Improvement of the Existing Power Network of Industrial Enterprises through the Hybrid Microgrids

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***Abstract*— The shipbuilding industry is developing rapidly in our country and around the world. Thus, along with the construction and installation of new types of ships, the repair and periodic inspection of existing ships is also an important issue. Ship repairs are carried out at shipyards dry dock area. Preliminary research has shown that ships located in dry dock for maintenance and inspection receive electricity from external diesel generators. This is because the ships lost contact with the sea surface and can't use its own power generation network without a water-cooling system. There are shipyards with dry-dock that are not designed to meet additional power needs. Thus, the diesel generator systems used to power the ships while they are in the shipyard are accompanied by additional costs and harmful CO2 emissions. The novelty of this article is to show the possibility of Renewable Energy Sources penetration in industrial enterprises based on their working principles and to show the new approach of RES usage. The aim in this research is to optimize the net present cost of the power supply system, highlight the amount of the CO2 emission and to decrease it, accordingly. Our proposed project is to study the extent to which this problem can be solved using hybrid microgrids. To substantiate this idea, the following issues explored: (1) the structure of the existing electrical network of one of the shipyards and its annual energy consumption, (2) geolocation and potential solar energy sources for the area, (3) the design of a possible microgrid in island mode and its components, (4) simulation of microgrid design with HOMER software, (5) economic and environmental feasibility, (6) possibility of integration into the existing shipyard network, (7) simulation of microgrid design with HOMER Pro software.**

The disadvantage of using renewable energy networks is that the energy obtained is intermittent. However, since we are proposing a hybrid microgrid in parallel with the generator, this factor will not affect the new power supply network and will lead to a more stable and environment friendly system. The proposed system will provide power to ships with different power consumption requirements, as well as power-up other electrical consumers at the plant, when the dry dock is empty.

Keywords-component; Renewable energy sources, hybrid, microgrids, solar power potential, power system improvement

I. INTRODUCTION

There are a lot of ships in the world available for passenger, construction, transportation, and different kind of purposes and all these ships periodically requires hull and underwater parts and equipment inspection, maintenance, and Class reviews. For these reasons, the ships shall be separated from the sea and lifted on a dry dock.

During this period where the ship in dry dock, she can't be powered up from the own power network since the main diesel generators can't be used. The reason is that the generators are cooled by the seawater and since the ship have no contact with water the generators can't be cooled. In such case to power up the ship during dry dock external diesel generators are used.

Based on the ship load consumption required, diesel generators can be different size. In this study we use the two of 1010kW and 810kW diesel generators to power up a ship (medium-sized ship) with a load of 1000kW, 1650A. In addition to the cost of the generators, diesel consumption, special marine type of cables and accessories needed to connect the generators to the ship. According to preliminary reports, these generators can emit approximately 150 tons of CO2 gas into the environment within a week.

A. Methodology

This paper uses HOMER software to analyze the sensitivity, feasibility, and economic aspects of power system improvement via hybrid microgrid. The input data contains generator parameters, load profiles, fuel price, the installation cost of PV system, the operation constraints and so on. By using the following and some assumptions, the lowest cost can be calculated for PV/diesel system [1].

