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Available Transfer Capability Enhancement with Load Rescheduling using Cat Swarm Optimization

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ABSTRACT

Available transfer capability (ATC) calculation is a complicated task and improving of ATC is an important issue in the current de-regulated environment of power systems. Power transactions between a specific seller area and a buyer area can be committed only when sufficient ATC is available. This paper proposed a method of load rescheduling which is ATC based incentive to the loads like in smart grid. The Continuation Power Flow (CPF) method is used for getting the power flow results. A new Artificial Intelligence Technique known as Cat Swam Optimization (CSO) is used to maximize ATC. The load control can significantly affect the operation of the system and it will be very important for ISO. The proposed technique is implemented for the analysis of ATC on IEEE 14 bus system and IEEE 24 RTS bus System.

General Terms

Deregulated power system, Available transfer Capability

Keywords

Available Transfer Capability (ATC), Cat Swam Optimization (CSO), Continuation Power Flow (CPF), Load Rescheduling, Deregulation.

1. INTRODUCTION

Promote competitive electric markets for electric power trading is the main aim of an electric industry restructuring. Under deregulated environment, the substantial increase in power transfer is the important requirement. Over a wide range of system operating conditions and constraints, it is necessary to maintain economical and secure operation. However the restrictions to provide new facilities can be economic, ecological and social problems that minimize the operational alternatives. Sometimes the accessible transmission services are intensively used. On the other hand, benefits the power suppliers from more market opportunities with reduced possibility of congestion incorporating power system security augmentation. It will be more profitable for transmission system owners is that the maximum consumption of accessible transmission assets. The better services and reduced prices can be provided to the customers.

Various ATC boosting approaches have been experienced by rescheduling generator outputs, adjusting terminal voltages of generators and by using Under Load Tap Changers (ULTCs). Tae Kyung Hahn evaluated ATC using fuzzy with OPF [1]. Rashidinejad implemented a methodology for ATC enhancement using repeated Power flow procedure [2]. S. C. Srivastava used bifurcation approach for ATC assessment [3]. R.D. Christie proposed an AC OPF and DC OPF for ATC analysis [4]. G.C. Ejebe did fast calculation of linear ATC [5-6]. C. Y. Li proposed a new algorithm for ATC determination [7]. B. V. Manikandan employed PSO and GA to obtain the optimal settings of TCSC [8]. P. Priyadarsini used Quantum Inspired PSO to enhance ATC [9]. Here CSO algorithm is implemented to enhance the ATC in a simple manner.

2. AVAILABLE TRANSFER CAPABILITY

In the developing and the developed countries, more so in the latter, the available electrical power supply-demand mismatch is continuously increasing, often resulting in forced power cuts to the customers. This situation is brought in by the fact that the rate at which the demand is increasing is much more than that of the supply. The system operator with a view to supply power reliably likes to know about the capacity of power available for transfer at any moment of time and under all system states. In a deregulated system operation, both the operator and the customers must be knowledgeable about this important system variable known as Available Transfer Capacity (ATC). In United States, the electric transmission utilities are required to post the information of ATC. Their transmission network ATCs are posted through the Open Access Same time Information System (OASIS) [10].

To maximize utilization of existing transmission grids, accurate evaluation of ATC is essential while maintaining system security. Here the power system dependability meets electricity market competence. ATC may have a huge force on market outcomes and system dependability.

The function of ATC is to

- Electric power must be delivered reliably
- For changing system conditions flexibility should be provided
- Reduce the need for installed generating capacity
- Trading of electric power among systems must be allowed

Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM). ATC can be expressed as:

$$ATC = TTC - TRM - \text{Existing Transmission Commitments (including CBM)} \quad (1)$$

3. PROBLEM FORMULATION

The problem formulation for ATC calculation is the basic concept of OPF as an optimization problem, with an equity and inequality constraints. The stability limits are also considered as the main constraints. Obviously, the objective function is the maximum power flow on the specified transmission path. The objective is to determine the ATC to maximize the power transfer between the two areas subjected to the conditions that there are no violations of thermal or voltage or stability limits.

