# Minimization of Reactive Power Using Particle Swarm Optimization

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**Abstract—** This paper presents an efficient and reliable Particle Swarm Optimization (PSO) algorithm for solving Reactive power optimization including voltage deviation in Power System. Voltage deviation is the capability of a power system to maintain up to standard voltages at all buses in the system under standard conditions and under being subjected to a disturbance. Reactive power optimization is a complex combinatorial programming problem that reduces power loses and improves voltage profiles in a power system. To overcome this shortcoming, a multi-objective particle swarm optimization is proposed and applied in reactive power optimization on IEEE-30 bus, Here the RPO problem has been formulated as a constrained multi-objective optimization problem by combining of two objective functions (real power loss and voltage profile improvement) linearly shows that the particle swarm optimization more effectively solve the reactive power optimization problem in power system.

**Keywords —** Reactive power optimization, multi-objective particle swarm optimization, voltage deviation and loss minimization.

## I. INTRODUCTION

The difficulty of reactive power optimization is in a straight line concerned not only with service excellence and reliability of supply, but also with financial system and safety of the power systems. It is of large importance to preserve suitable voltage levels at all power system buses, since every part of current day equipments which extend electric power such as illumination; thermal appliances, electronic appliances and motors, are designed for use surrounded by a definite workstation voltage, the nameplate voltage. If the voltage deviates from this value, the helpfulness, life suspense, and the superiority of performance of the equipment will suffer. Some electrical equipment is more sensitive to voltage variations than others such as motors. Even though the fact that more than a few voltage-deviation techniques are accessible to electric power system operational staff, power systems are silent subjected to voltage instabilities and in some belongings to voltage collapses that could lead to unexpected system breakdowns. Reactive power organize has become an important aspect for many reasons.

The need for most efficient operation of power systems has increased with price of fuel. For a given distribution of power, the losses in the system can be reduced by minimizing the flow of reactive power. In many case power transmitted through older circuit has been increased, requiring the application of reactive power control measures to restore stability margins.

Different techniques have been descriptions [18 - 19] to assess voltage deviation of power systems to find the possible ways to improve the voltage stability boundary. Voltage is considered as one of the most important parameters of the quality of power supply. Its deviation from the normal value may be damaging and luxurious. Therefore, the RPO problem is large-scale extremely constrained nonlinear non-convex optimization difficulty [1].In this paper, the main concerns are proper planning and organization of control variables which are whichever transformer tap chargers, shunt capacitors, generators reactive Vars in an interconnected power system such that real power becomes least. [4-9]. Here the RPO problem has been formulated as a constrained multi-objective optimization problem by combining of two objective functions (real power loss and voltage profile improvement) linearly. Usually, PSO has a more global searching ability at the found of the sprint and a local search in close proximity to the end of the sprint. Therefore, while solving problems with more some degree of optima, there are more potential for the PSO to find out local optima at the finish of sprint. However, the reactive power optimization problem does have these properties itself. For these reasons, a reliable global advance to power system optimization problems would be of significant value to power engineering civilization. The problem of reactive power planning in a power system can be exposed to be a combinational optimization problem through a number of methods have been proposed to solve the problem using the particle swarm optimization algorithm. Compared with other optimization techniques, particle swarm optimization has comparable or even superior search performance for some hard optimization problems in real power systems [2-3].

PSO was applied to different areas of power systems. It was used to optimize the reactive power flow in the power system network to minimize real power system losses [10]. Several evolutionary algorithms such at the same time as genetic algorithms (GA) [13-16]; ant colony optimization (ACO) [11–12] have been used for optimization of structures. These optimization algorithms are all the rage and widely used due to their high possible for modeling engineering problems and simple programming in computers. These optimization algorithms have many similarities. All of them discover the aim freedom by a population of potential designs using some simulation development operators with accidental environment. A power system needs to be with sufficient reactive coffers to meet the improved reactive power demand under seriously loaded conditions and to avoid voltage instability problems.

The proposed come within reach of has been examined and tested on the standard IEEE 30-bus test system with different objectives that reproduce voltage profile improvement, and voltage deviation improvement. Leaving presented an A Reactive Power Optimization Solution Based on multi-objective Particle Swarm Optimization in Power Systems [17]. The optimality of the proposed approach has been tested by comparing the results obtained by other evolutionary algorithms.