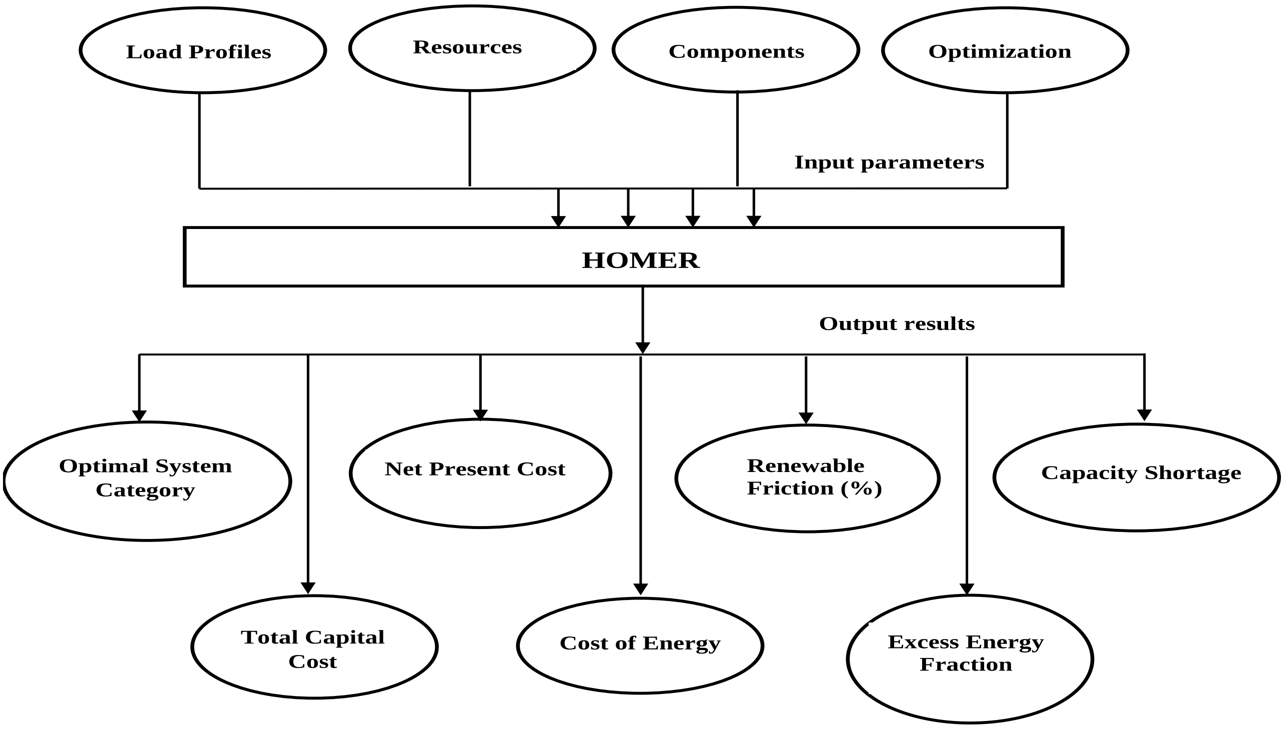

Figure 1. Simulation software architecture

B. *Simulation software*

HOMER is a simulation software developed by National Renewable Energy Laboratory (NREL). It combines engineering and economics to rapidly perform complex calculations, enabling you to compare design outcomes and consider options for minimizing project risk and reducing energy expenditures. The simulation analysis process of HOMER software architecture diagram presented in Fig. 1. [2]

C. *Location and background information*

This research study focuses on techno-economic feasibility analysis of the installation of hybrid microgrid to fulfill the additional power needs, thus, to improve the existing network of Baku Shipyard LLC enterprise located in Baku, Azerbaijan (Latitude 40.25, Longitude 49.75), Fig.2 and decrease fuel consumption and consequently the CO2 emission.

The enterprise is connected to the grid and has its own main and secondary substations to feed the shipyard load. Monthly energy consumption of the shipyard is shown in Table 1 and Fig.3:

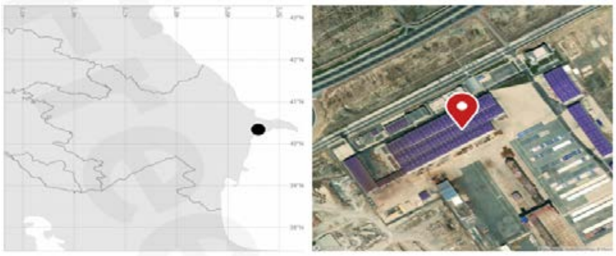

Figure 2. Geolocation of Baku Shipyard LLC

However, when there is a ship in a dry dock and it requires power supply, it is an additional load for the shipyard. It can be seen from the data presented that the shipyard annual energy consumption equals 15MWh.

Table 1. Monthly power consumption of Baku Shipyard

Monthly Power Demand	Active Power (MW)	Reactive Power (MVAR)
January	0	438
February	1588	438
March	1562	664
April	1128	1.1
May	1209.3	969
June	1134.5	506.2
July	1413.2	606
August	1018	379
September	826.5	306.4
October	1279.5	478.1
November	1164.8	543.1
December	1486.7	423.1
Total	**13810.5**	**5752**

