Yanbu Journal of Engineering and Science

Volume 17 | Issue 1 Article 2

2019

OPTIMIZATION AND SIZING OF AN ISLAND MICROGRID BASED ON PHOTOVOLTAIC/FUEL CELL (PV/FC) IN KSA

M. M. Samy
Beni-Suef University, Beni Suef, Egypt.

K.A. Alkhuzal
Albaha University, Albaha, Kingdom of Saudi Arabia.

Follow this and additional works at: https://yjes.researchcommons.org/yjes

The journal in which this article appears is hosted on Digital Commons, an Elsevier platform.

Recommended Citation

Samy, M. M. and Alkhuzal, K.A. (2019), OPTIMIZATION AND SIZING OF AN ISLAND MICROGRID BASED ON PHOTOVOLTAIC/FUEL CELL (PV/FC) IN KSA, *Yanbu Journal of Engineering and Science*: Vol. 17: Iss. 1, 15-25.
DOI: https://doi.org/10.53370/001c.23728
Available at: https://yjes.researchcommons.org/yjes/vol17/iss1/2

This Research Article is brought to you for free and open access by Yanbu Journal of Engineering and Science. It has been accepted for inclusion in Yanbu Journal of Engineering and Science by an authorized editor of Yanbu Journal of Engineering and Science.

Yanbu Journal
of
Engineering
and Science
ISSN: 1658-5321

Vol. 17, December 2019 (1441H)
www.yjes.org.sa

OPTIMIZATION AND SIZING OF AN ISLAND MICROGRID BASED ON PHOTOVOLTAIC/FUEL CELL (PV/FC) IN KSA

M. M. Samy[1*] and K. A. Alkhuzai[2]

[1]Electrical Engineering Department, Beni-Suef University, Beni Suef, Egypt.

[*]Electrical Engineering Department, Faculty of Engineering, Albaha University, Albaha, Kingdom of Saudi Arabia.

[2]Civil Engineering Department, Faculty of Engineering, Albaha University, Albaha, Kingdom of Saudi Arabia.

E-mail: mohamed_227@hotmail.com

ABSTRACT

The major goal of this research manuscript is to conduct economical and feasibility studies of an island photovoltaic/fuel cell (PV/FC) hybrid system. It has been designed to feed electricity to a remote area positioned in albaha zone in Kingdom of Saudi Arabia. To achieve this mission, all system devices are modelled and simulated via optimization mechanisms. An objective function is formulated relied on the total annual cost (TAC). An optimization mechanism, the Flower Pollination Algorithm (FPA) has been applied to obtain the optimum number of the photovoltaic (PV) panels, the electrolyzers; the H_2 storage tanks the fuel cells (FCs) and the number of batteries for the proposed system with the least total net present value (TNPV) of the hybrid system. The loss of power supply probability (LPSP) has been utilized to improve the performance of the proposed system. The premier estimation fluctuation effect of the FC, the electrolyzer and the H_2 storage tanks on the levelized cost of energy (LCOE) has been applied in the sensitivity test.

Keywords: *Solar photovoltaics, Fuel Cells, Optimization Mechanisms, Flower Pollination Algorithm, Total Net Present Value, LPSP, Artificial Bee Colony, Kingdom of Saudi Arabia.*

1. INTRODUCTION

In developing nations, provincial areas suffer from drastic shortage of electricity, where it is not economically feasible to connect these areas to the electrical utility. The insufficiency of electrical power supply has led to the mitigation of economic progress in these regions. The most commonly proposed solution of this problem is to install off-grid renewable energy systems [1]. Recently there has been significant mitigation in the estimate of these technologies as due to technological progress within them, as well as government policies that encourage to utilize these technologies. In KSA, SEC is obliged to buy the generation of renewable resources at the prices stated by the cabinet of ministers through PPA for time interval of twenty five years for PV and wind projects. The reliability of the hybrid system design is based on true combinations of renewable energy sources, and depends on the climatic conditions of the studied area, as well as the initial cost of the components of system. To reach an optimal solution, extensive studies need to be carried out. In the proposed study the

