ATC Enhancement with Facts Devices using Quantum Inspired PSO

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ABSTRACT

Under new de-regulated environment an open access to transmission system seems to be desired. Determination and enhancement of available transfer capability (ATC) are important issues in deregulated operation of power systems. This paper focuses on the best location and optimal allocation of FACTS devices to improve maximum available transfer capacity (ATC). ATC is computed using repeated power flow method considering voltage profile. Quantum inspired PSO is used for optimization of FACTs requirement for maximizing ATC. The suggested methodology is tested on IEEE 30-bus system.

Keywords

Available Transfer Capability (ATC), Flexible AC Transmission Systems (FACTS), Quantum inspired PSO (QPSO), Deregulation.

1. INTRODUCTION

One of the principle characteristics of a competitive structure is the identification and separation of the various tasks which normally carried out within the traditional organization so that these tasks can be open to competition whenever practical and profitable. This process is called unbundling. An unbundled structure contrasts with the so called vertically integrated utility of today where all tasks are coordinated jointly under one umbrella under one common goal, that is, to minimize the total cost of operating the utility [1]. Under deregulation, the former vertically integrated utility [1], which performed all the functions involved in power, i.e. generation, transmission, distribution and retail sales, is dis-aggregated into separate companies devoted to each function.

In a deregulated power system structure, power producers and customers share a common transmission network for wheeling power from the point of generation to the point of consumption. All parties in this open access environment may try to produce the energy from the cheaper source for greater profit margin. It may lead to overloading and congestion of certain corridors of the transmission network. This may result in violation of line flow, voltage and stability limits and thereby undermine the system security. Utilities therefore need to determine adequately their ‘‘Available Transfer Capability’’ to ensure that system reliability is maintained while serving a wide range of bilateral and multilateral transactions [2].

The aim of electric industry restructuring is to promote competitive markets for electric power trading. The Available Transfer Capability (ATC) of a transmission network is the unutilized transfer capabilities of a transmission network for the power transfer for further commercial activity, over and above already committed usage [3-4]. Adequate Available Transfer Capacity (AATC) is needed to ensure all economic transactions, and to facilitate electricity market liquidity. Maximum use of existing transmission assets will be more profitable for transmission system owners and customers will receive better services with reduced price. Various ATC boosting approaches have been suggested adjusting terminal voltages through under load tap changers (ULTCs) and rescheduling generation.

Based upon the NERCs definition of ATC and its determination, transmission network can be restricted by thermal, voltage, and stability limits [3], but needs huge mathematical calculations. On the other hand, it is well recognized that the introduction of FACTs devices into transmission network resulted in severe impact in system utilization. From the steady state power flow viewpoint, networks do not normally share power in proportion to their ratings, whereas in most situations, voltage profile cannot be smooth. Therefore, ATC values are always limited by heavily loaded buses with relatively low voltage. FACTS concept makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile. Theoretically FACTS devices can offer an effective and promising alternative to conventional methods of ATC enhancement.

They will provide new control facilities, both in steady state power flow control and dynamic stability control [5]. Congestion management can also be achieved by improving Available Transfer Capability (ATC) of the network. Modern heuristic techniques such as QPSO have been demonstrated to be suitable approaches in solving non-linear power system problems.

Thus, transfer capability can be used for reserving transmission services, scheduling firm and non-firm transactions and for arranging emergency transfers between seller bus/areas or buyer bus/areas of an interconnected power system network. ATC among areas of an interconnected power system network and also for critical transmission paths between areas are required to be continuously computed.

2. AVAILABLE TRANSFER CAPABILITY

Available transfer capability is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses.

Total Transfer Capability is defined as the quantity of electric power that can be transferred over the interconnected transmission path reliably without violating the predefined set of conditions of the system.

A number of methods have been proposed in the literature for calculating Available transfer capability. These methods are classified as,

Continuation methods in which the transfer capability is computed using a software model called continuation [6]. This process requires a series of load flow solutions to be solved and tested for limits.