## II. PROBLEM FORMULATION

The aim of reactive power optimization problem is to minimize the power losses in the transmission network and develop voltage quality. The control variables are generators bus voltages, transformer tap positions and switch-able shunt capacitor banks.

The equality constraints are power/reactive power equalities, the inequality constraints include bus voltage constraints, generator reactive power constraints, reactive source reactive power capacity constraints and the transformer tap position constraints, etc [12]. The equality constraints can be automatically satisfied by load flow calculation, while the lower/upper limit of control variables corresponds to the coding on the Particle Swarm optimization so the inequality constraints of the control variables are satisfied which can be described as follows:

Objective Function:

$$F = F_1 + F_2 = P_{Loss} + VD \tag{1}$$

Where,

$P_L$ = network real power loss

nl = Number of line

VD = Voltage deviation

This is mathematically stated as:

$$F_1 = P_{Loss} = \sum_{k=1}^{nl} g_k\left[V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right] \tag{2}$$

Constraints:

1. Real Power Constraints:

$$P_{Gi} - P_{Di} - V_i\sum_{j=1}^{N_B} V_j\left(G_{ij}Cos(\theta_i - \theta_j) + B_{ij}Sin(\theta_i - \theta_j)\right) = 0,$$

$$i = 1,2 \ldots\ldots N_B \tag{3}$$

2. Reactive Power Constraints:

$$Q_{Gi} - Q_{Di} - V_i\sum_{j=1}^{N_B} V_j\left(G_{ij}Sin\theta_{ij} - B_{ij}Cos\theta_{ij}\right) = 0,$$

$$i = 1,2 \ldots\ldots N_B \tag{4}$$

Where,

$V_i$ = Voltage magnitude at bus I

$V_j$ = Voltage magnitude at bus j

$P_i, Q_i$ = Real and reactive powers injected into network at bus i

$G_{ij}, B_{ij}$ = Mutual conductance and susceptance between bus i and bus j

$Q_{gi}$ = Reactive power generation at bus i

$N_B$ = Total number of buses excluding slack bus

$N_{PQ}$ =Number of PQ buses

$\theta_{ij}$ = Voltage angle difference between bus i and bus j

3. Bus Voltage magnitude contraints :

$$V_i^{min} \le V_i \le V_i^{max} \quad ; \quad i \in N_B \tag{5}$$

4. Transformer Tap position contraints :

$$t_k^{min} \le t_k \le t_k^{max} \quad ; \quad i \in N_T \tag{6}$$

5. Generator bus reactive power constraint:

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \quad ; \quad i \in N_g \tag{7}$$

6. Reactive power source capacity constraints

$$Q_{ci}^{min} \le Q_{ci} \le Q_{ci}^{max} \quad ; \quad i \in N_c \tag{8}$$

7. Transmission line flow constraints:

$$|s_1| \le |s_1^{max}|$$

$$S_l \le S_l^{max} \quad ; \quad l \in N_l \tag{9}$$

The symbol used is follows:

$t_k$= Tap setting of transformer at branch k

$Q_{Ci}$= Reactive power generated by $i^{th}$ capacitor bank

$Q_{gi}$ = Reactive power generation at bus i

$S_l$ = Apparent power flow through the $i^{th}$ branch

$N_B$ = Total number of buses

$g_k$ = Conductance of buses

$N_T$= Number of tap-setting transformer branches

$N_c$ = Number of capacitor banks

$N_g$ = Number of generator buses

State variable are restricted by adding them as a quadratic penalty terms to the objective function. Therefore the equation (1) is changed to the following form:

$$Min.F_T = f + K_v \sum_{i=1}^{N_{pq}} (V_i - V_i^{lim})^2 + K_q \sum_{i=1}^{N_g} (Q_{gi} - Q_{gi}^{lim})^2 + K_f \sum_{i=1}^{N_b} (S_i - S_i^{lim})^2 \quad (10)$$

Where $K_v$ , $K_q$ and $K_f$ are the penalty factors for the bus voltage limit violations, generator reactive power limit violations and line flow violations respectively.

$$X_i^{lim} = X_i^{max} \; if \; X_i > X_i^{max} \quad (11)$$
$$X_i^{lim} = X_i^{min} \; if \; X_i < X_i^{min} \quad (12)$$

$$F = \frac{K}{F_T} \quad (13)$$

Where k is a large constant this is used to amplify $1/F_T$ the value of which is usually small, so that the fitness value of the chromosome will span a wider range.

