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Augmentation of Power System Stability through Optimal Reactive Power Control using Artificial Bee Colony Algorithm

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Abstract: *Voltage stability is a major issue in planning and operation of secured power system economically. An optimal reactive power and voltage control based on Artificial Bee Colony algorithm assisted new evolutionary algorithm for voltage stability development is planned. In this approach the voltage stability index is used to formulate to identify the most critical bus at stressed conditions. In which bus with the value of maximum voltage stability index and that bus is considered as the most critical bus. The objective function formulation is examined in standard IEEE 30 bus test system with the given objective function of real power loss minimization, minimization of voltage stability index and generation cost for the important of voltage stability. This can be achieved by the optimal setting of control variables. The test results are compared with the previous approach discussed in the literature.*

Keyword: *Artificial Bee Colony (ABC); Particle Swarm Optimization(PSO); Reactive power and Voltage Control; Voltage Stability Index.*

1. INTRODUCTION

A power system should always have stable operation meeting various operational criteria and it should also be secure in the event of any incredible contingencies. Maintaining a stable and secure operation of a power system is therefore a very significant and challenging issue. The power system researchers paid more attention on voltage instability problem in these recent years as it is the major cause for power system insecurity. Voltage instability phenomena happens when the receiving end voltage decreases well below its normal value and does not come back even after restoring mechanisms such as Voltage Ampere Reactive (VAR) compensators, or it may continue to oscillate for lack of damping against the disturbances. Voltage collapse is the situation by which the voltage falls to a unacceptable low value as a result of an avalanche of events accompanying voltage instability [1]. This can be prevented by the suitable control of reactive power and voltage control wherever necessary conditions [2].

In order to maintain the stability of the system successfully the system operator must be aware of voltage instability conditions [2,3]. To predict these conditions various methods are available by calculating the voltage stability margin. Reactive power and voltage control are very significant to power system security and economical operation. Conventionally it involves parameter of voltage and reactive power in power system [4]. Proper control and operation of the power system may regulate the system voltage and reduce the real power losses. The combination of real and reactive power control subsequently helps in reduction of the total cost of operation as explained in [5].

Several techniques and algorithms have been analyzed for optimization [6-8] and setting of control variables [9-11]. Hybrid optimization methods have

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also been implemented [12,13]. The main purpose of the approach in [14] is to evaluate proper adjustment of control variables such as generator voltages and powers, transformer tap settings, and switchable VAR sources that it would minimize the real power loss, the generation cost and consequently progress the voltage profile in the power system. Recently the Artificial Bee Colony (ABC) algorithm is developed and implemented to solve reactive power control problem for the enhancement of voltage stability in power system network [15].

In this paper, minimization of real power losses, minimization of generation cost and minimization of voltage stability index are the objective functions considered. The best solution for these objective functions is obtained by the proper settings of control variables. The proposed approach has been verified on standard IEEE 30 bus test system. The organization of the paper is as follows: introduction and problem formulation in section 1 and 2 respectively. The implementation of the proposed algorithm is given in section 3, results and discussion in section 4 followed by the conclusion in section 5.

2. PROBLEM FORMULATION

2.1. Objective function

The objective of this approach is to find the optimal value of reactive power and voltage control variables to get the best solution for the objective functions based on Artificial Bee Colony algorithm. In this formulation the objective functions minimization of real power loss, minimization of generation cost and minimization of voltage stability index are considered.

