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# Optimal Network Reconfiguration in Presence of Renewable Distributed Generation Using Evolutionary Algorithm

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***Abstract*- Utilization of new technologies and people lifestyle has greatly affected the world's electricity market. This demands to design innovative renewable energy systems for efficient use of green energy. In terms of greenhouse gas emissions, electricity from traditional energy supplies has become particularly harmful for the world. To decrease the reliance on fossil fuels, it is need of time to enhance the renewable energy integration in the conventional energy systems. Renewable DGs integration in existing energy systems is not a simple task. To overcome challenges caused by enhanced penetration of renewable energy systems in existing networks, adaptation of smart techniques is essential. DGs Optimal size and selection of their suitable location for integration is crucial for cost effective power delivery to the consumers without compromising the quality of power. This paper presents impartial performance management by optimal network reconfiguration in parallel with renewable DGs and selecting suitable size for reducing active power losses, pollutant gas emissions and costs of annual operation. For analysis of active power losses, Fuzzy and SPEA2 based algorithms are used in MATLAB with IEEE BUS14 acting as load bus. While the cost of power generation and pollutant gases emissions are estimated using HOMER Pro software.**

***Index Terms*-- Distribution network, Evolutionary Algorithm, Homer Pro, Multi-objective optimization, Pareto optimality**

## I. INTRODUCTION

Over the past decade, due to notable deficiency of fossil fuel and the increasing demand of electricity so the renewable energy sources become more engrossment. Therefore, the work on the integration of DGs into distribution network possess become very popular. Certainly, with the suitable sizes and the position of DGs in optimal locations can bring various advantages to the power system such as voltage profile improvement, reactive power requirement mitigation, active power loss and line loading reduction [1]. To optimize this problems, diverse optimization techniques have been proposed by many researches (e.g. hybrid intelligent, artificial intelligent and conventional techniques).

Power losses can be reduced through conventional methods like optimal network techniques. By changing the state of network switches, this method can be achieved. Normally closed switching scheme is employed in fault localization and normally open switching scheme is used in line reconfiguration. By using this method, faulty system is isolated from main system to avoid more damages [2][3]. This topology is changed through reversing the condition that is by closing the open switches and opening the close switches. This situation will mitigate the power losses and voltage outline will be improved.

So, optimum network reconfiguration can be evaluated. In this result, load is shifted to those feeders which are less loaded and altogether power loss would decrease. Generally, network reconfiguration is needed to recognize the configuration that is best among different configurations by altering the states of switches [4][5].

In different studies of optimal DG network, power loss is observed as primary objective to sort out. So various analytical perspectives [6] or optimization algorithm [7], genetic algorithm [8], non-linear programming [9] are introduced as optimization approach.

After that, multi-objective viewpoint was also addressed to optimize the issue of sizing and sitting of DG by utilizing two different procedures. In first situation, various sub tasks of main objective are accumulated to form a single goal. Various studies show this method by employing artificial intelligent methods as computational techniques [10], hybrid optimization techniques and genetic algorithm methods [11]. Hybrid optimization methods include Fuzzy or GA [12] and HPSO [13] algorithms. But this method has some restriction of not having features to optimize various goals equally.

In second situation, Pareto optimality method is employed to tackle multiple objectives. In this method, there is no drawback of having no approach to optimize multiple objectives equally. To determine best placement and sizing for DGs, investigators evaluated the multiple goal algorithms rooted on the Pareto optimality conception. NSGAII [14], IMOHS [15], MOShBAT [16], and INSGAII [17] are included in this concept. An option can be selected by system by Pareto optimal solutions.

Heuristic method is useful in approximation analyze the optimal solution to a problem. For this purpose, there must be correct function to elaborate. Example of this method is Trial and Error technique [18]. Meta Heuristic method is employed to recognize near-optimal solution using various concepts. This method is also categorized into different categories as unique solution and Population solution [19]. Although, optimal DGs integration and reconfiguration of network are determined individually. But these issues can be aggregated to solve them conveniently that provide welfare to entire network. In literature, some researchers studied the network reconfiguration concomitantly along with sizing and placement of DGs. Mostly, active power losses are examined as individual objective to resolve by researchers.

