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Minimization of Expected Security Cost Using Bacterial Swarming Algorithm

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***Abstract*-This paper deals with the objective to minimize the expected security cost of operating the power system subjected to certain constraints. This expected cost includes the summation cost of operating in both normal and contingency states along with their probability of occurrence. In normal state maximizing social welfare is the main objective. Contingency state is considered since it can cause the system to be unstable. At that state, corrective as well as preventive measures have to be followed to relieve congestion. The new cost under post-contingency state is called the security cost which includes the cost of generation ramping along with social welfare maximization. Particle Swarm Optimization (PSO) is used in computing the optimal pre-contingency and for all credible post-contingency operating points by creating an optimal power flow (OPF) problem. Thus Expected Security Cost Optimal Power Flow (ESCOPF) problem has been proposed.**

***Keywords*- Expected security cost, congestion relief, optimal power flow, particle swarm optimization.**

NOMENCLATURE

CO	Normal state operating cost.
Ck	Contingency state operating cost.
C, B	Generation cost and consumer benefit, respectively.
G,D	Set of generators and demands, respectively
P_G	Active power generation.
P_D,Q_D	Active and reactive power demand, respectively
f	Linear or nonlinear equality constraints such as constant load power factor equation, active and reactive power balance equations for current and stressed loading condition, respectively.
g	Linear or nonlinear inequality constraints such as generation limits, load limits, voltage limits, transmission line thermal limits for current loading condition.
x	State vector of power system consisting of voltage magnitudes and phase angles.
u	Control vector excluding FACTS devices
Δp_g	Generation re- scheduling vector (Δp_g =0 at normal state).
Δp_d	Load shedding vector (Δp_d =0 at normal state).
C_{GD}^{up}	Compensation paid to generator for increasing active power.
$C_{GD}down$	Compensation paid to generator for decreasing active power.
C_{LS}	Compensation paid to demand for decreasing active power.
ΔP_G^{up}	Active power generation adjustment up.
$\Delta P_G down$	Active power generation adjustment down.
$\Delta P_D down$	Active power demand adjustment down.
$R_G up$	Generation ramping limit for adjustment up.
$R_G down$	Generation ramping limit adjusted down.
Δt	Time required to adjust generator output.
O	Symbol indicating under normal state.
k	Symbol indicating under contingency state.
K	Total number of credible contingency.

1 INTRODUCTION

In a competitive electricity market, independent system operator (ISO) has the authority to facilitate a secure and economic operation of power system. So, in order to reveal congestion and to ensure security ISO should undergo commitment or dispatch of all or some part of the system resources and also load curtailment.

Social welfare maximization in a double-sided auction market is a general concept of capitalism. If a fair and equitable market structures are created, which give all market participants incentives to maximize their own individual welfare, then the market as a whole will behave in a manner which maximizes welfare for everyone. This objective can be achieved, in electricity industry by new algorithms which help market participants behave in an efficient manner, helping them maximize their own welfare. In normal state, social welfare maximization is done by minimizing the generation cost and maximizing the consumer benefit.

Whenever a transmission line or transformer is removed from service, we say that an outage has occurred. Outages may be planned for purposes of scheduled maintenance or they may be forced by weather conditions, faults or other contingencies. Congestion is the condition where overload in transmission line or transformers occur. Congestion in transmission network is a major problem while considering inter-zonal/intra-zonal schemes is implemented. Line outages can be simulated in the system

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model by adding the negative of the series impedance of the line between its two end buses.

Optimal power flow was first introduced by Carpenter in 1962, which now has become a useful tool in planning and operation of power system. The optimal power flow is used in optimizing power flow solution of a large power system. Optimization is done by minimizing (or maximizing) the selected objective subjected to constraints. Constraints include both equality constraints and inequality constraints. This paper attempts to minimize expected security cost of a network system using intelligent algorithm like Particle Swarm Optimization (PSO). PSO based OPF is simulated separately for both normal state and contingency states.

II PROBLEM FORMULATION

The main objective function is to minimize ESC of operating cost under normal and contingency states. Optimal power flow is run separately for both normal and contingency state.