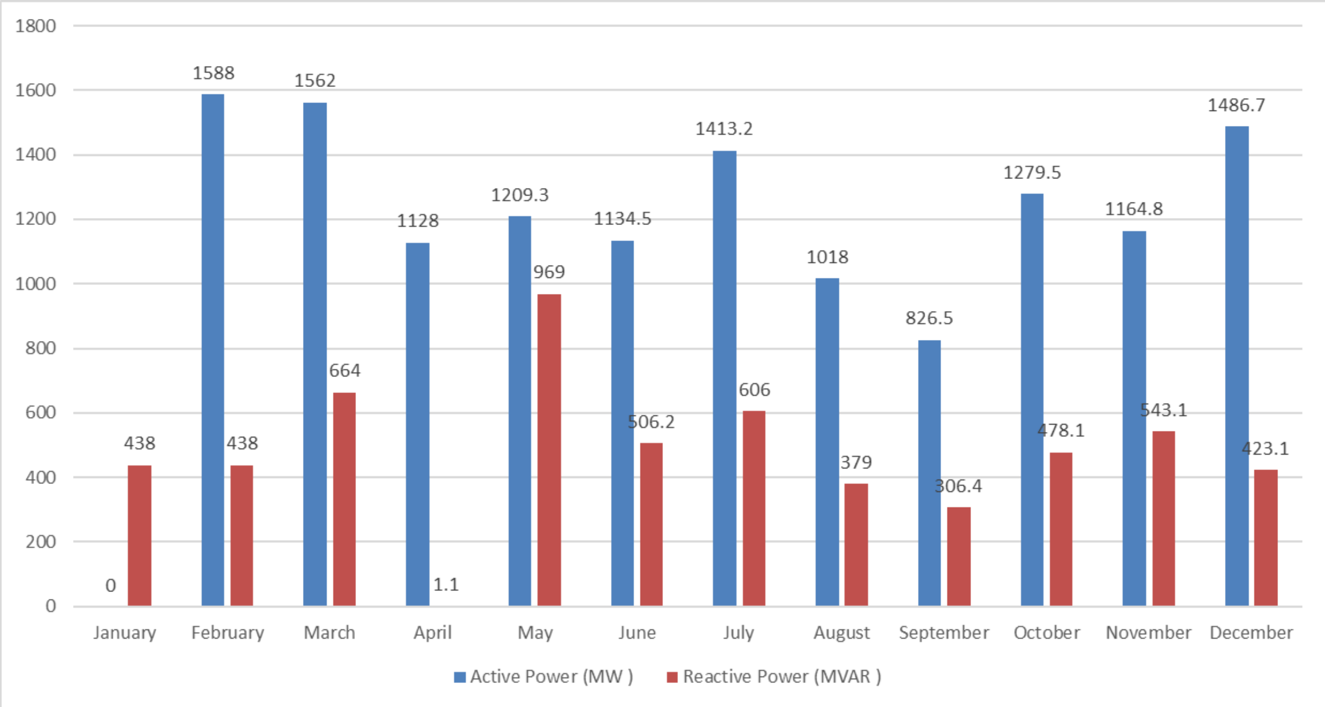

Figure 3. Monthly energy consumption of Baku Shipyard LLC

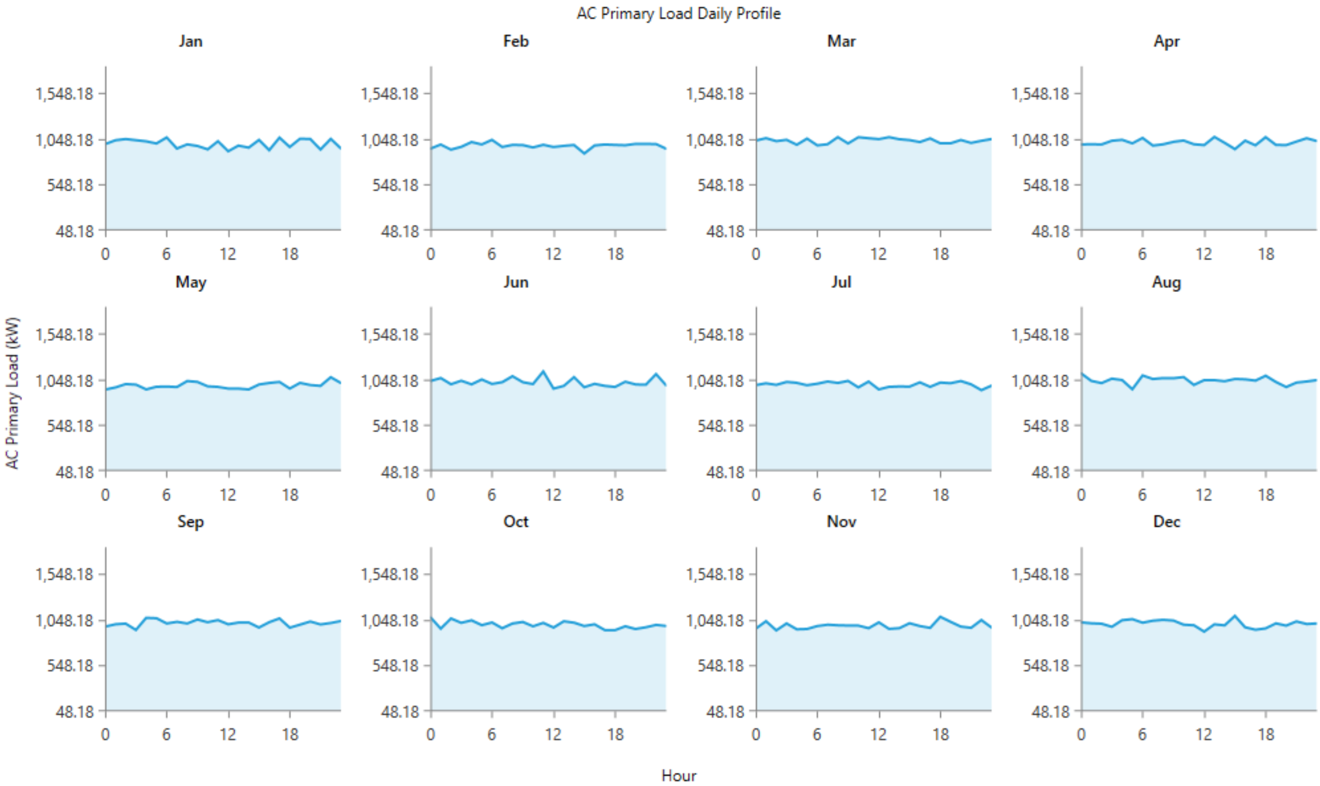

Figure 4. Daily Load profile of the ship in dry dock

Initially, we have considered that the hybrid microgrid can be integrated in the existing network and can feed the factory energy demand as well. But, in that case, a huge area will be required to install the PV power plant to get the required amount of energy. But the small PV/ diesel hybrid system can meet additional load demand of the shipyard. Therefore, in this study we have considered hybrid microgrid in an island mode to feed the ship in the dry dock of the shipyard with less environment harm and cost [2].

D. Load Profile

In this section, we present the load profile of the ship in dry dock. The required consumers to be powered up are the ship service load consisting of compressors, water mist system, galley, laundry and ventilation and heating equipment. All this