Newly, few studies evaluate some objectives to resolve these problems efficiently. In [20], fuzzy-ACO (Ant Colony Optimization) rooted on Pareto optimality conception is utilized to solve this matter. But single DG with PV array was considered to evaluate specific optimal placement and DG sizing. Recently, scholars used multi-objective technique that is established on bang-big crunch algorithm that focused on DG size having no involvement of optimal location [21]. In [20], improved particle swarm optimization technique (IPSO) was employed by authors to gain improvement in multi-objective issue. As mentioned above, prototype of DGs are considered to be passive but they act like isolation in DG based on RERs. It is expected that perception of distributed generation will increase more in future. Scholars showed that pollution and impurities could mitigate by 60-65% by employing of DG based on REs [22]. Distributed generation helps in betterment of voltage outline, maintain efficiency and reliability and balancing of load.

The reconfiguration of the network as mentioned above is another solution to minimize the losses in distribution system. Merlin and Back researched the reconfiguration of the network in 1975 to minimize active power losses [23]. To solve the issue of network reconfiguration, different studies have made by evaluating various criteria to optimize the network. A comprehensive study on network reconfiguration elaborates different techniques to resolve multi-objective issue as modified optimization [24], genetic algorithms and Pareto optimality methods. NSGAII and artificial immune networks are included in Pareto optimality methods. Further, there are various topologies used for reconfiguration of network.

DG is being installed by evaluating the appropriate location for optimal DG and size of DG is selected by choosing the power amount of DG. If, size of DG is not appropriate then active power losses will be increased from the network. This will result in increasing the operational expenses involve in DG installation. This review helps to identify the fact that optimal size of DG and optimal location mitigate the overall power losses to maintain the stability of network [25].

Further, this paper involves the characteristics of resolving issue in reconfiguration of network and optimal DGs placement and sizing that is rooted on wind and solar energy based on study discussed earlier. SPEA2 (Strength Pareto Evolutionary Algorithm 2) method is modeled to optimize the multi-objective problem. Pareto optimal solutions are involved in this method. This suggested model comprises of various objectives such as power loss reduction, cost reduction and reduction in gas emission. Afterwards, to get best method, fuzzy set is utilized, and DG based on REs are used to solve the problem by taking into consideration of hourly deviation of solar radiance and speed of wind and variation of load and DGs.

In section 2 demonstrate the proposed methodology of the system, section 3 describes the mathematical and statistical modeling of the system and section 4 presents the tests and results. Finally, section 5 conclude this paper.

## II. PROPOSED OPTIMIZATION METHOD

Research methodology that is employed in this paper is the fuzzy set theory and SPEA 2 algorithm to reduce active power losses and resolve the problem of reconfiguration of network along with placements and sizing of DGs. In this study, genetic algorithms are having similar features of that evolutionary algorithms. Moreover, Pareto optimality provides basis for evolutionary algorithms. Pareto optimality has characteristics of solving multi-objectives. This would have feature of obtaining optimized solutions in one iteration rather multiple runs like classical techniques. Finally, optimized solution set is achieved from which an option can be selected by an optimizer.

### A. OUTLINE OF STRENGTH PARETO EVOLUTIONARY ALGORITM

Strength Pareto Evolutionary Algorithm 2(SPEA2) is an evolutionary algorithm that is utilized to resolve the problem of reconfiguration of network along with placements and sizing of DGs. Basically, Strength Pareto Evolutionary Algorithm 2 has properties of genetic algorithms along with refinement in various operations. Further, biology evolution provides basis for genetic algorithms and employs chromosomes. The value of fitness is allocated to each one solitary that depends on their characteristics to perform. Fitness feature distinguishes all evolutionary algorithms from genetic algorithm through the concept of dominance. Pareto optimal solutions are obtained by using this concept. So that more precise solutions can be obtained by this concept.

