Particle Swarm Optimization: A Tool Development Case Study of Optimal Capacitor Placement

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***Abstract* — Today reliability is an important parameter in Electrical industry to achieve high security and adequacy of the system. There are three important parameters required to introduce in reliability viz customer composite damage function, average load and failure rate. Most of the intelligent methods include capacitor cost and savings due to reduction in power losses. In this research work particle swarm optimization (PSO) tool is developed and implemented for optimal capacitor placement and sizing in distribution system using dot net framework based software. Various constraints like voltage and power factor in addition to harmonic distortion is discussed for enhancement of distribution system reliability. Modified failure rate is applied to calculate reliability cost and hence accordingly objective function is calculated. Distribution system bus data and branch data are passed through ETAP load flow study. Load flow data is processed through optimal capacitor placement (OCP-PSO) module designed in the software. Results are used for comparison of voltage profile, power factor improvement, loss reduction, capacity release and objective cost reduction in OCP.**

***Key Words* — particle swarm optimization, Optimal capacitor placement, Reliability indices.**

I. INTRODUCTION

Eberhart and Kennedy had developed biologically inspired Particle Swarm Optimization (PSO) which is computational search and optimization method based on the social behaviors of birds flocking or fish schooling. Basic PSO is more appropriate to process static, simple optimization problem. Various observations advantages and disadvantages are discussed in (Dian P. R. et al., 2011).

Particle swarm optimization is implemented for solving mixed integer nonlinear reliability optimization problems in series, series-parallel and bridge systems discussed by (Laxminarayan Sahoo,et al., 2014). Overall system reliability subject to the nonlinear resource constraints consist of system cost, volume and weight are considered to develop hybrid algorithm with the features of advanced genetic algorithm and particle swarm optimization.

Adaptive Differential Harmony Search Based Optimization method is discussed in (Rajashree Dash et al., 2014). A Modified Particle Swarm Optimizer (MPSO) based method is discussed in Naveen Jain et al. (2014) for placement of multiple WPDGs and capacitors. One of method in reliability evaluation is Monte Carlo Simulation based on probabilistic load flow study is discussed.

Power losses in distribution system can be reduced by optimal capacitor placement method. Other benefits of OCP is reactive power compensation, power factor improvement, reliability enhancement, maintaining voltage profile. Then the problem is the process of determination of the location, size and number of the capacitor to be placed in a radial distribution system such that maximum benefits can be achieved. Objectives are to reduce the losses in the system and to maintain the desired voltage profile within the limits.

Since capacitor supply reactive load locally they improve the load carrying capability of the lines and therefore plays the same role as redundant lines and optimum capacitor configuration can also improve reliability indices of the distribution system. Since the capacitor bank is added in discrete steps the objective function is not differentiable and the capacitor placement problem is a mixed integer nonlinear program. Capacitors are inadequate in discrete sizes and only fixed capacitors are used in distribution system. Calculations of optimal capacitor configuration needs to take into multiple objective functions as discussed in (Sonwane, P.M. et al.; Kennedy J. et al., 2008).

