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Multi-Objective Self-Adaptive a Non-Dominated Sorting Genetic (NSGA) Algorithm for Optimal Sizing of PV/Wind/Diesel Hybrid Microgrid System

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Abstract— In this article, A mix of different types of micro grid system (Hybrid Micro grid System-HMS) such as solar photovoltaic (PV) power, wind energy (WT), and diesel generators with storage system is presented. Multi-Objective Self-Adaptive a non-dominated sorting genetic (NSGA) algorithm is used to find the optimal sizing of a PV/wind/diesel HMS with battery storage for the city of Yanbu, Saudi Arabia. The problem of optimal component sizing is formulated in multi-objective optimization framework to analyze the Loss of Power Supply Probability (LPSP), the Cost of Electricity (COE), and the Renewable Factor (RF) in relation to HMS cost and reliability considering three objective functions, and is tested using three cases studies involving differing house numbers. The proposed algorithm is carried out on the city of Yanbu with various cases.

Keywords: — Non-dominated Sorting Genetic Algorithm III; Power loss reduction; renewable factor; cost; renewable energy source.

1. Introduction

In recent years, distributed energy resources (DERs) became a one of the most important components of the modern distributed system. Optimum location, parameters, size, and number of required DERs for optimum power network performance are an urgent need for operating engineers. The selection process for the DERs source is very important to avoid increasing losses and or losing system stability [1-18].

Wind and solar energy are complementary to each other on a daily, annual, and regional basis; accordingly, the energy provided by WT and PV has become a major resource for renewable energy in stand-alone systems [19], such is used in the kingdom of Saudi Arabia and are prominently used in coastal areas, a certain amount of research and feasibility studies have been conducted regarding the implementation of a wind energy system at sites around the Kingdom [20-21]. However, storage resources and diesel generators are also used to overcome the intermittent nature of wind and solar energy.

A single source system for renewable energy source cannot be used to provide the energy needed to feed demand as the power generated from these sources depends upon climate conditions; therefore a hybrid micro grid system-HMS is used. HMS is a system that uses a mix of different types of RES [22]. Hybrid renewable energy (RE) systems such as PV and WT energy systems are known and integrated successfully in different sites, which have a long lifetime [23].Focusing on improving the hybrid energy sources economically and technically receives much attention from the researchers in both off-grid and on-grid. The integration of hybrid energy sources improves the performance of the system, and more economic than integrating PV energy system or wind energy system individually [24].

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One of the main disadvantages in the administration of renewable energy system based on wind and solar energies is the issue of uncertainty in their behavior. Uncertainty is defined as the difference between the expected value and the real value [25]. So that, in realistic solution, the inherent uncertain nature of solar radiation and wind speed must be incorporated in OPF.

Many optimization techniques have been employed to deal with the problem of DERs optimal allocation to maximize their benefits [26-27]. The main different between these optimization techniques are the objectives being considered, the control variables, and the assumptions. Optimization objectives can be achieved in single or multi-objective spaces. In practice, multi-objective optimization has become a very important decision-making tool rather than the single objective optimization, due to it is given a set of non-dominated solutions [1, 28].

A review of approaches implemented for the optimal allocation of DERs in power distribution systems is tabulated in Table 1.

Table.1 Review of approaches implemented for the optimal allocation of distributed generation (DG) in power distribution systems.

Ref	**Optimization algorithms**	**IEEE bus System**	**HMS**			**battery**
			PV	**WT**	**diesel**	
[29]	multi-objective self-adaptive differential evolution algorithm	city of Yanbu	✓	✓	✓	✓
[30]	Water cycle algorithm	118-bus	✓	✓		
[31]	Neuro-Fuzzy	Two locations in East Malaysa	✓	✓		✓
[24]	Multi-Objective Water Cycle Algorithm	33, 69-bus	✓	✓		
[32]	Multi-Objective Natural Aggregation Algorithm (MONAA).	25- node	✓	✓		
[33]	**Three multi-objective optimization algorithms**	The city of SHLATEEN	✓	✓	✓	✓
[34]	Firefly Algorithm (FA)	69-bus	✓			
[35]	bat optimization algorithm (BOA)	33-bus	✓			
[36]	Multi-objective chaotic symbiotic organisms search (MOCSOS)	33, 69-bus				
[37]	Improved bee algorithm (IBA)	37, 123-bus	✓	✓		
[38]	Mixed integer conic programming (MICP)	69-bus	✓	✓		
[39]	Craziness-based particle swarm optimization (CRPSO) algorithm	33- bus	✓	✓		
[40]	Cuckoo search algorithm (CSA) and Flower pollination algorithm (FPA).	57- bus	✓	✓		
[41]	multi-objective dragonfly algorithm (MODA) and multi-objective differential evolution (MODE)	33, 69- bus		✓		
[*]	Multi-Objective Self-Adaptive a non-dominated sorting genetic (NSGA) algorithm	city of Yanbu	✓	✓	✓	✓

This article presents Non-dominated Sorting Genetic Algorithm III, which has been used to optimize the optimal location and size of WT, PV, and diesel generator with Battery for reducing total network power losses, cost, and renewable factor. The performance of study system has been analyzed under three values of house number.