SPEA2 has different features from various evolutionary algorithms as SPEA, NSGAII etc. only because of its performance towards fitness assignment. Further, density method estimation is used by only evolutionary algorithm SPEA2 that makes it more reliable to furnish precise and accurate solutions as compared to other techniques [26]. Having better structure other than various evolutionary techniques makes the SPEA2 more effective to solve problem of network reconfiguration.

### B. OPTIMIZATION PROBLEM UNDERTAKING USING SPEA2

In this study, to solve the problem, multi-objectives are examined to fulfill the main objectives that are to minimize the active power loss, pollutant gas emissions and operational cost. Various portion of optimization complication are as under:

a) Production of inceptive population
b) To assign the fitness values to each individual
c) To select the fittest individual
d) Selection of individual for reproduction. This reproduction shows the variety of solutions.

C. SELECTION OF BEST SOLUTION

Pareto optimal solutions can be obtained by resolution of issue of network configuration and location of DG. Terminal solution is selected from set of Pareto optimal solutions by network manager depends on his preference. Otherwise, to get best solution from Pareto optimal solutions, fuzzy set theory can be employed [27]. Fuzzy decision-making process is utilized to select best solution from the set.

## III. MATHEMATICAL AND STATISTICAL MODELING

By altering the state of switches would alter the topography of network of distribution. This is essential to balance the load between the feeders in order to avoid overburden.

D. REDUTION OF ACTIVE POWER LOSS

This goal is to mitigate the network's active power losses.

Equation of power loss for a system of distribution is as under [28],

$$P_{loss} = \sum_{M=1}^{M} R_M \times I^2 \quad (1)$$

Where,

M is number of branch network

$P_{loss}$ is active power loss in entire network

$R_M$ is resistance in the whole branches of network M

I is the current in branch M

Basically, radial network is the most conventional layout and employed in clogged area where load center and generating station are at same location. Radial line is used to supply power to consumers. Radial configuration is shown in fig. 1. [29].

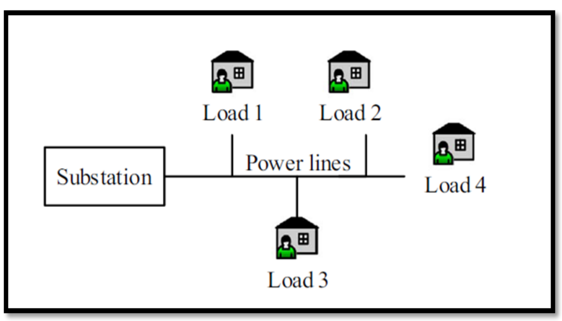


Fig. 1. Radial Network in Power Distribution, Source [29]

This configuration is simple and having low cost, but this network has some drawbacks of influencing heavy power failure. Tie switches are also included in this network in order to network reconfiguration [30]. Following are various limitations to optimize the reconfiguration of network and DG sizing.

E. RESTRICTIONs ON DISTRIBUTED GENERATION ACTION

Restriction of distributed generation action is illustrated by following pattern,

$$P_i(min) < P_{DG} < P_i(max) \quad (2)$$

Where,

$P_i$(min) is the lower limit of sizing of DG

$P_i$(max) is the upper limit of sizing of DG

These bounds are compulsory to show the performance of DGs within specific limits.

F. RESTRICTION ON BALANCING OF POWER

Restriction on balancing of power is expressed with the following relationship.

$$\sum_{i=1}^{m} P_{DG} + P_{Substation} = P_{LOAD} + P_{LOSS} \quad (3)$$

This is equilibrium law that specifies the principle that power supply and power demand must be equal.

G. RESTRICTION ON INJECTION OF POWER

Restrictions on the injection of power is expressed using following equation.

$$\sum_{i=1}^{m} P_{DG} < P_{LOAD} + P_{LOSS} \quad (4)$$

Where,

$P_{LOAD}$ is accumulative active power load

$P_{LOSS}$ are the complete active power losses

m is number of DGs

The total output power of the DG must be less than the total load in the configuration in order to prevent power from being fed into the main source. This will balance the whole system by managing the power flow continuously from main source to network.

