Microgrid cost optimization: a case study on Abu Dhabi

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Microgrid Cost Optimization:
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Abstract– **This paper presents a microgrid cost optimization study specifically focused on the United Arab Emirates (UAE) based on the Genetic and Ant-Bee Colony algorithms. The main objective of the paper is to identify size and amount of power supply sources in Microgrids that result in minimum cost. Specific parameters pertaining to the UAE were employed within the new objective function and constraints. Two different scenarios were tested, and their results have been discussed. During this study, it was evident that solar-PV systems were the second most cost-effective way to reduce cost of microgrids preceded by micro-turbines.**

Keywords- **Genetic algorithms; microgrids; optimization; power-generation dispatch; power systems.**

I. INTRODUCTION

The increasing consumer demand for clean energy has resulted in a global shift towards harvest of renewable energy; smart grids have become a focal concern for power distribu-tion companies. Renewable sources depend on environmental factors such as weather, making them unreliable as compared to non renewable sources of energy. Solar cells and batteries used should ensure continuous power supply while maintaining a long life-span. The disadvantages of batteries are its high initial cost and short life-span. Solar cells help charge the batteries during the day and are later discharged during the night. Therefore, optimization techniques must be applied to increase efficiency while decreasing cost of smart grids which will help toward better energy management in the region. [1]

Integration of the latest innovation and research into existing infrastructure will help the community grow. Several farms (known locally as "Ezba") and minor communities in the UAE are ready to be transformed using microgrids. The power grid infrastructure and weather conditions are unique in the region and are different as compared to other parts of the world in several ways such as reliable grid supply that exceeds demand, temperature conditions that shorten equipment life, sunlight is strong, day time is long, and weather is mostly clear, sandstorms and dust accumulation (sand movement) are also critical factors. The possible power load demands in such a country are as follows: air conditioners are considered the main loads in the UAE, followed by refrigerators, lighting, and TV's. For the farms, water pumps along with purifiers, to control the salt percentage in the water, are important. There are two types of lighting scenarios: the regular one allows workers to work at night, and special lights which are used for controlled plantation conditions. Environmental conditions, such as humidity might also need to be controlled. However, during the winter, electric heaters are a huge contributor to the loads, especially in the desert camps. Power demand by the community is mainly for cooling and heating systems. In the desert, the temperature is extremely high during the day, and cold at night. Therefore, it is common to have an almost constant power consumption during the day for cooling and heating systems. Farm equipment, timers, and other equipment also consumer power and add to the overall power demand. Additionally, the demand on electrical vehicles is growing dramatically. With the availability of electrical charging stations, electric vehicles are mostly promoted in remote areas such as the western Al Dhafrah region of the UAE. These loads follow specific pattern during the day, month, and the year. To simplify the analysis, we will be dealing with the averaged value of these parameters.

Hence, parameters used in existing researches conducted in Europe and eastern countries needs to be changed to match the Abu Dhabi data and constraints. Therefore, the objective function and constraint equations also needs to be changed to fit the UAE conditions. In this research paper, we present advanced algorithms to help optimize power sources in future microgrids in the UAE resulting in reduction of instantaneous costs and giving an insight into selecting the correct equipment to purchase for in case of an expansion.

II. LITERATURE REVIEW

In recent years, with the widespread effect of global warming, there has been a technological shift from non-renewable to renewable energy resources to produce electricity that can support a single or several cities [2]. A few countries have become almost completely reliable on clean energy. Within the clean energy sector, smart microgrids can help improve reliability and cost of microgrids. The idea is to have a clean energy generation coupled with smart distribution of power supply based on consumer side demands. Smart microgrids may be integrated to be a part of the community or part of the power generation grid [3]. The use of a hybrid systems was concluded to be the best to provide power to remote areas and to cut down on cost and power transmission loss without polluting the environment. Micro-grids are a hybrid energy system usually combining power grids with wind and solar or other various combinations to provide continuous and reliable power. The basic idea is to use the strength of one to overcome the weakness of the other [4, 5]. According to S. M. Dawoud et al, both wind and solar systems are non-reliable if there are insufficient capacity storage units like storage batteries or backup units like diesel generators. Thus, the reliability of the microgrids increases when both systems (wind turbine and photovoltaic) are combined with the storage devices. So, optimizing the system not only decides the required power generation by each device, but also the required parts and components associated with achieving this optimal value [6]. A microgrid is a hybrid system that usually consists of solar panels, wind turbines, charge controller, battery bank, and an inverter. The charge controller helps in controlling the power generation when needed and it is necessary to prevent overcharging the batteries. While, the inverter helps convert DC to AC for the AC loads [4, 7]. Renewable sources, batteries, and diesel generators are parts of a microgrid. The modern electric vehicle can act as both a source or end-product that requires charging [1].

