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# Multi Objective Optimal Planning of Fast Charging station and Distributed Generators in a Distribution System

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***Abstract*—Electrification in road networks plays an essential role in developing smart cities. The increasing demand for Electric Vehicles (EVs), Fast Charging Stations (FCT) is integrating into the Distribution System (DTS). Improper allocation of FCT in DST leads to an increase in active power loss, voltage deviation, and an increase in the cost of electrical energy consumption. In this paper, optimal placement and sizing of FCT and Distributed Generators (DGs) in DTS with multi-objective problems such as minimization of Real Power loss cost of DTS (RPD), Voltage Deviation (DVN), FCT Development Cost (SDFT), the EV User Cost Energy Consumption (ECUT) and Cost of DG (CDGs). To solve optimal citing and placement problems Pareto dominance-based GWO (Grey wolf optimizer) algorithm was used on the 118-bus distribution system. The Pareto optimal solutions were compared by fuzzy decision-making. Simulation results were compared with other algorithms such as NSGA-2 and PSO.**

***Index Terms*—Electric Vehicles, Fast Charging Stations, Distribution System, Grey wolf optimizer**

## I. INTRODUCTION

The burning of fossil fuels leads to climate change. In order to tackle climate change, many industries sectors are shifting towards renewable energy sources[1]. This development leads to the increasing demand for FCT and DGS in the DTS. Improper allocation of FCT and DGs creates a negative impact on the performance of DTS [2]. Increasing demand for EVs leads to the allocation of FCT in the DTS. Many researchers have listed the effects of FCT on the DTS. In [3] designed the framework for the analysis of EVs in the unbalanced distribution system. Teng, F., Mu, Y [4], et al. proposed a model framework respond primary frequency control with the advantage of the economics and environment. Dubey et al. [5] discussed the impact of domestic EVs charging on the DTS and proposed a method to mitigate the effect. Papadopoulos et al. Richardson et al. [6] propose a strategy where charging rates of EVs are regulated, which yields a better usage of the present DTS. The above review discussed the FCT without DGs. The incorporation of DG units and FCT has gained a lot of thought among scholars. Integration of DGS and EVs in the DTS with reduced losses and an increase in voltage profile is explained by Thunuguntla et al.[7]. Chen et al. [8] give a new technique, for the optimal location of hybrid EVs with optimal parking. In the paper [9] optimal allocation of charging stations is implemented using the Jaya algorithm. Deb et al. Singh et al. [10] proposed GWO algorithm to reduce the power loss of the smart grid with EVs. Most of the authors discuss only optimal planning of FCT. Very few researchers considering optimal planning of FCT and DGs, but in those papers DVN, SDFT, ECUT, and CDGs are not mentioned. In this work, the first-time road network coupled with DTS and simultaneous optimal placement of FCT and DGs, to minimize real power loss of DTS, voltage deviations, development cost of FCT, the energy consumption of EV user cost, and CDGs. The contribution of this paper is represented as follows: 1. The optimal location and no-of FCT based on the behaviour of EVs users, active power loss, and voltage profile of the DST is determined. 2. The optimal location of DGs, considering FCT load to reduce active power loss and to improve the voltage profile of DTS. 3. For the first time in this work, a multi-objective GWO optimization algorithm is proposed to find the optimal location and sizing of FCT and DGs.

The rest of this paper is organized as follows: The multi-objective problem formulation and its constraints are explained in Section II. The proposed multi-objective GWO algorithm is presented for the considered system in Section III. The results and analysis are shown in Section IV and finally, conclusions are presented in Section V.

## II. PROBLEM FORMULATION

In this section minimization of the objective functions such as SDFT, ECUT, RPD, DVN and CDGs are formulated. To find the optimal location of FCT and the positions of EVs an arbitrary area is shown in Fig.1. In this work, the total number of EVs (TEVN) is charged by the FCT in the assumed area. TEVN is calculated as

$$TEVN = \sum_{(z=1)}^{zon} EV_{(n,zon)} \tag{1}$$

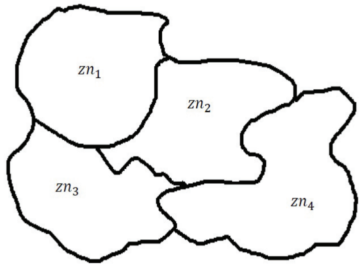


Fig. 1. Zones with area

$EV_{n,zon}$ is the total no-of committed EVs in zone zon, i.e., all EVs are charge their vehicles from the zonary FCT and zon is the no-of zones in the study area.

