Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2017, 4(9):383-391**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Effect of Some Parameters on the Cost of Energy Generated from Renewable Energy based Micro Grid System

M.A. Fouad[1], M.A. Badr[2], Z.S. Abd El-Rehim[2], Taher Halawa[1], M.M. Ibrahim[2]

[1]Mechanical Power Engineering Dept, Faculty of Engineering, Cairo University, Egypt
[2]Mechanical Engineering Dept, National Research Centre, Cairo, Egypt

Abstract Smart grid system is presently considered a reliable solution for the expected deficiency in the power required from future power systems. The objective of this study is to investigate the effect of some economical parameters such as the change in inflation rate, diesel fuel price, purchase, and selling price of electricity, on the cost of energy generated from the system. In addition to these parameters, the effect of the expected increase in Photovoltaic (PV) efficiency as stated in recent reviewed researches is also investigated. The study also illustrates the cash flow diagram for on-off grid system. The results showed that the effect of grid connection increased Net Present Value (NPV) from $14528 of off-grid system to $18106 of on-grid system, decreased Cost of Energy (COE) from 0.316$/kWh; for off-grid system, to 0.266$/kWh for on-grid system. The investigation of the effect of inflation rate showed that the increase in inflation rate from 3% to 7% causes an increase of 9% in the Net Present Cost decrease of 7% in COE (from 0.287 to 0.21$/kWh). At higher grid selling price (0.1125 $/kWh) & lower purchase price (0.088$/kWh) grid cost, Minimum Net Present Cost (NPC) and Cost Of Energy (COE) happened. The recorded increase in the NPV of the micro-grid due to increase in PV efficiency, hence PV output; was 15% for an increase of 45% PV efficiency.

Keywords Micro-grid system, Renewable Energy Sources, Distributed Generation, Economical Evaluation, Net Present Value, Cost of Energy, PV Efficiency

1. Introduction

As development is quickly taking place all around the world, in the requirement for electricity is extremely increasing and expected to continue in the future. To moderate climate change, clean energy generation is the answer. Thus it is vital now to rely on renewable energy sources to supply as much as possible energy demand, saving the limited fuel resource and reduce green house gases emissions [1]. Hence, more attention is directed to renewable energy smart-grid technology. The mixing of a large number of distributed generations into distribution networks is limited due to the constraint of the networks capacity and unidirectional power flow behavior [2, 3]. This integration results in progressing the system efficiency and reliability raising the awareness of the significance of using renewable energy sources.

Smart grid is a model of energy management in which the users are occupied in producing energy as well as consuming it, while having information systems fully aware of the energy demand-response of the network and of dynamically varying prices. This study [4] proposal, enhanced with economic considerations of the costs of such revolutions in terms of cabling expenses and economic benefits of evolving the grid.

Smart grid technology can be defined as independent systems that can get quick solutions to problems in an available system that reduces the labor force and targets sustainable, reliable, and safe quality electricity to consumers [5]. In this prospect, different technological applications can be seen from the viewpoint of researchers and investors. Even though these technical studies are just considered as an initial step for the structure of the smart grid, they are not totally completed in many countries. The authors of this research reviewed the scientific methods of data transmission and the energy efficiency in smart grids plus smart grid applications that proposed an important directing source for researchers and engineers studying the smart grid.

In addition, they are able to develop system reliability, efficiency, and security leading to more endorsement of the renewable energy sources integration [6]. Adopting micro-grid concept enables the integration of several micro generators without disturbing the network operation, synchronizing micro generation with loads [7].

Two studies of the micro-grid effect on the decreasing of cost though improving the reliability of small scale distributed generators using different optimization techniques were exhibited [8, 9].

Sigrist et al developed an incorporated approach to cost-effective charge initiatives that can transform island power systems into smart ones. Single and multi-action initiatives that promote the use of RES, Energy Storage, and Load Management are considered. The different investment costs of the initiatives are accounted for determining their equivalent Internal Rate of Return (IRR) through their lifetime [10]. Multi-action initiatives achieve highest system operation cost reduction, while single action initiatives yield to maximum IRR.

Among the expanding PV technological and economic development, there is a prospective for mass-scale operation of grid-connected and off-grid power systems. The challenge arises in analyzing the economic projection on compound hybrid systems utilizing PV. A new metric levelized cost of delivery was investigated to estimate the levelized cost of electricity for using Photovoltaic in the smart grid system [11]. Another review [12] on up-to-date levelized cost of electricity calculation methods for PV system was described, highlighting the possible shortcoming of existing methods.