Received: 17 November 2018, Accepted: 13 January 2019

solar radiation and hydrogen resource data of the study area were used in order to develop the optimal sizing model according to LPSP and EXC [2-6]. Designing dynamic system requires promotion optimization mechanisms to reach the optimal grouping of renewable resources that consider the mention measures. Previous manuscripts have been focused on utilizing evolutionary algorithms. Kalantar et al [7] utilized GA to mitigate the annual cost of an off-grid PV/wind/micro-turbine system with battery storage. Koutroulis et al [8], also has been developed the GA to obtain the optimal size of isolated hybrid system while achieving the least cost. Singh et al [4], proposed the ABC algorithm to perform an economical study of hybrid PV/wind/biomass system, the proposed algorithm results has been verified compared with HOMER package and the PSO algorithm results. Paliwal et al [9] has been presented a systematic technique for determining an optimal mix of resources for an autonomous power system. The PSO has been applied to determine the optimal component sizing. Sharafi et al [10], have been proposed multi objective PSO approach to optimize the size of hybrid system based on the ε-constraint method which has been applied to reduce the system cost, unmet load and GHG emissions. Tahani et al [11] optimized the PV/Wind/Battery remote system, using hybrid FPA/SA algorithm. Oda et al [12] applied FPA approach for the planning of distributed generators and to enhance the voltage stability of the system. The FPA has been succeeded for testing the PV parameters assessment, it has been demonstrated to be an efficacious optimization method in multi objective optimization of isolated micro grids [13] compared with non-overpower sorting GA. Fortunately, rural areas in KSA have abundant solar power (14) and biomass sources used in constituting hybrid island off-grid systems for meeting their energy needs. Recently mix of solar and wind with FC has been received worthy awareness. Dash & Bajpai [15] have progressed a power management control planning for isolated PV/FC/battery system, while Saravanan & Thangavel [16] have submitted energy management system depending on immediate reference existing project for the PV/Wind/FC system. Chen [17] has proposed an arrangement of solar-hydrogen mild FC systems for the electric vehicles. Bezmalinovi et al [18] have leaded a techno-economic analysis of the PEM FCs with PVs for the distant base stations. This work introduces really approach of an optimal island system qualified for feeding electric power to rustic district in KSA. The system is consisting of PV arrays and FCs. The FPA approach is used to select the capacity of the solar PV, PEM FCs, electrolyzers and hydrogen storage tanks. The selection is based upon reducing TNPV of the system for a specified LPSP and EXC using FPA. The FPA is applied due to its effectiveness and few parameters required compared to other optimization techniques which makes it easier to implement and simulate [19].

2. PORPOSED HYBRID SYSTEM MODEL

The proposed system is shown in Figure 1. The surplus energy that exceeds the load is then used to charge the electrolyzers which produces H_2 and stores it in the tanks. The stored energy within H_2 tanks is used to run the FCs to satisfy the load needs via the time intervals of low energy produced by PV.

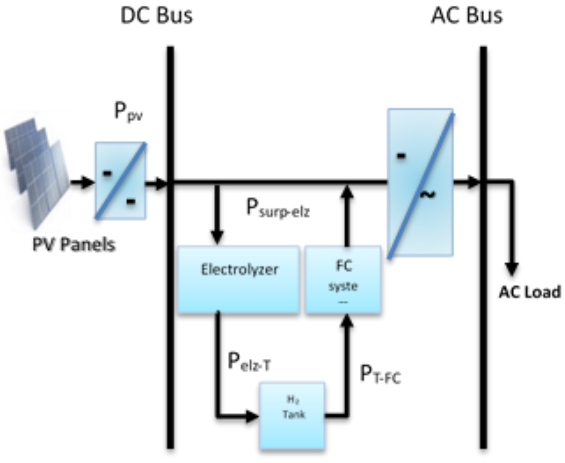

Fig. 1: The proposed PV/FC design for the studied region.