Micro-grids have a huge impact on today's power grids. This is mainly due to their flexibility and scalability that have become a huge contributor towards smart grids. The distribution complexity in the case of smart grids is handled by considering them as Virtual Power Plants (VPP). Micro-grids operate both as a connected grid mode or as islanded mode. The microgrids as VPP can be controlled using software and hence become smart grids. In the grid connected mode the microgrid is controlled using current, while in the islanded mode, the VPP is controlled using voltage. The VPP may consist of several microgrids to help with communication and computation [8]. We can calculate reduced cost efficiency for power grids by using various meta-heuristic algorithms. Various algorithms developed throughout the decades since power optimization has been recognized as a potential problem that will only keep growing with time due to demand [1]. Various population sizes: 25, 50, 100, and 200 were run for 500 iterations in various optimization techniques to generate and compare best results [1].

Novel ideas of using flexible microgrids to increase power grid reliability is explored in [9]. Genetic Algorithm is used to control when the switches are thrown and the grid size to match the demand response. Although, reliability and cost has been improved in the study, power loss and power quality are neglected. Depending on the demand response, various microgrids can be formed to minimize cost and increase reliability [9].

Artificial Bee Colony (ABC) [10] is an evolutionary algorithm based on the Fibonacci sequence. It is interesting to note that it can be closely related to bees, wherein there are two types of bees, male and female. The male is the worker bee and the female are the queen. ABC assigns one queen for every food source while the worker bees scout for new food sources. The queen bee is responsible to make trips between the hive and the food source and to recognize the neighborhood of food sources and to calculate the food nutrition value. Food sources represent a possible solution, the nutrition value represents the quality of the food source. When a new food source is identified, a queen is allocated to it. The queen is responsible for bringing back the food. The scouts are responsible for finding every possible food source. Once the food source is depleted, the queen returns to the hive. If a better food source is found, the queen from a weaker food source will be reallocated else the queen with remain [10].

Optimization techniques has many applications in Power Engineering. Researchers in [11] developed an algorithm to minimize the cost to find the best size of PV-Wind-Biomass Grid-connected power system. Total cost of renewable energy's life cycle was compared to the expected revenue using Genetic Algorithm [11]. Other researchers [12] used both GA and PSO optimization algorithms to reconfigure shipboard microgrid power system. Reconfiguring the SMPS after the fault is very important to isolate the faulty part and maintain the power on the remaining system [12]. Furthermore, another group researched the problem of reactive power sharing in networked microgrid and proposed a virtual impedance optimization method [13]. The objective function is solved using GA in finding optimal parameters for virtual impedance controller [13].

This work covers microgrids and the design parameters and constraints specifically for the Abu Dhabi region. The design and implementation of the system is covered in Section III. Section IV includes the analysis and discussion of the results obtained. Finally, the conclusions are drawn in Section V.

III. Design and Implementation

The total cost per hour for system power generation is written as follows:

$$C_T = c_G + FM_{DG} + C_f(aP^2{}_{DiG} + bP_{DiG} + c) \tag{1}$$

where C_T is the total cost, FM_{DG} is the fixed and maintenance cost of the diesel generator, C_f is the diesel generator fuel cost multiplied by the quadratic function where P_{DiG} is the power generated by the diesel generator.