Photovoltaic panels are one of the majority useful, sustainable, and environmental products in the field of renewable energy [13, 14]. Photovoltaic module efficiency decreases as module temperature increases [15]. Radziemska [16] experimentally investigated the result of temperature and initiate a decrease of about 0.65% power output and 0.08% efficiency conversion of the Photovoltaic cell for every $1^{o}K$ increase in cell temperature.

This paper is organized as follows: Section 1 reviews of economical smart grids; Section 2 presents system parts; Section 3 shows effect results of the financial analysis of smart grid evaluation and Section 4 illustrates conclusions that concluded this study.

2. System Components

The suggested system is applied on a case study in an Egyptian site [17]. The site is National Research Centre (NRC) farm in Noubarya which is considered as an experimental field for different research activities. The main farm activity is agricultural; hence the crop residues are used to produce fodders for the animal farm. As the farm has a sandy soil, hence it is recommended to add hydrogel to reduce the amount of water required for irrigation. Based on these needs, two small factories are established; one for animal fodders production; with 26 kW peak load, and the other for hydrogel production with 18 kW peak load. The Micro-Grid System (MGS) is planned to supply the required electricity of these small factories. The In this study the system comprises a small wind turbine and photovoltaic, in addition to battery bank and diesel generator in off-grid case. The MGS system components as follows:

2.1. Photovoltaic Panel (PV)

Photovoltaic panels are usually manufactured from semiconducting materials that transform light into electricity. The PV power depends mainly on solar radiation and efficiency of solar panel.

There have been key changes in the principal costs, industry structure, and market prices of solar photovoltaics technology over the years. This is due to the fast price change, PV supply chain which involves a large number of manufacturing processes, stability of PV system, and their installation costs. Financial incentives for photovoltaics, such as feed-in tariffs, should be established in order to enable consumers and private sector to install and operate solar-electric generating systems [18]. Some governments offer incentives to encourage the PV industry to compete when the cost of PV-generated electricity is above the cost from the existing grid. As the demand for PV is increasing, their cost and price is expected to decrease in the years to come.

There has been aggressive competition in the supply chain and further improvements in the levelized cost of energy, posing a growing threat to the control of fossil fuel generation sources in the next few years [19]. As time progresses, renewable energy technologies generally get cheaper, while fossil fuels generally get more expensive.

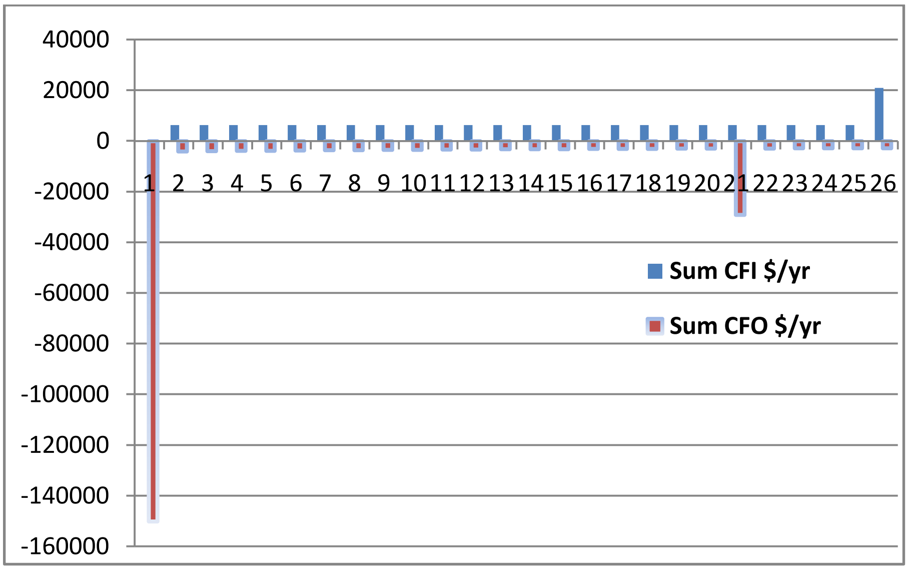

Figure 1: Cash Flow Summary In/Out of On-Grid System

The calculated Net Present Value (NPV) of this system is $18106.