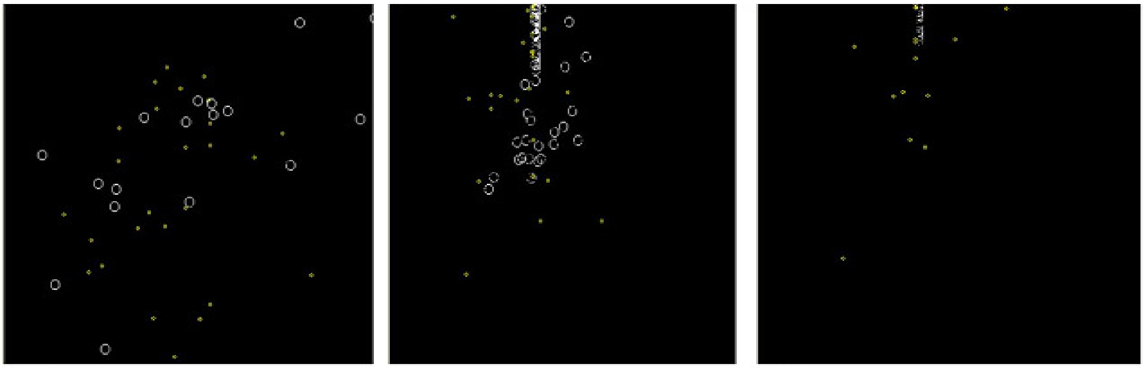
II. PARTICLE SWARM OPTIMIZATION

A. Swarm size

Iteration count is not really a relevant criterion for faster searching of particle. In fact, the counts is the number of times to minimize the function must be evaluated, which requires a considerable time. And, obviously, for an iteration, the number of evaluations is equal to the number of particles. Therefore to reduce the total number of evaluations needes to decrease the size of the swarm. But small swarm size is likely to take longer to find a solution or even not to find it at all. In short, a compromise must be reached. Mostly, the researchers proposed sizes of particles around 20 to 30 to solve almost all classic optimization problems. In the examples below we will systematically use a swarm of particles size as per objective functions achieved due to voltage and power factor constraint. If constraints are neglected, swarm size is equal to number of capacitors supplied (30).

B. Initialization

A search space is defined with the limits of minimum and maximum, for example, like one (hyper) cube of the form $[x_{min}; x_{max}]^D$.



(a) Particle positions at initialization (b) Particle positions at end of 100 iteration (c) Particle positions at end of 200 iteration

Fig. 1. Particles in PSO Tool

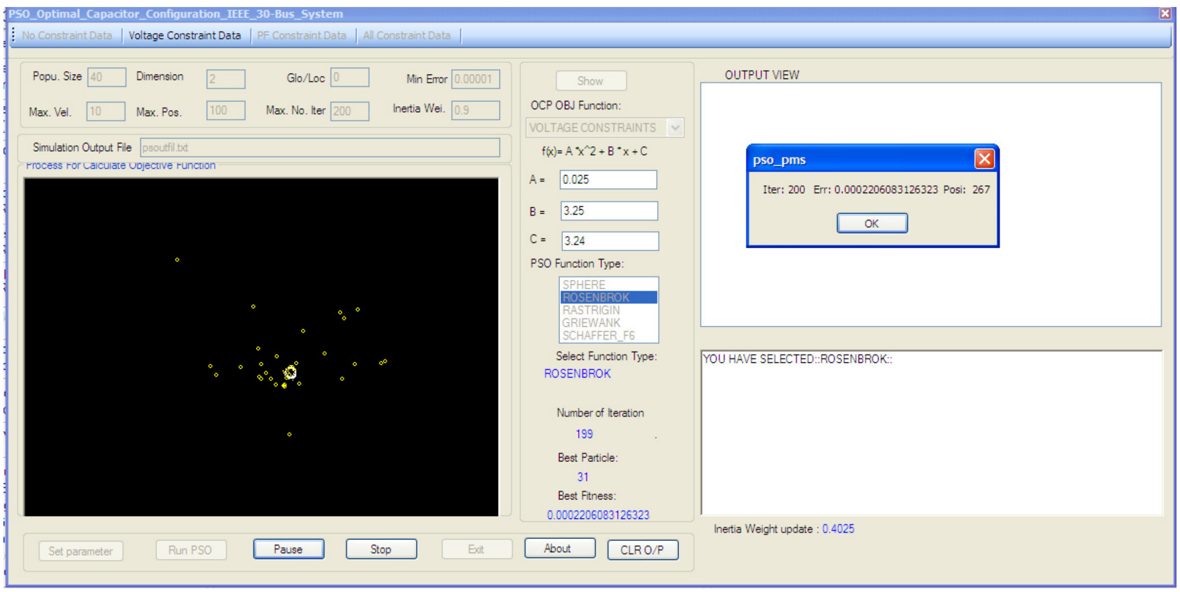


Fig. 2. PSO Tool developed

Initialization simply consists of randomly placing the particles according to a uniform distribution in search space. In this stage, stochastic iterative optimization can be found. Particles have velocities which is a vector or, more precisely, an operator, applied to a particle to evaluate a position. Velocity and position of particles need to update to achieve best solution (objective function).