H. RESTRICTION ON VOLTAGE BUS

The voltage values of bus must have specific limits through the process of optimization. This must follow the following pattern:

$$V_i(\text{min}) < V_i < V_i(\text{max}) \quad (5)$$

Where,

$V_i$(min) is the lower limit of voltage

$V_i$(min) is the upper limit of voltage bus

$V_i$ is the magnitude of voltage shown on $i^{th}$ bus number

I. DEPLETION OF YEARLY OPERATION COSTS

This is impact problem in distribution configuration. Complete maintenance costs, DG installation and power losses are part of this problem. This role is elaborated, as below,

$$opf_{cost} = (C_{inv}(PV) + C_{main}(PV))\, P_{PV} + (C_{inv}(wind) + C_{main}(wind))\, P_{wind} + C_L \quad (6)$$

Where,

$C_L$ is cost of power losses

$C_{main}$ is maintenance cost

$C_{inv}$ is the investment cost

$P_{PV}$ and $P_{wind}$ are optimal sizes DGs

J. DEPLETION OF POLLUTANT GAS EMISSIONS

The following equation illustrates this function:

$$f_{emit} = \sum_{i=1}^{n} G_i \times P_{substation} \qquad (7)$$

Where,

G is intensity of emission

n is number of kinds pollutant gas

$P_{substation}$ is the power produced by the substation.

The emission potential of different gases is referred to in Table 1. [31] below.

Table 1. POTENCY OF POLLUTANT GASES, Source [31]

| Gas | $CO_2$ | $CO$ | $NO_x$ | $SO_2$ |
|---|---|---|---|---|
| Emission Intensity | 622 | 0.1085 | 2.88 | 6.48 |

## IV. TEST AND RESULTS

Active power losses reduction is simulated using MATLAB software. Therefore, IEEE 14-Bus System is used to perform SPEA2 and fuzzy logic, with a more active response. While to check the amount of operation cost and gases emission after the addition of DG's and system reconfiguration HOMER Pro software is used.

a. MATLAB SIMULATED RESULTS

Case 1. Solar DGs

In this case, 1~4th, and 20~24th periods of time, there is no ideal solution for the position and size PV DGs; this is mainly due to the deficiency or luck of solar irradiance in these time sequences.

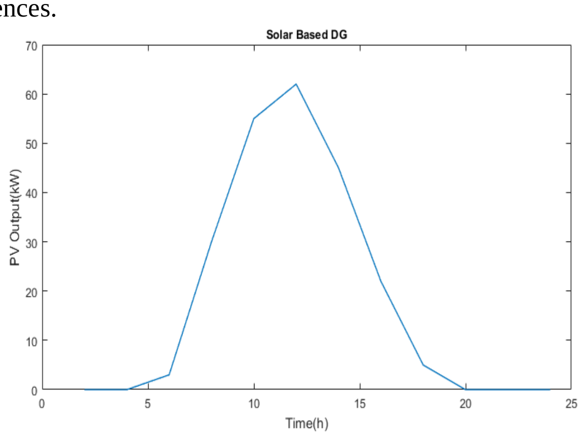


Fig. 2. PV Output

Case 2. Wind Power DGs

There are no optimal solutions for WT DG location and sizing at 1~8th time period because strength of the wind speed is lower than the value of interlocking the wind turbine. In exchange, the duration of common functioning of PV DG and WT DG is where the optimum position and size of both renewable DGs are obtained during 9~19th period.