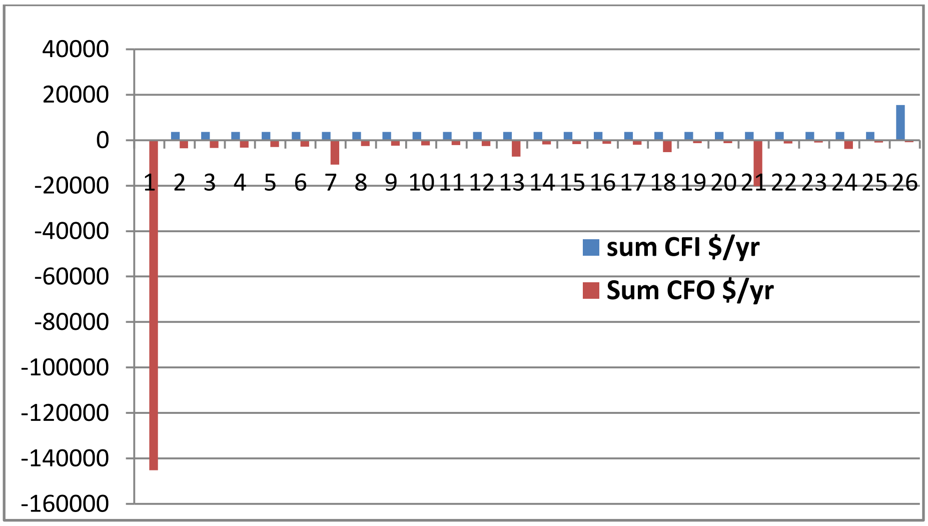

Figure 2: Cash Flow Summary In/Out of Off-Grid System

2.2. Wind Turbine (WT)

The price of wind power is much more stable than the unpredictable prices of fossil fuel sources. However, the estimated average cost per unit of electric power must include the cost of construction of the turbine and transmission facilities, interest of borrowed funds, return to investors (with cost of risk) [20], anticipated annual production, averaged over the projected useful life of the equipment, which can be beyond twenty years. The cost is continuously reduced as the technology improves; i.e. improvement in turbine performance and better power generation efficiency.

2.3. Battery Bank (BB)

Two important factors are taken into consideration when sizing battery bank; allowable bank capacity and Depth of Discharge (DOD). Some of the benefits of including energy storage in the electricity system are the storage' abilities to help integrate wind and solar energy, improve grid reliability, and increase the economic efficiency of the electricity system. Grid-scale battery storage has been deployed in a number of applications.

2.4. Diesel Generator (DG)

Photovoltaic panel and wind turbine are known to be irregular, so a backup source is needed to guarantee supply stability. Diesel generators are generally used in remote sites not connected to the utility grids or as emergency power-supply in case of grid failure. In case of off-grid system (e.g. renewable sources) it is used as a backup. DG is sometimes used to charge the batteries to increase its state of charge to an adequate state. Proper sizing of diesel generators is critical to avoid low-load ratio or power shortage. The diesel generator size depends mainly on operating working hours.

2.5. Converter

Bi-directional converter is crucial in case of integrated energy system. Converter used for convert the dc to ac current as an inverter and from ac to dc current as a rectifier. Efficiency is very important factor in choosing converter size.

3. Results of Investigated Parameters

3.1. Cash Flow Diagram (CFD)

Figure 1 shows the cash in and out of on-grid system while figure 2 presents cash flow in and out for off-grid system. The cash flow-in is mainly the price of all generated electricity (solar, wind, and excess) and cash flow-out includes the costs of (capital, replacement and operation). In case of on-grid the price of energy sold to the grid is added to the cash flow-in and the cost of energy purchased from grid is added to the cash flow out.

The calculated NPV of this system is $14528. Then the on-grid system is more economical than off-grid system as it has a higher NPV.

From figure 1 & 2 it seen that the salvage value at the end year of on-grid system is about $15000 and $11000 for off-grid system so.

3.2. Effect of Change in Inflation Rate on NPC

Nowadays, the prices of all goods and services have increased in Egypt as a result of the liberation of the Egyptian pound [21] which these rates are taken into consideration comparing to dollar price in 2016. This caused an increase of the inflation rate. Thus, sensitivity analysis is applied to investigate the effect of the change in inflation rate on NPC, COE. The results of inflation rate sensitivity analysis are shown in table 1 and figure 3.