equipment is AC load and need to be powered up for 24 hours a day. Monthly and seasonal load profiles are shown in Fig. 4 and 5. The load is considered industrial with no major changes in profiles. Average daily energy consumption is 24000 kWh/day, with 1833 kW peak. The shipyard dry dock is occupied with the ship during 80% of the year. For the simplicity of the research, we have considered that during the entire year the dock is full.

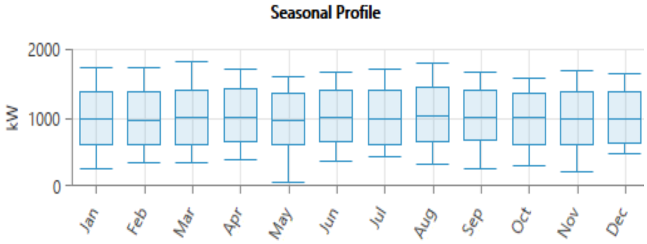

Figure 3. Seasonal load profile of the ship in dry-dock

E. Solar Irradiation Data

The statistic of global horizontal irradiation (GHI) is download via HOMER Software from NASA Prediction of Worldwide energy resources database and presented in Table 2 and Fig. 7. Table 2 shows the monthly averages of the GHI for the period of 22 years (1983-2005). The annual average of GHI is 3.85 (kWh/m2/day). The value of GHI is highest in July 5.99 (kWh/m2/day), lowest in December 1.64 (kWh/m2/day).