### A. FCT Development Cost (SDFT)

SDFT involves the cost of land and the equipment of FCT. The capacity and number of connectors of FCT are functions of FCT equipment. FCT land cost depends on the number of connectors of FCT.

$$SDFT = C_{fd} + 24 \times C_{ln} \times NC(j) \times n_{year} + C_{cnd} \times (NCT(j) - 1) \times P_{cgt} \quad (2)$$

$C_{fd}$ represents the fixed cost of FCT (in dollars) which includes the equipment and arrangements to set-up FCT.$C_{ln}$ is land rent cost yearly$n_{year}$is the number of years.$C_{cnd}$ is the cost of chargers, $NCT(j)$ is the number of connectors in $j^{th}$ FCT.

$$NCT(j) = \sum_{z=1}^{zon} (\max(PB_{EV}) \times EV_{n,zon} \times DFB(z,j)) \quad (3)$$

$PB_{EV}$is the probability of charging of EVs in hour (h) in a day. If EVs are charged in the $j^{th}$FCT then decision binary variable $DFB(z,j) = 1$otherwise it is zero. The rating of $j^{th}$FCT is :

$$P_{FCT} = NCT(i) \times P_{ct} \quad (4)$$

### B. EV User Cost of Energy Consumption (ECUT)

To reach FCT, EV user drives in a path and consumes energy. ECUT is the cost associated with the consumption of energy.

$$ECUT(zon,j) = Ln(zon,j) \sum_{hr=1}^{24} PB_{EV}(h) \times EV(zon)_h \quad (5)$$

Here $Ln(zon,j)$is the trajectory length between zone zon and $j^{th}$ FCT. $CE$ is the specific energy consumption of EVs and $E_h$ is the electricity price in dollars.

### C. Real Power loss Cost of DTS (RPD)

Due to the increase in demand for EVs, there is an increase in real power loss in DTS. DTS real power loss has non-linear characteristics with loading. Calculation of real power loss cost of DTS due to charging of EVs in a year is:

$$RPD = \sum_{sn=1}^{n_{sn}} \sum_{h=1}^{24} TLP(h,s) \times NS_h(sn) \times EP_{hn} \quad (6)$$

Where $n_{sn}$ is no-of seasons, $TLP$is the total power loss of the DTS which includes EV load, $NS_h$ is the total no-of hours of all seasons in a year.

### D. Cost of DGs (CDGs)

CDGs includes investment cost $C_{IVT}$ , operation cost $C_{OPT}$, and maintenance cost $C_{MNT}$ of DGs.

- Investment cost: It associates with unit construction, installation, and equipment.

$$C_{IVT} = \sum_{k=1}^{dgn} (P_{dgs,k} \times Cost_{INV}) \quad (7)$$

- Cost of operation: It associates with cost of generation and fuel.

$$C_{OPT} = \sum_{yer=1}^{n_{yer}} \sum_{k=1}^{dgn} (P_{dgs,k} \times TL_{hr} \times COR \times \left(\frac{1+RT_I NF}{1+RT_I NT}\right)^{yer} \quad (8)$$

- Cost of Maintenance: It involves cost for renewal and repairing.

$$C_{MNT} = \sum_{yer=1}^{n_{yer}} \sum_{d=1}^{n_{dg}} (P_{dgs,k} \times TL_{hr} \times CMT \times \left(\frac{1+RT_I NF}{1+RT_I NT}\right)^{yer} \quad (9)$$

Where $TL_{hr}$ is no-of hours in a year, $yer$ is the total no-of years for planning of DGs and $dgn$ the number of DGs consider in this work. Finally cost of DGs can be calculated as:

$$DGs = C_{IVT} + C_{OPT} + C_{MNT} \quad (10)$$

### E. DVN

If FCT and DGs are placed improper than DTS leads to voltage unstable. Therefore, calculation of DVN is necessary for all seasons of 24 hours . The DVN of DTS is calculated as:

$$DVN = max\{1 - v(i)\} \qquad i = 1, 2 \ldots nbs \quad (11)$$

Where $v(i)$ is the voltage of $i^{th}$ bus and $nbs$ is DTS bus number.