Optimal power flow approach is another method to formulate an optimization problem. Equality constraints obtained from power flow are used in this approach.

Linear methods use PTDFs (power flow distribution factors) to express the percentage of power transfer that occurs on a transmission path.

Further it is also solved by probabilistic approach, it is very complicated involves many mathematical calculations [7-8]. Even approaches are there computing security and boundary, involves many complicated calculations [5]. Here, Gauss Seidal load flow method in repeated power flow approach is used.

3. PROBLEM FORMULATION

3.1 Objective Function

The problem is formulated as shown below, in which ATC is the measure of the transfer capability remaining in the physical transmission network for further commercial activity over and already committed uses. So ATC equals the difference between the total transfer capability (TTC), which is the transfer increase between the selected source and sink with no violation of any security constraints or contingency and the Base case transfer. It is expressed as,

F(x) = ATC,

ATC= TTC- Base case transfer (1)

3.2 Equality Constraints

$$Pi - \Sigma Vi Vj Yij \cos\left(\theta ij + \delta j - \delta i\right) = 0 \qquad (2)$$

$$Qi - \Sigma Vi Vj Yij \cos\left(\theta ij + \delta j - \delta i\right) = 0 \qquad (3)$$

Where,

Pi Real power in the i th bus,

Qi Reactive power at ith bus,

Vi, Vj Voltage of bus i and j respectively,

Yij Magnitude of admittance matrix,

θij Angle of admittance,

δi ,δj Angles of the Voltages.

3.3 Inequality Constraints

3.3.1 Real Power Constraint

Pi min≤ Pi ≤ Pi max (4)

It is the real power generation between minimum and maximum real power generated in the i^{th} bus

3.3.2 Reactive Power Constraint:

It is the reactive power generation between minimum and maximum real power generated in the i^{th} bus.

Qi min ≤ Qi ≤ Qi max (5)

3.3.3 Voltage Limit Constraint:

It is the voltage between minimum and maximum voltage magnitude in the i^{th} bus.

Vi min ≤ Vi≤ Vi max (6)

i= 1, 2 …N

4. SOLUTION METHODOLOGY

4.1 Repeated Power Flow Method

It is proposed for calculating ATC due to the ease of implementation [5]. In this method the available transfer capability (ATC) from one bus/area to another bus/area can be found by varying the amount of transaction until one or more line flows in the transmission system is considered or a bus voltage reaching the limiting value.

The calculation of ATC is done by using the Gauss seidal load flow solution to compute the power flow of each transfer case. The total transfer capability is the sum of transfers through the interconnecting lines. So,

ATC=TTC- Base case transfer

4.2 FACTs Devices

FACTS devices have the ability to modify power flow pattern. More importantly, they can change their parameters smoothly and rapidly, allowing a more desirable control on power flow. Therefore, FACTS devices are good candidates for transfer capability improvement of transmission systems. In addition, there are fewer restrictions on the installation of FACTS devices than on the construction of new transmission lines or power plants. Thus, it is proposed, the use of these devices as the tools for the enhancement of transfer capability [9-10]. There are three important operational parameters that FACTS devices can control, i.e., impedance [11-12], voltage and phase angle. Here, FACTS is allocated by Quantum inspired PSO. So, exact amount of power needed is injected, thereby saving power and also due to allocation low capacity FACTS can be used, which costs lower than FACTS designed with higher capacity. Thereby both power and considerable amount of money can be saved.

4.1 Quantum Inspired Particle Swarm Optimization (QPSO)

The QPSO algorithm allows all particles to move under quantum-mechanical rules rather than the classical Newtonian random motion. In terms of classical mechanics, a particle is depicted by its position vector X_i and velocity vector V_i, which determine the trajectory of the particle.

In quantum world, X_i and V_i of a particle cannot be determined simultaneously according to uncertainty principle [13]. Therefore, if individual particles in a PSO system have quantum behaviour, the PSO algorithm is bound to work different.