2.1 SOLAR PV MODEL

For the present work, the simulation model is utilized to determine the PV module efficiency. The solar irradiation used for the studied area is located at 29°1' N latitude and 30°52' E longitude has been get using HelioClim-3 which is a database including surface solar radiation appreciated each fifteen minutes from images drawn by the Meteosat series of satellites since 2004 (14). Equation one has been applied to estimate the output of the PV modules.

$$P_{PV} = \left(P_{rated} N_{pv} A_m D_f\right)\left(\frac{G}{G_{ref}}\right)\left(1 + K_T\left(T_C - T_{ref}\right)\right) \quad (1)$$

Where $K_T = -3.7 \times 10^{-3}(1/°C)$ for poly-crystalline and mono silicon. Depending on the energy equilibrium, T_c can be shown as follows in equation two as [21]:

$$T_c = T_{amb} + G\left(\frac{\tau\alpha}{U_l}\right) \quad (2)$$

The overall heat loss coefficient, $\frac{\tau\alpha}{U_l}$, can be expressed as the NOCT as [20]:

$$\frac{\tau\alpha}{U_l} = \frac{NOCT - 20}{0.8} \quad (3)$$

Figure 2 shows the solar radiation of the study area while Table 1 lists the manufacture data for the PV module.

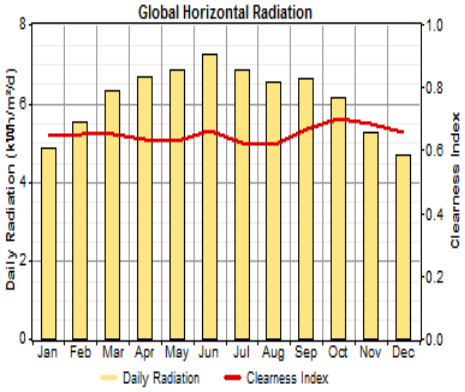

Fig. 2: Solar radiation in the studied region.

TABLE 1: MANUFACTURE DATA FOR PV MODULE

Cell type	Poly-crystalline
The NOCT	43±2°C
Module efficiency	15.9%
Outer dimensions (L x W x H)	1648 x 990 x 40 mm
STC rated output (P_{mpp})	260 w_p
Derating factor	90%
Ground reflection	20%
Operating temperature	47 °C

2.2 POWER INVERTER MODEL

The inverter is applied to change the DC output from the PV modules and the battery to AC power. The inverter is chosen depending on the maximum load needs. The input power of the inverter (P_{inv}) is estimated as:

$$P_{inv}(t) = \frac{P_L(t)}{\eta_{inv}} \quad (4)$$

Technical description of the selected Inverter/Charger utilized in this work are shown in Table 2.

TABLE 2: TECHNICAL SPECIFICATIONS OF THE USED INVERTER

Inverter Specifications	
Model	**MS4448PAE**
Input battery voltage range	36.0 - 64.0 VDC
Nominal AC output voltage	120/240 VAC split phase (± 5%)
Continuous power output at 25° C	4400 VA (L-L)
Inverter efficiency (peak)	94%
Waveform	Pure Sine Wave
Charger Specifications	
Continuous output at 25° C	60 ADC
Charger efficiency	85%
Power factor	> 0.95

2.3 Modeling of Fuel Cell System

In the present work, the PEM FC is used, electrolyzer hardware contains an anode, cathode, and an electrolyte. The water electrolysis happens in the electrolyzer utilizing electricity to separate water into hydrogen and oxygen. In PEM electrolyzer, the protons moves from anode to cathode via a proton exchange membrane. Transferred power from electrolyzer to H_2 tank can be defined as:

$$P_{elz-T} = P_{surp-elz} * \eta_{elz} \quad (5)$$

$$where\ P_{surp}(t) = P_{pv}(t) - P_{inv}(t) \quad (6)$$

The energy of H_2 stored in the tank at time step t can be acquired by using Eq. 7:

$$E_{H2}(t) = E_{H2}(t-1) + P_{elz-T} \times \Delta t \quad (7)$$

$$where\ \ E_{H2-max} \leq E_{H2} \leq E_{H2-min}$$

The type of the H_2 tank used is ultra-light composite storage cylinder with H_2 capacity of 2700 (std. L), the corresponding peak energy capacity of that tank can be calculated as in Eq. 8 [22]:

$$E_{H2-max} = 0.27 \times H_2\ heating\ value \quad (8)$$

Where the H2 heating value is 3.4 kWh/m3 in the standard condition, the maximum storage electric capacity of the tank is 9.18 kWh while the minimum electric capacity is set to be 5% of the maximum capacity. FCs are electrochemical equipment that change the chemical energy to electrical. The PEM FCs has reliable efficiency under discontinuous supply and is commercially obtainable at wide industrial range. This type of FCs are sufficient for large scale stationary generation and have rapid dynamic response with a power release time of 1-3 s [21]. It`s output power is considered to be about 40% and computed as:

$$P_{FC} = P_{T-FC} * \eta_{FC} \quad (9)$$

2.4 Load Profile Model

An annual hourly load profile is simulated using the average daily load demand of the studied zone. The load profile was created using micro power optimization and simulation software tool Homer® [22, 23]. To account for the random variations of the hourly and daily loads, random noise was added to the average daily load to create the annual load profile. Figure 3 illustrates the daily profile of the load demand that used in the studied region.

3. PROBLEM FORMULATION

The goal of this manuscript is to introduce an efficient, cost-effective and credible isolated micro-grid based on PV and FCs. This have been reached via optimizing the number of PV modules, FCs, electrolyzers and the H2 storage tanks, which are looked as the main ruling parameters of the task.

3.1 Objective Function and Constraints

The aim of the optimization is to minimize the TNPV, and maximize the reliability of the system, proved as LPSP, and preservation the EXC of the system as lesser as possible. In this case, four continuous ruling parameters of $\mathbf{N_{PV}}$, $\mathbf{N_{FC}}$, $\mathbf{N_{Elz}}$ and $\mathbf{N_{H2T}}$ must be optimized.

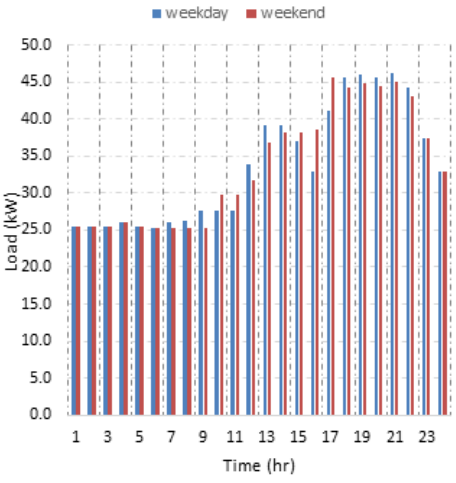

Fig. 3: The daily load profile of the studied area.

The objective function is introduced in Eq. 10, subject to the constraints in Eqs. 11 – 15. Subject to:

$$Objective\ function = min.TNPV(N_{PV}, N_{FC}, N_{Elz}, N_{H2T}) \quad (10)$$

$$0 \leq N_{PV} \leq N_{PV}^{max} \quad (11)$$

$$0 \leq N_{FC} \leq N_{FC}^{max} \quad (12)$$

$$0 \leq N_{Elz} \leq N_{Elz}^{max} \quad (13)$$

$$0 \leq N_{H2T} \leq N_{H2T}^{max} \quad (14)$$

$$LPSP \leq LPSP_{max} \quad (15)$$

Where: $LPSP_{max}$ is the peak permissible $LPSP$ given.