Available Transfer Capability problem formulation can be explained as follows.
Maximize

$$P_i = \sum_{j\in i} P_{kj} \qquad (2)$$

Subjected to

$$P_i - \sum_{j\in i} V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_i - \delta_j) = 0 \qquad (3)$$

$$Q_i - \sum_{j\in i} V_i V_j Y_{ij} Sin(\theta_{ij} + \delta_i - \delta_j) = 0 \qquad (4)$$

$$P_g^{\min} \le P_g \le P_g^{\max} \qquad (5)$$

$$Q_g^{\min} \le Q_g \le Q_g^{\max} \qquad (6)$$

$$S_{ij} \le S_{ij}^{\max} \qquad (7)$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (8)$$

4. CONTINUATION POWER FLOW APPROACH

The method, Continuation power flow (CPF) is a comprehensive tool for tracing the steady state behavior of the power system due to parametric variation [11,18]. The area real and /or reactive loads, bus real and/or reactive loads and real power generations at generator or PV buses are the parameters which are varied. Continuation methods are also nown as path following or curve tracing which are used to trace solution curves. This is for general non-linear algebraic equations with a parametric variation. The CPF method has four basic elements:

- Parameterization is a mathematical way of identifying each solution for quantifying previous solution or next solution.
- Predictor is to find an approximate point for the next solution. Tangent or secant method is used for this purpose.
- Corrector is to correct error in an approximation produced by the predictor before it accumulates.
- Step size control is to adapt the step length for shaping the traced solution curve.

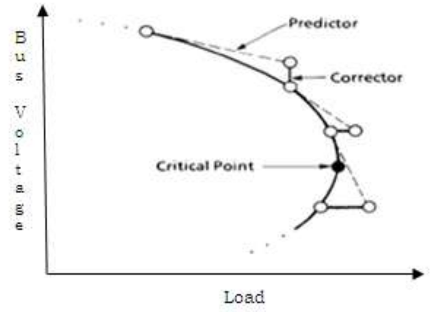

Fig. 1 Predictor and corrector method of CPF

As shown in Fig. 1, it starts from a known solution and uses a tangent predictor to estimate a subsequent solution corresponding to a different value of the load parameter.

5. CAT SWARM OPTIMIZATION (CSO)

The idea of computational intelligence may come from observing the behavior of creature. Ant Colony Optimization is proposed by studying the behavior of ants, and Particle Swarm Optimization (PSO) is proposed by examining the movements of flocking gulls [12] - [14]. In 2006, CSO has been proposed by Chu, Pan and Tsai. By the common behavior of cats, the artificial structure can be viewed for modeling. CSO one way or another belongs to the swarm intelligence. Usually, PSO finds the optimal solution faster than the others [15], but the CSO gives much better performance than PSO. The CSO gives the accurate and fast solution for the required objective function when compared to other Artificial Intelligence techniques [16].

In CSO, the number of cats to be used in the iteration is determined and to solve the problem the cats are applied into CSO. Every cat has its own position composed of M number of dimensions, a fitness value, and velocities for each dimension, which represents the accommodation of the cat to the fitness function. It also has a flag to identify whether the cat is in seeking mode or tracking mode. The final solution would be the best position, for one of the cats. The CSO keeps the best solution until it reaches the end of the iterations.

5.1 Behavior of Cats

In Cat Swarm Optimization, the major two behaviors of cats are modeled into two sub-models, namely, (i) seeking mode and (ii) tracking mode.

5.1.1 Seeking Mode

The seeking mode is a sub-model used to model the situation of the cat, which is resting, looking around and seeking the next position to move. The four essential factors are defined in seeking mode. They are Self Position Considering (SPC), Counts of Dimension Change (CDC) and seeking Range of Selected Dimension (SRD).

To define the size of seeking memory for each cat, Seeking Memory Pool (SMP) is used, which indicates the points hunted by the cat. From the memory pool, the cat would pick a point according to the rules described. For the selected dimensions SRD declares the mutative ratio. All these factors are playing important roles in the seeking mode. SPC is also a variable which decides the point, where the cat is already standing will be one of the candidates to move.

