Integration of solar energy and optimized economic dispatch using genetic algorithm: A case-study of Abu Dhabi

AKMAL, Muhammad <http://orcid.org/0000-0002-3498-4146>, ALI, Samr, AL KHALIL, Yasmina, IQBAL, Nusrat Binte and ALZAABI, Aalim

Integration of Solar Energy and Optimized Economic Dispatch using Genetic Algorithm

A case-study of Abu Dhabi

Muhammad Akmal, Samr Ali, Yasmina Al Khalil, Nusrat Binte Iqbal, Salim Alzaabi and Anas Al Tarabsheh
Electrical and Computer Engineering Department
Abu Dhabi University
Abu Dhabi, United Arab Emirates
muhammad.akmal@adu.ac.ae

Abstract— **The United Arab Emirates is focusing on cultivating Renewable Energy (RE) to meet its growing power demand. This also brings power planning to the forefront in regards to keen interests in renewable constrained economic dispatch. This paper takes note of UAE's vision in incorporating a better energy mix of Renewable Energy (RE), nuclear, hybrid system along with the existing power plants mostly utilizing natural gas; with further attention for a sound economic dispatch scenario. The paper describes economic dispatch and delves into the usage of Genetic Algorithm to optimize the proposed system of thermal plants and solar systems. The paper explains the problem formulation, describes the system used, and illustrates the results achieved. The aim of the research is in line with the objective function to minimize the total costs of production and to serve the purpose of integrating renewable energy into the traditional power production in UAE. The generation mix scenarios are assessed using genetic algorithm using MATLAB simulation for the optimization problem.**

Index Terms— **Economic dispatch, optimization, renewable energy, genetic algorithm.**

I. Introduction

United Arab Emirates (UAE) is one of major oil producers around the world and ranked 7th top country with the biggest proven oil reserves, it has realized the importance of renewable energy and the use of such energy has become a national strategic goal for the coming years for keeping a steady export of oil reserves and meeting growing demand of UAE from renewable energy. The interest on the renewable energy has led the UAE government to establish Masdar city, which is running at 100% renewable energy [1]. The energy demand of UAE has been recorded to increase significantly in the last decade with peak energy demand of UAE estimated to increase between 16 to 24GW by 2018, which indicates an average growth rate of 9% to 16% per year [2], [3]. In 2010, it was recorded that the total generation capacity of UAE was 23 GW, producing 98 TWh of electricity, where the emirates of Abu Dhabi and Dubai consumed around 78 TWh alone [4]. A high level of energy consumption and hydrocarbon fuels burning increase carbon emissions; thus, it is not surprising that UAE's per capita carbon emissions are at least 10 times larger than annual average emission [5]. This indicates a need for change towards a more sustainable energy mix, for a more sustainable economic development in the short, medium, and long terms. Therefore, solar energy has started to emerge as quite a significant factor in UAE's energy mix. A notable presence is taken by the 100 MW Shams 1 CSP plant initiated in 2013 in Abu Dhabi [4], and a 13 MW Mohammed Bin Rashid Al-Maktoum Solar Park in Dubai, targeted to reach 1000 MW. Finally, further developments in the solar energy field is set to take place with the Sweihan solar project of 350 MW in Abu Dhabi where bidding is underway [6].

The paper is organized as follows: Section II states literature involving different algorithms for economic dispatch, Section III discusses our proposed system, Section IV presents our results, and Section V concludes the paper.

II. Background and Literature Review

One of the vital steps in the power system operational planning is considering the problem of the economic dispatch.

