Voltage Stability Enhancement for Iraqi (400 kV) Super High Voltage Grid System based on Cat Swarm Optimization Algorithm

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ABSTRACT
Voltage stability is the ability of a power system to maintain acceptable voltages at all nodes in the system under normal condition and after being subject to a disturbance which has a closely relationship with the reactive power of the system. This paper presents an algorithm for solving the voltage stability and Reactive Power Dispatch problem in a power system. The Cat Swarm Optimization algorithm employs for optimal settings of Reactive Power Dispatch control variables. Cat Swarm Optimization algorithm is applied on Iraqi Super High Voltage grid system and the results are compared with Particle Swarm Optimization algorithm. As a result, the proposed method was shown to be the best for solving Optimal Reactive Power Dispatch problem and hence the voltage stability enhancement

Keywords
ORPD problem, voltage stability enhancement, PSO, and CSO.

1. INTRODUCTION
Reactive Power Dispatch is one of the important tasks in the operation and control of power system. Efficient distribution of reactive power in an electric network leads to minimization of the system losses and improvement of the system voltage profile [1].

To solve the RPD problem a number of classical and artificial intelligence methods have been proposed and given below [2].

Classical methods:

a) Linear programming method.

b) Newton Raphson method.

c) Quadratic programming method.

d) Nonlinear programming method.

e) Interior point method.

Artificial intelligence methods:

a) Artificial neural network.

b) Fuzzy logic method.

c) Genetic algorithm method.

d) Evolutionary programming.

e) Ant colony optimization.

f) Particle swarm optimization.

Nowadays voltage instability has become a new challenge to power system planning and operation. By reallocating reactive power generations in the system by adjusting transformer taps, generator voltages and switchable VAR sources, the problem can be solved to a far extent. The proposed algorithm identifies the optimal values of generation bus voltage magnitudes, transformer tap setting and the output of the reactive power sources so as to improve the voltage stability [1].

2. VOLTAGE STABILITY ENHANCEMENT

2.1 Voltage Stability
Voltage stability is of major concern in power systems stability. Main reason for the cause of voltage instability is the sag in reactive power at various locations in an interconnected power system. Voltage stability is a problem in power systems which are heavily loaded, faulted or have a shortage of reactive power. Voltage stability is concerned with the ability of a power system to maintain steady voltages at all buses in the system under normal operating conditions, and after being subjected to a disturbance [3].

2.2 Type of Indices
Different types of indices were used in literatures for optimization of power systems. Some of the available indices are:

a) Line Stability Index.

b) Voltage Collapse Prediction Index.

c) Power Transfer Stability Index.

d) Line Voltage Stability Index.

e) Equivalent Node Voltage Collapse Index.

f) L-Index.

g) Fast Voltage Stability Index.

Among the different indices for voltage stability and voltage collapse prediction, the L-index gives fairly consistent results [4].

2.3 L-index Criteria for Voltage Stability Computation
Voltage Stability Index can be used to calculate the stability indices for all the load buses [5]. For a given system operating condition, by using the load flow results obtained from Newton Raphson Technique, the Voltage Stability Index (L-Index) for load buses is to be computed as:

$$L_j = 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \quad (1)$$

The values of F_{ji} can be obtained from Y bus matrix.

$$F_{ji} = [Y_{LL}]^{-1}[Y_{LG}] \quad (2)$$

Where Y_{LL} and Y_{LG} are corresponding partitioned portion of the Y-bus matrix. The L-indices for a given load condition are computed for all load buses. The L-index value is moving towards zero, then the system is considered as stable and also improves system security. When this index value moves away from zero, the stability of system is relatively decreases then the system is considered as unstable. The L indices are calculated for all the load buses and the maximum of the L indices gives the proximity to the system to voltage collapse [6].

3. PROBLEM FORMULATION

The general optimal power flow problem can be expressed as a constrained optimization problem as follows [7]:

Minimize f(x)

Subject to g(x) = 0, equality constraints

h(x) ≤ 0, inequality constraints

The objective of Optimal Reactive Power Dispatch is to identify the reactive power control variables, which minimizes the L-index value. This is mathematically stated as follows [8]:

Minimize F=max (Lj; j=1, 2,..., n) (3)

The reactive power optimization problem is subject to the following constraints.