## III. Reactive Power Optimization With Voltage Profile

The significance of reactive power supervision increases regularly, in the direction of increasing reactive power require. Here the RPO problem has been formulated as a constrained particular objective optimization problem by combining of two objective functions (real power loss and voltage profile improvement) linearly. Voltage is very significant in power management; as it must be high sufficient to support loads and must be in the neighborhood of to the position plenty not to cause any responsibility of equipment. Hence, voltage must be controlled from every position and should be maintained. This can be recognized to a great amount by controlling reactive power utilization and resources.

The controllable devices such as generator, capacitor, and reactor devices are used for decreasing the loss and increasing the voltage control in reactive power optimization. At the same time, these devices consist of constraints for the optimization problem. In this study, there are three object function optimization called RPOVD. These functions are: active power loss, voltage profile of load buses and penalty function of reactive power sources. Generally Vref. Is taken as 1.0 p.u.

$$F_2 = V_{dev} = \frac{\sum_{i \in N_{PQ}} |V_i - V_{ref}|}{N_{PQ}} \quad (14)$$

Where,

$V_{dev}$ = Voltage deviation

$V_{ref}$ = load bus reference voltage value.

$V_i$ = load bus voltage

$N_{PQ}$ = load bus number

## IV. Particle Swarm Optimization Approach

PSO algorithm, originally introduced by Kennedy and Eberhart (1995). Similar to evolutionary algorithm, the PSO technique conducts searches using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the reactive power problem. In a PSO system, particles change their positions by flying around in a multidimensional search space until a relatively unchanged position has been encountered, or until computational limitations are exceeded. In social science context, a PSO system combines a social –only model and a cognition-only model. These particles are randomly initialized and freely fly diagonally the multidimensional investigate space. Throughout flight, each particle updates its own velocity and position based on the best experience of its own and the complete population. The social-only component suggests that individuals ignore their own experience and adjust their behavior according to the successful beliefs of the individual in the neighborhood. On the other hand, the cognition-only component treats individuals as isolated beings. A particle changes its position using these models. [21-22] The PSO system simulates the knowledge evolvement of a Social organism, in which *N* individuals, a potential Solution to a problem is represented as a particle flying in D-dimensional search space, with the position vector $X_i = (X_{i1}, X_{i2}, X_{i3}, \dots \dots X_{iD})$ and velocity $V_i = (V_{i1}, V_{i2}, V_{i3}, \dots \dots V_{iD})$ Each particle records its best previous position (the position giving the best fitness value) as $P_{besti} = P_{besti_1}, P_{besti_2}, \dots \dots P_{best_{id}}$ called personal best position. The global version of the PSO keeps track of the overall best value ($g^{best}$), and its location, obtained thus far by any particle in the population. At each iteration, each particle competes with the others in the neighborhood or in the whole population for the best particle (with best fitness value among neighborhood or the population) with best position $g_{besti} = g_{best\,i_1}, g_{besti_2} \dots \dots g_{best_{id}}$ called global best position. Each particle tries to modify its position using the following information:

The velocity and position of all particles are randomly set to within pre-defined ranges. And velocity updating (fig 1). At each iteration, the velocities of all particles are updated according to:

$$V_{id} = w_i v_{id}^k + C_1 rand_1 (P_{id} - X_{id}) + C_2 rand_2 (P_{gd} - X_{id}) \quad (15)$$

And

$$w_i = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (16)$$

i = Index of particle, i∈ {1……….n},n= Population size

d= Dimension, d∈ {1…………….N}

$X_{id}$ = present position of particle i on dimension d

$C_1$ = Self confidence factor

$C_2$= Swarm confidence factor

$P_{id}$ = Personal best

$P_{gd}$ = Global best

W= Inertia weight

$w_{max}$ =initial weight

$w_{min}$ = final weight

$I_{ter}$ = current iteration

$Iter_{max}$ = maximum iteration

The use of the inertia weight w has provided improved performance in a number of applications. As originally developed, w often is decreased linearly from about 0.9 and 0.4 during a run. Suitable collection of the inertia weight provides a balance between global and local examination, and results in less iteration on average to find a sufficiently optimal solution. $C_1$ and $C_2$ are known as learning factors. They represent the weighting of stochastic acceleration terms that pull every one particle towards the $p^{best}$ and $g^{best}$ positions. Commonly $C_1$ and $C_2$ are set to 2.0 which will make the search cover neighboring sections centered at $p^{best}$ and $g^{best}$ .

$$X_{id} = X_{id} + V_{id} \qquad (17)$$

The current position that is the searching point in the solution breathing space can be modified by the equation and as shown in Fig. 1.