Finally, a, b, c are constants with values 0.246, 0.0815, and 0.4333 respectively.
The generation cost for various power generation equipment is:

$$c_G = Cost_{grid} + Cost_{DG} + Cost_{BES} + SUC_{MT} \quad (2)$$

where c_G is the summation of the cost of power grid supply, distributed generators, battery energy storage, and the start-up cost of the Micro Turbine. The grid supply cost is assumed to be consumed in the smart power grid.
If the power consumed from the grid is less than or equal to 200 kW, then:

$$Cost_{grid} = Bid_{gridLOW} P_{grid} \quad (3)$$

where $Bid_{gridLOW}$ is the minimum or lowest fixed trade rate for consumption of P_{grid} – supply power from the grid. The rate is fixed by the power distribution company from whom the consumer purchases power as required.
If the power consumed from the grid is greater than 200 kW, then:

$$Cost_{grid} = Bid_{gridLOW} P_{grid} + Bid_{gridHIGH}(P_{grid} - 200) \quad (4)$$

where $Bid_{gridHIGH}$ is the maximum or highest fixed rate for consumption of P_{grid} above 200 kW, as set by the power distribution company.
The cost of other distributed generators is given as:

$$Cost_{DG} = Bid_{MT} P_{MT} u_{MT} + Bid_{PV} P_{PV} + Bid_{WT} P_{WT} \quad (5)$$

where Bid_{MT} is the bid of the Micro Turbine, P_{MT} is the Power generated by the Micro Turbine, u_{MT} depicts the status of the Micro Turbine, either on or off, u_{MT} is taken as 1-unit value. Bid_{PV} is the bid of the Photovoltaic, and P_{PV} is the power generated by the Photovoltaic. Bid_{WT} is the bid of the Wind Turbine, and P_{WT} is the power generated by the Wind Turbine.
The cost for battery storage is assumed a constant that includes the fixed and maintenance cost of a 500 kWh battery that has been reduced to an hourly rate to suit the total cost per hour criteria, as introduced in [1].

$$Cost_{BS} = (FM_{BS})/(24 * 365 * Ex_{life}) \quad (6)$$

where Ex_{life} is the expected life of battery storage in years, and the constants are used to convert it into hours. The startup cost for the Micro Turbine is a constant as well where $Start_{MT}$ is the start-up charge of the Micro Turbine.

$$SUC_{MT} = Start_{MT} \quad (7)$$

$$FM_{DG} = NT(FM_{MT} + FM_{PV} + FM_{WT}) \quad (8)$$

The fixed and maintenance cost for the distributed generators include the Micro Turbine, Photovoltaic and Wind Turbines. NT is the operation duration in days. The layout of system structure under study is illustrated in Figure 1. Grid is considered as two-way component since it can be power source or power sink.

Genetic algorithm helps optimize the cost of a system depending on the load connected to the system. This helps to ensure minimized cost of operation of the smart grid. The equations mentioned in the previous section are used as the objective function in the fitness function of the genetic algorithm. The load power was assumed as 500 kW per day. In this paper, we present two scenarios. We identify the minimum constraint for all the source to be zero. Moreover, the maximum power supplied from Grid and Diesel Generator is set at 300 kW and 200 kW respectively. The first scenario allows high power supply from the remaining sources; Micro Turbine, Photovoltaic and Wind Turbine at 100 kW, 250 kW and 150 kW respectively. On the other hand, second scenario set low power supply for these sources at 10 kW each. The constraints are shown in the Table I for first scenario and Table II for the second one.

TABLE I. GENERATOR POWER CONSTRAINTS: SCENARIO 1

Generator	*Min Power (kW)*	*Max Power (kW)*
Micro Turbine	0	100
Photo-Voltaic	0	250
Wind Turbine	0	150
Grid	0	300
Diesel Generator	0	200

IV. RESULTS AND DISCUSSION

In this section, we tackle the results for both scenarios as follows:

A. *Scenario 1*

The optimized solution produced by the algorithm for a power demand of 500 kW per day was 11.43 AED/hour.

TABLE II. GENERATOR POWER CONSTRAINTS: SCENARIO 2

Generator	*Min Power (kW)*	*Max Power (kW)*
Micro Turbine	0	10
Photo-Voltaic	0	10
Wind Turbine	0	10
Grid	0	300
Diesel Generator	0	200