The seeking mode can be described in 5 steps as follows.
Step 1: Select the total number cats that has to be considered

Step 2: Assume a fixed range of velocities for each cat
Step 3: Calculate the fitness values (FS) of all candidate points
Step 4: Select the number of cats available in seeking mode
Step 5: Randomly pick the cat from the total number of cats and apply to seeking mode

$$Pkn = [(1 \pm 0.3)\ Rand\ (\ )]\ X\ Pk \quad n=1, 2, 3, 4, 5 \qquad (9)$$

Where
Rand ( ): is a random value in the range of [0, 1] and Pk is the best fitness value.

5.1.2 Tracking Mode

Tracking mode is a sub-model for modeling the case of the cat in tracking some targets. Once a cat goes into tracking mode, it moves according to its own velocities for every dimension. The action of tracking mode can be described in 3 steps as follows.

Step 1: Update the velocities for every dimension ($V_{k,d}$) according to equation (10).

$$V_{k,d} = V_{k,d} + r_1.c_1.(P_{best,d} - P_{k,d}), d = 1,2,......M \quad (10)$$

Where Pbest,d is the position of the cat, who has the best fitness value; Pk,d is the position of cat k, c1 is a constant and r1 is a random value in the range of [0, 1].
Step 2: Check if the velocities are in the range of maximum velocity. In Case the new velocity is over-range, set it to be equal to the limit.

Step 3: Update the position of catk according to equation (11).

$$P_{k,d} = P_{k,d} + V_{k,d} \quad (11)$$

It is proceeded till the best fitness value is obtained and the corresponding cat location and velocity be the best values. The best fitness value is to be calculated.

5.2 Implementation Procedure of CSO Technique

The implementation procedure of CSO technique for base case is explained by the flow chart as shown in figure 2.

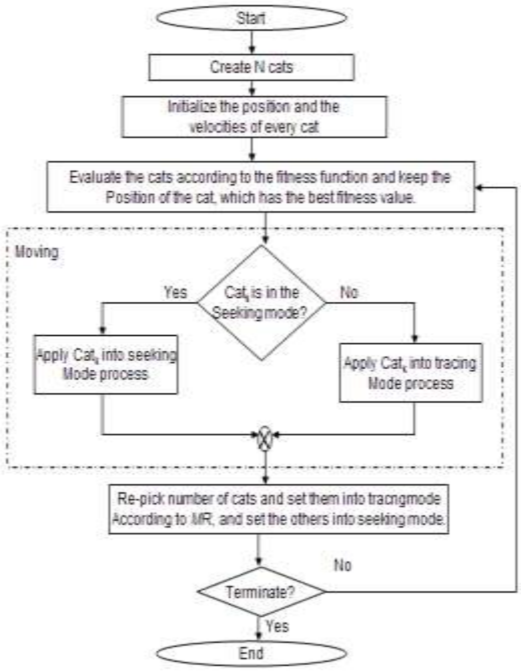

Fig 2: Flow chart for CSO Technique

6. CONTINGENCY BASED ON PERFORMANCE INDEX

An outage in the power system cause changes in the line flows and bus voltages. The new line flows and bus voltages can be predicted by an analysis which is known as contingency analysis. It is one of the most important and basic analysis for assessment of power system security. The critical lines or credible contingencies are identified by contingency analysis and only these critical lines need to be taken to assess the power system security. The parameter which is known as performance index is used for security analysis. The line which has highest value is most critical line and is ranked as one. The process of critical line selection is known as contingency ranking.

The most severe lines are identified for the contingency analysis; the severity of the line is calculated as follows:

$$\text{Performance Index} = \left(\frac{S_l}{S_l^{\max}}\right)^{2m} \quad (12)$$

Where S_l and $S_l^{\max}$ are MVA flow in line l and MVA rating of the line l respectively and 'm' is an integer exponent. Here it is considered as 1.