The formulation of ESC is given by:

Minimize

$$ESC = \sum_{t=1}^{T}\left[\pi^{(0,t)}C^{(0,t)} + \sum_{k=1}^{K}\pi^{(k,t)}\,C^{(k,t)}\right] \qquad (1)$$

subjected to

$$\sum_{t=1}^{T}\pi^{(0,t)} + \sum_{t=1}^{T}\cdot\sum_{k=1}^{K}\pi^{(k,t)} = 8760 \qquad (2)$$

where π represents the probability of occurrence of normal state as well as contingency state in a day. $C^{(0,t)}$and $C^{(k,t)}$ are hourly operating cost of normal state and contingency k for load level t, respectively; and 8760 is hours in a year. As probability of each state is defined as $\prod$ divided by 8760, summation of all probabilities is equal to 1. The three load levels considered for simulation are 100%, 80% & 60% of peak load. During the first load level condition (100% load level) congestion is likely to occur not only during contingency but also during normal state. 80% load level corresponds to average load level in which congestion is likely to occur only during contingency. Third load level i.e, 60% load level (below average load level) in which there is only slight possibility that congestion will occur during normal and contingency state.

A. Normal State Subproblem

Social welfare maximization is the main objective in normal state. It is expressed as minimizing generation cost and maximising consumer benefit treated as negative cost and can be written as follows:

Minimize

$$C^o = \sum_{i\epsilon G} C_i(P_{Gi}{}^o) - \sum_{j\epsilon D} B_j(P_{Dj}{}^o) \qquad (3)$$

subject to

$$P_{Gi}^{k} = P_{Gi}^{o} + \Delta P_{Gi}^{up,k} - \Delta P_{Gi}^{down,k} \qquad (4)$$

$$P_{Dj}^{k} = P_{Dj}^{o} - \Delta P_{Dj}^{down,k} \qquad (5)$$

The objective function in (3) represents the operating cost function which comprises of generation cost function and consumer benefit function. Constraints (4) and (5) give the equality and inequality constraints. In this paper, ISO clears the energy market based on the submitted generation and demand bids. Lagrange multiplier associated with real power balance equations will become the market clearing price.

B. Contingency State Subproblem

During contingency, apart from maximizing social welfare, minimizing compensations due to generation re-scheduling is done to reveal congestion. This function is formulated as follows:

Minimize

$$Ck = \sum_{i\in G} Ci(PGik) - \sum_{j\epsilon D} Bj(PDjk) + \sum_{i\epsilon G}(CGDup\Delta PGupi,k + CGDdown\Delta PGidown,k) \qquad (6)$$

subject to

$$P_{Gi}^{k} = P_{Gi}^{o} + \Delta P_{Gi}^{up,k} - \Delta P_{Gi}^{down,k} \qquad (7)$$

$$P_{Dj}^{k} = P_{Dj}^{o} - \Delta P_{Dj}^{down,k} \qquad (8)$$

$$\Delta P_{Gi}^{down,k} \leq R_{Gi}^{down}.\Delta t \qquad (9)$$

$$\Delta P_{Gi}^{up,k}, \Delta P_{Gi}^{down,k}, \Delta P_{Dj}^{down,k} \geq 0 \qquad (10)$$

Generation re-scheduling constraints are intended to express coupling between normal state and contingency states and to ensure that compensations are always positive values. In case of contingency, demands have no option to increase their power exceeding the power demand determined in normal state.

III.SOLUTION METHODOLOGY

Bacterial Foraging Algorithm (BFA) has been proposed by Kevin Passino in 2002, which was inspired by E. coli bacterial chemo tactic behavior. The movement of E. coli consists of two modes: forward movement (running) and tumbling. We have further studied the detailed knowledge of these movements and simulated in our BSA to assist the convergence processes in solving optimization problems. Moreover, following the preliminary study of cell-cell communication between bacteria undertaken in [8], the group information has also been incorporated in BSA. Generally, BSA can be categorized into three processes: chemotaxis, a simplified quorum sensing (cell-cell communication) and mutation.

A. Chemotaxis

Chemotaxis is the ability of the cells moving toward distant sources of food molecules. It is based on the suppression of tumbles in cells happened by chance to be moving up the gradient. In BSA, nourishment environment stands for an optimization objective function. The algorithm imitates bacterial swimming motion.