3.1 Equality Constraints

These constraints represent load flow equation such as [8]:

$$P_i - V_i \sum_{j=1}^{N_B} V_j \left(G_{ij}\, cos\theta_{ij} + B_{ij}\, sin\theta_{ij}\right) = 0 \quad (4)$$

$$Q_i - V_i \sum_{j=1}^{N_B} V_j \left(G_{ij}\, cos\theta_{ij} - B_{ij}\, sin\theta_{ij}\right) = 0 \quad (5)$$

3.2 Inequality Constraints

The inequality constraints represents the system operating constraint, which can be given as in below [8]:

a. Generator bus voltage limits

$$V_{Gi}{}^{min} \le V_{Gi} \le V_{Gi}{}^{max} \; ; i \in N_B \quad (6)$$

b. Load bus voltage limits

$$V_{Li}{}^{min} \le V_{Li} \le V_{Li}{}^{max} \; ; i \in N_B \quad (7)$$

c.Generator reactive power capability limit

$$Q_{gi}{}^{min} \le Q_{gi} \le Q_{gi}{}^{max} \; ; i \in N_g \quad (8)$$

d. Capacitor reactive power generation limit

$$Q_{ci}{}^{min} \le Q_{ci} \le Q_{ci}{}^{max} \; ; i \in N_c \quad (9)$$

e. Transformer tap setting limit

$$t_k{}^{min} \le t_k \le t_k{}^{max} \; ; i \in N_T \quad (10)$$

4. NOMENCLATURE

N_B	Total number of buses
N_T	Number of tap setting transformer branches
N_c	Number of capacitor banks
N_g	The number of generator buses
B_{ij}	Mutual susceptance between bus i and bus j
FS_b	Best of fitness value
FS_{max}	Largest FS presented in the candidates
FS_{min}	Smallest FS presented in the candidates
G_{ij}	Mutual conductance between bus i and bus j
L_j	L-index
P_{i}	Probability of each candidate point
P_i	The real power injection at bus i
Q_{ci}	Reactive power generation by i^{th} capacitor bank, i ∈ N_c
Q_{gi}	The generator reactive power capability
Q_i	The reactive power injection at bus i
V_{Gi}	Generator bus voltages
V_L	Voltages vectors at the load nodes
V_{Li}	Load bus voltages at bus i
V_{Li}^{max}	Maximum limit for the load bus voltages
V_{Li}^{min}	Minimum limit for the load bus voltages
V_i	Voltage magnitude at bus i
V_j	Voltage magnitude at bus j
v_k^{i}	Current velocity of cat_k
$v_k^{\mathrm{i}+1}$	New velocity of cat_k
w_{i}	Inertia weight
x_{best}	Best position of cat
x_k^{i}	Current position of cat_k
$x_k^{\mathrm{i}+1}$	New position of cat_k
C	Constant number
f(x)	Objective function to be optimized
FS	Fitness value
g(x)	State variable limits and functional operating Constraints
h(x)	Power flow equations
i	Current iteration number
K	Number of iteration
N	Number of cats
R	Random value in the range of [0,1]
W	Inertia weight
x	Vector of state variables
j	Number of copies
θ_{ij}	The voltage angle difference between bus i and bus j

5. CAT SWARM OPTIMIZATION ALGORITHM [8]

CSO algorithm is divided into two sub models based on two of major behavioral traits of cats. These are termed as “Seeking mode” and “Tracing mode”. Seeking mode has four essential factors. Such as SMP, SRD, CDC, SPC which are designed as follows:

- Seeking Memory pool (SMP): It is used to define the size of seeking memory of each cat, indication any points sort by cat.
- Seeking Rang of Selected Dimensions (SRD): It is used to declare mutative ration for selected dimensions. While in seeking mode; if a dimension is selected for mutation, the difference between old and new ones may not be out of range, the range defines by SRD.
- Counts of Dimensions to Change (CDC): It is used tell how many dimensions to will be varied. All these factors play important roles in seeking mode.
- Self Position Consideration (SPC): It is a Boolean valued variable, and indicates whether the point at which the cat is already standing will be one of the candidate point to move to.SPC cannot influence SMP.