$$[\ (x_{min} - x_{max})/2\ ,\ (x_{max} - x_{min})/\ 2]$$

C. *Equations of motion*

The velocity and position update as given by equation (1) is in the dimension of the search space D. Therefore, the current position of a particle in this space at the moment t is given by a vector x(t), with D components. In OCP PSO tool development we believed in 2D search space for fastening the evaluation process. Some researchers can use search space dimension from 2 to 10. The d^{th} component of one of these vectors is indicated by the index d, for example x_d.

With these notations, the equations of velocity and position of a given particles are formulated by,

$$\begin{cases} V_d \leftarrow C_1 V_d + C_2\,(p_d - x_d) + C_3\,(g_d - x_d) \\ x_d \leftarrow x_d + v_d \end{cases} \qquad (1)$$

C_1, C_2 and C_3 are the confidence coefficients or learning factors depending on random variables r_1 and r_2 (0 to 1) is selected to each step improvement in evaluation up to the last iteration. Fig. 1 indicates the particle position in initial state, after 100 iteration state and after final i.e., 200 iteration state. It is observed from above figure that the particle moves towards objectives.

III. Tool Requirements

A. *Population Size*

Population size depends on particle size. It is advised to select particle size should be within 30 and 100.

B. *Dimension*

In this research work two dimensional PSO architecture is selected as PSO parameter.

C. Maximum Positions

In most of the cases maximum position is selected on type of problem required to evaluate using PSO. In this research work we have selected IEEE 30 bus system for optimal capacitor placement. Number of capacitors are restricted to a value 30 and hence particle size is selected as 30. Objective function is simulated and PSOFEED expression is developed using regration analysis. These equations are evaluated as particle positions equal to 100 as maximum position, which can be traced by providing modified velocities and positions as discussed in Eqn. (1).

D. Inertia Weight

Inertia weight is updated as per the following formula and it will retain within the limit of 0.4 to 0.9

Inertia $W = ((w_{old} - 0.4) * (I_{max} - I) / I_{max}) + 0.4$ (2)

E. Minimum Error

Minimum error selected is 0.00001 for suitability of simulation required within the constraint of iteration number selected as 200 to 10000. User may increase or decrease the upper and lower limit of iteration number but this will cause increase in simulation time for upper limit and accuracy of result in lower limit.

F. Function Type

```
Select Case optimizeFUNC
        Case 0
          Call SPHERE(indpopIndex)
        Case 1
          Call ROSENBROK(indpopIndex)
        Case 2
          Call RASTRIGIN(indpopIndex)
        Case 3
          Call GRIEWANK(indpopIndex)
        Case 4
          Call SCHAFFER_F6(indpopIndex)
         Case 5
            Call Rosenbrock(indpopIndex)
      End Select
```

G. Fitness Function

Fitness function is error function required to evaluate in PSO. This depends on function type selection. If Rosenbrok function is selected then following code will execute.

```
FuncERRval(indpopIndex) = 0.0#
For Dimensionindex As Integer = 1 To indexDimension - 1
      FuncERRvalDim = 100.0# *
(eachPOSIparticle(indpopIndex, Dimensionindex + 1) -
(eachPOSIparticle(indpopIndex, Dimensionindex)) ^ 2) ^ 2 +
(eachPOSIparticle(indpopIndex, Dimensionindex) - 1) ^ 2
      FuncERRval(indpopIndex) = FuncERRval(indpopIndex) +
FuncERRvalDim
Next Dimensionindex
```