In the quantum model of a PSO called here QPSO, the state of a particle is depicted by wave function Ψ(x, y) (Schrödinger equation), instead of position and velocity. The dynamic behaviour of the particle is widely divergent form that of the particle in classical PSO systems, in that the exact values of X_i and V_i cannot be determined simultaneously. In this context, the probability of the particles appears in position X_i from probability density function $|\Psi(x, y)|^2$. Employing the Monte Carlo method, the particles move according to the following iterative equation,

$$x(t+1) = P + \beta * (Mbest - x(t)) / \ln(1/a), \text{if } k \geq 0.5 \quad (7)$$

$$x(t+1) = P - \beta * (Mbest - x(t)) / \ln(1/a), \text{if } k < 0.5 \quad (8)$$

Where,

B Design parameter called contraction–expansion coefficient.

a, k Values generated using the uniform probability distribution functions in the range [0, 1].

g Index of the best particle among all the particles in the swarm.

The mean of the pbest positions of all particles is called Mainstream Thought or Mean Best (M best) and it is given by

$$Mbest = \frac{1}{N}\sum_{d=1}^{N} p_{g,d}(t) \quad (9)$$

Here, the following coordinates are presented for the local attractor to guarantee convergence of the PSO:

$$P = \frac{C_1 p_{i,d} + C_2 p_{g,d}}{C_1 + C_2} \quad (10)$$

Where,

N Number of buses in the system,

C_1, C_2 Acceleration factors or social and cognitive attraction respectively.

The overall flowchart,

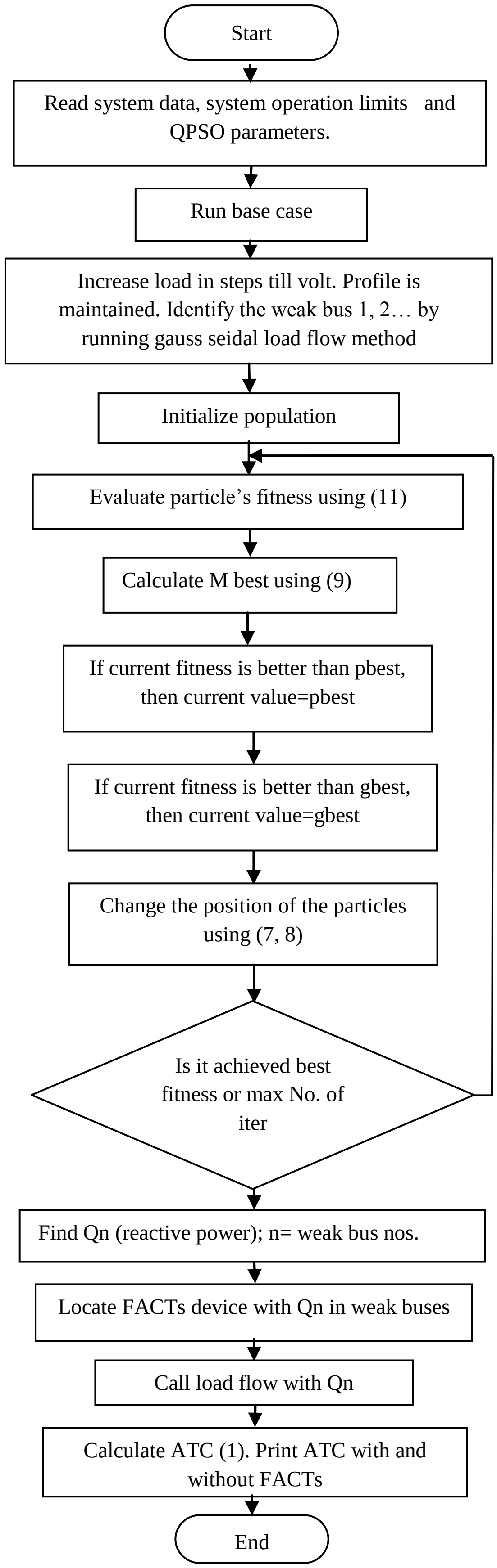

Fig 1: The Overall Flow Diagram

5. CASE STUDY AND RESULTS

The IEEE 30-bus system is adopted as the test system using the proposed methodology QPSO. The ATC has been determined using gauss siedal load flow method. The methodology is developed using the Matlab Package.