In an *n*-dimension search space, the i^{th} bacterium at the k^{th} tumble-run process has a current position $X_i^k \in R^n$, a moving angle and a moving direction which can be calculated from φ_i^k via a Polar to Cartesian coordinate transform:

$$d_{i}{}^{k}{}_{1} = \prod_{p=1}^{n-1} co(\varphi_{ip}{}^{k}),$$

$$d_{ij}{}^{k} = \sin(\varphi_{i}{}^{k}{}_{(j-1)}).\prod_{p=1}^{n\_1} co(\varphi_{ip}{}^{k}), \qquad (11)$$

$$d_{in}{}^{k} = \sin(\varphi_{i}{}^{k}{}_{(}j-1)).$$

At the k^{th} tumble process, the p^{th} bacterium generates a random turning angle $\Delta\varphi$, which is within the range of θ_{max}. The new direction of the run process is formulated as a hypercube, which is calculated from a new angle. During the run process, a bacterium moves toward the hypercube direction. A step of tumble-run process is expressed as:

$$\Delta\varphi = \frac{r_2\theta max}{2},$$

$$X_p^{k+1}(1) = X_p^k + r_1 l_{max} D_p^k(\varphi^k + \Delta\varphi) \qquad (12)$$

where $X_p{}^k$ indicates the position of the p^{th} bacterium at kth tumble-rum process. r_1 is a normally distributed random number which has mean 0 and standard deviation 1, N(0,1). r_2 is a random sequence in range (0,1), and l_{max} is the maximal step length of a run.

X_p^{k+1} is the position of the bacterium p after the tumble process.

The tumble-run process consists of a tumble process and one or more run steps. After the angle is decided by a tumble process, a bacterium will run until it meets the maximal run step, n_c, or reaches a position having a worse evaluation value. The process can be described as:

$$X_p{}^{k+1}(h+1) = X_p(h) + r_1 l_{max} D_p{}^k(\varphi^k + \Delta\varphi) \qquad (13)$$

where h represents the counter of the run steps (h =1,2,⋯ ,n_c). The run step will repeat until h reaches the maximal run step n or the evaluation value of X_p^{k+1}(h) is worse than that of X_p^{k+1}(h-1).

B. Simplified Quorum Sensing

The bacterial sensors are the receptor proteins that are signaled directly by external substances or via the piroplasmic substrate-binding proteins. Bacteria use sensing to produce and secrete certain signaling compounds (called autoinducers or pheromone). These bacteria also have a receptor that can specifically detect the pheromone. When the inducer binds the receptor, it activates the transcription of certain genes, including those for inducer synthesis. Bacteria gather together by releasing and sensing these molecules, thus, the ones with higher fitness release more molecules. Based on this assumption, the density of the pheromone is increased at the position, where the fitness value is maximum. Each individual is attracted by the pheromone randomly. The mathematical description is denoted as follows:

$$X_p^{k+1} = \delta \cdot (X_{best}^{k+1} - X_p^{k+1}) \qquad (14)$$

where δ indicates a gain parameter for the bacterial attraction, $X_{best}{}^{k+1}$ indicates the position of the global best solution in the (k +1)th optimization process, and $X_p^{k+1}$is the position of the p^{th} bacterium after the tumble-run process.

C. Mutation

Simplified quorum sensing increases convergence speed, however, it also leads to premature results. Mutation is introduced to enhance the diversity of the algorithm. The mutation can be described as:

$$\Delta\varphi = r_2 \cdot \pi/2,$$

$$Xpk{+}1 = Xpk{+}1 + r3lrangeDpk{+}1(\varphi k{+}1 + \Delta\varphi) \qquad (15)$$

where r3 is a normally distributed random number drawn from N(0,1), and l_{range} is the range of search space. In each generation, 20% of the bacteria are mutated.

When a bacterium turns into the mutation process, a mutation angle $\Delta\varphi$ is generated. The angle is within the range of [0,*π*/2], which makes the mutation process smooth. The mutation can be considered as an uncontrolled tumble-run process. As a result, the bacterium has a probability to jump out of local minima.

IV. CASE STUDY

The numerical simulations have been performed in MATLAB software.

A. IEEE 14- Bus System Case Study

The proposed method has been applied to the sample power system shown in fig 1. In normal state all the values are within the constraints. The objective under normal state is minimizing generation cost and maximizing social welfare treated as negative cost.