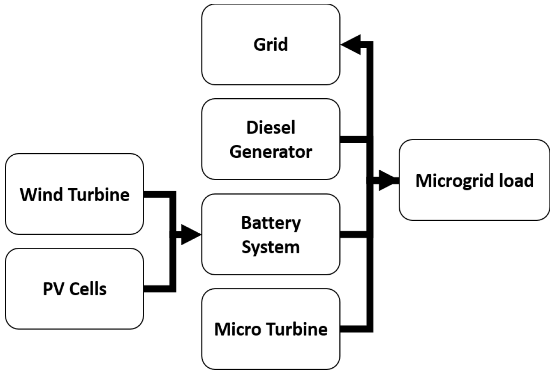

Figure 1: Layout of microgrid structure under study

The grid cost was taken as 26.8 fils/kWh and 30.5 fils/kWh if power consumption is below or above 200 kWh respectively on a monthly consumption basis. The optimized power generated by various generators is shown in Table III, where both optimization algorithms resulted in equal value. Among various possible supplied power variations, this was the most optimized power generation to acquire the minimum cost of power generation. We can see from Table III that Micro Turbine alone is very economical in this case. However, the two algorithms vary in terms of convergence, iteration and populations. These parameters are shown in Table IV. While fixing the population size of both algorithms at 500, GA finishes 15 iterations in 13.7 seconds, whereas ABC completes 200 iterations in only 10.8 seconds. Figures 2 and 3 present the convergence of the algorithms toward optimal value over the iterations. Since ABC has much more iteration number, we can see that the convergence curve smoothens and converges faster than GA.

TABLE III. RESULT OF OPTIMIZATION ALGORITHMS: SCENARIO 1

Power Component	***Optimized Power Generation (kWh)***
Micro Turbine	20.8333
Photo-Voltaic	0
Wind Turbine	0
Grid	0
Diesel Generator	0

TABLE IV. COMPARE RESULTS OF OPTIMIZATION ALGORITHMS: SCENARIO 1

	GA	***ABC***
Time (Sec)	13.6975	10.8285
Iterations	15	200
Population	500	500
Best value (AED)	11.4391	11.4278

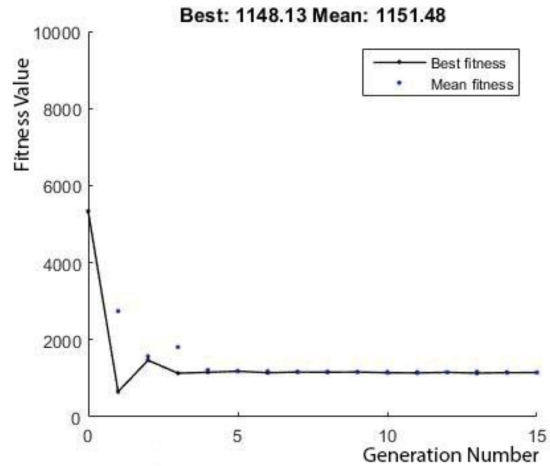

Figure 2. Convergence curve of GA for scenario 1

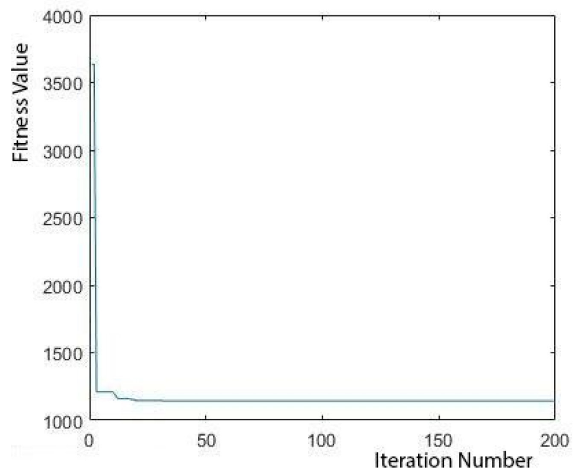

Figure 3. Convergence curve of ABC for scenario 1

B. Scenario 2

The optimized solution for scenario 2 where an upper bound was set to the micro turbine and a power demand of 500 kW per day was 18.76 AED/hour. The optimized power generated by various generators are shown in Table V, where both optimization algorithms resulted in equal value. ABC algorithm completed 200 iterations in 10.13 seconds whereas GA completed 15 iterations in 12.7 seconds. Furthermore, although ABC finished faster, the final best value settled much faster than GA. Therefore, ABC algorithm is much more reliable in seeking the best optimized result as compare to genetic algorithm where time is a crucial factor. Figures 4 and 5 present the convergence of the algorithms toward optimal value over the iterations. From these figures, it can be concluded that the best values in GA algorithm are not necessarily a valid value (i.e. the parameters are outside the constraints). This behavior is marked in red circle in Figure 4. Finally, the total saving by utilizing power sources and selling power to grid is shown in Table VII. We can see that even low power contribution by sources other than grid as in scenario 2 will result savings exceeding 126 AED.