Table 2. Monthly averages of Global Horizontal Irradiation

Month	Clearness Index	Daily Radiation (kWh/m2/day)
Jan	0.455	1.91
Feb	0.472	2.64
Mar	0.473	3.59
Apr	0.489	4.7
May	0.506	5.58
Jun	0.536	6.21
Jul	0.531	5.99
Aug	0.509	5.14
Sep	0.489	4.04
Oct	0.463	2.86
Nov	0.433	1.95
Dec	0.435	1.64

F. Diesel Price Data

The diesel price in Azerbaijan has changed twice during the last 10 years. From 2013 till 2021 the price was 0.35 USD/l. In 2021 the price increased till 0.47USD/ l in order to increase the diesel quality and increase usage of renewable energy sources in country. This is regulated by Tariff Council of Azerbaijan republic and the rates will be valid till July 2022. Fig .6 [3]

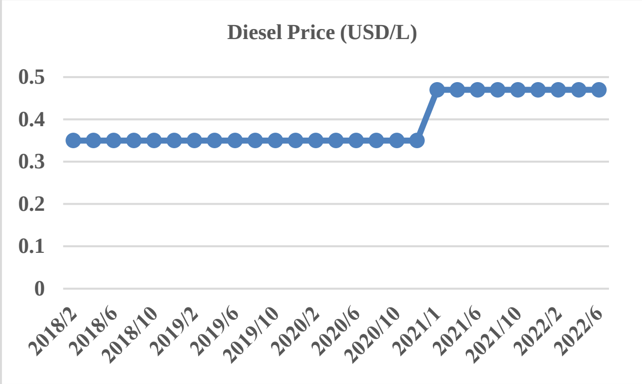

Figure 4. Diesel Price data variation

G. Economic assignment criteria

The annual interest rate, net present cost (NPC), capital recovery factor (CRF) and cost of energy (COE) are the main constraints considered in economic assignment criteria.

Annual real interest rate (1) is used to convert between one-time cost and annualized costs. HOMER uses the annual real interest rate to calculate discount factor and to calculate annualized costs from present costs [2]:

$$i = \frac{i' - f}{1 + f} \tag{1}$$

where i is annual real interest rate (%); i' is nominal interest rate (bank board rate) (%); f is expected inflation rate (%). The total of net present cost (NPC) value represents the cost of system life cycle in HOMER. Equation (2) shows the summation of the cash flow of the t-year over the factor and the initial capital cost. The costs contain capital cost, replacement cost, operation cost, maintenance cost, fuel cost and so on. The income contains electricity selling and the residual value after life cycle:

$$NPC = CF_0 + \left\{ \frac{CF_1}{(1+i)^1} + \frac{CF_2}{(1+i)^2} + \frac{CF_3}{(1+i)^3} + \cdots + \frac{CF_N}{(1+i)^N} \right\} = CF_0 + \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t} \tag{2}$$

where CFt is the cash flow of the t-year and based on the definition of the HOMER software the expenditure is positive and the income is negative ($); i is the annual real interest rate (%); N is the project life time (year); t is the number of years (year); CF0 is the initial capital cost ($).

The capital recovery factor (CRF) is the ratio used to calculate the present value of the annuity during the project lifetime [4]:

$$CRF(i,t) = \frac{i(1+i)^t}{(1+i)^t - 1} \tag{3}$$

where t is the number of years (year); i is the annual real interest rate (%).

Figure 5. Global Horizontal Irradiation

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electric energy generated by the system. It is calculated by dividing the total annualized cost (TAC) by the total annualized useful electric energy production. The COE unit is $/kWh. The TAC is the annualized value of NPC, and its unit is $/year.The equation is as follow [3]:

$$TAC = NPC * CRF(i, N) \quad (4)$$

$$COE = \frac{TAC}{E_{prim}} \quad (5)$$

where E_{prim} is the annualized primary served load (kWh/year); N is the project lifetime (year).

II. HYBRID SYSTEM DESCRIPTION

A. System Schematic

The schematic diagram of proposed hybrid system revealed in Fig. 10, and it consists of diesel generator and PV system. The storage system and power conversion system are not considered in this study. The PV system operated in parallel with the bigger diesel generator, which is 1010kW and uses AC coupled. The electricity produced by the PV system during the day can be supplied to the AC load to decrease the output of diesel generators and reduce fuel consumption [5] and [6]. The other generator 810kW is considered to be used only in an emergency or main generator maintenance period.

B. PV System

The method of power generation by PV module is through the conversion of solar energy into DC power. The identification, adoption, and utilization of reliable interconnection technology to assembly crystalline silicon solar cells in PV module are critical to ensure that the device performs continually up to 25 years of its design life span [5] (Zarmai et al. 2015). For the simulation, the PV module selected is a LONGi Solar LR6-60PB model with mono-crystalline silicon solar cell type and the specifications are as follows: 305 Wp rated power, 18.7% efficiency, 0.380 coefficient of power temperature, 25 years working life and 80% derating factor.