The main contributions of the paper can be summarized as.

i. New electric resources with suitable size, placement, and type are integrated.
ii. The optimal location and size of WT, PV, and diesel generator with Battery are obtained by Non-dominated Sorting Genetic Algorithm III.
iii. The effect of different number of house on the network performance is covered.

The rest of this paper is organized as follows: Section 2, the problem is described in detail. Section 3, this section presents the mathematical model of the HMS. The mathematical model of the proposed method is displayed in section 4. The simulation results for the proposed method and the other algorithms under three studied system displays in section 5.

2. Problem Formulation

The main goal of this work is to minimize the cost of Electricity (COE) of the HMS, ***power loss***, and renewable factor. This subsection contains a detailed formulation of these objectives and their practical constraints. The optimization techniques were applied for microgrid system with different configuration [42-46].

2. 1Cost of Electricity (COE) of the HMS:

The cost of electricity (COE) is the first objective will be presented, which is an important factor to consider during the planning process. The cost of electricity has initial capital cost, operation and maintenance cost. It is defined as unit of price per unit of produced energy from the HMS ($/kWh) as in the following equation[47-48].

$$COE = \frac{Total\ Net\ Presnt\ Cost\ (NPC)}{\sum_{h=1}^{h=8760} P_l(h)} \times CRF \quad (1)$$

Where, Total Net Present Cost includes all initial hardware cost, operation and maintenance cost (O&M), fuel cost, and replacement cost. The hourly consumed load is presented by $P_l(h)$, the capital recovery factor (CRF) can be shown as,

$$CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (2)$$

2. 2Minimization Of power loss (LPSP):

The system loss of power supply probability is the second objective will be presented in this paper. It is important to increase the system reliability by reducing the probability of loss of power supply due to unmet the load demand when the micro-grid operation in islanded mode. loss of power supply probability (LPSP) can be found as follows [49-50]:

$$LPSP = \frac{\sum P_L(t) - (P_W(t) + P_{PV}(t) + (E_b(t-1) - E_{bmin}) + P_{diesel})}{\sum P_L(t)} \quad (3)$$

2. 3Renewable factor(RF)

The Renewable Factor (RF) is the third objective function used, which is calculated to indicate the amount of diesel generation to renewable generation; the objective is to reduce diesel output which in case will reduce operation cost and CO2 emissions. RF can be found as follows [29]:

$$RF = \left(1 - \frac{\sum P_{diesel}}{\sum P_{pv} + P_w}\right) \times 100 \quad (4)$$

Where, 100% RF means that the load is supplied by renewable generation, which is best condition for lower cost and lower CO_2 emissions. The control variables to be optimized in this study are nominal power of PV system (PV), number of wind turbines (WT), Autonomy Days (AD), and the output power of diesel generator (Pg.). The parameters of differeny type of generator, battery and inverter are listed in Table 2 [29].

Table.2 The parameters of differeny type of generator, battery and inverter.

Com	Parameter	Value	Unit
Diesel generator	Rated power Initial cost Life time	4 1000 24,000	Kw $/kw Hours
Inverter	Initial cost Life time Efficiency	2500 24 92	$ Year %
Battery	Rated power Initial cost Life time Efficiency	40 280 12 85	KWh $/kwh Year %
Economic parameters	Project life time Fuel inflation rate O&M running cost Real interest Discount rate	24 5 20 13 8	Year % % % %

3. Hybrid microgrid system (HMS) modeling

In this paper, the HMS is represented as a PV system, wind turbines, diesel generators, an inverter, and a battery bank. The Schematic of a HMS is shown in Fig. 1 [29].

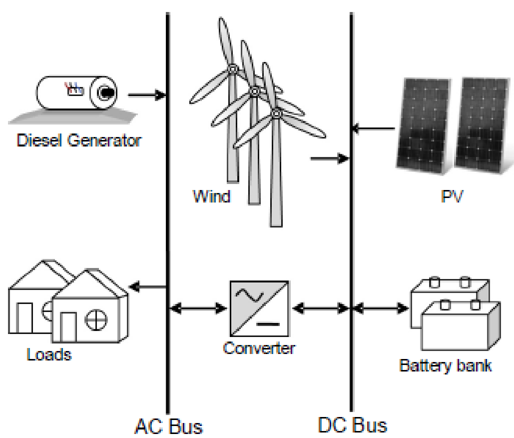


Fig. 1. Configuration of HMS.

3.1. Photovoltaic system (PVS)

Sunlight is converted into electrical energy by a photovoltaic generator. PV output of panels calculated by equation[33]:

$$P_{PV_{OUT}} = P_{N-PV} \times \frac{G}{G_{ref}}\left[1 + k_t\left(\left(T_{amb} + (0.0256 \times G)\right) - T_{ref}\right)\right] \quad (5)$$

Where P_{N-PV} is the pv rated power at standard test condition (STC) ; G is the solar radiation (W/ m^2); G_{ref} is; 1K W/ m^2; k_t is a constant, -3.7× 10^{-3} (1/C); T_{amb} is the ambient temperature ; and T_{ref} is the temperature of the PV cell at STC (25^0 C).