Economic dispatch is defined as an optimization problem that attempts to allocate power to each generation unit in order to minimize the total cost, usually conditional to particular constraints [7]. Including the renewable generation units into the economic dispatch represents an additional challenge due to the unsteadiness of renewable resources. Recently, a lot of research has been done on the issue of generating the best solution to the problem of optimizing the economic dispatch. In [8], the issue of combined heat and power economic dispatch (CHPED) and attempts have been discussed to provide an implementation of time varying acceleration coefficients particle swarm optimization (TVAPSO) algorithm. The authors of [9] address the economic dispatch issue in a distributed scenario using self-organizing dynamic agents with focus on the need for a decentralized due to the increase in smart grid deployments. Banos et al. [10] reviewed over two hundreds papers in the field of renewable energy optimization in general. Many techniques are listed for the purpose of optimization such as artificial neural networks, genetic algorithms, neuro-fuzzy algorithm, non-dominated sorting genetic algorithm, stochastic programming and Monte Carlo simulations. A Generalized Ant Colony Optimization (GACO) optimization algorithm to solve the discontinuous, non-convex, nonlinear constrained optimization problems has been proposed in addition to studying the convergence property of GACO based on the fixed-point theorem on a complete metric space in [11]. In [12], the authors presented an improved differential evolution algorithm for solving economic dispatch problems that takes into account nonlinear generator features such as ramp rate limits and prohibited operating zones. Paper [13] proposed Particle Swarm Optimization (PSO) method for solving economic dispatch problem in comparison with Genetic Algorithm (GA) considering nonlinear characteristics of the generator such as ramp rate limits, valve-point zones, and non-smooth cost functions [13]. Authors in [14] have discussed the important multi-objective optimization problem that attempts to efficiently distribute the amount of generation among thermal generation units, which include renewable resource, with the aim of minimizing the total cost of generation, as well as the pollution during emission.

Even though a lot of research has been done on optimizing the economic dispatch problem for generation mix, but still a lot of research is in focus on better integration and increasing penetration of renewable energy. Since, UAE is planning to increase renewable energy in the near future, the study is very important by selecting the system as a case study and using the data from Abu Dhabi Power System. Thus, in this paper we study the deployment of a diversified generation mix in UAE, specifically Abu Dhabi, and propose a genetic algorithm (GA) for optimizing the economic dispatch of the proposed system. GA is chosen as the technique to be investigated, as it is not widely used for solar energy optimization. The paper uses hypothesize a combination of solar plants, based on the current and upcoming installations in Abu Dhabi, with the conventional thermal plants, to meet the peak energy demand for Abu Dhabi in July and January, the two months that observe the maximum and minimum demand, respectively.

III. Proposed System

Our proposed system consists of three main models. These are the formulation of the economic dispatch problem as discussed in Section III-A, the model for the solar power integration as analyzed in Section III-B, and the study of the genetic algorithm (GA) optimization technique in Section III-C.

A. Economic Dispatch Formulation

Classical model of the fuel cost of thermal generators is given in Eq. 1

$$\Phi = \sum_{x=1}^{K} \zeta_x = \sum_{x=1}^{K} \alpha_x p_x^2 + \beta_x p_x + \delta_x \tag{1}$$

Where Φ is the total cost function of the thermal generators, x is a dummy variable to indicate the respective thermal generator out of K generators, and ζ is the polynomial fuel cost function of each generator x. This comprises of the fuel coefficients α, β, and δ of each of the respective x generators and p_x is its generated power in MW. This formulation obeys both equality and inequality constraints. The equality constraint addresses the power balance with the respect to the generated power, transmission losses and demand load. This is denoted as Eq. 2:

$$\sum_{x=1}^{K} p_x = p_D + p_L \tag{2}$$

Where p_D is the load demand and p_L is the total line transmission losses. p_L is defined as Eq. 3:

$$p_L = \sum_{x=1}^{K}\sum_{y=1}^{N} p_x^T B_{xy} p_y + \sum_{x=1}^{K} p_x B_{ox} + B_{oo} \tag{3}$$

Where y is a dummy variable for the summation, N is the number of generators ($K = N$), p_{Tx} is the transpose of the vector that consists of the power from all K thermal generators, and B_{xy}, B_{ox}, and B_{oo} are transmission line loss coefficients. Mathematically, B_{xy} is a square matrix of size K by N, Box is a vector of length K, and B_{oo} is a single natural number. The load demand has been considered as a single concentrated load and the loss coefficients are with respect to that concentrated load location at the location of dispatch center.