Load flow analysis consists of determination of magnitude and phase angle of voltage at each bus and active and reactive power flow in each line. Four quantities are associated with each bus. These are voltage magnitude V, phase angle, real power P and reactive power Q

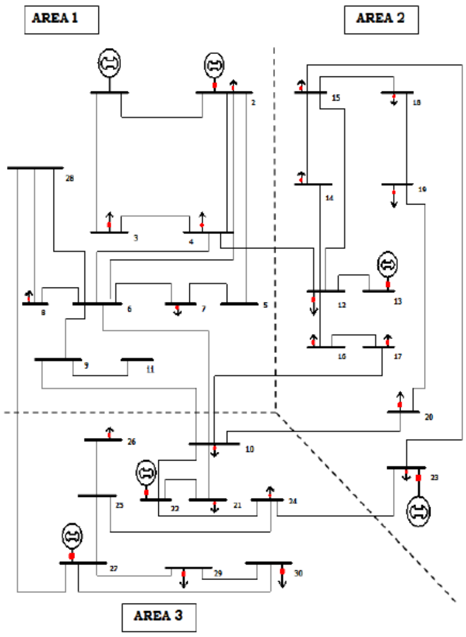

Fig 2: IEEE 30 Bus System

IEEE 30 bus system is divided into 3 control areas and Load flow analysis of system is calculated by using Gauss Seidel Method or Newton Raphson Method in MATLAB software.

5.1 Case 1

Power Transfer Without FACTs Device

Area 1 is increased in load till voltage profile is maintained whereas Area 2 and Area 3 are kept constant. Likewise area 2 and area 3 are increased in load individually keeping other two areas constant. The base case transfer of Area 1= 84. 50 MW, Area 2= 52. 70 MW, Area 3= 48.50 MW

Table-1: Power transfer in Area 1

Bus No's	Base case (MW)	After overloading (MW)
2	21.7	21.7
3	2.4	2.4

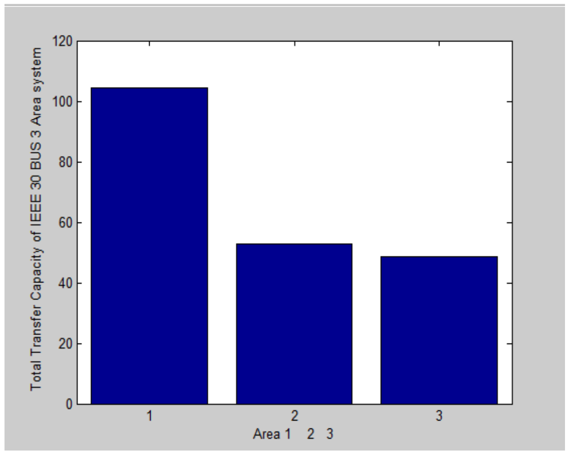

Fig 3: Total Transfer Capability of Area 1 is 104.50 MW and Area 2, Area 3 are kept constant.

Table-2: Power transfer in Area 2

Bus Nos	Base case (MW)	After overloading (MW)
12	11.2	28.2
14	6.2	6.2
15	8.2	8.2
17	9	9
18	3.2	3.2
19	9.5	9.5
20	2.2	2.2
23	3.2	3.2

Thus Total Transfer Capability of Area 2 is 69.70 MW

4	7.6	7.6
7	23.8	42.8
8	30	30

Thus the total transfer capability of Area 1 is 104.50 MW

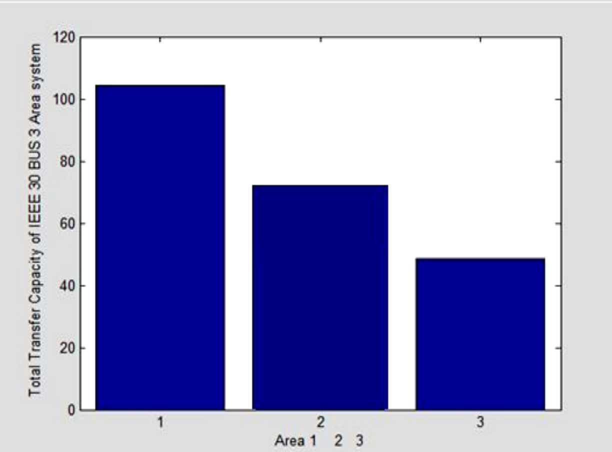

Fig 4: Total Transfer Capability of Area 2 is 69.70 MW and Area 1, Area 3 are kept constant.

