. Stopping criteria

The stopping criteria will be, if the number of generations equals to the specified maximum number of generations.

- **IPFC device limits**

$0 \le V_{se\,A} \le 0.1\,p.u.$; $0 \le V_{se\,B} \le 0.1\,p.u.$; $0 \le \theta_{se\,A} \le 360^0$;

$0 \le \theta_{se\,B} \le 360^o$; $0 \le X_{se\,A} \le 0.1\,p.u.$; $0 \le X_{se\,B} \le 0.1\,p.u.$;

5. RESULTS AND ANALYSIS

An IEEE-14 bus system is considered as first example for which the single line diagram, line data and bus data are given in Appendix-A. In this system, first bus is taken as swing bus, while buses 2, 3, 6 and 8 are PV buses, other buses are PQ buses. The IPFC installation location is identified as per the procedure described in section 3.7. For this system there is only one possible location with IPFC and corresponding severity value is tabulated in Table 5.1. From this table it is observed that, severity function value is minimum with 2.3098 when IPFC is located in location-1. The IPFC is placed in between buses 13-12 and 13-14 for the further analysis

Table 1. Possible locations of IPFC and its severity value in IEEE 14 bus system

Location No	IPFC Sending end bus	IPFC Receiving end bus-1	IPFC Receiving end bus-2	Severity value
1	13	12	14	2.3098

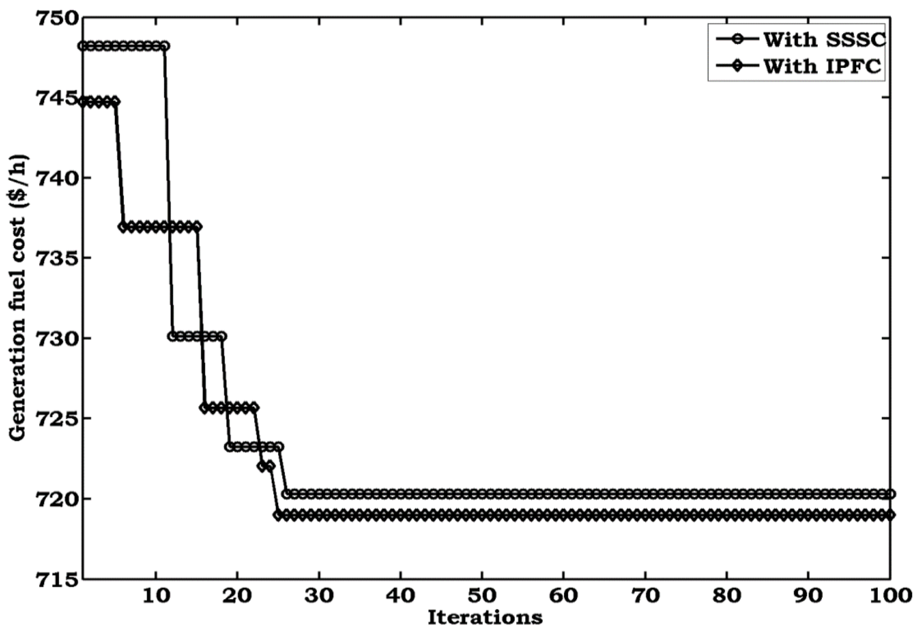

Figure 3. Convergence characteristics of generation fuel cost with SSSC and IPFC for IEEE 14 bus system

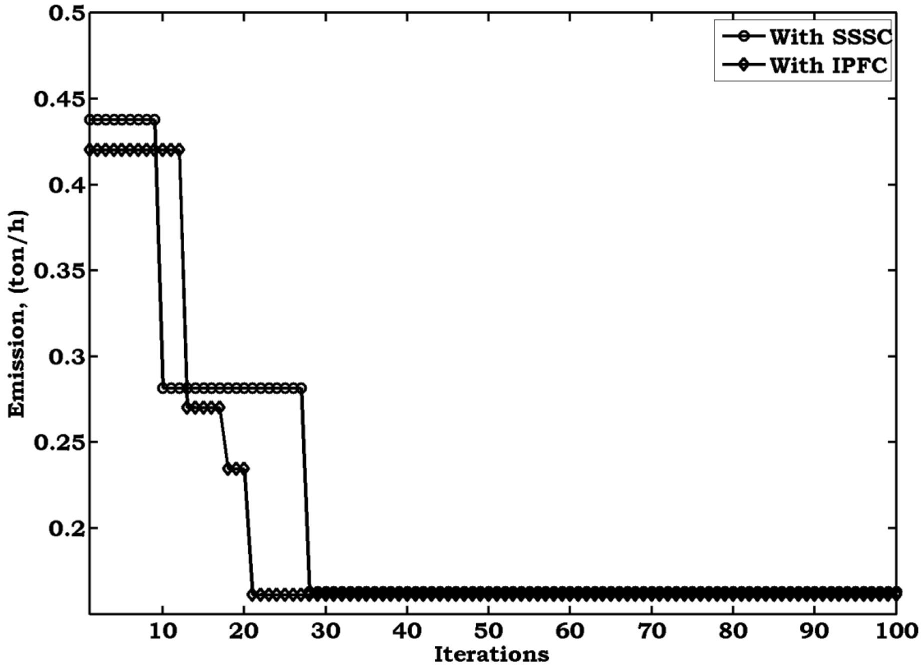

Figure 4. Convergence characteristics of emission with SSSC and IPFC for IEEE 14 bus system