On the other hand, the inequality constraint is the modeling of the maximum and minimum generating limits of each thermal generator x, as Eq. 4:

$$p_{x,a} \leqslant p_x \leqslant p_{x,b} \tag{4}$$

where $p_{x,a}$ and $p_{x,b}$ are the respective minimum and maximum generated power constraint of generator x.

Then to incorporate the solar power generated as explained in Section III-B, we consider it as negative demand to then calculate the new power demand, p^1_D as Eq. 5:

$$p_D^1 = p_D - \sum_{s=1}^{n} p_s \quad . \tag{5}$$

Where $\sum_{s=1}^{n} p_s$ is the total of the power generated by n solar power generators considering the season and solar irradiance.

B. Solar Power Model

To calculate the power output from the solar plant or the solar array, we assume that it is linearly related to the amount of incident solar radiation reaching the panels, while considering the solar arrays are equipped with maximum power point tracking (MPPT) devices. We represent the power generated from a solar plant, p_s as follows, as Eq. 6:

$$p_s = p_r\,[\,1 + (\,T_r - T_a\,) * \eta_t] * \frac{Hi}{1000}\,. \tag{6}$$

Where p_r represents the rated power of the solar plant under standard test conditions, T_r is the reference temperature, T_a is the ambient temperature, η_t is the temperature coefficient, and Hi is the amount of solar incident radiation. We consider the reference temperature T_r to be the PV cell temperature under standard test conditions, which is 25ºC. The temperature coefficient η_t indicates the dependence of the output power of the plant on the surface temperature of the PV cells. Since it is a negative number, it specifies that the power output decreases with the increase in the cell temperature. The value of η_t is usually provided by the manufacturer. Considering the usage of polycrystalline-based solar panels, we take η_t to be -0.485%/ºC. Having n solar patch participating in the economic dispatch, we define the total scheduled solar power p_{st} as, Eq. 7:

$$p_{st} = \sum_{j=1}^{n} p_{s_j}\,, \tag{7}$$

where p_{sj} is the power from the j^{th} solar plant. Thus, the overall cost C_s of the solar power generated is defined as Eq. 8:

$$C_s = \sum_{j=1}^{n} C_{pu_j} * p_{s_j}\,, \tag{8}$$

where C_{puj} represents the per unit cost of the j^{th} solar plant.

C. Genetic Algorithm Optimization Method

We optimize our system using GA technique; an established global optimization method based on natural selection that is derived from biological evolution [15]. One of the advantages of using GA is its ability to handle large amount of variables whether in continuous or discrete format regardless of how complex the cost function is. It also supplies an extensive record of the optimal values rather than only the single final solution. The procedure of the GA method starts with the definition of an objective function and the number of variables to be optimized. For our system, that is Φ and K respectively. Its population is then randomly generated and fitness values are used to select parents. Next, crossover and mutation takes place for and upon the production of the children. This is the new population. This cycle continues until GA reaches the optimum solution or a termination condition. Termination conditions include number of iterations, time spent in optimization, or minimum change of best solution reached thus far. Figure 1 depicts the detailed flowchart of the execution of the genetic algorithm applied in the proposed system.

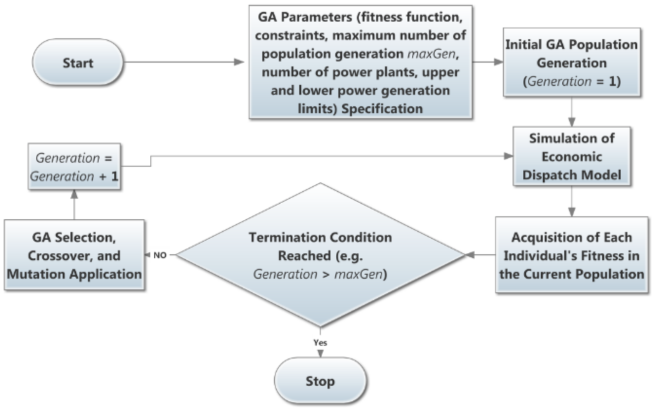

Fig. 1. Genetic Algorithm Optimization Method in MATLAB.