2.1.1. Minimization of Real Power Losses (F_1)

The objective is to minimize the total real power losses in the system. This can be calculated as

Where

$$F_1 = P_{loss} = \sum_{k=1}^{nl} g_k[v_i^2 + v_j^2 - 2v_i v_j \cos(\delta_i - \delta_j)] \quad (1)$$

nl : is the number of lines

g_k : is the conductance of the K^{th} line

V_i&V_j : are the voltage magnitude at the buses i & j. δ_i & δ_j : are the voltage phase angle at the buses i & j

2.1.2. Minimization of Generation Cost (F_2)

The main objective function is to minimize the generation cost. This can be calculated by

$$F_2 = \text{generation cost} = \sum_{i=1}^{ng} F_i \quad (2)$$

$$F_i = \sum_{i=1}^{ng}(a_i + b_i Pg_i + c_i Pg_i^{\,2}) \quad (3)$$

Where

P_{Gi} = the generating of i^{th} generator

ng = the number of participating generator

a_i, b_i, c_i=the cost coefficients of generator i

2.1.3. Minimization of Voltage Stability Index (F_3)

The calculation of voltage stability index (VSI) is discussed below. The voltage stability index values lies between 0 to 1, in which load bus having the high value of stability index that bus is taken as a critical bus. It uses the information from the load flow analysis by N-R method. Let consider the n-bus system, the current and voltage expressions are

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (4)$$

Where,

I_G & I_L are the generators and load bus current

V_G &V_L are the generators and load bus voltage

Rearranging the above equation we get,

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (5)$$

Where

$$F_{LG} = [Y_{LL}]^{-1}[Y_{LG}] \quad (6)$$

The objective function voltage stability index is given below,

$$VSI_j = \left| 1 - \sum_{i=1}^{ng} F_{ij} \frac{V_i}{V_j} \right| i = ng+1, \ldots\ldots, n \quad (7)$$

The value of is F_{ij} calculated from Y bus matrix. The voltage stability index is calculated for all the load buses under the given loaded condition.

2.2. Problem Constraints

2.2.1. Equality Constraints

The equality constrains are framed by the real and reactive power balance equations at all the buses.
This can be expressed as show below,

$$P_{gi} - P_{di} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (8)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (9)$$

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where,

n	:	number of buses
Y_{ij}	:	mutual admittance between node i and j
δ_i & δ_j	:	the bus voltage angle of bus i and j
P_{gi},Q_{gi}	:	the real and reactive power generation at bus i
P_{di},Q_{di}	:	real and reactive power demand at bus i
θ_{ij}	:	the admittance angle of line between bus i and j
V_{ni}	:	Voltage of bus ni
R_{ni}	:	resistance of branches i
X_{ni}	:	reactance of branch i

2.2.2 Inequality Constraints

The inequality constraints consist of the limits are state variables and control variables in transmission line. This can be formulated by below,

$$1. P_s \min \le P_s \le P_s \max \quad (10)$$

$$2. Q_{gi} \min \le Q_{gi} \le Q_{gi} \max \quad (11)$$

$$3. V_{gi} \min \le V_{gi} \le V_{gi} \max \quad (12)$$

$$4. T_i \min \le T_i \le T_i \max \quad (13)$$

$$5. Qc_i \min \le Qc_i \le Qc_i \max \quad (14)$$

$$6. S_i \min \le S_i \le S_i \max \quad (15)$$

Where,

$P_s \min$ $P_s \max$	:	Minimum and maximum slack bus real powers.
$Q_{gi} \min$ $Q_{gi} \max$	:	Minimum and maximum reactive power generation.
$V_{gi} \min$ $V_{gi} \max$	:	Minimum and maximum values of generator voltages.
$T_i \min$ $T_i \max$	:	Minimum and maximum ranges of tap changing transformer.
$Qc_i \min$ $Qc_i \max$	:	Minimum and maximum of reactive power compensation equipment.
$S_i \min$ & $S_i \max$	:	Minimum and maximum line flow limit.