*F. Objective Problems*

$$Min \left\{ \sum_{m=1}^{N_{FCT}} SDFT\left(m\right) + \sum_{l=1}^{TEVN} ECUT(l) \right. \\ \left. + RPD + CDGs + DVN \right\} \quad (12)$$

*G. Constraints*

At least one FCT should be placed to charge the EVs.

$$\sum_{k=1}^{NP_{FCT}} BN\left(k\right) > 0 \qquad k = 1, 2, \ldots,\ NP_{FCT} \quad (13)$$

where $NP_{FCT}$ is the no of possible FCT, $BN\left(k\right)$ is binary decision variable, if $k^{th}$ FCT is selected then $BN\left(k\right)$ =1, otherwise 0. From selected FCT at least one connector should be utilised.

$$NCT\left(k\right) \geq 0 \qquad k = 1, 2, 3 \ldots,\ NP_{FCT} \quad (14)$$

From each zone $zon$, one optimal FCT is selected by EVs.

$$\sum_{z=1}^{zon} DFB\left(z, k\right) \times BN\left(k\right) = 1 \quad (15)$$

## III. GWO ALGORITHM

In this work, GWO algorithm is used to optimised for proposed objective function. GWO GWO is based on the leadership of hierarchy. Grey wolves always remain in a group and they are always loyal to the group. They are classified into 4 types based on the fitness value i.e., Alpha ($\alpha$), Beta ($\beta$), delta ($\delta$), and omega ($\omega$). $\alpha$ is the supreme leader in the group. $\alpha$ can be either male or female.$\alpha$ decides and gives the order to other members. $\beta$ is subordinate to alpha and helps$\alpha$ in decision making. $\delta$ and $\omega$ are other subordinates, where $\omega$ occupies the lowest level in the group.

*A. Encircling the victim*

While hunting, the grey wolves encircle the victim. In mathematical expression the Encircling strategy is explained as:

$$\vec{La} = \left| \vec{S}.\vec{Z_p} - \vec{Z}(itr) \right| \quad (16)$$

$$\vec{Z}(itr) = \vec{Z_{ps}}(itr) - \vec{R}.\vec{Lat} \quad (17)$$

Here $itr$ is the present iteration, $Z_{ps}$ is the position of prey, $Z_g$ is the position of grey wolf. $\vec{S}$ and $\vec{R}$ are coefficient vector which can be calculated as

$$\vec{R} = 2.\vec{r}.rad_1 - \vec{r} \quad (18)$$

$$\vec{S} = 2.rad_2 \quad (19)$$

$rad_1$, $rad_2$ are random vectors in the range [0, 1], coefficient $\vec{r}$ are linearly decreases from 2 to 0 over the course of iterations.

*B. Process of hunting*

The hunting process is guided by $\alpha$. $\alpha$, $\beta$, $\delta$ have the better knowledge about the prey (optimal solution). Other wolves at the back update the positions according to the position of $\alpha$, $\beta$, $\delta$. The following mathematical expression for attacking is: -

$$\vec{La_\alpha} = \left| \vec{S}.\vec{Z_\alpha} - \vec{Z_g} \right| \quad (20)$$

$$\vec{La_\beta} = \left| \vec{S}.\vec{Z_\beta} - \vec{Z_g} \right| \quad (21)$$

$$\vec{La_\delta} = \left| \vec{S}.\vec{Z_\delta} - \vec{Z_g} \right| \quad (22)$$

$$\vec{Z_{t1}} = \vec{Z_\alpha} - \vec{R_1}.(\vec{La_\alpha}) \quad (23)$$

$$\vec{Zt_2} = \vec{Z_\beta} - \vec{R_2}.(\vec{La_\beta}) \quad (24)$$

$$\vec{Z_{t3}} = \vec{Z_\delta} - \vec{R_3}.(\vec{La_\delta}) \quad (25)$$

$$\vec{Z}\left(itr + 1\right) = \frac{\vec{Zt_1} + \vec{Zt_2} + \vec{Zt_3}}{3} \quad (26)$$

*C. Attacking and Exploring of a Victim*

The value of R should be in the range of [-2r, 2r], wolves attack the prey, when $|R| < 1$. Attacking prey is known as exploitation. Searching for prey is known as exploration means they diverge to search for prey. If $|R| > 1$, then it forces wolves to search the prey. The basic procedure of GWO

- From the given space, initialize the search agent and generate a random population.
- GWO technique is applied.
- Minimum values of all searching agent are generated
- The updated position is to pass back to GWO technique
- Repeat this procedure until the ceasing criteria are achieved.