IV. TOOL DEVELOPMENT

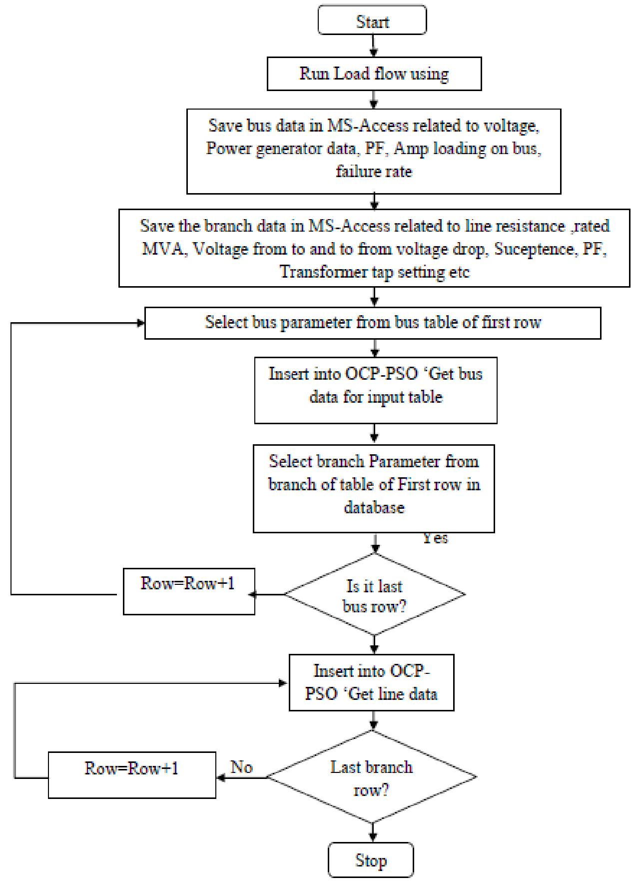


Fig. 3. Algorithm for Bus/Branch data in to OCP-PSO

Constraints in OCP-PSO

Optimal capacitor placement simulation is started with pressing a tab (button) 'OCP Simulation With' where four options are provided for constraint selection as given below.

i. Voltage constraint
ii. PF constraint
iii. All constraint (Voltage and PF)
iv. Harmonic constraint

Out of these four, one constraint can be selected from first three constraints as Harmonic constraint is applicable after the simulation to check total harmonic distortion in voltage.

V. PSO TESTING AND VALIDATING

PSO tool is developed in dot net framework with database management technique. Sequel query is written for most of the algorithms. Initially software is developed for optimal capacitor placement and sizing. Tool is improved for usual functions like

Rosenbrok, sphere and other function used. The developed PSO program is used for these functions to validate the software. It is observed that the PSO tool works properly for these functions also. After validation objective function developed for this work is simulated using software and results are compared with the other tools like genetic algorithm and DIgSAILENT software and observed that results obtained using PSO is much superior than other tools.

VI. Simulation Results And Discussions

TABLE 1. RESULT ANALYSIS

Bus	No Cap	ECOST old	ECOST mod	Obj Fun old	Obj Fun mod
10	3	3420640	1081711	3420724	1081760
14	0	557963	557963	557964	557964
15	0	1380328	995869.4	1380349	995885
16	4	535484.1	387776.8	535487.9	489571.7
17	4	744030.1	534375	744031.8	585261.7
18	0	419591.9	419591.9	419593.4	419593.4
19	0	701160.4	701160.4	701161	701161
20	0	643551.6	643551.6	643556.7	643556.7
21	4	1443767	1073926	1443767	1124729
22	6	582583.5	240557.8	582590.6	316523.4
23	5	388984.4	237489.1	388985.5	251089.1
24	6	763062	404079.1	763062	479679.1
27	7	1246194	772084.2	1246241	1001664
29	4	426997.7	359544.1	427003.5	436693.1
30	8	748333.6	748333.6	748333.6	748333.6