C. Diesel Generation

For this research, two of diesel generator (DG) used with different capacity as shown in Table 3. The schedule of power supply is according to the load as to meet the power demand of the ship, where the minimum load is 50% of the total rated capacity. In the existing power supply system, the two number of generators are working in parallel, however in a proposed system PV station is working in parallel with one of the generators. The second generator is an emergency power supply.

Table 3. Generator simulation parameters

Generator	Technical Parameters			
	Rated Capacity (kW)	***Model / Type***	***Fuel Consumption (l/hrs)***	***Running time (hrs/day)***
DG1	1010	CAT-1010kW-60Hz-CP	36.4	24
DG2	810	CAT-810kW-60Hz-PP	21.7	12

D. Componenets cost

The cost of components for the simulation is based on market survey and shown in Table 4. The cost can be divided into capital cost, replacement cost, operation, and maintenance cost (O&M). The cost of capital is as the same as the cost of replacement so that simplify the analysis. In PV system, the capital cost is 1500 US$/kW, and it contains PV module, PV inverter, mounting hardware and other balance of system, transportation, installation engineering and so on [6].

III. SIMULATION RESULTS

A. Stand alone diesel generation

In this section the result of the simulations for the current and proposed configuration is presented. The simulation with 2 generator is done to see the initial values of CO2, fuel consumption, NPC and other economical parameters and be able to compare with the proposed solution [7],[8],[9].

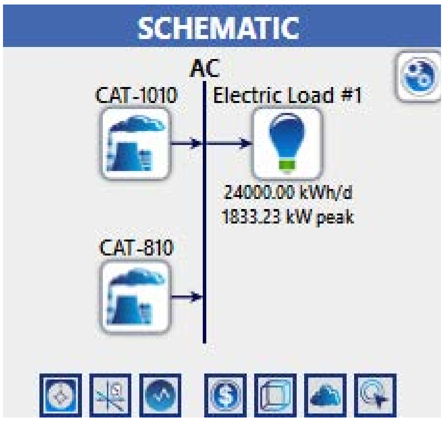

Figure 6. Existing system schematic diagram

Table 4. Summary of components cost for the hybrid PV/Diesel generation

Description	Capital Cost
PV System	
Capital Cost (USD/kW)	2000
Replacement cost (USD/kW)	2000
Operation and Maintenance cost (USD/kW)/year)	20
Diesel Generator	
Capital Cost (USD/kW)	500
Replacement cost (USD/kW)	400
Operation and Maintenance cost (USD/h)	0.005

Table 5. Economical characteristics and simulation results of stand-alone diesel generation (a); (b)

Generator	**Economic characteristics**					
	Capital Cost (USD)	***Replacement cost (USD)***	***O&M (USD)***	***Fuel Cost (USD)***	***NPC (USD)***	***COE (USD)***
DG1	1,050,000.00	1,570,685.86	$498.36	6,942,479.88	9,527,312.14	0.1686
DG2	1,000,000.00	466,252.50	$435.72	8,125,998.40	9,562,174.94	0.1686

Generator	**Simulation Results**			
	Hours of Operation (h/year)	***Electrical Production (kWh/year)***	***Fuel Consumption (l/year)***	***Specific Fuel Consumption (l/year)***
DG1	7,710	3,656,534	1,142,620	0.312
DG2	7,710	5,103,619	1,337,408	0.262