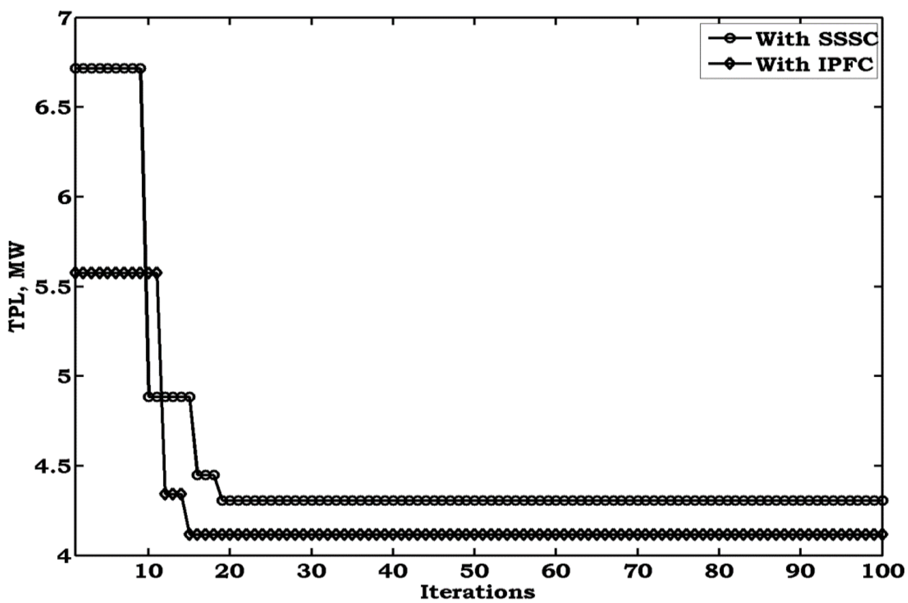

Figure 5. Convergence characteristics of total power loss with SSSC and IPFC for IEEE 14 bus system

Table 2. OPF solution of considered objective minimization with SSSC and IPFC for IEEE-14 bus system

Control Variables	Fuel cost ($/h)		Emission (ton/h)		TPL (MW)	
	With SSSC	With IPFC	With SSSC	With IPFC	With SSSC	With IPFC
P_{G1} (MW)	165	178	72.0092	72.192	51.2307	13.8681
P_{G2} (MW)	46.1	38.3	76.5829	70.9823	124.9842	143.9575
P_{G3} (MW)	20	20	33.8292	31.0923	60	59.8399
P_{G6} (MW)	31.2	26.5	34.9182	35.9201	20.8308	40.1228
P_{G8} (MW)	5	5	47.8192	55.2131	6.2615	5.33
V_{G1} (p.u.)	1.1	1.1	1.0257	1.0694	1.1	1.0304
V_{G2} (p.u.)	0.9	0.9	0.9872	0.9	0.936	0.9
V_{G3} (p.u.)	1.1	1.1	0.9241	0.9	0.9	1.1
V_{G6} (p.u.)	0.9	1.1	1.0887	0.9	1.0586	0.9964
V_{G8} (p.u.)	0.9162	0.9	1.1	1.0228	0.9	0.9987
T_{4-7} (p.u.)	1.1	1.0599	1.1	0.9	1.0189	0.9639
T_{4-9} (p.u.)	0.9521	1.0288	0.9865	0.9	1.0288	0.9255
T_{5-6} (p.u.)	0.9882	1.0615	1.059	0.9	1.0365	1.1
Q_{C9} (p.u.)	30	13.2312	21.108	29.9972	23.9384	19.5631
V_{se1} (p.u.)	0.00001	1.0E-6	1.0E-5	0.0009	0.00103	0.001
V_{se2} (p.u.)		0.014221		0.0001		0.0352
θ_{se1} (deg)	360	110.482	20.2381	360	286.1666	360
θ_{se2} (deg)		360		22.3123		279.7993
X_{se1} (p.u.)	0.04012	0.09210	0.0246	0.1	0.05	0.1
X_{se2} (p.u.)		0.07836		0.0213		0.0931
Cost ($/h)	**720.3240**	**719.003**	829.7524	837.1860	980.478	1087.215
Emission (ton/h)	0.2837	0.31520	**0.16311**	**0.16113**	0.2191	0.26817
TPL (MW)	8.2675	8.5548	6.1587	6.3998	**4.3072**	**4.1183**
Severity value	4.2393	4.1029	3.8763	3.0912	3.7674	3.2938

The analysis is extended for considered objectives with IPFC by satisfying the constraints. The OPF solution of considered objectives are tabulated in Table 2. From this table the following observations as follows:

- In the presence of SSSC between buses 12 and 13 the fuel cost is 720.3240 $/h, emission is 0.16311 ton/h and total power loss is 4.3072 MW. IPFC is installed between buses 13-12 & 13-14 the fuel cost is 719.003 $/h, emission is 0.16113 ton/h and total power loss is 4.1183 MW. The objective function values are less with IPFC when compared to SSSC.

The severity function value is also less with IPFC than the SSSC which indicates the power system security enhance more in IPFC.

The convergence patterns for fuel cost, emission and total power loss minimization objectives are shown in Figs. 3-5. From these it is observed that with IPFC has started with good initial value and reaches final best value in less number of iterations compared to SSSC

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