3. ARTIFICIAL BEE COLONY (ABC) ALGORITHM

3.1. Overview

Artificial bee colony algorithm was Artificial Bee Colony algorithm was developed by Dervis Karaboga in 2005. This algorithm is mimicked from the behaviour of honey bees. It is a new intelligent search algorithm having the basic components such as employed foraging bees, unemployed foraging bee's food sources. There are two feedbacks associated in this algorithm, the positive feedback is the recruitment of foragers to rich food sources and negative feedback is the foragers for poor food sources. In this algorithm the solution is the position of a food source and the fitness correspond to the nectar amount of a food source. The number of solutions in the population is equivalent to the number of the employed bees or the onlooker bees. The parameters used in this algorithm are the number of food sources, the trial limit and the maximum number of cycles. To apply ABC algorithm first the given problem is converted into parameter based problem then implement the optimization for good solution. The first points for the algorithm and the food sources that the worker bees will fly to are determined by the below equation

$$u_{\max} = u_{\min j} + rand \times (u_{\max j -} u_{\min j}) \quad (16)$$

where the parameters $u_{\min j}$ and $u_{\max j}$ show the minimum and maximum of the variable u_j. After the initial bee population is produced, the sources that the onlooker bees will fly to are determined by the equation

$$v_{ij} = \min(u_{ij}, u_{kj}) + (\max(u_{ij}, u_{kj}) - \min(u_{ij}, u_{kj})) \times (rand - 0.5) \times 2 \quad (17)$$

where v_{ij}, $\min(u_{ij}, u_{kj})$, $\max(u_{ij}, u_{kj})$ represent the onlooker bee to be produced and the minimum and maximum of the variables of bees u_{ij} *and* u_{kj} respectively. The rand value is between 0 and 1. The effectively of a bee within the population in roulette wheel selection is given in equation. The more nectar amount of a source means more possibility that the source would be chosen. That is, the possibility of choosing a nectar source in the position θ_i is:

$$p_i = \frac{fit_i}{\sum_{j=1}^{NF} fit_j} \quad (18)$$

where fit_i and *NF* show the modified fitness value of i^{th} solution and the number of the food sources, respectively. The term fit_i is calculated by equation.

$$fit_i = \frac{1}{f_i} \quad (19)$$

Worker bees whose source have come to an end become scout bees and start to arbitrarily search for new food source nectar. There is no leadership for the scout bees when searching for new food source. They primarily try to find any kind of the food source [7]. As such, the scout bee makes random researches and finds a new source and the new found source is assigned to θ_i. The obtained nectar amount represents the solution of the object function.

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3.2 Implementation of Proposed ABC based Approach