5.1 Seeking Mode

The seeking mode of the CSO algorithm models the behavior of the cats during the period of resting but staying alert observing its environment for its next move.The seeking mode of the CSO algorithm can be described as follows:

Step1: Make j copies of the present position of each cat, where j=SMP. if the value of SPC is true. Let j=(SMP-1), then retain present position as one of the candidates.

Step2: For each copy according to CDC add or subtract SRD percent values and replace the old ones.

Step3: Calculate the fitness values (FS) of all candidate points.

Step4: If all the FS are not exactly equal calculate the selecting probability (11) of each candidate point. Otherwise set all the selecting probability of each candidate point to 1.

$$P_i = \frac{|FS_i - FS_b|}{FS_{max} - FS_{min}} \quad (11)$$

If the global of the fitness is to find the minimum solution; FSb=FSmax, otherwise FSb=FSmin.

Step5: Randomly pick the point to move to form the candidate points, and replace the position of cat.

5.2 Tracing Mode

Step1: Update the velocities for every dimension (Vid) according to (12).

Step2: Check if the velocities are in the range of maximum velocity is over-range, it is set equal to the limit.

Step3: Update the position of catk according to (13).

$$v_k^{i+1} = w * v_k^i + c * r * (x_{best} - x_k^i) \quad (12)$$

where, *w* is inertia weight, Pgd is position of cat, who has the best fitness value. Xid is the position of catk, C is constant r is a random value in the range of [0,1].

$$x_k^{i+1} = x_k^i + v_k^{i+1} \quad (13)$$

5.3 Cat Swarm Optimization

When applying the CSO algorithm to solve optimization

problems, the initial step is to make a decision on the number of individuals or cats to use. Each cat in the population has the following attributes:

1. A position made up of M dimensions.
2. Velocities for each dimension in the position.
3. A fitness value of the cat according to the fitness function.
4. A flag to indicate whether the cat is in seeking mode ortracing mode.

The CSO algorithm keeps the best solution after each cycle and when the termination condition is satisfied, the final solution is the best position of one of the cats in the population. CSO has two sub-modes, namely seeking mode and tracing mode and the mixture ratio *MR* dictates the joining of seeking mode with tracing mode. To ensure that the cats spend most of their time resting and observing their environment, the *MR* is initialized with a small value. The CSO algorithm can be described in 6 steps as presented in [7]-[9].

Step1: Create *N* cats in the process.

Step2: Randomly sprinkle the cats into the *M*-dimensionalsolution space and randomly give values, which are in the range of the maximum velocity, to the velocities of every cat. Then haphazardly pick number of cats and set them into tracing mode according to *MR*, and the others set into seeking mode.

Step3: Evaluate the fitness value of each cat by applying the positions of cats into the fitness function, which represents the criteria of our goal, and keep the best cat into memory. Noting that the position of the best cat *(xbest)* must be remeberd because it represents the best solution so far.

Step4: Move the cats according to their *flags*, if *catk* is in seeking mode, apply the cat to the seeking mode process, otherwise apply it to the tracing mode process.

Step5: Re-pick number of cats and set them into tracing mode according to *MR*, then set the other cats into seekingmode.

Step6: Check the termination condition, if satisfied, terminate the program, and otherwise repeat Step 3 to Step 5.

The flowchart of the Cat Swarm Optimization algorithm shown in figure 1.