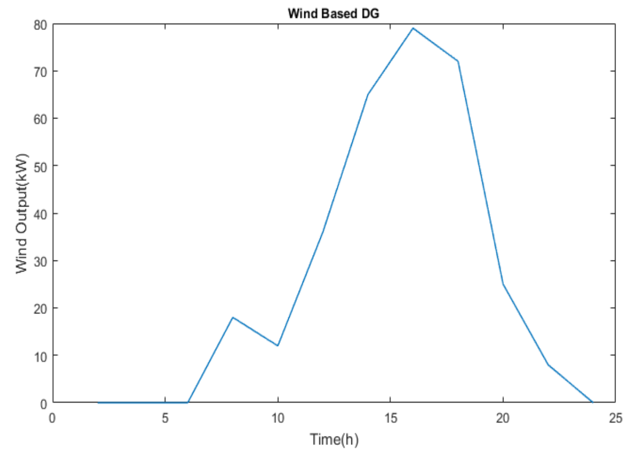


Fig. 3. Wind Power Output

Case 3. Optimal sizing and allocation of DGs for active power losses before and after network optimization

In simulated results where the red line shows the active power losses for the base case while blue line below the red line shows the decreased amount of active power loss after optimal DG sizing and reconfiguration of the system. Analyzing the results shows that after the implementation of proposed scheme for DG optimal sizing, location and system reconfiguration reduced active power losses to a great extent. SPEA2 and fuzzy logics used IEEE 14-BUS SYSTEM to reconfigure the entire system along with DG optimal sizing and locations which gave greatly reduced active power losses.

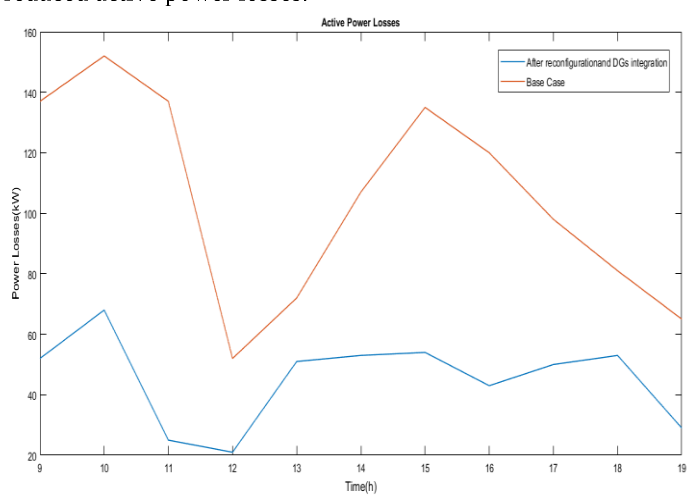


Fig. 4. Active Power Loss Vs Hours of a Day

In below figure load variation is displayed against different hours of an entire day for DG system.

b. HOMER PRO SOFTWARE SIMULATIONS

Schematic built for proposed system having system reconfiguration and DG's in HOMER Pro is shown in fig. 6.

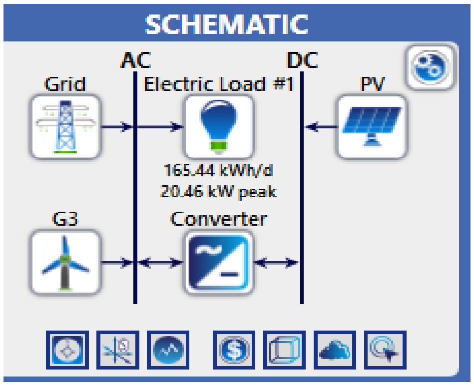


Fig. 5. Schematic of System Having System Reconfiguration and DGs Using HOMER Pro

In this above figure the wind resources show the average speed of the subjected area which is for Baluchistan's Sea Shore. The full wind power plant with AC outcome is G3 here. This is the most acceptable turbine size for the suggested power plant. They are therefore necessary for the production of electricity at the optimum level for given site.

Table 2. INPUT DATA FOR THE COMPONENTS IN HOMER Pro

| Component | Size | O & M Cost per year ($) | Lifetime | Capital Cost per Unit ($) |
|---|---|---|---|---|
| PV Array | 31 KW | 302.00 | 27 Years | 91,000.00 |
| Wind turbine | 9 KW | 298..90 | 27 Years | 19,000.00 |
| Converter | 26 KW | 0 | 17Years | 77.00.00 |

Load is shown in hybrid power plant schematics as deferrable load. A standard feeder is taken for load demand estimation as a load whose standard load demand is around 165.47KWh/Day and 20.49KW is the peak load demand. As a primary load demand, this data is sustained to HOMER Pro. The simulation and compare economics results for the first case is depicted in Table 3.