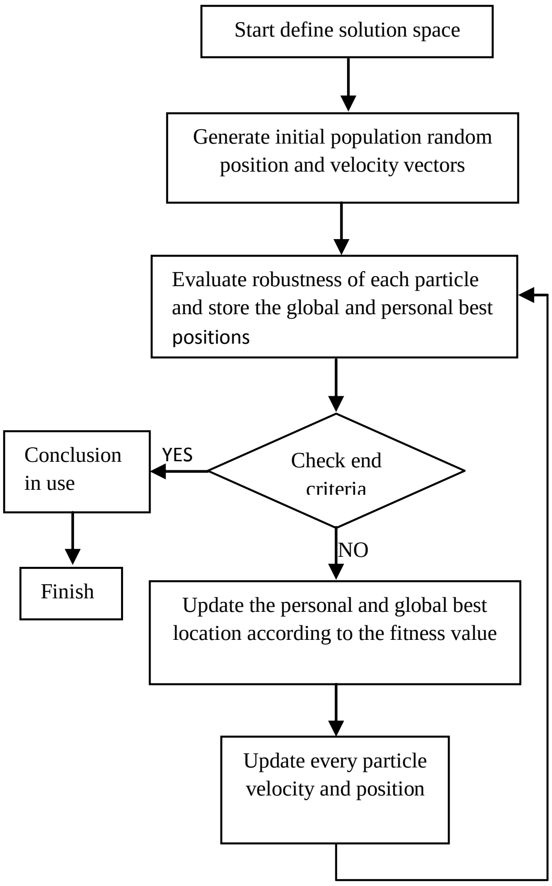


Fig-1 Flow Chart for PSO

The PSO algorithm simple in thought, trouble-free to implement and computational efficient. The unique process for establishing PSO is as follows:

1. Initialize population of particle with random position and velocities and N dimensions in the difficulty space.
2. Identify the particle in the swarm through the best achievement so far, and assign its index to the changeable g.
3. For every particle, assess the desired optimization fitness function in N variables. Evaluate particle's robustness evaluation with its . If present value is better than , then set equal to the current value, and equals to the current location in N-dimensional space.
4. Modify the velocity and position of particle according to equations (15) and (17).
5. Loop to stop 3 until a principle is met, typically a productively superior fitness or a maximum number of iterations.

## V. Multi-Objective RPO With Particle Swarm Optimization Including VD

Multi-objective Reactive power optimization (RPO) is a significant optimization procedure in terms of voltage deviation and active power loss. The reactive power optimization is realized on IEE30 bus test system with particle swarm optimization and voltage deviation. There are 6 generator bus, 24 load bus and 41 transmission lines with tap setting transformers.

Bus voltage is one of the largest part significant security and service excellence indices. Improving voltage profile can be obtained by minimizing the load bus voltage deviations from 1.0 per unit. The most favorable settings of the PSO were obtained by the following parameters are given below:

| | | |
|---|---|---|
| Maximum no. of iteration | : | 250 |
| Population size | : | 30 |
| $W_{max}$ | : | 0.9 |
| $W_{min.}$ | : | 0.4 |
| $C_1$ | : | 2 |
| $C_2$ | : | 2 |

The effectiveness of the PSO algorithm has been demonstrated through solution of multi-objective reactive power optimization with voltage deviation problem in, IEEE 30-bus test system.

## VI. Result And Discussion

The voltage deviation and reactive power optimization applied on different particle swarm optimization in power system with loss coefficient. The software programs were written in MATLAB 7.8 Language for Reactive Power Optimization, Voltage Deviation and implemented on PSO (particle swarm optimization) with system configuration HP Core 2 Second Gen. i3 Processor and 2 GB RAM. The system data is given in Table2 and Table3 [20, 22]. These system minimum and maximum limits for the control variables along with the initial settings are given in the Table1. The problem was handled as a multi-objective optimization problem where both power loss and voltage deviations shown in fig.2 (Pareto optimal graph between v d and ploss) were optimized simultaneously with the proposed approach.