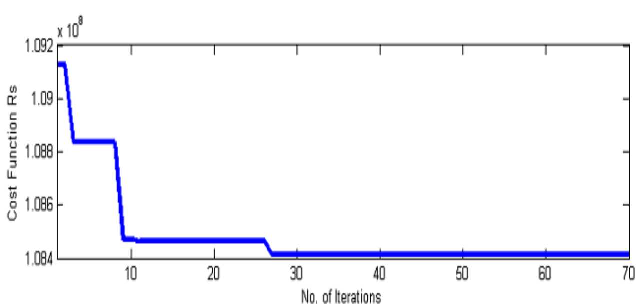


Fig. 4. Cost Function Vs No of Iteration in PSO

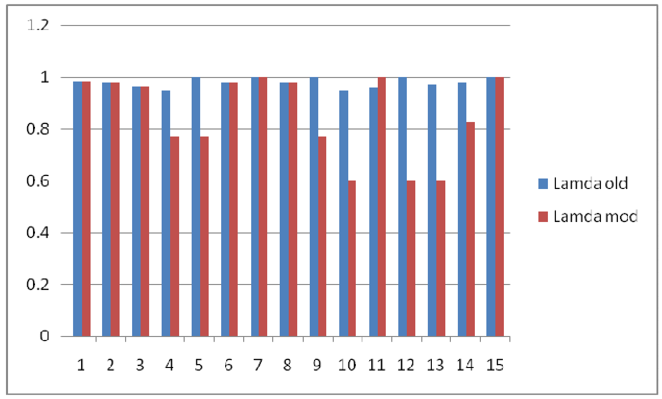


Fig. 5. Comparision of failure rate Lambda

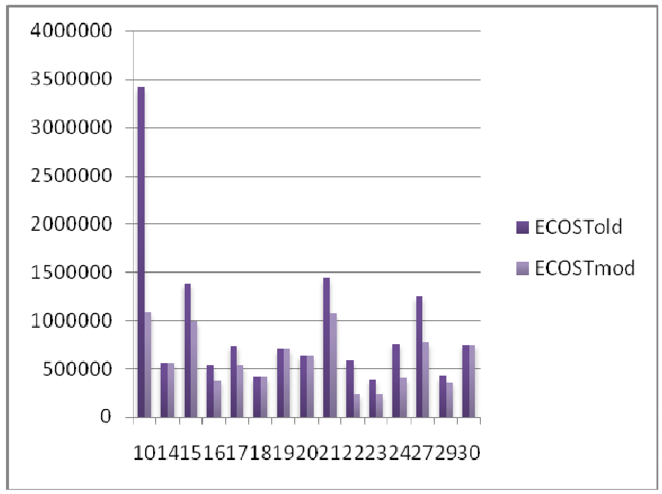


Fig. 6. Comparision of reliability cost

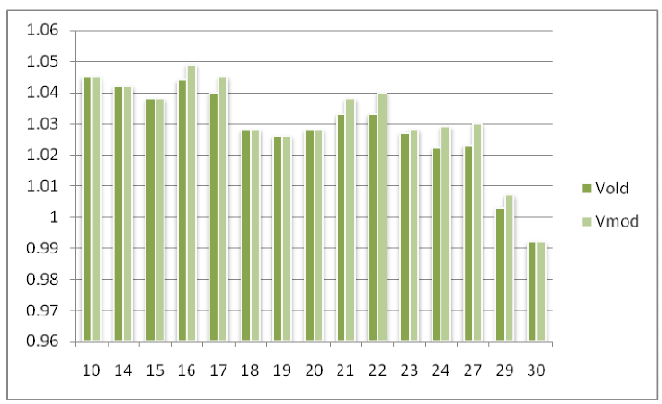


Fig. 7. Comparision of voltage

Fig. 4 introduces objective cost function for a sample bus number 10. Upto iteration 27 cost function is decreasing and then remains steady. So in PSO 70 or 100 or 200 iteration is sufficient. Fig. 5 is the graphical representation of failure rate. It is observed that failure is decreased in each bus.

Reliability cost is compaired as shown in Fig. 6. Voltage profile is graphically represented in Fig. 7 and opbserved that voltage is modified and increased but remain within limit.