Table 3. SIMULATION AND COMPARE ECONOMICS OUTCOMES FOR FIRST-CASE

| | |
|---|---|
| **Simulation Result** | |
| PV (kW) | 31 |
| Wind Turbine | 2 |
| COE ($) | 0.148 |
| Operating Cost ($) | 3,599 |
| Converter (kW) | 26 |
| NPC ($) | 180,029 |
| Ren Frac (%) | 72.7 |
| **Compare economics Results** | |
| Existent worth ($) | $54,166 |
| Yearly worth($/yr.) | $4,190 |
| Rate of return (%) | 6.9 |
| Internal rate of return (yr.) | 9.9 |
| Refund (yr.) | 9.07 |
| Discounted payback(yr.) | 13.35 |

Second case is designed where the local grid and Solar are combined, and outcomes are shown in Table 4.

Table 4. SIMULATION AND COMPARE ECONOMICS OUTCOMES FOR SECOND-CASE

| | |
|---|---|
| **Simulation Result** | |
| PV (kW) | 50 |
| COE ($) | 0.117 |
| Operating Cost ($) | 1,309 |
| NPC ($) | 181,89 |
| Converter (kW) | 51 |
| Ren Frac (%) | 74.2 |
| **Compare economics Results** | |
| Existent worth ($) | $52,302 |
| Yearly worth($/yr.) | $4,046 |
| Rate of return (%) | 6.2 |
| Internal rate of return (yr.) | 9.0 |
| Refund (yr.) | 9.59 |
| Discounted payback(yr.) | 15.43 |

The third case is the combination of local grids and Wind and the outcome is given in Table 5.

Table 5. SIMULATION AND COMPARE ECONOMICS OUTCOMES FOR THIRD-CASE

| | |
|---|---|
| **Simulation Result** | |
| Wind Turbine | 4 |
| COE ($) | 0.243 |
| Operating Cost ($) | 10,675 |
| NPC ($) | 209,937 |
| Ren Frac (%) | 45.5 |
| **Compare economics Results** | |
| Existent worth ($) | $24,256 |
| Yearly worth($/yr.) | $1,876 |
| Rate of return (%) | 6.3 |
| Internal rate of return (yr.) | 9.2 |
| Refund (yr.) | 9.67 |
| Discounted payback(yr.) | 14.72 |

The last case shows the power supplied by the local grid only, and the outcomes are depicted in Table 6.

Table 6. SIMULATION AND CMPARE ECONOMICS OUTCOMES FOR FOUR-CASE

| | |
|---|---|
| **Simulation Result** | |
| COE ($) | 0.305 |
| Operating Cost ($) | 18,117 |
| NPC ($) | 234,192 |
| Ren Frac (%) | 0 |
| **Compare economics Results** | |
| Existent worth ($) | $ 0 |
| Yearly worth($/yr.) | $ 0 |
| Rate of return (%) | 0.0 |
| Internal rate of return (yr.) | n/a |
| Refund (yr.) | n/a |
| Discounted payback(yr.) | n/a |

These outcomes are categorized in such a way that, in terms of emissions of gases, operating cost and net present cost, the first case is the most economical and last case has the highest values for all these parameters

## V. CONCLUSION

In this work, for simultaneous network reconfiguration and efficient sizing and allocation of renewable DGs a multi-objective optimization technique is utilized. The basic objective is to minimization of active power losses, pollution gas emission and operational cost. The Strength Pareto Evolutionary Algorithm 2 is utilized for solving the optimization problems described above. The best optimal solutions are given by SPEA2 so that the network manager can select the best option for our system. This approach is tested for combinations of network reconfiguration and integration of renewable DGs with and without them. After analyzing the obtained results, this proposed method provides the best compromise solution which is extracted by using fuzzy set theory. The results obtained indicate a great reduction of 84% of active power losses and 64% of pollution gas emissions with a large reduction of operation cost (67409M$/Year).

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