3.2.Wind Energy System (WES)

The Wind Energy System is the secondary power source. As wind speed changes considerably with height, conversion from wind speed measured at anemometer height to a desired hub height can be made according to the power law equation [51]

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \quad (6)$$

Where v_1 is the speed at a reference height, h_1; v_2 is the speed at a hub height, h_2; and α is the coefficient of friction. α is defined by certain parameters, i.e. roughness of terrain, wind speed, temperature, height above ground, hour of the day, and time of year [34]. In technical literature, it is commonly defined by different types of terrain; however, the recommendations of IEC standards give a friction coefficient value of 0.11 for extreme wind conditions, and 0.20 for normal wind conditions. The expected power output of a wind turbine is expressed as [51]

$$\left\{\begin{array}{ll} 0 & V < V_{cut-in}\ V > V_{cut-out} \\ V^3\left(\frac{P_{rated}}{V^3_{rated}-V^3_{cut_{in}}}\right)-P_{rated}\left(\frac{V^3_{cut}}{V^3_{rated}-V^3_{cut_{in}}}\right) & V_{cut-in} \leq V < V_{rated} \\ P_{rated} & V_{rated} \leq V < V_{cut-out} \end{array}\right\} \quad (7)$$

Where V is the current time step wind speed, V_{rated} is the nominal wind speed, $V_{cut-out}$ is the cut out wind speed, V_{cut-in} is the cut in wind speed, and P_{rated} is the rated power.

3.3.Disel generator

The diesel generator is the third power source, and thus plays a significant role in maintaining stable system operation. Therefore, maintaining diesel generation within a safe range is of considerable importance. With a low loading rate the generator works at a low efficiency [52-53]. Therefore, to take advantage of energy efficiently and achieve an adequate safety margin for power fluctuations, such as a sudden increase in load consumption, diesel generation must be operated within its normal operating range to avoid unloading and light loading conditions [29].

The fuel consumption of a diesel generator, q(t), can be calculated as [29]

$$q(t) = aP(t) + bP_{rated} \quad (8)$$

Where P(t) is the generated power, a and b are coefficients of the fuel consumption parameters, and P_rated is the rated power. In this study, a and b are approximated as 0.246 and 0.08415 [29].

The overall efficiency of diesel generator can be formulated as [54]:

$$\eta_{overall} = \eta_{brake\ thermal} \times \eta_{generator} \quad (9)$$

Where $\eta_{overall}$ is the overall efficiency and $\eta_{brake\ thermal}$ is the brake thermal efficiency. Diesel generator data used in optimization are provided in Table 1.

3.4.Inverter

The efficiency of the inverter can be formulated by:

$$\eta_{inv} = \frac{P}{P+P_0+KP^2} \quad (10)$$

Where,P_0, and k can be expressed as follows [55-56]:

$$P = \frac{P_{out}}{P_{in}} \quad (11)$$

$$P_0 = 1 - 99\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right)^2 \quad (12)$$

$$K = \frac{1}{\eta_{100}} - P_0 \quad (13)$$

in which η_{10} and η_{100} represent the inverter efficiency at 10% and 100% of nominal por (values given by manufacturers). Data for the diesel generator are provided in Table 2.

3.5.Battery

The battery capacity is calculated based on demand and autonomy days, which can be formulated as:

$$C_B = \frac{E_L AD}{DOD \eta_{inv} \eta_b} \quad (14)$$

Where E_L is the load, AD is the autonomy days, DOD is the depth of discharge (80%), ηinv is the inverter efficiency (95%), and ηb is the battery efficiency (85%). Economical parameters of HMS [57].

4. Proposed Method

In this study, One optimizations algorithms are used namely, Non-dominated Sorting Genetic Algorithm III (NDSGA-III)

4.1 Non dominated Sorting Genetic Algorithm III (NSGA-III)

NSGA-III is a Pareto optimization method that works well with problems that have multiple objectives (three or more) at the same time, This algorithm was proposed by Deb and Jain (2014) changing some selection mechanisms [58]. The flow chart of NSGA-III algorithm is illustrated in Fig. 2. [59]. the steps involved in the optimization algorithmic are as follows.

The steps involved in the optimization algorithmic of the particle swarm are as follows;

1) Start algorithm.
2) read system data(bus and branch data) and define the upper and lower bounds of the variables(location and size of DG and bus voltage)
3) Calculate the number of reference points (H) to place on the hyper-plan

$$H = \frac{C+g-1}{g} \quad (15)$$

4) Generate the initial population at random
5) Realize the non-dominated population sorting
6) for i = 1 Stopping criteria do
7) two parents P1 and P2 have been selected using the tournament method
8) the crossover between P1 and P2 has been Apply with a probability Pc
9) Realize the non-dominated population sorting
10) Normalize the population members
11) Associate the population member with the reference points
12) Check the stop criterion if it is satisfied then go to step (15) else go to step (13).
13) Update the iter counter iter= itert + 1.
14) Create new populations of sitting of DG go to step (4).
15) Check the stop criterion, if it is satisfied then stop, else go to step (14).