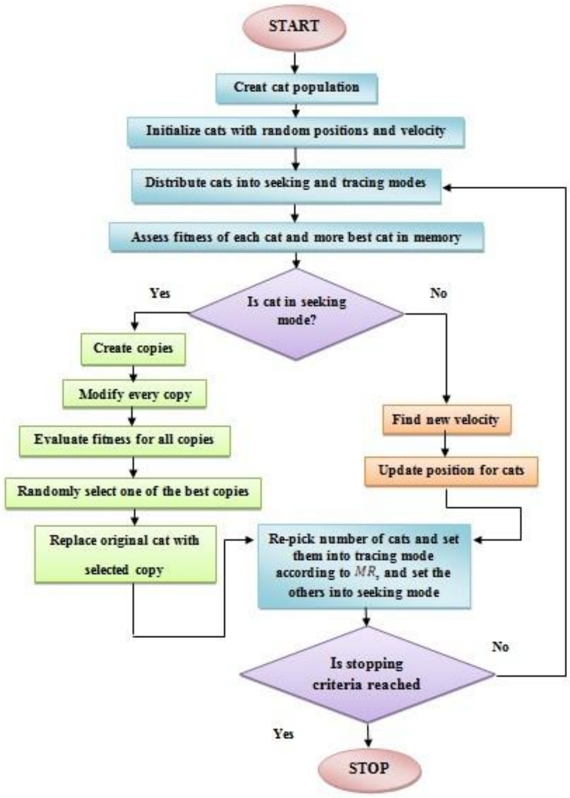

Fig 1: Flowchart of CSO algorithm

6. RESULTS AND DISCUSSION

In order to check the effectiveness of the CSO algorithm on identifying the optimal control variables under base load condition, for the Iraqi (400 kV) Super High Voltage (SHV) grid system shown in Figure 2, according to Spring season the proposed algorithm was compared with the Particle Swarm Optimization algorithm by considering the voltage stability of the system. The Iraqi (400 kV) SHV grid system contains (32) busbars, (16) generators and (48) transmission lines. No branches have tap changing transformers. In Iraqi (400 kV) SHV grid system the reactive power source is only capacitor banks.

Table 1 and Table 2 shows the parameters used for PSO and CSO respectively. Table 3 gives optimal control variable settings of Iraqi SHV grid system for PSO and CSO algorithm. Bus voltages magnitudes after applying PSO and CSO algorithms are given in Table 4. Table 5 shows comparison between the results obtained from applying PSO and CSO method.

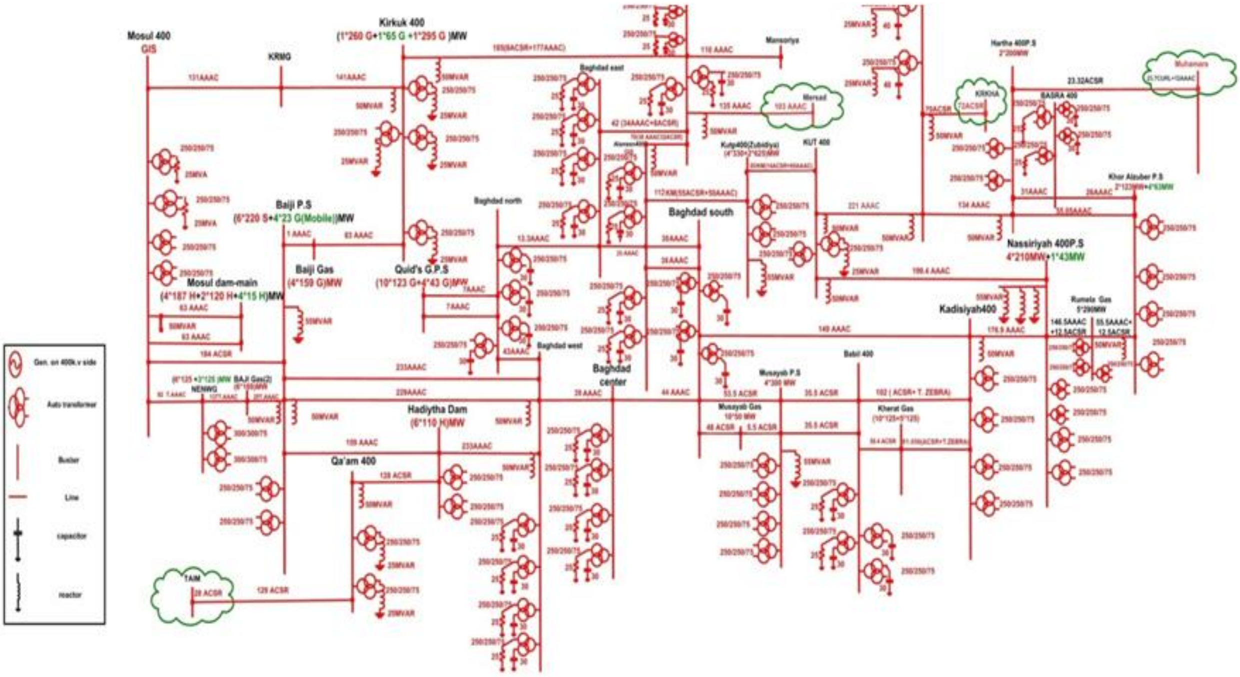

Fig 2: Iraqi National (400 kV) Super High Voltage Grid System

Table 1. The parameters used for Particle Swarm Optimization algorithm

Parameters	Values
Number of Particles	25
W_{max}.	0.9
W_{min}.	0.4
Individual Learning Rate (C_1)	2
Social Learning Rate (C_2)	2
$rand_1$	0.3
$rand_2$	0.2