Table 1: Sensitivity Analysis Results of the Change in Inflation Rate (%)

Interest rate (%)	Inflation rate (%)	Real interest rate (%)	NPC ($)	COE ($/kWh)
10	3	7	180,955	0.287
10	4	6	184,374	0.266
10	5	5	188,243	0.247
10	6	4	192,606	0.228
10	7	3	197,501	0.210

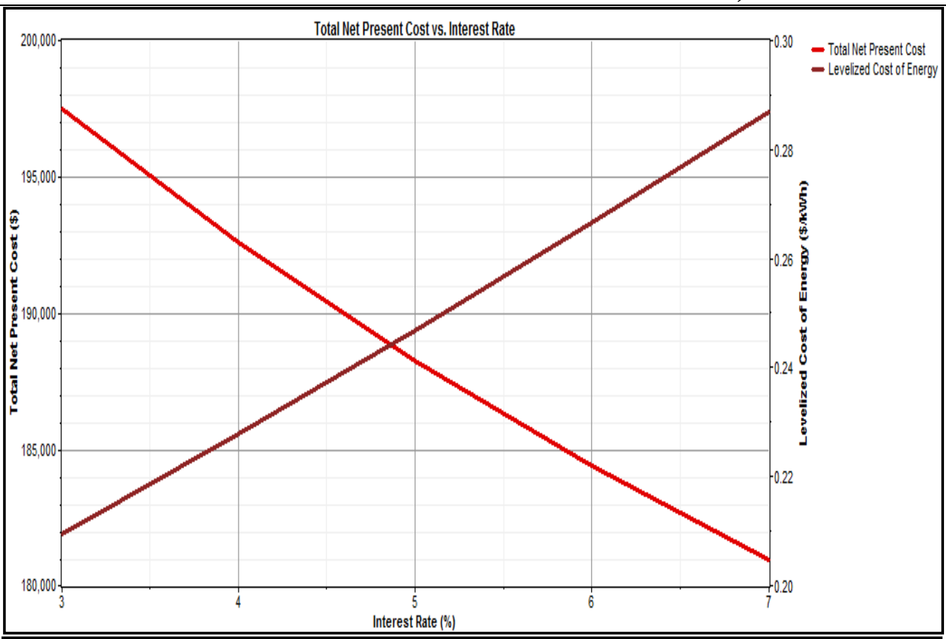

Figure 3: Sensitivity Analysis Results of Inflation Rate %

It is noticed from above figure that NPC increases and COE decreases when inflation rate increases following real interest rate decreases. Inflation rate has significant effect on NPC and COE.

3.3. Effect of the Price of Electricity Grid on NPC & COE

The effect of changing wind speed, purchase and selling price of electricity are presented in table 2. For the case under study the investigated purchase and selling price are (0.088, 0.156, 0.169 & 0.1125, 0.156) $/kWh [22]. Average solar radiation and wind speed used in this analysis are 2.57 kWh/m^2/day, 5.5 m/s respectively, and the optimum system configurations are:

- 137 PV panel, 0.180 kW rated power each, 25 kW overall
- 3 wind turbines, Generic 10, 10 kW rated power each.
- 20kW grid purchases.
- Converter, 20 kW size.
- Initial capital cost = 150,167$
- Dispatch strategy: Load Following (LF)

The net present cost (NPC) of the system is 184,347$ over 25years (project life time). The cost of energy (COE) is 0.266$/kWh and the renewable fraction is 71%.

Table 2: Optimization Results of Sensitivity Analysis of Grid electricity Price for Noubarya Site

Purchase From Grid $/kWh	Selling to Grid $/kW	Total NPC ($)	COE ($/kWh)	Renewable Fraction (%)	Exc. Electricity (%)
0.088	0.1125	184,347	0.266	71	9
0.156	0.1125	190,337	0.275	71	9
0.156	0.156	187,621	0.271	71	9
0.169	0.1125	191,547	0.277	71	9

From the above table, it is clear the minimum Net Present Cost (NPC) and Cost Of Energy (COE) occurs at higher selling price & lower purchase price. An increase of 8.3% in the price of electricity purchased from grid causes an increase of 0.64% in the NPC, and a decrease of 1.14% in COE. While an increase in the selling price of 4.35% will cause a decrease of 1.43% in NPC and 1.45% in COE. Figure 4 is an illustration for these relations.