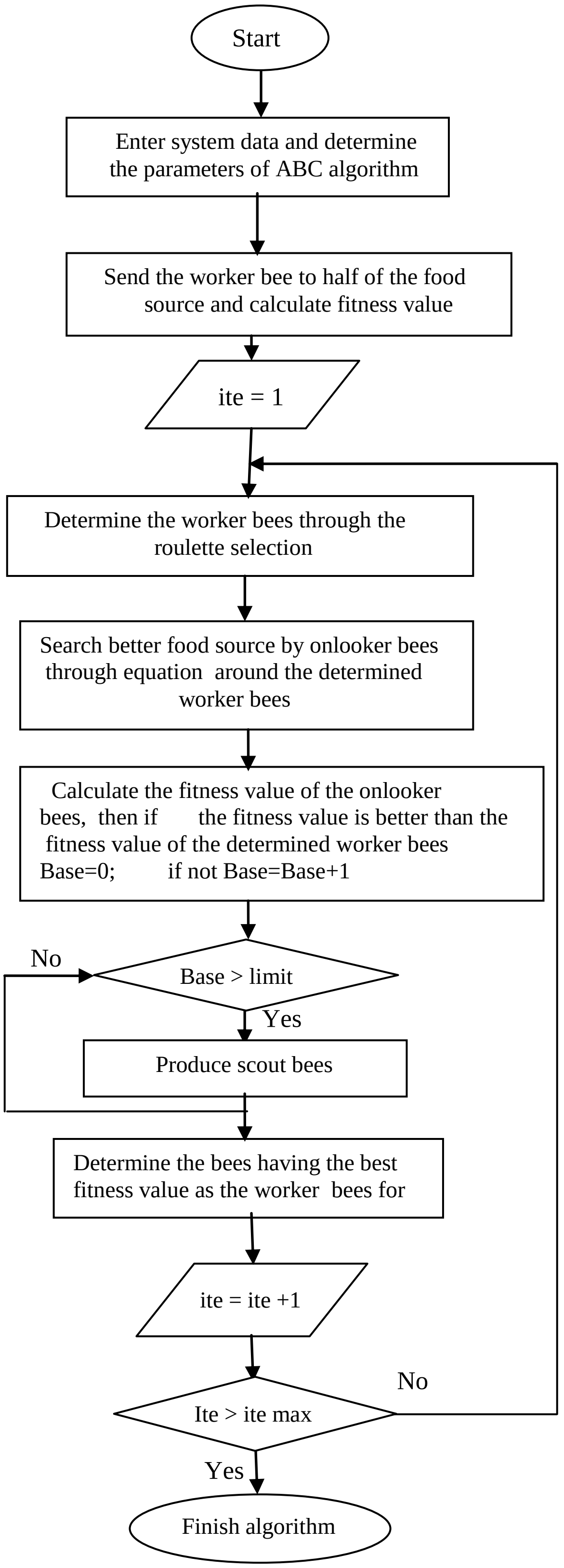

Figure:1 Flowchart of the ABC algorithm.

The proposed Artificial Bee Colony approach for optimal reactive power and voltage control for voltage stability improvement has been developed and implemented using Matlab. In this approach the voltage level in all the load buses are improved by the minimization of real power losses in the system, minimization of generation cost, as well as minimization of voltage stability index. This can be achieved by the optimal settings of control variables by the proposed algorithm. The first step in this approach is initializing the artificial bee colony.

Search the optimal solution by moving towards the better point by local search methods. From the Newton Raphson power flow solutions obtain the dependent and independent variables and verify all the constraints within the limit. The generator voltages can be varied within the range of 0.95 to 1.1 p.u the transformer tap settings varies within the range of 0.9 to 1.1 p.u and the switchable var sources are varies within the range from 0 to 5 with a step size of 1 p.u. The stopping criterion is the number of iterations, chosen to be 100 iterations. The key parameters selected for the optimization of reactive power and voltage control based on Artificial Bee Colony Algorithm is

Number of control variables: 14
Colony dimension: 10
Limit parameter: 120
Number of cycles: 100

4. RESULTS AND DISCUSSION

The methodology used here has been tested on standard IEEE 30-bus system using Artificial Bee Colony algorithm. The system consist of 41 transmission lines, 4 tap changing transformers, 6 generators and 5 static VAR compensators. This algorithm has been tested for 125% of load which indicates a stressed condition in IEEE-30 bus system.

TABLE-I GENERATOR COST CO EFFICIENTS FOR IEEE 30 BUS SYSTEM

Bus No	P min Mw	P max Mw	Cost Coefficient		
			a $/Hr	b $/Hr	c $/Hr
1	50	200	0.0	2.0	0.00375
2	20	80	0.0	1.75	0.01750
5	15	50	0.0	1.0	0.06250
8	10	35	0.0	3.25	0.00834
11	10	30	0.0	3.0	0.02500
13	12	40	0.0	3.0	0.02500

The Calculation of VSI for all the load buses is performed and its ranking is based on tis severity. The bus which has maximum value of VSI is considered to be the most vulnerable bus. Here the VSI value 0.1978 indicates the most critical bus at bus 30. Pick

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up the most critical five numbers of load buses, 30, 29, 26, 25 and 24. Execution of the system using proposed algorithm leads to reduction of load bus 30 VSI to 0.1601 and the voltage level of all the other load buses are increased which is depicted in Fig.1.

Therefore it is perceived that the performance or effectiveness of the system is upgraded while comparing with PSO and ABC [5]. Table-III depicts the optimal settings of control variables for IEEE 30 bus for base case, particle swarm optimization and Artificial Bee Colony Algorithm. The generator data for the IEEE 30 bus system is provided in Table-1.

The most favorable solution of the planned algorithm can be established by three different cases. In first case is the Minimization of Real power losses, Second case is the Minimization of Generation cost, and third case is the Minimization of Voltage Stability Index. These are all the objective function of this proposed ABC algorithm. For all the three cases the problem is resolved by single objective function.