The flow chart of the GWO algorithm is shown in figure Fig.2.

## IV. RESULT AND DISCUSSIONS

In this work, to find the optimal location and sizing of FCT, and DGs distribution system where a transportation network is coupled, 2 scenarios with different cases are studied with the help of the proposed test system.

*A. Proposed methodology*

In this work, the proposed method is applied to a test area of 720 $km^2$ as shown in the figure Fig.3 this test area consists of 180 zones, where each zone has an area of 4 $km^2$ ($2km \times 2km$). In this work, 1632 EVs, 5 DGs unit, and 118 distribution buses are carried out for analysis. The base value of DTS is 100 MW, 11kV, 22.71 MW active power, and 1.7041MVAr reactive power. In figure Fig.4. for different seasons load curve is shown. MATLAB 2020a software is used for the proposed problem simulation.

118 DTS are coupled with the tested area shown in figure Fig.5. In this work, 16 FCTs are installed on the main road with satisfying constraints such as distances between FCTS are almost equal. Possible locations of FCT are represented

TABLE I
OPTIMAL LOCATION OF FCE AND OPTIMAL NUMBER OF EVS IN SCENARIO 1

| **Case number** | **NSGA -2** | | **PSO** | | **GWO** | |
|---|---|---|---|---|---|---|
| Case-1 | Location of FCT | No-of EVs in FCT | Location of FCT | No-of Evs in FCT | Location of FCT | No-of Evs in FCT |
| | 80 | 559 | 22 | 291 | 40 | 291 |
| | 103 | 83 | 35 | 413 | 11 | 170 |
| | 40 | 395 | 13 | 122 | 80 | 413 |
| | 13 | 112 | 80 | 397 | 13 | 137 |
| | 22 | 329 | 11 | 170 | 22 | 224 |
| | 11 | 154 | 40 | 239 | 35 | 397 |
| Case-2 | 370 | 11 | 114 | 40 | 344 | 344 |
| | 253 | 28 | 170 | 61 | 173 | 173 |
| | 408 | 40 | 253 | 22 | 177 | 177 |
| | 114 | 22 | 285 | 11 | 150 | 150 |
| | 210 | 80 | 397 | 35 | 383 | 383 |
| | 277 | 35 | 413 | 80 | 405 | 405 |
| Case-3 | 40 | 383 | 13 | 137 | 11 | 170 |
| | 61 | 177 | 11 | 170 | 28 | 114 |
| | 22 | 173 | 22 | 291 | 40 | 285 |
| | 11 | 150 | 80 | 397 | 22 | 253 |
| | 35 | 344 | 40 | 224 | 80 | 413 |
| | 80 | 405 | 35 | 413 | 35 | 397 |

TABLE II
OPTIMAL OBJECTIVE PARAMETERS OF SCENARIO 1

| **Algorithm** | **Case** | **SDFT (M$)** | **ECUT (M$/year)** | **RPD (M$/year)** | **DVN (p.u.)** |
|---|---|---|---|---|---|
| NSGA -2 | 1 | 4.2235 | 0.09233 | 0.6823 | 0.1325 |
| | 2 | 4.2225 | 0.09422 | 0.67730 | 0.1309 |
| | 3 | 4.2614 | 0.09078 | 0.68153 | 0.1308 |
| PSO | 1 | 4.2312 | 0.103231 | 0.69853 | 0.1345 |
| | 2 | 4.2309 | 0.105019 | 0.68730 | 0.1319 |
| | 3 | 4.3301 | 0.103618 | 0.69853 | 0.13173 |
| GWO | 1 | 4.2152 | 0.085878 | 0.68243 | 0.1308 |
| | 2 | 4.2140 | 0.086632 | 0.66840 | 0.1301 |
| | 3 | 4.224 | 0.084653 | 0.68129 | 0.1300 |