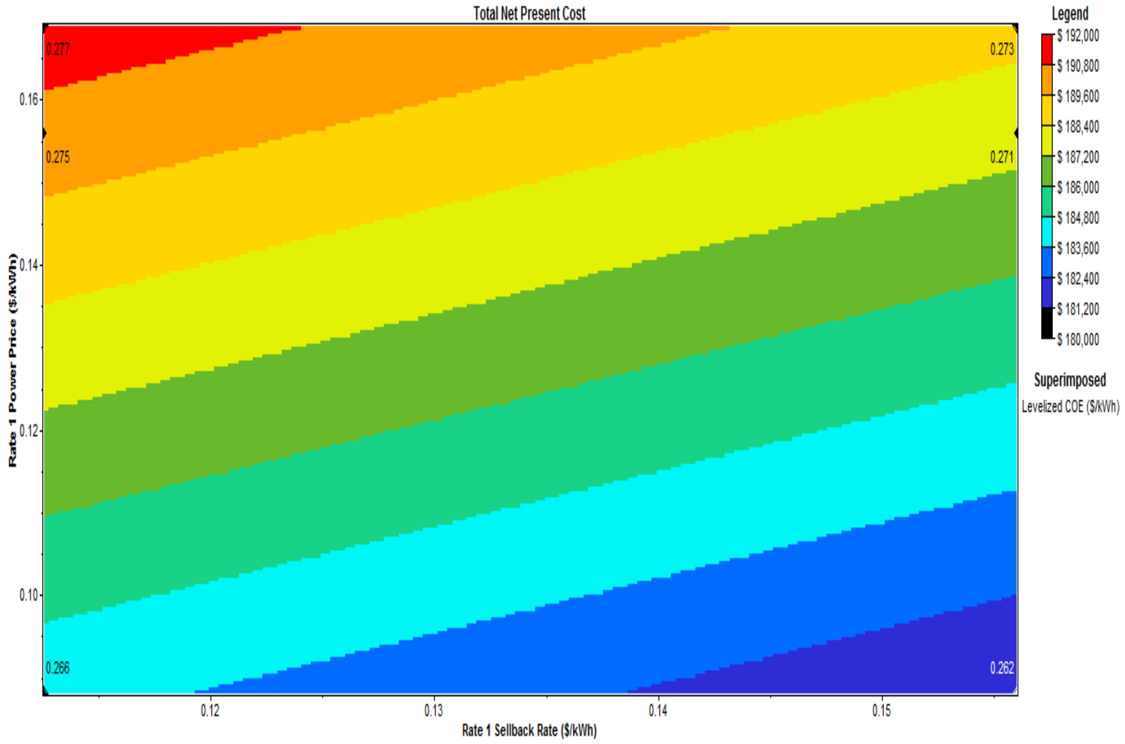

Figure 4: Grid Electricity Price relation versus NPC & COE

3.4 Effect of the Diesel Fuel Price on NPC & COE

Table 3 shows a summary of the optimization results using different diesel fuel prices. The investigated average diesel price is (0.15, 0.2, 0.25, 0.3, and 0.1) $. Average wind speed and solar radiation used in this analysis are (5.5m/s, 2.57 kWh/m^2/day) respectively.

Table 3: Optimization Results of Sensitivity Analysis of Diesel Price for Noubarya Site

Diesel Price ($/L)	D.G (kW)	Disp. Strategy	Initial Capital Cost ($)	Operating Cost ($/yr)	Total NPC ($)	COE ($/KWh)	R. F. (%)	Excess Elec (%)
0.1	20	LF	145,138	5,820	219,543	0.313	72	19.8
0.15	20	CC	145,138	6,061	222,617	0.316	71	19.8
0.2	20	CC	145,138	6,519	228,467	0.324	71	19.8
0.25	20	CC	145,138	7,013	234,786	0.334	72	19.8
0.3	20	CC	145,138	7,466	240,583	0.342	72	19.8

In the previous table, the optimum system configurations are:

- 167 PV panel, 0.180 kW rated power each, 30 kW overall
- 2 wind turbines, Generic 10, 10 kW rated power each.
- 70battery bank, Trojan T-105, 6v-225Ah each.
- 20 kW diesel generator.
- Converter, 20 kW size.