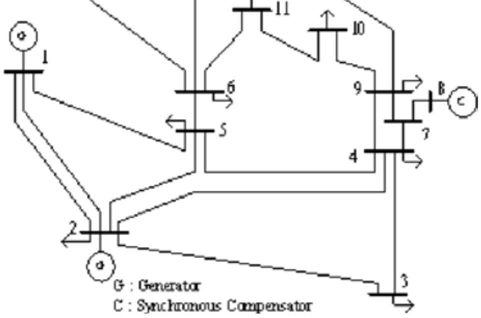

Fig 1. IEEE 14 bus system

The result of simulation can be seen in Table 1.

Table 1 Generated MW values for normal state

Gen Bus	Generated Pg for different load levels		
	100%	80%	60%
1	178.9414	182.1470	175.1273
2	68.8834	43.9445	73.1025
3	19.4445	43.0183	19.1354

Table 2 Security cost for normal state

Load level	100%	80%	60%
Duration (hrs.)	10	4	4
Security cost ($)	16207	4898.4	3991.1

If contingency occurs, corrective actions such as, generation re-scheduling are utilized to avoid line overload and maintain power flow within their constraints. Generators participating to increase their power output will not only receive profit from selling additional energy but also compensations for providing emergency reserve while generators decreasing their power output will also obtain compensations for lost of opportunity cost [15]. In the paper only two contingency are presented. Congestion is made in transmission line by making a line outage in line 1-2 and 2-3.

Table 3 Generated MW values for contingency state 1

Gen Bus	Generated Pg for different load levels		
	100%	80%	60%
1	199.1513	173.6429	156.655
2	24.9451	73.7545	59.1081
3	45.7266	23.1207	45.5825

Table 4 Security cost for contingency state 1

Load level	100%	80%	60%
Duration in hours	1	1	1
Security cost in $	1510.2	1287.7	953.3501

Table 5 Generated MW values for contingency state 2
Table 6 Security cost for contingency state 2

Gen Bus	Generated Pg for different load levels		
	100%	80%	60%
1	175.1273	201.7213	203.1513
2	73.1025	34.9538	20.9451
3	19.1354	33.5328	45.7266

Load level	100%	80%	60%
Duration in hours	1	1	1
Security cost in $	1612.3	1250.5	955.7447

Expected security cost can be calculated as the sum of probability of system operating in normal state and contingency state for different load levels.

Annual ESC = 11,923,197.6 $

V. CONCLUSION

This paper describes the ESCOPF problem. This type of OPF addresses security as an economic cost rather than as a constraint. This is done through the ability to re-dispatch the system when a contingency occurs. This paper investigates the applicability of the PSO in solving the OPF problem. Moreover, inequality constraints have been added in the formulation in order to improve the voltage profile. Traditionally, PSO handles constraints by the objective function penalization.

The proposed methodology is able to take into account feasible and satisfactory solutions for both the base case and for a set of credible contingencies. In case that the power system is capable of getting ahead from the pre-contingency state to a post-contingency state, generation and branches' operative constraints are satisfied. The PSO is able to deal with mixed type control variables, so that the OPF-SC solution assures an improved voltage profile.

APPENDIX

Setting of parameters and constants used in simulation are given as follows.

1. Ramping limit $\Delta R_{Gi}^{up} and \Delta R_{Gi}^{down}$ are assumed to be 5 MW/min while $\Delta t$is 10 min [16].
2. We assume that both $C_{GD}{}^{up} and C_{GD}{}^{down}$are 0.4 times to power price in normal state [13].
3. Parameters c_1, $c_{2},_{max} and w_{min}$ used in PSO are 1, 1,0.9, and 0.3, respectively.
4. The duration of load levels 100%, 80%, and 60% are assumed to be 12, 6, and 6 hr per day, respectively.

Table A.1 DEMAND DATA

Demand Bus No.	A	B	C
2	-0.15	100	0
3	-0.15	100	0
4	-0.15	100	0
5	-0.15	100	0
6	-0.15	100	0
9	-0.10	50	0
10	-0.15	100	0

Demand bus no.	A	B	C
11	-0.15	100	0
12	-0.18	120	0
13	-0.18	120	0
14	-0.18	120	0

Table A.2 GENERATOR DATA

Gen Bus No.	a	b	c	Pg max	Pg min	Q max	Q min	V max	V min
1	0.005	2.45	105	200	50	200	-200	1.05	0.95
2	0.005	3.51	44.1	80	20	60	-20	1.05	0.95
3	0.005	3.89	40.6	50	15	62.5	-15	1.05	0.95

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