TABLE III
OPTIMAL LOCATION AND SIZING OF DGS FOR SCENARIO 2

| **Case number** | NSGA -2 | | PSO | | GWO | |
|---|---|---|---|---|---|---|
| | Location of DG | Size of DG (MW) | Location of DG | Size of DG(MW) | Location of DG | Size of DG(MW) |
| Case-4 | 102 | 0.5020 | 75 | 0.5118 | 43 | 0.3764 |
| | 75 | 0.7563 | 73 | 0.7723 | 77 | 0.9332 |
| | 42 | 0.5002 | 48 | 0.9579 | 50 | 0.2400 |
| | 62 | 0.5039 | 52 | 0.6249 | 53 | 0.7050 |
| | 51 | 0.6407 | 108 | 0.5352 | 110 | 0.3217 |
| Case-5 | 73 | 1.3467 | 49 | 0.5641 | 47 | 0.7505 |
| | 35 | 1.3012 | 113 | 0.8880 | 72 | 0.7327 |
| | 80 | 1.1789 | 51 | 0.8688 | 75 | 0.5569 |
| | 111 | 1.0722 | 83 | 0.6051 | 111 | 1.2189 |
| | 51 | 0.6969 | 73 | 1.1742 | 50 | 0.8504 |
| Case-6 | 111 | 1.0385 | 110 | 1.2682 | 76 | 0.9847 |
| | 74 | 1.4989 | 74 | 1.4116 | 111 | 0.8272 |
| | 42 | 0.7511 | 82 | 0.5486 | 53 | 0.7631 |
| | 54 | 0.9941 | 50 | 1.1380 | 70 | 0.7140 |
| | 49 | 0.8780 | 53 | 0.7769 | 49 | 0.8662 |

in the symbol rhombus in the assumed DTS shown in Fig.5. Fig. 6 shows the probability of charging EVs. The DTS, FCT, and DGs parameters are obtained from [3], [5]. The GWO algorithm optimization technique is implemented for the proposed problem.

### B. *Scenario 1: Optimal planning of FCT in DTS coupled with transportation network*

Optimal planning of FCT is obtained with the help of the GWO technique by minimizing of RPD, DVN, SDFT, and ECUT of the DTS. DGs are not included in this scenario. Three cases are considered in this scenario. Three cases are considered in this scenario.

- Case 1: - Minimization of ECUT and cost of RPD

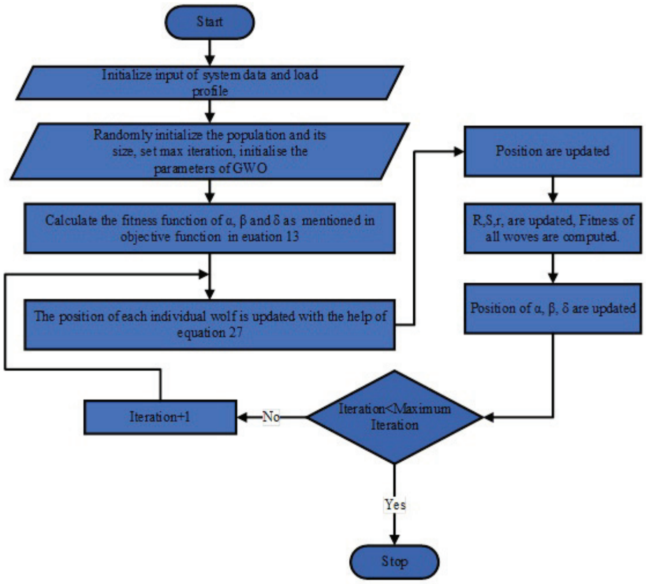


Fig. 2. Flow chart of the GWO algorithm

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 3 | 5 | 3 | 4 | 6 | 4 | 0 | 0 | 3 | 7 | 5 | 6 | 4 | 0 |
| 3 | 5 | 4 | 6 | 4 | 6 | 7 | 8 | 7 | 9 | 8 | 7 | 5 | 6 | 4 |
| 7 | 11 | 16 | 9 | 9 | 13 | 12 | 10 | 11 | 14 | 17 | 6 | 9 | 5 | 3 |
| 6 | 1 | 7 | 15 | 16 | 17 | 17 | 9 | 15 | 7 | 14 | 17 | 9 | 15 | 1 |
| 4 | 6 | 9 | 10 | 8 | 16 | 16 | 14 | 0 | 14 | 16 | 11 | 7 | 9 | 7 |
| 0 | 13 | 14 | 10 | 16 | 14 | 19 | 15 | 17 | 14 | 12 | 8 | 15 | 9 | 4 |
| 7 | 11 | 0 | 16 | 16 | 17 | 13 | 18 | 17 | 15 | 9 | 19 | 12 | 8 | 0 |
| 4 | 9 | 15 | 14 | 12 | 11 | 4 | 16 | 19 | 9 | 12 | 17 | 17 | 12 | 6 |
| 8 | 13 | 14 | 19 | 17 | 15 | 17 | 0 | 13 | 12 | 11 | 13 | 9 | 15 | 8 |
| 3 | 12 | 9 | 16 | 13 | 14 | 9 | 14 | 16 | 15 | 17 | 16 | 15 | 13 | 3 |
| 0 | 6 | 7 | 8 | 7 | 5 | 6 | 4 | 8 | 5 | 4 | 6 | 4 | 0 | 0 |
| 0 | 5 | 3 | 4 | 6 | 4 | 0 | 7 | 3 | 0 | 5 | 6 | 4 | 3 | 4 |