end for

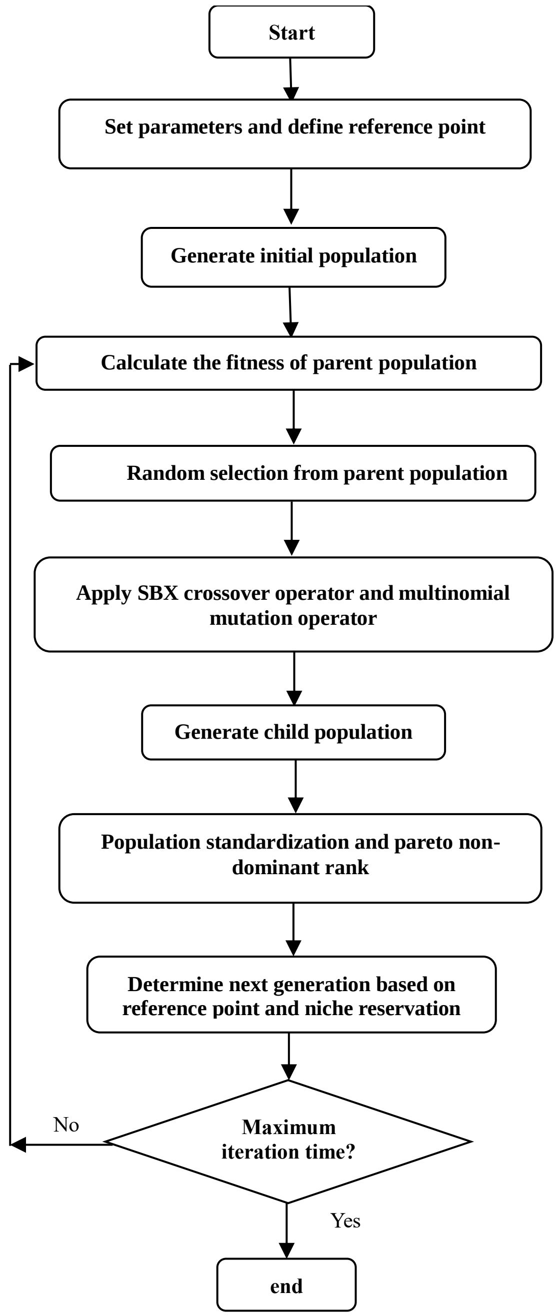


Fig. 1 Flowchart of Non-dominated Sorting Genetic Algorithm III (NSGA-III)

5. Simulation results based on Non-dominated Sorting Genetic Algorithm III (NSGA-III)

This section demonstrates the effectiveness of the proposed method (NSGA-III method) considering minimization of power losses, cost, and renewable factor. The proposed algorithm has been implemented on Yanbu, Saudi Arabia area [47]. When renewable generation is low and the battery bank is depilated, the Diesel generator is used as a backup energy system to supply the load. An analytical software tool has been developed in MATLAB to run load flow, and determine optimal location and size of DES.

Three cases are considered: Case 1, Case 2, and Case 3 correspond to 10, 15, and 20 houses, respectively. The MOSaDE is run for each case using a population of 100 individuals and 200 iterations, and the lower and upper bounds for PV, AD and WTare [15 45], [28] and [0 10], respectively.

5. 1 Case 1: n=10 (number of house = 10)

In this scenario, the proposed objective optimization technique is used to optimize suitable size, location, of DES considering number of house equall 10. The optimization results achieved by proposed the NSGA-III is given in Table 3. The Pareto solutions for proposed algorithm are visualized in Fig. 3.

From these results, it is evident that very interesting sets of solutions are determined for each case when the NSGA is applied to HMS optimization. A system designer would therefore be able to select a solution based on his experience and the associated specifications. For example, solution # 11 of CASE 1 has a power of 40.855 kW for PV panels, 5 autonomy days, and 9 wind turbines. This solution corresponds to a COE of 0.39754 $/kWh, an LPSP of 0.03398, and a RF of 89.111 %. It is of note that the COE has a higher value and the LPSP a lower value than the other available solutions. For solution # 20 of CASE 1, we can find that the COE is 0.23855 $/kWh, an LPSP of 0.25567, and a RF of 67.862 %. It is of note that the COE has a lower value and the LPSP a higher value than the other available solutions. Contribution of energy supplied by PV panels and WT panels are 16.33 kW and 7 wind turbine which are lower as compared to solution # 11. Diesel contributed the same percentage for all solutions.