The net present cost (NPC) of the system is 219,543$ over 25years (project life time). The cost of energy (COE) is 0.313$/KWh and the renewable fraction is 72%. From table 3 it could be seen that an increase of 50% in the fuel price will cause an increase in NPC and COE of about 14% and 0.96%, respectively. The effect of change in diesel price in NPC & COE is shown in figure 5.

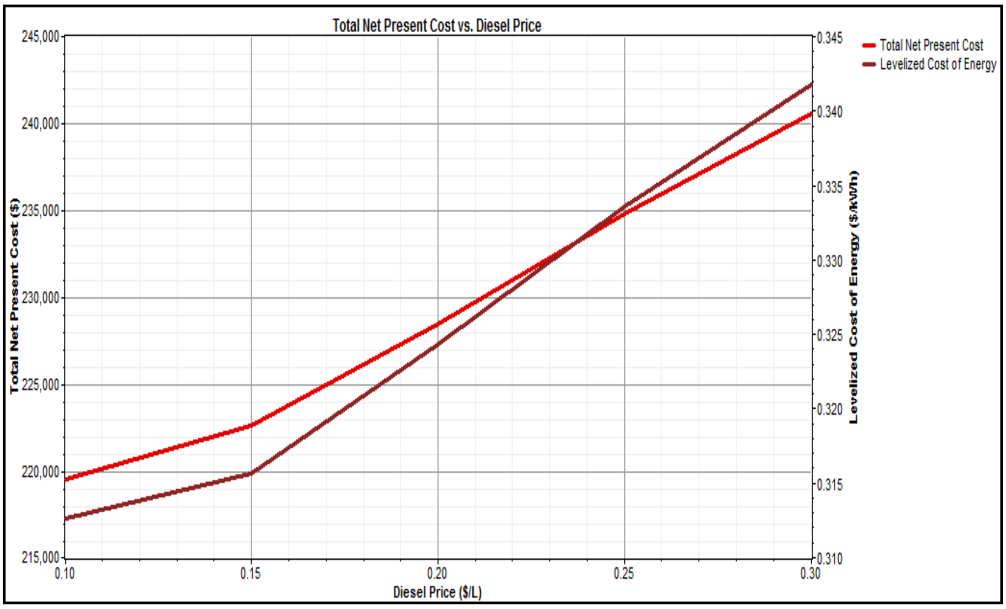

Figure 5: Diesel Price Relation versus NPC & COE

From above figure, it is clear the minimum Net Present Cost (NPC) and Cost Of Energy (COE) occurs at lower diesel price.

3.5. Effect of PV Panel Efficiency on NPV

The total peak power of the PV generator essential to supply definite load depends on demand, solar radiation, ambient temperature, power temperature coefficient, efficiencies of solar inverter adding the safety factor taken into consideration to compensate for losses and temperature result. This totality energy generated and its power stated as follows, [23]:

$$E = A \times r \times H \times PR \quad (1)$$

Where, E = Solar energy generated (kWh), A = Area of solar panel (m²),
r = Efficiency of solar panel or yield (%), H = Average solar radiation annually, and
PR = Performance ratio (0.5:0.9).
Several factors influence the measurement of PV efficiency, including:

- Wave length: PV cells act in response differently to varying wave lengths of light, producing differing electricity qualities.
- Materials: various PV materials perform differently.
- Temperature: PV cells operate improved at lower temperatures.
- Reflection: any reflected light reduces the PV cell efficiency.
- Resistance: PV cells electrical resistance makes losses, moving the efficiency.

A number of scientific researchers concerned the PV efficiency through modification of the PV cells [24]. A sensitivity analysis is performed to estimate the effect of the increase of PV efficiency on NPC. PV efficiency sensitivity analysis results are illustrated in table 4 and figure 6.