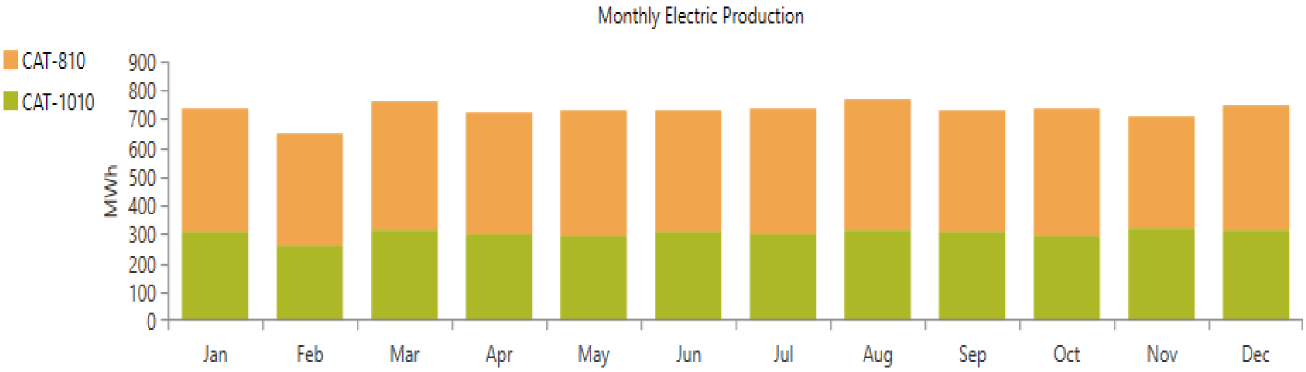

Figure 7. Monthly electric production

Table 4 shows the economical characteristics of the existing power supply system of the ship in dry dock. The total fuel consumption is 2,480,028 l/year and total CO2 emission is 6,553,025 kg/year. The output power supply for each month is illustrated in Fig.9. There is an unmet electrical load 13.2kwh/year and the capacity shortage 0.0125%. The total NPC of the system is 19.1M USD.

B. PV/Diesel Hybrid System

This section describes the proposed system parameters and the winning system architecture [10]. PV and Generator system have been simulated and the results are presented below:

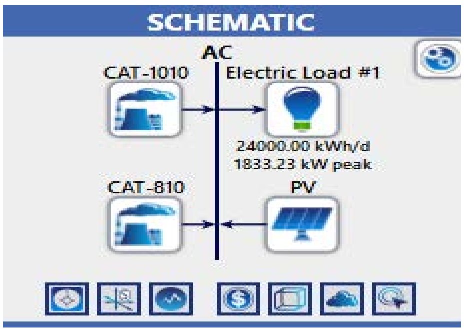

Figure 8. Winning system architecture

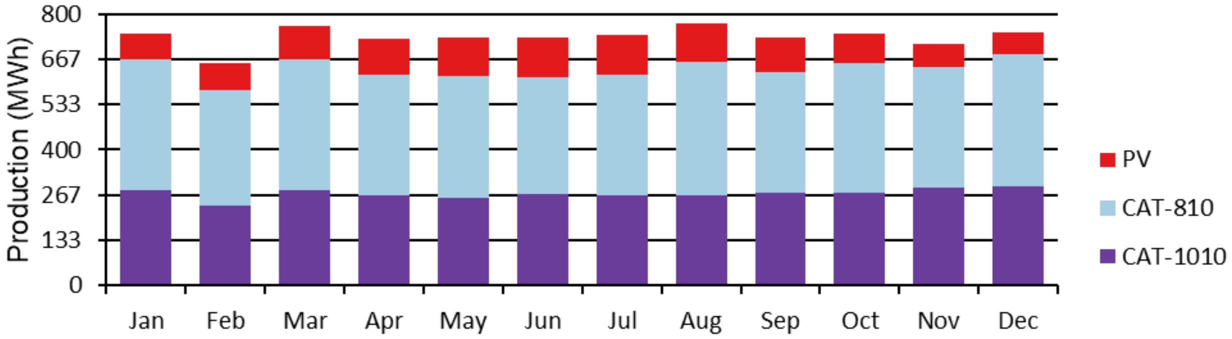

Figure 9 Monthly Electrical Production

Table 6. Economical characteristics and simulation results of hybrid PV/Diesel generation (a); (b)

PV/Diesel Generator	Simulation Results			
	Hours of Operation (h/year)	*Electrical Production (kWh/year)*	*Fuel Consumption (l/year)*	*Specific Fuel Consumption (l/year)*
DG1	7,496	3,247,995	1,038,497	0.320
DG2	6,578	4,401,830	1,170,047	0.266
PV System	4,379	1,144,215	0,00	0,00

PV/Diesel Generators	Economic characteristics					
	Capital Cost (USD)	*Replacement cost (USD)*	*O&M (USD)*	*Fuel Cost (USD)*	*NPC (USD)*	*COE (USD)*
DG1	1,050,000.00	1,541,790.84	484.52	6,309,835.75	8,838,844.84	0.1663
DG2	1,000,000.00	457,475.92	425.19	7,109,125.85	8,525,639.35	0.1663
PV System	1,350,056.25	0,00	117,262.21	0,00	1,466,408.75	0.1663