Table.3 Results for case 1(number of house = 10)

	PV	AD	WT	Diesel	COE	LPSP	RF
Solution 1	28.208	4.2872	9	1	0.2755	0.13347	0.88498
Solution 2	34.884	4.6514	9	2	0.37909	0.043182	0.86831
Solution 3	26.454	2.564	8	1	0.25309	0.18143	0.84513
Solution 4	36.537	4.6648	9	1	0.31205	0.089126	0.92724
Solution 5	25.503	3.3349	8	1	0.25961	0.16989	0.84806
Solution 6	25.641	3.8056	8	1	0.26573	0.162	0.85422
Solution 7	25.168	3.096	7	1	0.25257	0.1839	0.82961
Solution 8	27.23	2.5177	6	1	0.2512	0.18854	0.83566
Solution 9	25.307	2.5603	7	1	0.24586	0.19575	0.82037
Solution 10	33.29	4.6514	9	2	0.37571	0.045838	0.85904
Solution 11	40.855	4.6648	9	2	0.39754	0.03398	0.89111
Solution 12	34.574	4.632	9	1	0.30311	0.096701	0.92032
Solution 13	27.905	3.5544	7	1	0.26612	0.16001	0.85782
Solution 14	25.503	3.5553	8	1	0.26209	0.16691	0.84981
Solution 15	29.529	4.2872	9	1	0.27986	0.12616	0.89267
Solution 16	25.833	3.2895	8	1	0.2621	0.16412	0.85815
Solution 17	27.905	3.5544	7	1	0.26657	0.15884	0.8594
Solution 18	32.802	4.2322	10	1	0.29582	0.107	0.9159
Solution 19	27.028	1.9911	6	1	0.24551	0.20124	0.82644
Solution 20	16.333	2.583	7	1	0.23855	0.25567	0.67862
Solution 21	32.175	3.3716	7	1	0.27306	0.14588	0.88136
Solution 22	28.445	2.7804	7	1	0.25886	0.1753	0.85173
Solution 23	28.722	2.5177	6	1	0.25644	0.18244	0.84614
Solution 24	35.923	4.6021	9	2	0.38118	0.042748	0.87077
Solution 25	34.745	3.3914	9	1	0.289	0.12882	0.9047
Solution 26	34.252	3.0891	8	1	0.28159	0.14182	0.8936
Solution 27	36.503	4.6648	9	2	0.38374	0.03988	0.87666
Solution 28	25.121	2.5522	7	1	0.24839	0.18853	0.83219
Solution 29	27.905	3.5544	7	1	0.26612	0.16001	0.85782
Solution 30	27.226	3.1104	7	1	0.25831	0.17355	0.84609

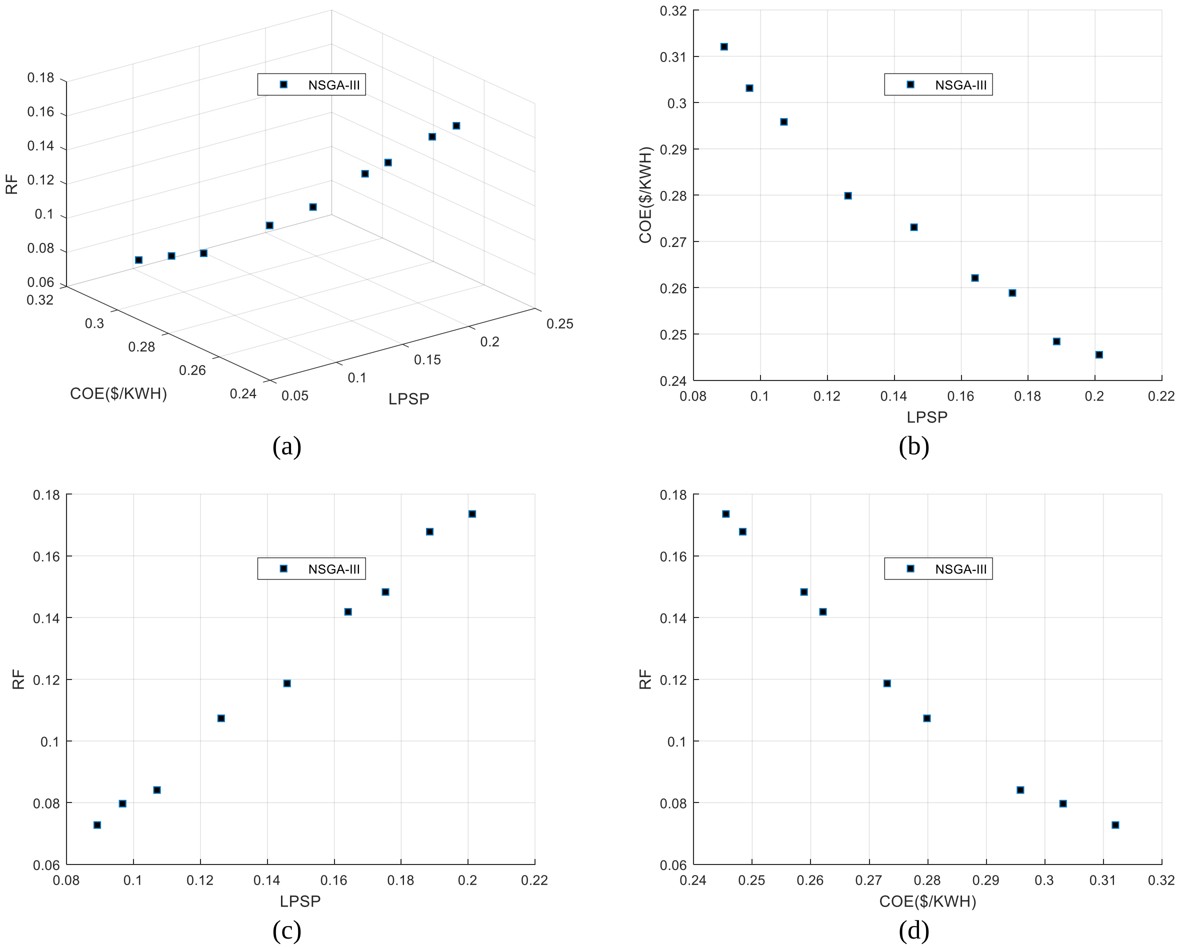


Fig. 2 The Pareto solutions for proposed algorithm for case 1

5. 2 Case 2: n=15 (number of house = 15)

In this case the performance of system analyzed under 15 house, The Pareto solutions for proposed algorithm are shown in Fig. 4, the optimal results are listed in Table 4.