7. RESULTS AND DISCUSSION

Enhancement of ATC is obtained with load rescheduling by applying CSO under both normal and contingency. The proposed algorithm is implemented for both IEEE 14 bus system and IEEE 24 bus RTS system.

The ATC margin is limited by bus voltage magnitude in the range 0.95 ≤ V_i ≤1.15 p.u. The CSO parameters are given in Table 1 and which are same for both the examples of 14 bus system and 24 bus system.

Table 1: Parameters for CSO

S. No.	Parameter	Value
1	Memory Point (MP)	5
2	Range of the selected Dimension (SRD)	30%
3	Counts of Dimensions Change (CDC)	100%
4	Mixture Ratio (MR)	20%
5	Constant (c1)	2.0
6	Random Value (r1)	[0.1]

7.1 IEEE 14 bus system

To demonstrate the CSO technique for ATC analysis IEEE 14 bus system is considered as an example 1. The system is divided into two areas, which are the area with voltage of 69kV and the area with voltage of 13.8kV. From power flow results, it is observed that line 10 (1-2) has the maximum line flow of 2.9833p.u and bus 14 has the lowest voltage of 0.76471p.u.
In contingency analysis, for each line Performance Index (P.I) is calculated and ranking is given based on this value and it is observed that the lines 9 (7-9), 10 (1-2) and 11 (6-13) are obtained as the most sever lines and ranked as 1, 2 and 3 respectively. The corresponding performance index values are shown in figure 3.

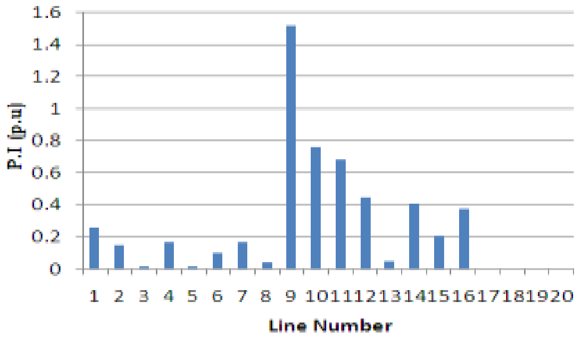

Fig 3: Performance Index of each line in 14 bus system

For each line outage ATCs are obtained and it is observed that when line 9 (7-9) outage, ATC is minimum when compared to all other line outage ATC. The corresponding ATC values are shown in figure 4 and the results for this case are same as in case 2 for IEEE 14 bus system; but it is different for IEEE 24 bus RTS bus system.

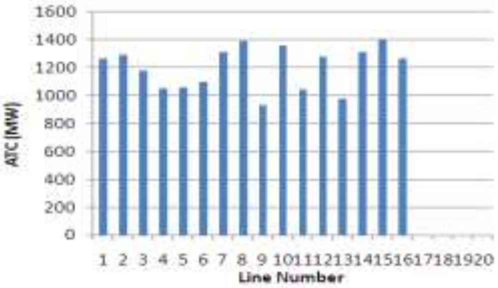

Fig 4: ATCs for each line outage in 14 bus system

Analysis on this system is made for ATC, bus voltage (Vi) and power flow (Sij) for following 6 different Cases, and also results are compared without and with load rescheduling using CSO.
Case-1: Base Case
Case-2: Rank 1 contingency – line 9 (7- 9) outage
Case-3: Rank 2 contingency – line 10(1- 2) outage
Case-4: Rank 3 contingency – line11 (6 -13) outage
Case-5: line outage at minimum ATC
Case-6: Change of system significance when load increased by 2% and generation increased by 1.5% at bus 2.

Out of which, The case 1 is the base case, case 2, 3, & 4 are obtained from Performance index analysis, case 5 is obtained from The line outage of minimum ATC and case 6 is change of nodal Injections.
ATC is calculated and enhanced to verify the result with the procedure of HRGA [17] for validation of result. The results for 9 bus system along with before and after load reschedules using CSO are tabulated in Table 2.