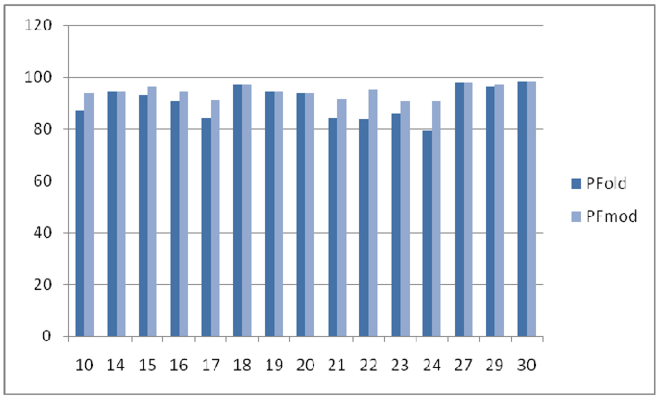


Fig. 8. Comparision of power factor

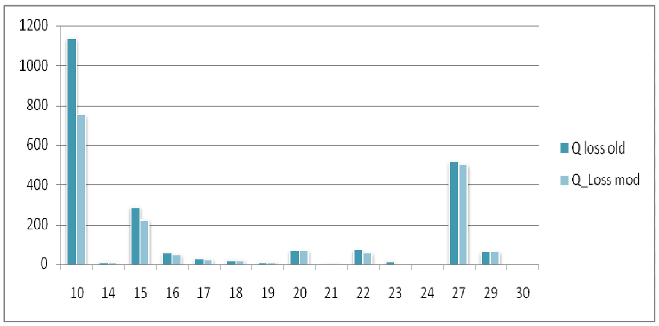


Fig. 9. Comparision of reactive power loss

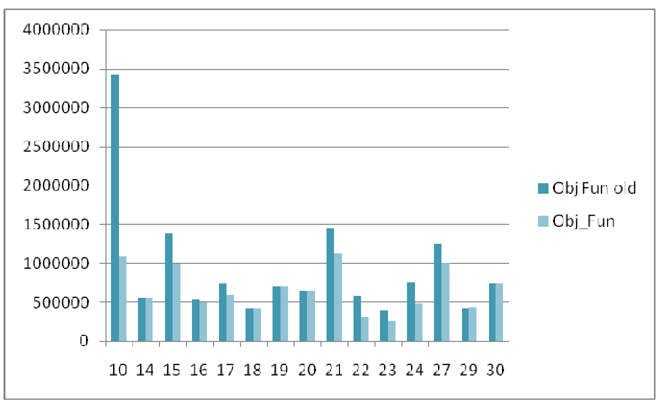


Fig. 10. Objective function comparison

In Fig. 8, power factor is compared and observed that it is also within the limit. Reactive power is the major issue in optimal capacitor placement. Reactive power loss is decreased using PSO as shown in Fig. 9.

Objective function used here, consist of cost of reliability, cost of capacitor and power loss cost. OCP PSO tool developed is used to simulated objective function cost. It is observed that cost is decreased in capacitor placement as shown in Fig. 10. This is cause to reduce the burden on transmission line by releasing capacity, benefits due to unity or towards unity power factor and loss saving. Cost of capacitor is recovered mostly in one planning year and then profit increases.

Conclusion

Optimal capacitor placement and sizing is implemented by using developed OCP-PSO tool in the Research Laboratory of Electrical Engineering department of K. K. Wagh Institute of Engineering Education and Research. This tool gives the result by implementing PSO for number of capacitors at bus number in IEEE 30 bus system. Simulation process is carried out for more than 10 cases with voltage constraint, power factor constraint and harmonic constraint. In the simulation process it is observed that the profit is available in the short time period with maximum benefits in saving power losses, saving in capacitor cost and saving due to reliability cost. The results are compared with ETAP simulation process which is available in the research laboratory in which genetic algorithm based simulation of capacitor placement is carried out. So the comparison of results between OCP-PSO and ETAP is the comparison of GA and PSO.

Investments in capacitor are recovered in almost within two years of time period. As life of capacitor by many manufacturer are around 25 years, so saving due to cost of losses and cost of reliability becomes profitable after two year and it become beneficial to utility as well as customer.

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