Comparing the results for solution # 2 with the results obtained with solution # 18 found that the COE is reduced from 0.45291 $/kWh to 0.1978 $/kWh and the LPSP is increased from 0.067309 p.u to 0.29428 p.u otherwise the RF is increased from 74.967 % to 80.434 % due to redused the contribution of energy supplied by PV panels from 39.798 kW to 28.277 kW. WT contributed the same percentage for two solutions.

Table.4 The optimal results for case 2 (number of house = 15)

	PV	AD	WT	Diesel	COE	LPSP	RF
Solution #1	37.402	3.3452	8	1	0.2336	0.22482	0.8674
Solution #2	39.798	4.1967	9	3	0.45291	0.067309	0.74967
Solution #3	42.891	3.4237	10	1	0.2545	0.18201	0.90655
Solution #4	37.923	3.3364	10	2	0.33374	0.13384	0.79815
Solution #5	38.695	3.9773	10	1	0.24998	0.18977	0.89418
Solution #6	32.911	1.5257	9	1	0.21159	0.26752	0.84242
Solution #7	42.34	4.3427	9	1	0.2624	0.16693	0.90835
Solution #8	37.858	3.1333	10	2	0.33238	0.13701	0.79555
Solution #9	38.158	3.5166	8	1	0.23992	0.20957	0.88019
Solution #10	37.35	3.1274	9	1	0.23412	0.21855	0.87667
Solution #11	28.277	2.3421	9	1	0.21093	0.27867	0.81483
Solution #12	43.176	4.3269	8	1	0.26155	0.17013	0.90471

Solution #13	37.923	3.3364	10	2	0.33347	0.13527	0.79498
Solution #14	43.348	4.7109	9	2	0.34364	0.10167	0.83907
Solution #15	39.188	3.7808	9	1	0.24703	0.19495	0.8915
Solution #16	38.217	3.5857	9	1	0.2428	0.20251	0.88674
Solution #17	43.063	4.1543	10	2	0.34075	0.10556	0.84117
Solution #18	28.277	1.1871	9	1	0.1978	0.29428	0.80434
Solution #19	28.277	1.1871	9	1	0.19803	0.29319	0.80666
Solution #20	42.891	3.4237	10	2	0.33626	0.11874	0.83178
Solution #21	23.666	1.1871	9	1	0.19343	0.31763	0.75828
Solution #22	34.923	2.7193	9	1	0.22475	0.23519	0.86555
Solution #23	36.038	2.8959	9	2	0.32939	0.1515	0.76186
Solution #24	37.35	3.3726	9	1	0.23708	0.21403	0.87796
Solution #25	26.291	2.3421	9	1	0.20731	0.29141	0.79474
Solution #26	37.35	3.3726	8	1	0.2359	0.21769	0.874
Solution #27	37.883	3.0497	9	2	0.33159	0.14166	0.78583
Solution #28	43.225	4.0096	9	1	0.25862	0.1748	0.90453
Solution #29	34.806	3.2015	10	2	0.33124	0.14744	0.76735
Solution #30	42.166	4.0069	2!9	2	0.33828	0.11284	0.82944