Table 2: Summary of ATCs for 9 bus system

	Before load reschedule	HRGA [17]	After load reschedule
ATC (MW)	298.482	308.731	342.3829

From this table, it is clearly observed that the ATC value after load reschedule using CSO is more when compared to existing HRGA. Hence the further analysis is performed with proposed CSO technique.
The three maximum loaded buses are chosen for the application of CSO i.e. L3, L4 and L9 having the loads 0.942p.u, 0.478p.u and 0.295p.u respectively. For the case 1, that is, base case results of ATC comparison, voltage profiles and line loadings are given in detail as follows:
The ATC values before load reschedule and after load reschedule are tabulated in Table 3.

Table 3: Summary of ATC for case-1

	Before load reschedule	After load reschedule
ATC(MW)	1254.078	1389.0871

From the table, it is clearly observed that ATC is enhanced after load reschedules using CSO when compared to before load reschedule.

At this value of ATC for case-1, the variation in voltage magnitudes at each bus Vi is computed and the corresponding line flows are compared before and after rescheduling of load as shown in fig 5 and fig. 6 respectively.

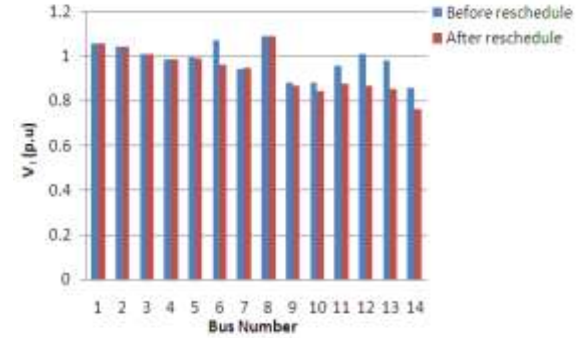

Fig 5: Voltage profile for case-1

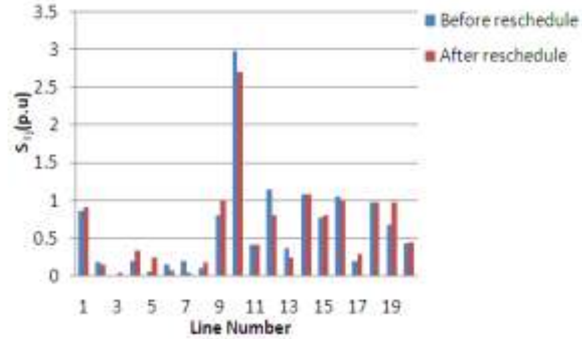

Fig 6: Power flows for case-1

For all the six cases the ATCs before load reschedule and after load reschedule using CSO are tabulated in Table 4.

Table 4: Summary of ATC for 14 bus system for 6 Cases

Cases	ATC (MW)	
	Before load reschedule	After load reschedule
Case-1	1254.078	1389.0871
Case-2	930.8844	1114.799
Case-3	1456.1062	1474.5675
Case-4	1046.4957	1189.4022
Case-5	930.8844	1114.799
Case-6	1188.2098	1228.6401

From the table 4 it is observed that the ATC has been enhanced after load reschedule using CSO when compared to before load reschedule for all the 6 Cases. The corresponding ATC values are shown in fig 7.

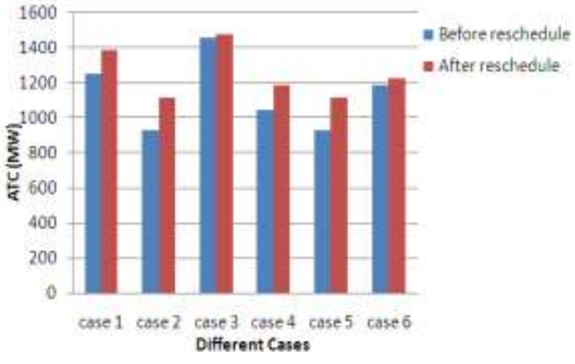

Fig 7: Summary of ATC for 14 bus system for 6 Cases

7.2 IEEE 24 RTS bus system

The similar analysis is made for IEEE 24 bus system which is considered as example 2. This system consists of 11 generators and 17 loads, 38 transmission lines (including transformers). The system is divided into two areas, which are the area with voltage of 230kV and the area with voltage of 138kV.From the performance index values for each line, the lines 20 (16-14), 26 (16-19) and 25 (17-16) are obtained as the most sever lines and ranked as 1, 2 and 3 respectively. The corresponding performance Index values are shown in figure 8.