IV. Results

A. Test System

The proposed generation mix consists of 6 thermal units and 2 solar plants. We assume, these are operated in Abu Dhabi, UAE, based on the 2 biggest solar plants that will be producing a significant amount of solar energy in Abu Dhabi in the next 10 years. We consider 2 solar plants in Abu Dhabi, one of which is the already established Shams-1 solar concentrated power plant with a maximum capacity of 100 MW, while the other one is a 350-MW solar power plant, which will start operating in the next 5 years. The data for thermal plants has been used from [16], and is presented in Table I. Table I represents fuel cost coefficients and minimum and maximum generating capacities.

TABLE I. Data for thermal plants.

Plant No.	p_i^{min}	p_i^{max}	$\alpha_i(\$)$	$\beta_i(\$/MW)$	$\gamma_i(\$/MW^2)$
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

Table II presents power ratings and per unit costs of the two solar plants presented in the system. The unit cost of the 350MW solar plant has been hypothesized based on a bid set by a team of Jinko Solar and Marubeni [6].

TABLE II. Power ratings and per unit rates of solar plants.

Plant No.	Rated Power (MW)	Unit Rate ($/kWh)
1	100	0.0598
2	350	0.0242

TABLE III. Average Values for Solar Radiation, Power Demand, and Temperature for July and January.

Month	Solar Rad (W/m2)	Demand (MW)	Temp (°C)
July	289.25	7750	34.6
January	179.104	3880	19.2

In Fig. 2, we show the average monthly peak electricity demand profile for Abu Dhabi, based on the data obtained by the Abu Dhabi Water and Electricity Company in 2014 [17]. We observe that the maximum demand is recorded for the month of July, with August coming up close, while the minimum demand is observed for the month of January, which results in the recorded total solar energy of 6.5 kWh/m^2/day and the direct normal solar radiation of 4 to 6 kWh/m^2/day, subjected to the location and time of the year [18]. Such high peak sun hours indicate that in ideal conditions, existing energy storage technologies are capable of achieving 24/7 operation [1].

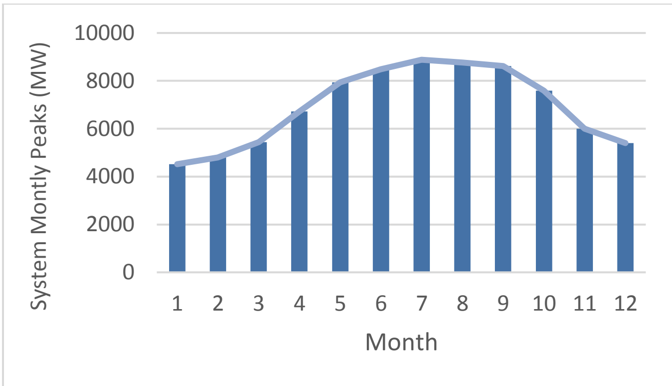

Fig. 2. Average monthly peak electricity demand for Abu Dhabi 2014

In Fig. 3, we can observe the monthly mean solar radiation in W/m^2/day for Abu Dhabi. We have included the time-series data of the NASA SSE model, which is more precisely the 22-year average global solar radiation data, as well as the currently obtained data in [19].