**TABLE 1.** Control Variables Setting And Best Results Of Ploss And Vd As A Main Function

| | Min. | Max. | initial (Base case) | Proposed PSO algorithm |
|---|---|---|---|---|
| V1 | 1.0 | 1.1 | 1.05 | 1.0824 |
| V2 | 1.0 | 1.1 | 1.04 | 1.0470 |
| V5 | 1.0 | 1.1 | 1.01 | 1.0347 |
| V8 | 1.0 | 1.1 | 1.01 | 1.0209 |
| V11 | 1.0 | 1.1 | 1.05 | 1.0376 |
| V13 | 1.0 | 1.1 | 1.05 | 1.0402 |
| T11 | 1.0 | 1.1 | 1.078 | 1.0196 |
| T12 | 1.0 | 1.1 | 1.069 | 1.0783 |
| T15 | 1.0 | 1.1 | 1.032 | 1.0573 |
| T36 | 1.0 | 1.1 | 1.068 | 1.0963 |
| Qc10 | 0.0 | 5.0 | 0.0 | 1.2677 |
| Qc12 | 0.0 | 5.0 | 0.0 | 1.0610 |
| Qc15 | 0.0 | 5.0 | 0.0 | 0.8607 |
| Qc17 | 0.0 | 5.0 | 0.0 | 0 |
| Qc20 | 0.0 | 5.0 | 0.0 | 2.5792 |
| Qc21 | 0.0 | 5.0 | 0.0 | 1.7678 |
| Qc23 | 0.0 | 5.0 | 0.0 | 1.6902 |
| Qc24 | 0.0 | 5.0 | 0.0 | 0.5076 |
| Qc29 | 0.0 | 5.0 | 0.0 | 0.6881 |
| **Power loss(MW)** | | | 5.8708 | **5.3714** |
| **Voltage deviation** | | | 1.4888 | **0.6190** |

The proposed particle swarm optimization based RPO algorithm has been applied to standard IEEE 30-bus test system with system line data and bus data as given in table 2 and 3.

**TABLE 2:** IEEE 30 BUS SYSTEM DATA

| Bus no. | Load | | Bus no. | Load | |
|---|---|---|---|---|---|
| | P(p.u.) | Q(p.u.) | | P(p.u.) | Q(p.u.) |
| 1 | 0.000 | 0.000 | 16 | 0.035 | 0.018 |
| 2 | 0.217 | 0.217 | 17 | 0.090 | 0.058 |
| 3 | 0.024 | 0.012 | 18 | 0.032 | 0.009 |
| 4 | 0.076 | 0.016 | 19 | 0.095 | 0.034 |
| 5 | 0.942 | 0.190 | 20 | 0.022 | 0.007 |
| 6 | 0.000 | 0.000 | 21 | 0.175 | 0.112 |
| 7 | 0.228 | 0.109 | 22 | 0.000 | 0.000 |
| 8 | 0.300 | 0.300 | 23 | 0.032 | 0.016 |
| 9 | 0.000 | 0.000 | 24 | 0.087 | 0.067 |
| 10 | 0.058 | 0.020 | 25 | 0.000 | 0.000 |
| 11 | 0.000 | 0.000 | 26 | 0.035 | 0.023 |
| 12 | 0.112 | 0.075 | 27 | 0.000 | 0.000 |
| 13 | 0.000 | 0.000 | 28 | 0.000 | 0.000 |
| 14 | 0.062 | 0.016 | 29 | 0.024 | 0.009 |
| 15 | 0.082 | 0.025 | 30 | 0.106 | 0.019 |

Helpfulness of PSO algorithm is established for solving RPO difficulty with linear arrangement of following two objective functions treating as a single objective function:

(1) Minimization of system power losses($P_{Loss}$)

(2) Voltage Profile Improvement (VD)

The parameters of the particle swarm optimization algorithm for solving reactive power optimization (RPO) problem in proposed PSO algorithm for best control variable settings shown in the Table1the real power loss and voltage deviation are 5.6252 **MW** and 0.4825**p.u** PSO algorithm gives the best results which illustrate the effectiveness of proposed algorithm.