Table 2. The parameters used for Cat Swarm Optimization algorithm

Parameters	Values
SMP	5
C	2.1
R	0.5
N	25
W	0.9
MR	0.8

Table 3. The optimal control variable settings

Control variables	PSO	CSO
V_{MMDH}	1.0097	1.0096
V_{NENWG}	1.0000	1.0000
V_{BAJP}	1.0051	1.0057
V_{BAJG}	1.0038	1.0032
V_{KRMG}	1.0127	1.0123
$V_{KRK\ 4}$	1.0080	1.0084
V_{QDSG}	1.0013	1.0010
V_{KUTP}	1.0000	1.0000
V_{HDTH}	1.0030	1.0000
V_{MUSP}	1.0000	1.0000
V_{MUSG}	1.0000	1.0000
V_{GKHER}	1.0000	1.0000
V_{NSRP}	1.0000	1.0000
V_{HRTP}	1.0000	1.0000
V_{KAZG}	1.0007	1.0005
V_{RMULG}	1.0047	1.0045
$Q_{C\ BGW\ 4}$	0.6	0.6
$Q_{C\ BGS\ 4}$	0.3	0.3
$Q_{C\ BGE\ 4}$	0	0
$Q_{C\ BGN\ 4}$	0.3	0.3
$Q_{C\ AMN\ 4}$	0.6	0.6
$Q_{C\ BGC\ 4}$	0	0
$Q_{C\ DAL\ 4}$	0.3	0.3
$Q_{C\ BAB\ 4}$	0.6	0.6
$Q_{C\ AMR\ 4}$	0.4	0.4
$Q_{C\ BSR\ 4}$	0.3	0.3

Table 4. Bus voltages magnitudes after applying PSO and CSO algorithms

Bus name	Voltage mag. From PSO	Voltage mag. From CSO
MSL4	1.0015	1.0012
MMDH	1.0100	1.0088
NENWG	1.0003	1.0001
BAJP	1.0085	1.0080
BAJG	1.0077	1.0073
BAJG(2)	1.0092	1.0080
KRMG	1.0157	1.0145
KRK4	1.0100	1.0091
BGW4	1.0000	1.0000
BGS4	0.9989	1.0000
BGE4	1.0022	1.0017
BGN4	1.0044	1.0036
QDSG	1.0053	1.0042
AMN4	1.0000	1.0000
BGC4	0.9969	0.9983
MANSG	1.0193	1.0180
DAL4	1.0103	1.0088
KUT4	1.0000	1.0000
KUTP	1.0000	1.0000
HDTH	1.0011	1.0002
QIM4	1.0000	1.0000
MUSP	0.9992	0.9997
MUSG	0.9900	0.9917
BAB4	0.9978	0.9983
GKHER	0.9973	0.9979
KDS4	0.9793	0.9817
NSRP	1.0003	1.0000
AMR4	0.9898	0.9900
HRTP	1.0000	1.0000
KAZG	1.0013	1.0010
RMULG	1.0068	1.0043
BSR4	1.0124	1.0100

Table 5. Comparison between the results obtained from applying PSO and CSO method

	PSO	CSO
L-index	0.2752	0.2328
Reactive power loss	193.46	173.37
Active power loss	35.77	31.34

7. CONCLUSION

CSO optimization algorithm has been proposed, developed and successfully applied to solve Optimal Reactive Power Dispatch problem to enhance the voltage stability. The ORPD has been formulated as a constrained optimization problem to enhance the voltage stability. The proposed approach has been tested and examined on the Iraqi (400 kV) SHV grid system in which the CSO results where compared with PSO method, as given in Table 4 and Table 5, when the voltage stability has been enhanced through minimizing the L-index. From results, the CSO is the best to enhance the voltage stability by solve the ORPD problem.

8. REFERENCES

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