Table -3: Power transfer in Area 3

Bus Nose	Base case (MW)	After over loading (MW)
10	5.8	5.8
21	17.5	17.5
24	8.7	8.7
25	0	0
26	3.5	3.5
29	2.4	2.4
30	13.6	13.6

Thus Total Transfer Capability of Area 3 will be 51.50 MW

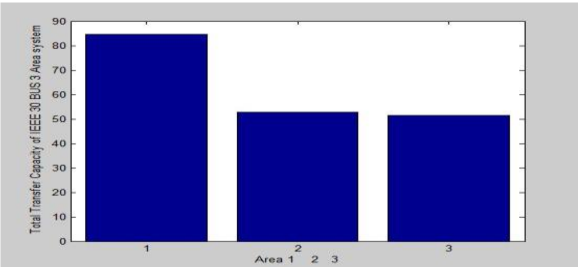

Fig 5: Total Transfer Capability of Area 3 is 51.50 MW and Area 1, Area 2 are kept constant.

By executing MATLAB programming, the following is found,

Total Transfer Capability of Area 1= 102.07 MW

Total Transfer Capability of Area 2= 69 MW

Total Transfer Capability of Area 3= 51.50 MW

The best locations of Facts are found by the weak buses by gauss siedal load flow method.

5.2 Case 2

Quantum inspired PSO being the tool used for optimization; it is tested for population size and parameters. The parameters selected are:

Table 4: QPSO Parameters

Parameters	Values
Accuracy	0.001
Acceleration	1.8
Max iteration	1000
C1 (social attraction)	1.25
C2 (cognitive attraction)	0.5
Population size	40

With the above parameters the capacity of Facts device is optimized using the cost eqn,

$$CE= \sum [1.0-Vm (i)]^2 \quad (11)$$

Thereby, the capacity can be allocated for Facts device.

5.3 Case 3

With the capacity allocated to Facts device the load flow is being run. The results obtained after allocation of Facts optimized by QPSO is tabulated below.

Power Transfer with FACTs Devices

Area 1 is increased in load till voltage profile is maintained whereas Area 2 and Area 3 are kept constant with FACTS device allocated by QPSO and not allocating any approximate value [14].

Table- 5: Power transfer in Area- 1

Bus No's	Base case (MW)	After overloading (MW)
2	21.7	21.7
3	2.4	2.4
4	7.6	7.6
7	23.8	60.8
8	30	30

Thus Total Transfer Capability of Area 1 will be 122.50 MW

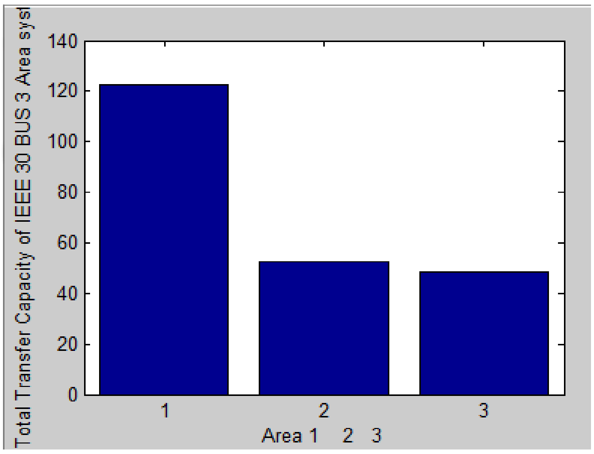

Fig 6: Total Transfer Capability of Area 1 is 122.50 MW, with FACTS device and Area 2, Area 3 are kept constant.