The first case corresponds to real power losses minimization as objective function. The minimum real power loss obtained is10.191 MW.

For second case generation, cost minimization is the objective function such that it attains the minimum cost of 807.76$/hr.

Third case deals with the objective function of minimization of voltage deviation which attains the value of 0.1605p.u. The performance of this scheme has been substantiated by relating the optimal solution with base case, PSO and ABC algorithm [11] provided in Table-II.

TABLE-II COMPARISON OF OBJECTIVE FUNCTION FOR DIFFERENT METHODS

Objective function	Base Case	Particle Swarm Optimization (PSO)	Artificial Bee Colony Algorithm (ABC)
Real Power Losses	10.752 MW	10.342 MW	10.191 MW
Generation Cost	900.47 $/Hr	810.005 $/Hr	807.76 $/Hr
Voltage Stability Index	0.1969 p.u	0.1631 p.u	0.1605 p.u

The optimization of reactive power control variables has been estimated under the 125% stressed load condition for IEEE-30 bus system. Inject the reactive power in the particular buses by VAR sources by considering vulnerable buses by taking account the values of VSI of each bus. In order to obtain the best solution this algorithm obtains the optimal settings of control variables. The optimal setting of the control variables for the test system using the proposed approach is compared with PSO algorithm. The test results show the potentiality of the proposed ABC algorithm in enhancing the power system stability satisfying all the equality and inequality constraints considered. The convergence of this algorithm is very fast and is highly efficient.

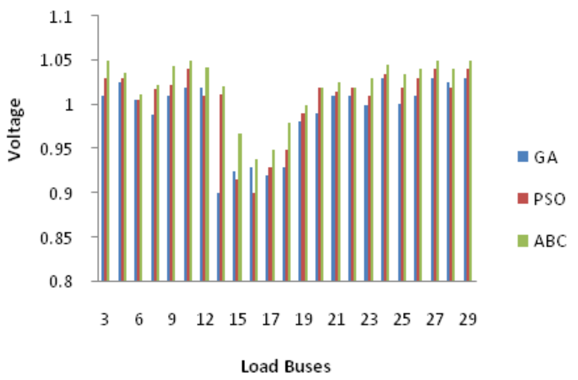

Figure.1 Voltage profile Improvement

Table-III OPTIMAL SETTINGS OF CONTROL VARIABLES FOR IEEE 30 BUS SYSTEM

S. NO	Control Variables	Base Case	Optimal setting using PSO	Optimal setting using ABC
1	V_1	1.050	1.050	1.050
2	V_2	1.040	1.029	1.034
3	V_3	1.009	1.005	1.011
4	V_4	1.011	1.017	1.022
5	V_5	1.050	1.020	1.044
6	V_6	1.050	1.050	1.050
7	T_1	0.976	1.002	1.033
8	T_2	0.965	1.011	1.020
9	T_3	0.931	0.914	0.966
10	T_4	0.967	0.901	0.937
11	Q_{30}	0	5	5
12	Q_{29}	0	5	4
13	Q_{26}	0	2	5
14	Q_{25}	0	1	3
15	Q_{24}	0	4	2
PLoss		10.752 Mw	10.342 Mw	10.191 Mw
Generation Cost		900.47 $/Hr	810.005 $/Hr	807.76 $/Hr
Voltage Stability Index		0.1969 p.u	0.1631 p.u	0.1605 p.u

5. CONCLUSION

In this paper, Artificial Bee Colony algorithm technique has been successfully upgraded and developed for the improvement of voltage stability by solving the issues in reactive power control. The effectiveness of the proposed approach has been inspected under the stressed condition of 125% of load in IEEE 30 bus test system by comparing base case, PSO and ABC based reactive power control optimization. For all the load buses, voltage profile improvement has been achieved by minimization of real power losses and

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reduction of voltage stability index proving the effectiveness of the proposed approach.

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