**TABLE 3:** IEEE 30 BUS LINE DATA

| Line no. | From bus | To bus | Line Impedance | |
|---|---|---|---|---|
| | | | R(p.u.) | X(p.u.) |
| 1 | 1 | 2 | 0.0192 | 0.0575 |
| 2 | 1 | 3 | 0.0452 | 0.1852 |
| 3 | 2 | 4 | 0.0570 | 0.1737 |
| 4 | 3 | 4 | 0.0132 | 0.0379 |
| 5 | 2 | 5 | 0.0472 | 0.1983 |
| 6 | 2 | 6 | 0.0581 | 0.1763 |
| 7 | 4 | 6 | 0.0119 | 0.0414 |
| 8 | 5 | 7 | 0.0460 | 0.1160 |
| 9 | 6 | 7 | 0.0267 | 0.0820 |
| 10 | 6 | 8 | 0.0120 | 0.0420 |
| 11 | 6 | 9 | 0.0000 | 0.2080 |
| 12 | 6 | 10 | 0.0000 | 0.5560 |
| 13 | 9 | 11 | 0.0000 | 0.2080 |
| 14 | 9 | 10 | 0.0000 | 0.1100 |
| 15 | 4 | 12 | 0.0000 | 0.2560 |
| 16 | 12 | 13 | 0.0000 | 0.1400 |
| 17 | 12 | 14 | 0.1231 | 0.2559 |
| 18 | 12 | 15 | 0.0662 | 0.1304 |
| 19 | 12 | 16 | 0.0945 | 0.1987 |
| 20 | 14 | 15 | 0.2210 | 0.1997 |
| 21 | 16 | 17 | 0.0824 | 0.1932 |
| 22 | 15 | 18 | 0.1070 | 0.2185 |
| 23 | 18 | 19 | 0.0639 | 0.1292 |
| 24 | 19 | 20 | 0.0340 | 0.0680 |
| 25 | 10 | 20 | 0.0936 | 0.2090 |
| 26 | 10 | 17 | 0.0324 | 0.0845 |
| 27 | 10 | 21 | 0.0348 | 0.0749 |
| 28 | 10 | 22 | 0.0727 | 0.1499 |
| 29 | 21 | 22 | 0.0116 | 0.0236 |
| 30 | 15 | 23 | 0.1000 | 0.2020 |
| 31 | 22 | 24 | 0.1150 | 0.1790 |
| 32 | 23 | 24 | 0.1320 | 0.2700 |
| 33 | 24 | 25 | 0.1885 | 0.3292 |
| 34 | 25 | 26 | 0.2544 | 0.3800 |
| 35 | 25 | 27 | 0.1093 | 0.2087 |
| 36 | 28 | 27 | 0.0000 | 0.3960 |
| 37 | 27 | 29 | 0.2198 | 0.4153 |
| 38 | 27 | 30 | 0.3202 | 0.6027 |
| 39 | 29 | 30 | 0.2399 | 0.4533 |
| 40 | 8 | 28 | 0.6360 | 0.2000 |
| 41 | 6 | 28 | 0.0169 | 0.0599 |

## Conclusion

In this paper, minimization of reactive power using particle swarm optimization (PSO) algorithm. In order to prove the usefulness of algorithm it is applied to standard reactive power with voltage deviation problem by combining of two objective functions (real power loss and voltage profile improvement) linearly. There are 6 generator bus, 24 load bus and 41 transmission lines with tap setting transformers. At the minimization of the voltage deviation, the more optimum result is taken as the active power loss. The proposed approach is analyzed and demonstrated on the standard IEEE-30 bus test system. The results obtained by proposed algorithm demonstrate its robustness and helpfulness.

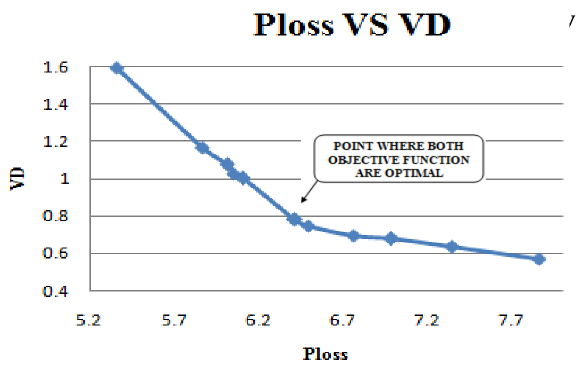


**Fig 2** Pareto optimal graph between VD and Ploss

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