TABLE V. RESULT OF OPTIMIZATION ALGORITHMS: SCENARIO 2

Power Component	***Optimized Power Generation (kWh)***
Micro Turbine	10.000
Photo-Voltaic	10.000
Wind Turbine	0. 8333
Grid	0
Diesel Generator	0

TABLE VI. COMPARE RESULTS OF OPTIMIZATION ALGORITHMS: SCENARIO 2

	GA	***ABC***
Time (Sec)	12.7014	10.1302
Iterations	15	200
Population	500	500
Best value (AED)	18.7641	18.7639

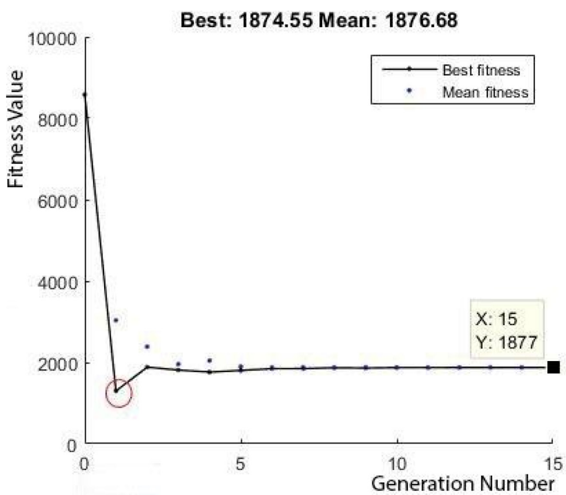

Figure 4: Convergence curve of GA for scenario 2

TABLE I. SAVINGS ANALYSIS FROM UTILIZING SOURCES WITHOUT GRID

	Cost (AED)	***Savings (AED)***
Grid only	145.1000	0
Scenario 1	11.43	133.67
Scenario 2	18.76	126.34

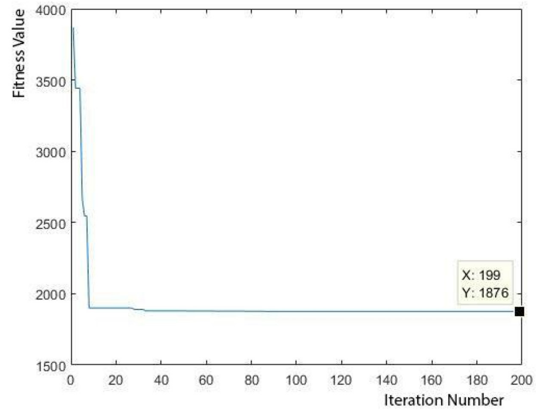

Figure 5: Convergence curve of ABC for scenario 2

V. CONCLUSION AND FUTURE WORK

The simulation results show that the use of micro turbines is the most cost-effective way to reduce cost of microgrids followed by solar panels. The other types of generators build up cost and is therefore not suited for microgrids. In scenario 2, an upper bound is set to the micro turbine to make use of the solar panels for power generation. The most cost-effective generators in descending order are as follows: Micro-Turbines, Solar Panels, Wind Turbines, Grid and Diesel Generator.

However, the cost can be further reduced if the generators can naturally generate power; solar panels and wind turbines; and the excess power is later sold back to the government. By allowing negative lower limit for grid power, the simulation yields a profit when power is traded at the same rate as it was purchased. Moreover, even with a vastly reduced sale rate by applying taxes up to 70%, the use of microgrids can be made quite profitable to sell to grid.

Utilization of different power sources and optimization method to find the best combination helps reduce the cost of microgrids. Genetic algorithm is the most commonly used algorithm. However, ABC algorithm is much faster and guarantees reliable results in a short period of time. The work was optimized for the United Arab Emirates, Abu Dhabi region using regional pricing for various generators and utility. UAE has a great scope for microgrids and can also become a future factor in contributing to the power grid of the region.

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