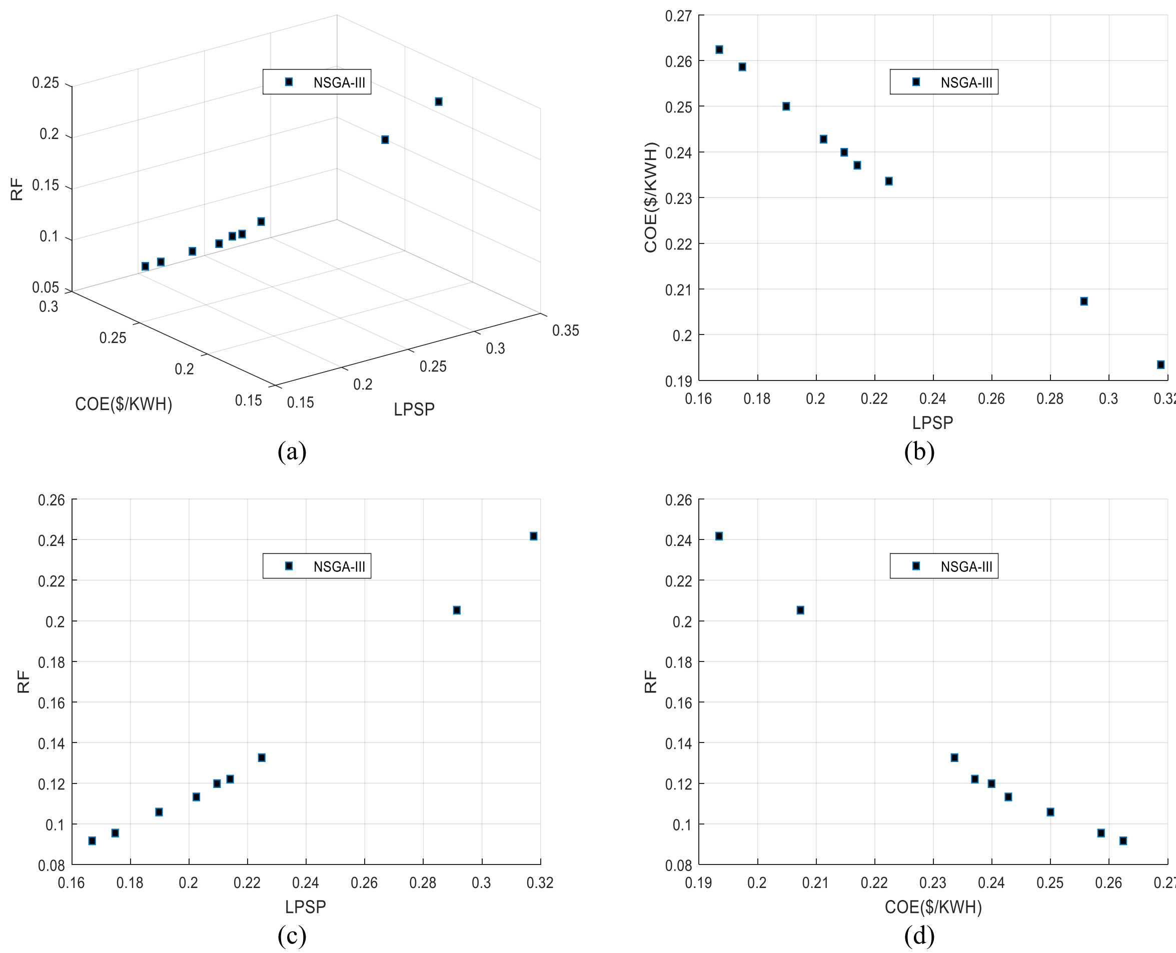


Fig. 3 The Pareto solutions for proposed algorithm case2

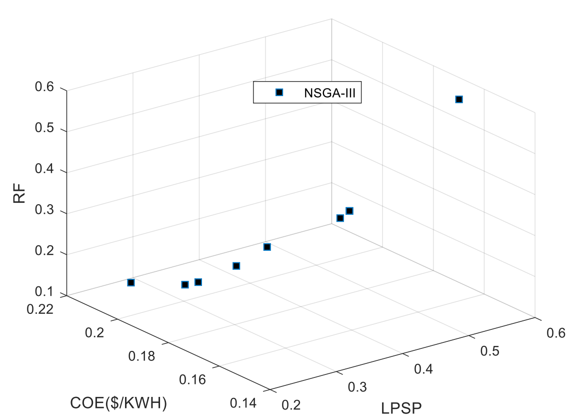
5. 3 Case 3: n=20 (number of house = 20)

In this scenario, the number of house equal 20 house. Pareto frontiers and their 2-d projections are shown in Fig.

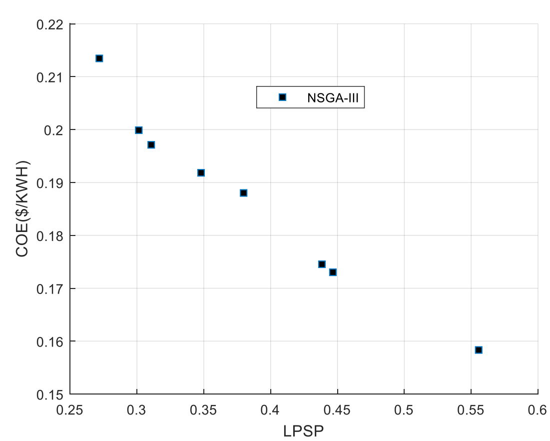
5, the obtimization results are tabulatated in table 5. It is observed that the solution # 17 has a power of 41.977 kW for PV panels, 5 autonomy days, and 8 wind turbines. This solution corresponds to a COE of 0.62298 $/kWh, an LPSP of 0.098907, and a RF of 53.631 %. It is of note that the COE has a higher value and the LPSP a lower value than the other available solutions. The lower value of COE and the higher value of LPSP than the other available solutions is optained from Solution #3. Contributions of energy supplied by PV panels and WT panels for Solution #3 are 31.241 kW and 3 wind turbine which are lower as compared to solution # 17. Diesel contributed are reduced from 4 to 1.