Fig. 3. EVs population in zone

- Case 2: - Minimization of DVN and cost of RPD
- Case 3: - Minimization of DVN, cost of RPD and ECUT

In Fig.7(a), Fig.7(b), and Fig.7(c) minimization of RPD and ECUT, minimization of RPD and DVN, and minimization of RPD, DVN, and ECUT are shown respectively. In table 1, optimal planning of FCT and no-of EVs are shown. In table 2 objective parameters are shown.

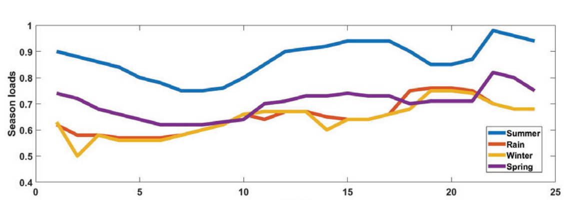


Fig. 4. Load curve for Different seasons on hourly basis

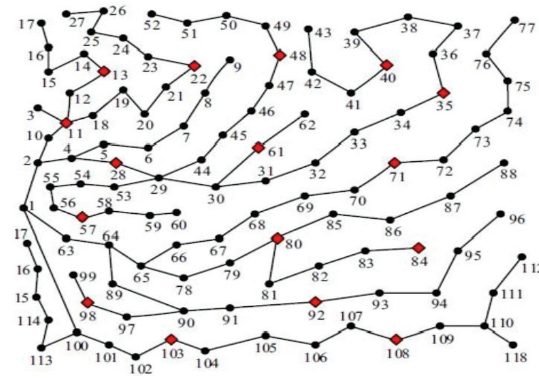

Fig. 5. 118 distribution bus in the assumed testing area

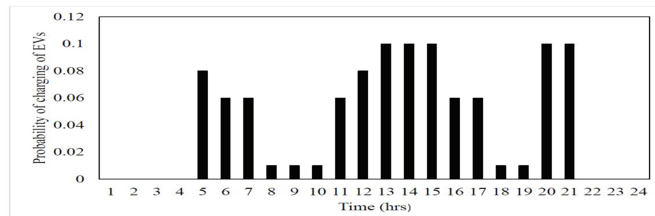


Fig. 6. Probability of charging of EVs

### C. *Scenario 2: Optimal planning of DGs in Distribution system with previous optimal FCT load*

DGs are considered to improve the voltage profile in DTS. From case 3 optimal load of FCT is taken to solve the minimization of the objective function (12), where the CDGs, ECUT, DVN, and RPD are considered. In this scenario, three cases are taken to find out the optimal sizing and location of DGs with the optimal load of FCT from case 3.

- Case 4: - Minimization cost of DG and DVN.
- Case 5: - Minimization cost of RPD and cost of DG.
- Case 6: - Minimization of cost of DG, DVN and cost of RPD.

Fig. 7(d),Fig. 7(e), Fig. 7(f) shows the non-dominated Pareto font of case 4 to case 6. From the max-min method, optimal planning of DGs is obtained, which is shown in Table 3 and Table 4.

TABLE IV
OPTIMAL OBJECTIVE PARAMETERS OF SCENARIO 2

| Algorithm | Case | RPD (M$/year) | CDGs (M$) | DVN (p.u.) |
|---|---|---|---|---|
| NSGA -2 | 4 | 0.5278 | 3.5326 | 0.0677 |
| | 5 | 0.3898 | 6.8091 | 0.0565 |
| | 6 | 0.4081 | 6.2795 | 0.0462 |
| PSO | 4 | 0.0476 | 4.1396 | 0.0592 |
| | 5 | 0.4404 | 4.9892 | 0.0566 |
| | 6 | 0.4042 | 7.1965 | 0.0457 |
| GWO | 4 | 0.5132 | 3.1348 | 0.0615 |
| | 5 | 0.4417 | 5.0003 | 0.0579 |
| | 6 | 0.4454 | 6.2583 | 0.0508 |