Table 4: Sensitivity Analysis Results of PV Efficiency %

PV Efficiency (%)	Production (kWh)	NPV ($)
15	19227	18106
30	38454	19469.56
40	51272	19880.7
50	64090	20292.92
60	76908	20704.72

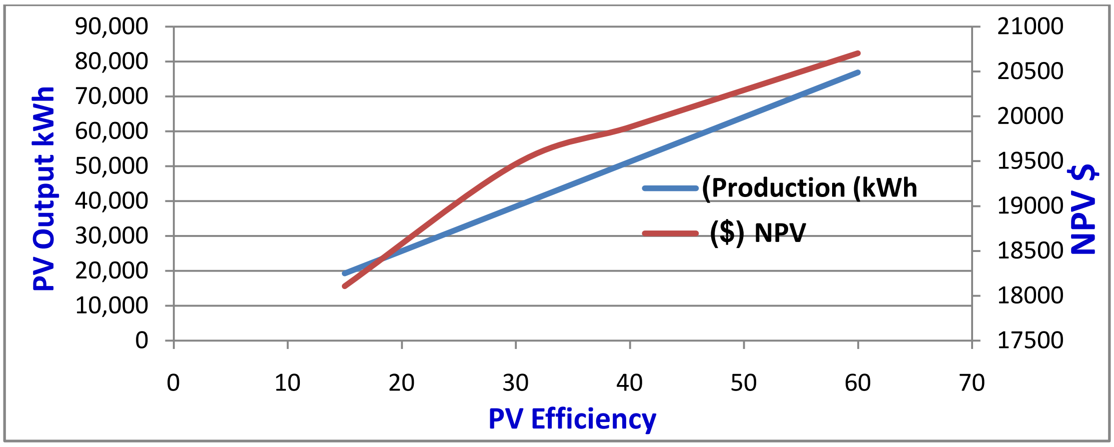

Figure 6: Sensitivity Analysis Results of PV Efficiency %

It is observed from above table and figure that solar production increases and NPV increases when PV efficiency increases. An increase of 45% in the PV efficiency causes a increase of about 15% in NPV.

4. Conclusions

This study exhibits effect of some economical and technical parameters on NPC and NPV micro-grid system. A sensitivity analysis is performed on the optimal micro-grid configuration for a case study; applied in Noubarya area in Egypt. The optimal configuration is obtained using HOMER Simulation package. The results showed that:

- On-grid system is more economical than off-grid system since NPV of on-grid system is $18106 and $14528 of off-grid system.
- Economic evaluation of the system is highly sensitive to the assumed economic parameters, especially inflation rate and to improvement in PV efficiency.
- Sensitivity analysis is applied to investigate the effect of the change in inflation rate on NPC, COE. The results presented that NPC increased by 9% and COE decreased about 7% when inflation rate increased from 3% to 7% (causing the decrease in real interest rate).

- Minimum Net Present Cost (NPC) and Cost Of Energy (COE) occurs at higher selling price to the grid (0.1125 $/kWh) & lower purchase price from the grid (0.088$/kWh).
- An increase of 8.3% in the price of electricity purchased from grid causes an increase of 0.64% in the NPC, and a decrease of 1.14% in COE. While an increase in the selling price of 4.35% will cause a decrease of 1.43% in NPC and 1.45% in COE.
- The results showed that as PV efficiency increases from 15% to 60%, NPV will increase about 15%.
- In case of standalone micro grid, NPC and COE are estimated in case of change in diesel fuel cost. It was found that an increase of 50% in the fuel price will cause an increase in NPC and COE of about 14% and 0.96%, respectively

References

[1]. N.L. Panwar, S.C. Kaushik, and S. Kothari, "Role of Renewable Energy Sources in Environmental Protection: A Review", Renewable and Sustainable Energy Reviews, a Vol.15, pp.1513-152, January 2011.

[2]. Frede Blaabjerg, Remus Teodorescu, Marco Liserre, Adrian V. Timbus, “Overview of Control and Grid Synchronization for Distributed Power Generation Systems”, IEEE Transactions on Indus- trial Electronics, Vol. 53, No. 5, October 2012.

[3]. F. Katiraei, C. Abbey, Richard Bahry, “Analysis of Voltage Regulation Problem for 25kV Distribution Network with Distributed Generation”, IEEE Power Engineering Society General Meeting, Montreal, Canda, 2013.

[4]. Dalia Eltigani, and Syafrudin Masri, "Challenges of integrating renewable energy sources to smart grids: A review", Renewable and Sustainable Energy Reviews, a Vol. 52, pp. 770-780, 2015.