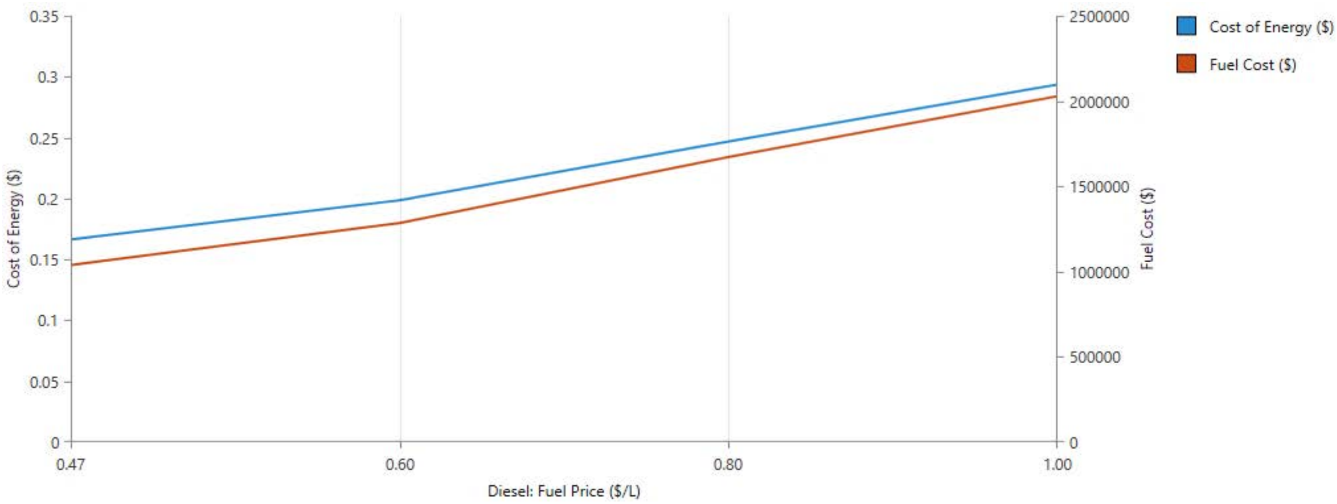

Figure 10.Effect of varying diesel price on COE.

By proposing hybrid microgrid we are adding 900 kW of PV to the existing system. This would reduce the operating costs to $1.19M/yr. The investment has a payback of 11.4 years and an IRR of 7.86%. This microgrid requires 23995 kWh/day and has a peak of 1820 kW. In the proposed system, the following generation sources serve the electrical load Fig.11. The PV system has a nominal capacity of 900 kW. The annual production is 1,144,215 kWh/yr. Power output from the Caterpillar Inc. generator system, rated at 1,010 kW using diesel as fuel, is 3,247,995 kWh/yr. Power output from the Caterpillar Inc. generator system, rated at 810 kW using diesel as fuel, is 4,401,830 kWh/yr as per Table 6. Since the system dispatch strategy has been changed the working hours of each generator decreased. This lead to fuel consumption and CO2 emission decrease 5,835,566 kg/year, which is 10% of the existing system. NPC decreased up to 3% due to O&M cost decrease. The capacity shortage is also decreased up to 0.00840%.

IV. Sensitivity analysis

As it was mentioned in the previous section the diesel price increase is expected in the coming years. The simulation results presented in previous section are done by taking into account the current price of diesel which is 0.47 USD/l. By using the HOMER software, we have done the sensitivity analysis for the diesel price increase up to 1USD/liter [11]. The results are shown on Fig.12. The effect of varying diesel price can be observed in a setting range of GHI and valid for the proposed solution. For example, when the fuel price is 0.6 USD/L the COE exceed 0.25 USD/kWh. In the extended version of this paper sensitivity analysis are performed for the load consumption and GHI increase.

V. Conclusion

The world experience of completed projects shows that autonomous electrification systems based on renewable energy sources are the most acceptable in comparison with systems with traditional sources. However, it should be noted that MG isolated systems require several technical and organizational problems to be solved. In fact, from each implemented project of the MG RES system, some recommendations can be drawn when designing similar projects in similar geographic locations. High penetration of PV system requires the number of calculations and simulation to choose the optimal size of the components, add conversion system or flywheel.

One of the important goals of the conducted research is the efficient use of the potential of renewable resources to cover the needs of industrial enterprises. It has been achieved reliable system with twice less capacity shortage percentage, decreased CO2 emission up to 10% and economically feasible with less O&M cost in comparison with the existing power supply system. Increasing the accuracy of determining the synchronous temporal variability of power generation by solar PV modules and will allow creating a model of a priority combination of PV and generation power values in the current periods of load power changes.

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