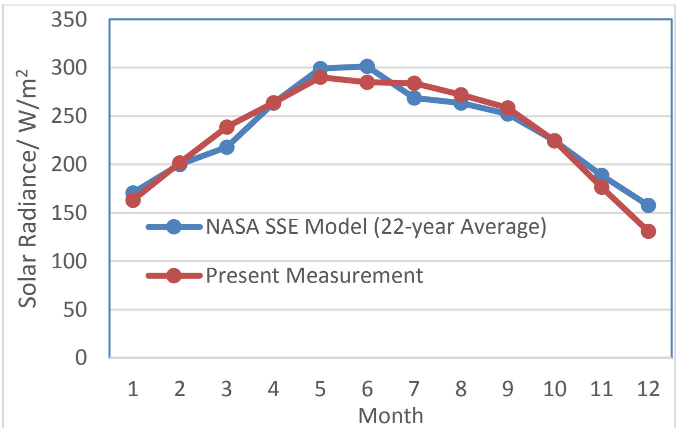

Fig. 3. Monthly mean solar radiation *W/m^2/day* for Abu Dhabi

Fig. 4 represents the temperature profile for Abu Dhabi, in terms of the highest, lowest, and average recorded temperatures in the last 5 years. Using this data, we define the parameters for obtaining the amount of produced solar energy by the two plants used in the proposed system, as shown in Table III. We use the data for July and January, where based on the average data in the last five years for Abu Dhabi, it is shown to exhibit the peak electricity demand and minimum demand, respectively. The global solar radiation and temperature data, as well as the data for the peak sunshine hours, has been generated using the Geospatial Toolkit.

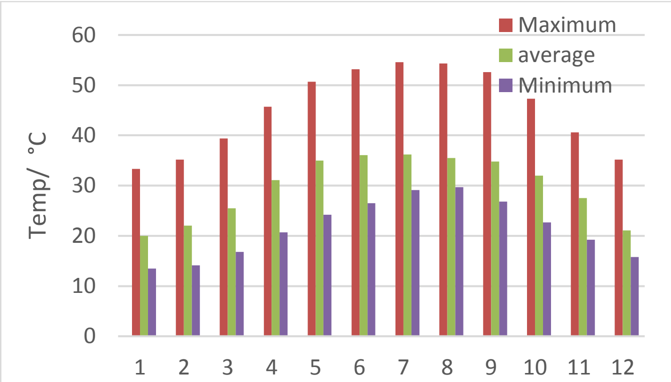

Fig. 4. Monthly temperature profile for Abu Dhabi.

MATLAB being the primary software used for running the optimization algorithm, and the optimized results we achieve are provided in Table IV. The results are within the minimum and maximum range of the generating units In addition to the tables containing the plant details required for simulation. Fig. 5 also shows the loss coefficients used for simulation. These results are then used to calculate the total cost of emission from the thermal generating units, as depicted in Table V with the optimized cost of emission being shown in Table VI. This is further illustrated using the graph Fig. 6 which shows that the total cost after optimization is less than a non-optimized case, as expected.

TABLE IV. OPTIMIZED POWER GENERATION USING GENETIC ALGORITHM.

Plant No.	p_i^{min}	p_i^{max}	Optimized Power 1 (MW)	Optimized Power 2 (MW)	Average Optimized Power (MW)
1	100	500	196.3489	196.3694	196.35915
2	50	200	135.6001	135.5750	135.58755
3	80	300	111.1526	111.1578	111.1552
4	50	250	247.7209	247.7227	247.7218
5	50	200	73.6140	73.6061	73.61005
6	50	120	55.6805	55.6777	55.6791

$$B_{ij} = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix},$$

$$B_{oi} = 1.0e^{-03*}[\,-0.3908 \quad -0.1297 \quad 0.7047 \quad 0.0591 \quad 0.2161 \quad -0.6635\,],$$

$$B_{oo} = 0.056.$$

Fig. 5. Loss coefficients.

Tables VII and VIII show the total cost when solar plants replace two of the thermal units. Their graphical illustration is shown in Fig. 7. It is noted in the tables that the total cost after optimization is less than without optimization in both the cases, and the scaled demand of 775MW is met. The location of loads has not been considered in this optimization. Also, the replacement is done by taking off the plants 1 and 6 because these thermal units are planned to retire in 2017 (Umn Al Nar an Al Mirfa) and the power generated from these plants is close to the output of solar plants. Also these are updated to meet the total power demand [20].

TABLE V. COST OF EMISSION FROM THERMAL GENERATING UNITS.

Plant No.	p_i^{max}	β_i($/MW)	Cost of Emission ($)
1	500	7.0	3500
2	200	10.0	2000
3	300	8.50	2550
4	150	11.0	1650
5	200	10.5	2100
6	120	12.0	1440
Total Power	1470	Total Cost	13240.0

TABLE VI. COST OF EMISSION FROM OPTIMIZED THERMAL GENERATING UNITS.