[5]. Liu Pingkuo and Tan Zhongfu "Smart Grid Technologies and Applications", Renewable and Sustainable Energy Reviews, a Vol.66, pp.499–516, 2016.

[6]. Lidula NWA and Rajapakse AD, "Micro-grids research: a review of experimental micro-grids and test systems", Renew Sustain Energy Rev, a Vol.15, pp.186–202, 2014.

[7]. Huang J., "A Review on Distributed Energy Resources and Micro-Grid", Renew Sustain Energy Rev, a Vol.12, pp.2472–83, 2012.

[8]. A. Fathima and K. Palanisamy, "Optimization in Micro-grids with Hybrid Energy Systems – A Review", Renewable and Sustainable Energy Reviews, a Vol.45, pp. 431-446, 2015.

[9]. R. Nazir, H. D. Laksono, E. P. Waldi, E. Ekaputra, and P. Coveriaa," Renewable Energy Sources Optimization: A Micro-Grid Model Design", Energy Procedia, a Vol. 52, pp. 316 – 327, 2014.

[10]. L. Sigrist, E. Lobato, L. Rouco, M. Gazzino and M. Cantu, "Economic Assessment of Smart Grid Initiatives for Island Power systems", Applied Energy, a Vol.189, pp.403–415, 2017.

[11]. Chun Sing Lai and Malcolm D. McCulloch, "Levelized Cost of Electricity for Solar Photovoltaic and Electrical Energy Storage", Applied Energy, a Vol. 190, pp.191–203, 2017.

[12]. G. Díaz, J. Gómez-Aleixandre, and J. Coto, "Dynamic Evaluation of the Levelized Cost of Wind Power Generation", Energy Converse Manage, a Vol.101, 2015.

[13]. M. Hosenuzzaman, N.A. Rahim, J. Selvaraj, ABMA Malek and A. Nahar, "Global Prospects, Progress, Policies, and Environmental Impact of Solar Photovoltaic Power Generation", Renewable Sustainable Energy Review, 2015.

[14]. F. Ahmed, AQ Al Amin, M. Hasanuzzaman and R .Saidur, "Alternative Energy Resources in Bangladesh and Future Prospect", Renewable Sustainable Energy Review, a Vol.25, pp.698–707, 2013.

[15]. F. Shan, F. Tang, L. Cao and G. Fang, "Comparative Simulation Analyses on Dynamic Performances of Photovoltaic–Thermal Solar Collectors with Different Configurations", Energy Converse Manage, pp.86-87, 2014.

[16]. E. Radziemska, "The Effect of Temperature on the Power Drop in crystalline Silicon Solar Cells", Renewable Energy, pp.1-12, 2013.

[17]. Mahmoud A. Fouad, M.A. Badr and M.M. Ibrahim, "Economic Evaluation of Micro-Grid System (On/Off Grid): Egyptian Case Study", International Journal of Scientific & Engineering Research, a Vol. 8, Issue 2, Feb. 2017.

[18]. M. Bazilian, I. Onyeji, M. Liebreich, I. MacGill, J. Chase, J. Shah, D. Gielen, D. Arent, and D. Landfear, "Re-considering the economics of photovoltaic power", *Renewable Energy*, a Vol. 53, pp.329–338, 2013.

[19]. Utilities' Honest Assessment of Solar in the Electricity Supply, Greentechmedia.com, May 2012).

[20]. Dolf Gielen, "Renewable Energy Technologies: Cost Analysis Series: Wind Power", International Renewable Energy Agency, June 2012.

[21]. https://www.focus-economics.com/country-indicator/egypt/inflation.

[22]. Ministry of Electricity and Renewable Energy, Egyptian Electricity Holding Company, & Egyptian Electricity Transmission Company, Presidential Decree, 2016.

[23]. T. Jima, "Simulation and Optimization of Wind Turbine, Solar PV, storage Battery and Diesel Generator Hybrid Power System for a Cluster of Micro and Small Enterprises Working on Wood and Metal Products", Addis Ababa Institute of Technology School of Graduate Studies Energy Center, Feb 2013.

[24]. O. Schultz, A. Mette, R. Preu and S.W. Glunz "Silicon Solar Cells with Screen-Printed Front Side Metallization Exceeding 19% Efficiency", European Photovoltaic Solar Energy Conference, EU PVSEC 2007, Proceedings of the international conference, Italy, September 2014.