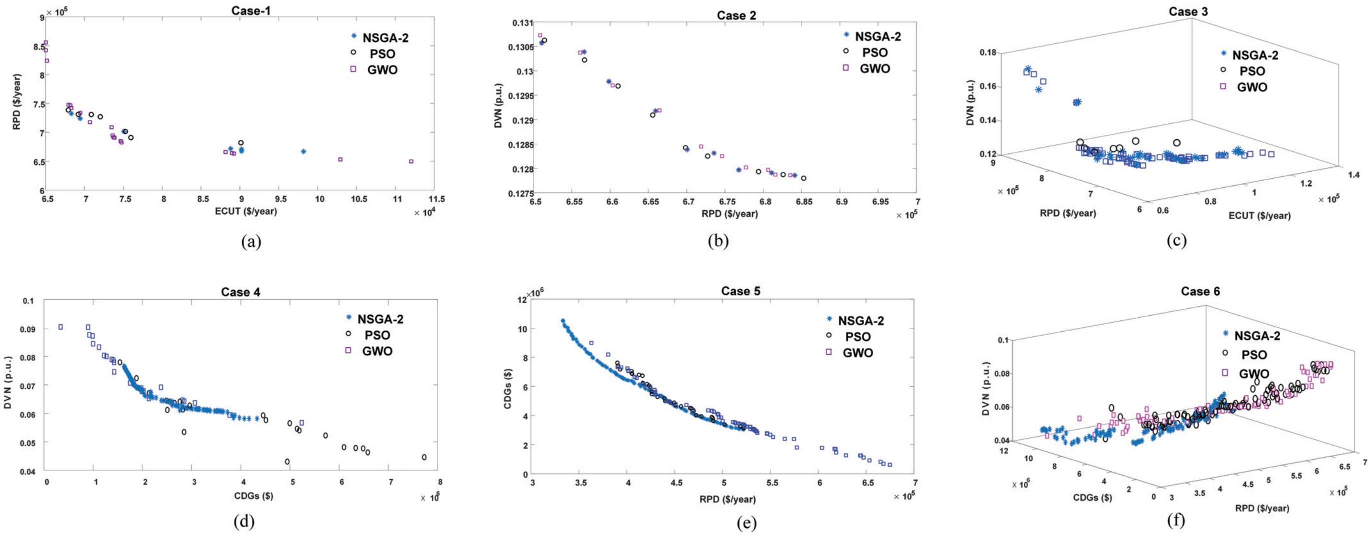


Fig. 7. Optimal font

TABLE V
COMPARISON RESULTS OF FOUR SCENARIOS

| Scenario | Case | Algorithms | SDFT (M$) | ECUT (M$/year) | RPD (M$/year) | CDGs (M$) | DVN (p.u.) |
|---|---|---|---|---|---|---|---|
| | | NSGA-2 | 4.421 | 0.09078 | 0.4081 | 6.2795 | 0.0462 |
| | | PSO | 4.383 | 0.103618 | 0.4042 | 7.1965 | 0.0457 |
| 2 | 6 | GWO | 4.052 | 0.084653 | 0.4454 | 6.2583 | 0.0508 |
| | | NSGA-2 | 4.421 | 0.09078 | 0.68153 | - | 0.1308 |
| | | PSO | 4.383 | 0.103618 | 0.69853 | - | 0.13173 |
| 1 | 3 | GWO | 4.252 | 0.084653 | 0.68129 | - | 0.1300 |

Comparison results of two scenarios are shown in Table 6. From Table 6 GWO shows better results compare to other algorithms. 61.1 perctange reduction of DVN in case 6 compared to case 3. 34.624 perctange reduction of RPD in case 6 compared to case 3.

## V. CONCLUSION

In this paper, optimal placement and sizing of FCT, DGs in coupled DTS, and road networks are done with multi-objective problems such as minimization of RPD, DVN, SDFT, ECUT, and CDGs. The proposed GWO algorithm is tested on 118 bus distribution systems. The results obtained using the GWO algorithm are compared with the PSO and NSGA-2. . The two stages give better results such that there is a reduction of RPD, CDGs, and DVN. Due to the reduction of cost, it gives benefits both to charging station owners and EV users. Besides, future work can be extended with the simultaneous placement of FCT, DGs, and vehicle to grid technology.

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