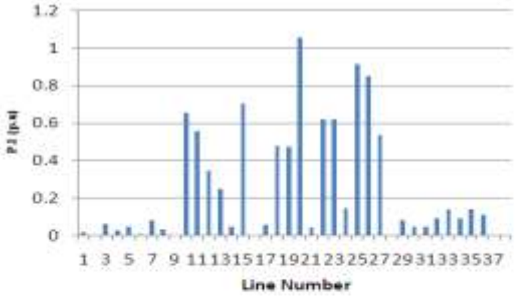

Fig 8: Performance Index of each line for 24 bus system

For each line outage the ATC is calculated and shown in figure 9 and the line 10(10-6) is having the minimum ATC which is selected for line outage contingency as considered as case 5.

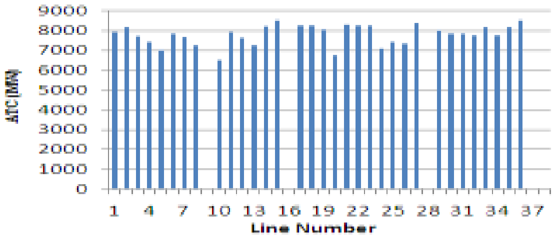

Fig 9: Summary of ATCs for each line outage for 24 bus system

Analysis on this system is made for ATC, bus voltage (V_i) and power flow (S_{ij}) for following 6 different cases and also results are compared without and with load reschedule using CSO.

Case-1: Base Case
Case-2: Rank 1 contingency – line 20(16-14) outage
Case-3: Rank 2 contingency – line 25(17-16) outage
Case-4: Rank 3 contingency – line 26(19-16) outage
Case-5: line outage at minimum ATC
Case-6: Change of system significance when load increased by 2 % and generation increased by 1.5% at bus 2.
For all the six cases the ATC values before load reschedule and after load reschedule are compared and tabulated in Table 5.

Table 5: Summary of ATC for 24 bus system

Cases	ATC (MW)	
	Before load reschedule	After load reschedule
Case-1	6703.44	7778.4802
Case-2	7050.78	7203.3545
Case-3	6342.15	7346.9676
Case-4	6703.44	7273.4474
Case-5	7053.638	7237.2413
Case-6	8413.77	8716.4188

From this table it is observed that when compared to before load reschedule the ATC has been enhanced after load reschedule using CSO in all the 6 different Cases. The corresponding ATC values are shown in fig 10.

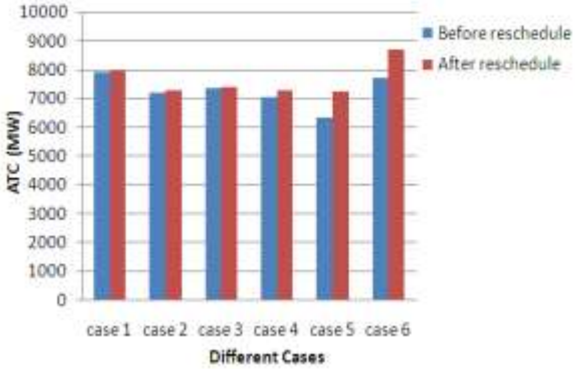

Fig 10: Summary of ATC for 24 bus system for 6 different Cases

8. CONCLUSIONS

ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity. Thus ATC is a vital parameter for any system and it has to be improved for the system to be self reliable and also to be in a position to export power to other systems. The CPF method is implemented for the entire power flows. ATC has been enhanced by load rescheduling as it is an incentive to the loads like in smart grids. The obtained results are validated with HRGA technique for base case in 9 bus system and compared to many optimization techniques; finally load reschedule is also enhances the ATC and CSO is the best optimization technique to load reschedule to enhance the ATC in deregulated market.

9. ACKNOWLEDGMENTS

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