Area 2 is increased in load till voltage profile is maintained whereas Area 1and Area 3 are kept constant.

Table- 6: Power transfer in Area- 2

Bus No's	Base case (MW)	After over loading (MW)
12	11.2	80.2
14	6.2	6.2
15	8.2	8.2
17	9	9
18	3.2	3.2
19	9.5	9.5
20	2.2	2.2
23	3.2	3.2

Thus Total Transfer Capability of Area 2 will be 121.70 MW

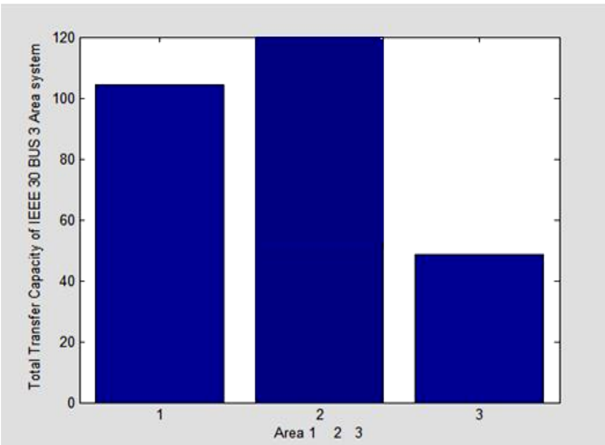

Fig 7: Total Transfer Capability of Area 2 is 121.70 MW, with FACTS device and Area 1, Area 3 are kept constant.

Table- 7: Power transfer in Area- 3

Bus No's	Base case (MW)	After overloading (MW)
10	5.8	5.8
21	17.5	17.5
24	8.7	8.7
25	0	0
26	3.5	3.5
29	2.4	2.4
30	13.6	13.6

Thus Total Transfer Capability of Area 3 will be 56.50 MW

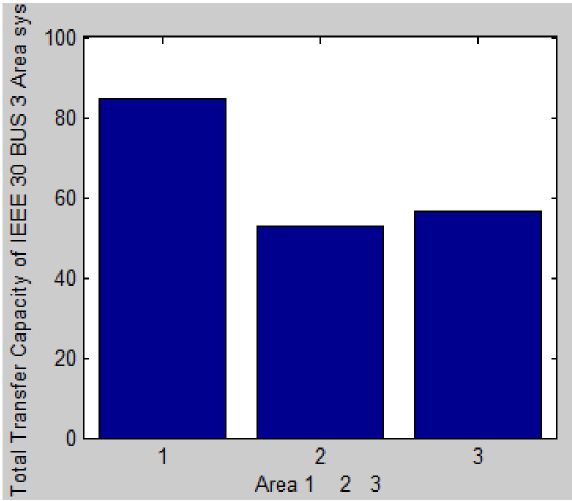

Fig 8: Total Transfer Capability of Area 3 is 56.50 MW with FACTS device and Area 1, Area 2 are kept constant.

So ATC can be calculated as,

TTC- Base case transfer

E.g.: Area 1 without FACTS:

ATC=104.50- 84. 50 MW

= 20MW

Table 8: Comparison between ATC with and Without FACTS.

Area Nos.	ATC Without FACTS (MW)	ATC With FACTS allocated by QPSO (MW)
Area 1	20	38
Area 2	17	69
Area 3	3	8

Thus ATC is enhanced to about 18 MW, 52 MW, 5 MW in Areas 1, 2 and 3 respectively.

6. CONCLUSION

The improvement of ATC using FACTs is studied with IEEE 30 Bus system during normal situation. It is well demonstrated through number of case studies. Thus FACTs is placed in a best location and the control strategy for maximizing the ATC is arrived at using Quantum inspired PSO. It is clearly seen that after the Facts being optimized voltage profile is improved, thereby ATC is enhanced. This enhancement will greatly improve the open access biding in deregulated environment and also promote competitive markets for electric power trading.

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