Table.5 obtimization results for Case 3 (number of house = 20)

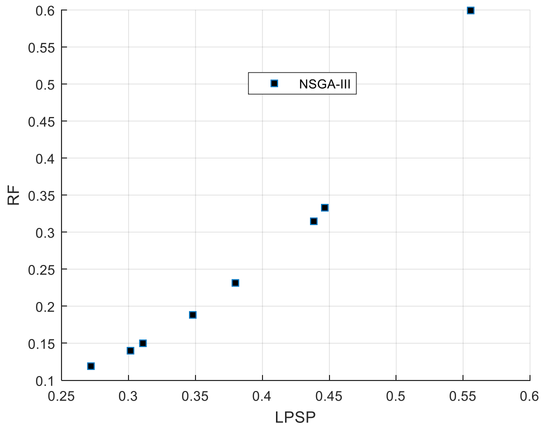
	PV	AD	WT	Diesel	COE	LPSP	RF
Solution #1	43.81	4.468	10	2	0.31688	0.1883	0.7859
Solution #2	44.082	2.9722	10	1	0.21345	0.27184	0.88093
Solution #3	31.241	1.8502	3	1	0.17303	0.4466	0.66704
Solution #4	44.353	4.6244	10	3	0.43678	0.13054	0.7081
Solution #5	42.02	2.3647	9	1	0.19988	0.30139	0.86008
Solution #6	41.656	2.9722	10	1	0.20923	0.28516	0.8698
Solution #7	42.838	3.1316	10	1	0.21216	0.28126	0.87217
Solution #8	44.353	5	3	3	0.44014	0.12931	0.71045
Solution #9	44.353	4.398	10	3	0.43469	0.13145	0.70677
Solution #10	44.078	3.1455	10	2	0.30267	0.19779	0.78035
Solution #11	44.078	3.1455	10	2	0.30286	0.19609	0.78291
Solution #12	42.831	3.1317	10	1	0.21289	0.2782	0.87483
Solution #13	39.227	3.13179	1	1	0.19657	0.31119	0.84982
Solution #14	42.495	3.1265	10	1	0.21329	0.27603	0.87656
Solution #15	42.832	3.1317	10	1	0.21242	0.28017	0.87305
Solution #16	37.303	2.3673	7	1	0.19183	0.34795	0.81175
Solution #17	41.977	4.4831	8	4	0.62298	0.098907	0.53631
Solution #18	44.082	2.9722	10	2	0.30096	0.20085	0.77709
Solution #19	42.277	3.0955	10	1	0.21133	0.28244	0.87136
Solution #20	44.078	2.5718	10	2	0.29789	0.203	0.7772
Solution #21	42.08	2.733	10	1	0.20673	0.28666	0.8699
Solution #22	39.227	2.4259	9	1	0.19712	0.37069	0.85005
Solution #23	44.078	3.5508	10	2	0.30706	0.1921	0.7855
Solution #24	43.81	3.5508	10	2	0.31569	0.18894	0.78553
Solution #25	39.626	1.567	8	2	0.29551	0.24633	0.69122
Solution #26	33.049	2.6003	7	1	0.18801	0.37979	0.76858
Solution #27	21.03	1.9824	2	1	0.15833	0.55564	0.4007
Solution #28	44.078	3.1455	10	2	0.30286	0.19609	0.78291
Solution #29	44.078	1.567	3	1	0.17454	0.43838	0.68534
Solution #30	31.241	1.8502	30	1	0.17303	0.4466	0.66704



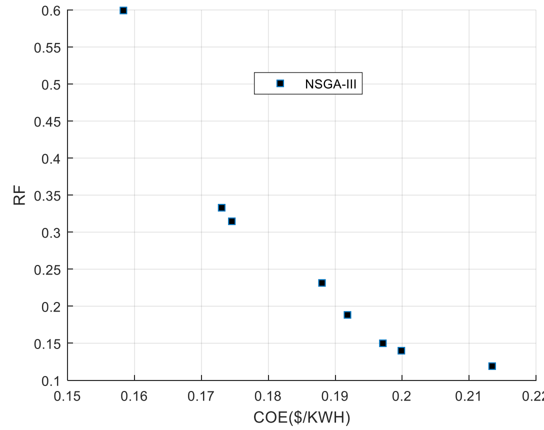
(a)



(b)



(c)



(d)

Fig. 4 The Pareto solutions for proposed algorithm case3

Conclusion

In this paper, the Non-dominated Sorting Genetic Algorithm III (NDSGA-III) is used to optimize the optimal capacities of hybrid micro-grid system (HMS) consist of solar photovoltaic (PV), wind turbines (WT), and diesel generator integrated with battery energy storage system.

The suggested technique is examined on in the city of Yanbu considering three case studies are performed, each of which includes a certain number of houses in Yanbu. The objective functions presented in this paper are cost of Electricity (COE), Loss of Power Supply Probability (LPSP), and Renewable Factor (RF).

The results of this paper can be used as a power reference for the economic operation of PV, WT and diesel generators. In addition, the results are also useful for ensuring a reliable power supply, regulating diesel generation within a normal range, operating the set points of PV and wind turbine generators, and providing an optimal energy storage system, and reducing the price of renewable energy resources, especially solar PV and WT, and to make products more competitive for use in the energy industry and market, with the ultimate aim of accelerating renewable energy resources development and energy diversification plans

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