Plant No.	p_i^{max}	β_i($/MW)	Cost of Emission ($)
1	196.35915	7.0	1374.51
2	135.58755	10.0	1355.88
3	111.1552	8.50	944.82
4	247.7227	11.0	2724.95
5	73.61005	10.5	772.91
6	55.6791	12.0	668.15
Total Power	820	Total Cost	7841.20

TABLE VII. COST OF EMISSION FROM FOUR THERMAL GENERATING UNITS AND TWO SOLAR PLANTS.

Plant No.	p_i^{max}	β_i($/MW)	Cost of Emission ($)
1	100	59.8	5980
2	200	10.0	2000
3	300	8.50	2550
4	150	11.0	1650
5	200	10.5	2100
6	350	24.2	8470
Total Power	1007.91	Total Cost	22750

TABLE VIII. COST OF EMISSION FROM FOUR OPTIMIZED THERMAL GENERATING UNITS AND TWO OPTIMIZED SOLAR PLANTS.

Plant No.	p_i^{max}	β_i($/MW)	Cost of Emission ($)
1	61.06	59.8	3650.79
2	135.58755	10.0	1355.88
3	111.1552	8.50	944.82
4	247.7227	11.0	2724.95
5	73.61005	10.5	772.91
6	96.86	24.2	2344.01
Total Power	726	Total Cost	12345.44

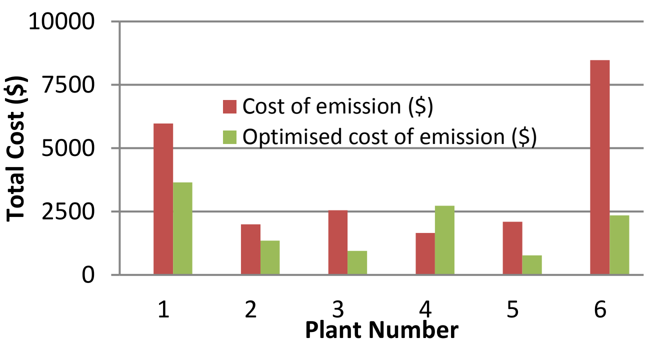

Fig. 6. Comparison of total costs for thermal generating units between the maximum power and the optimized powers.

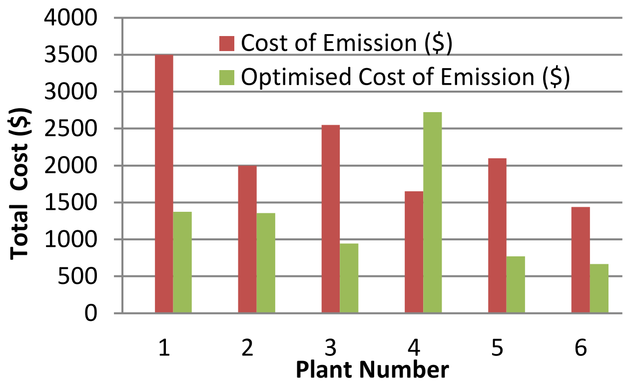

Fig. 7. Comparison of total cost for thermal generating units and solar plants between the maximum power and the optimized powers.

Thus, the aim of the paper to meet the objective function of minimizing cost is achieved. All capacities and costs used in the paper are according to the latest information available which may be subject to change when the bids are finalized [6]. Furthermore, the optimization of 1170MW in [6] has not been included as its viability is still being assessed by the relevant authorities in the UAE.

V. CONCLUSION

The aim of this research was to diversify the generation mix and economic dispatch for the most economic operation of power systems including renewable energy. This paper presents a detailed formulation of the economic dispatch problem, and the Genetic Algorithm is used to generate the optimum power from the proposed system. The aims to reduce the production costs were fulfilled and discrepancies in iterations can be contributed to the constraints imposed during the simulation. Hence, for future work this would be a major part to focus on i.e. to run OPF simulation using other power analysis softwares for comparison. Nevertheless, mathematical simulation itself helped to reach the conclusion that economic dispatch using Genetic Algorithm Optimization results in meeting the objective function of minimizing costs of production.

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