3.2 The Proposed System Strategy

In this work, the suggested model is based on two variables. The first parameter is the LPSP with the following constraints:

$$0 \leq \text{LPSP} \leq 1,$$

The LPSP is equal zero when the load demands is fully supplied, and equal one when the load demands is not supplied [24]. The second parameter is the EXC. The introduced techniques lookup the optimal grouping of the PV modules, the FCs, the electrolyzers and the H_2 storage tanks that reduces the cost of the LPSP and the EXC. The procedures for the working design can be brief in the followings:

1. At t=1, the H_2 tank is empty.
2. The overall output power of the PV modules at each hour is estimated as in Eq. 1.
3. The inverter input power $P_{inv}(t)$ is computed as in Eq. 4.

Three Scenarios of the introduced system are executed:

a. Generation Meets Demand:

b. If $P_{pv}(t) = P_{inv}(t)$, then the H_2 tanks storage capacity remains unchanged, and $LPS(t) = 0$.

c. Excess Generation:

If $P_{pv}(t) > P_{inv}(t)$, then the excess power can be applied to charge the electrolyzers, the new storage capacity is estimated utilizing Eq. 7. If the SOC of the H_2 tanks reaches its peak border, the rest of the increased power is looked as wasted energy $W_E(t)$ and will be used in a dump load, $LPS(t) = 0$.

$$WE(t) = P_{surp}(t) - \left(E_{H2-max} - E_{H2}(t-1)\right) \quad (16)$$

d. Excess Demand:

If $P_{pv}(t) < P_{inv}(t)$, then H_2 tanks is utilzied to satisfy the power deficit, and the new storage capacity is as:

$$P_{def}(t) = P_{inv}(t) - P_{pv}(t) \quad (17)$$

$$E_{H2}(t) = E_{H2}(t-1) - P_{def} \times \eta_{FC} \times \Delta t \quad (18)$$

$$LPS(t) = P_L(t) - \left(P_{pv}(t) + E_{H2}(t-1) - E_{H2-min}\right) \quad (19)$$

4. The LPSP for a specific period T, is computed as:

$$LPSP(t) = \sum_{t=1}^{T} \frac{LPS(t)}{P_L(t)}, T = 8760 \quad (20)$$

5. The EXC, for a specific period T, is defined as:

$$EXC(t) = \sum_{t=1}^{T} \frac{WE(t)}{P_{re}(t)}, T = 8760 \quad (21)$$

For one year study time and recognized value of the LPSP, different configurations have been covered the load needs in a reliable manner. Finally the optimum configuration can be given as a function of the LCOE. This can be completed by applying the economic model.

4. ECONOMICAL AND OPTIMIZATION MODEL

The economic model is sophisticated for the suggested system related to the TNPV, and the LCOE values. The LCOE is computed using (4, 25, 26):

$$\text{LCOE} = \frac{TNPV \times CRF}{E_{load}} \quad (22)$$

$$CRF = \frac{i(1+I_{real})^{R_{proj}}}{(1+I_{real})^{R_{proj}} - 1} \quad (23)$$

Where I_{real} is computed by Fisher's formula (4, 25, 26):

$$I_{real} = \frac{i + I_f}{1 + I_f} \quad (24)$$

and the TNPV is calculated using the followings (25, 26):

$$TNPV = C_{PV} + C_{FC} + C_{Elz} + C_{H2T} \quad (25)$$

Where $C_{PV}, C_{FC}, C_{Elz} and\ C_{H2T}$ are the cost per unit of the PV system, the FC, the electrolyzer and the H_2 storage tank respectively. Each component cost can be computed as:

$$C = C_I + C_R + C_{O\&M} - S \quad (26)$$

Where: C_I contains the BOS, the system design, $C_{O\&M}$ contains the operator's salaries, inspections, the insurance and the scheduled maintenance costs. It has been considered, the salvage value (S) based on C_R rather than C_I. S is estimated by:

$$S = C_R \left(\frac{R_{rem}}{R_{comp}}\right) \quad (27)$$

Where: R_{rem} is calculated using the following equations:

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \quad (28)$$

$$R_{rep} = R_{comp} \times INT\left(\frac{R_{proj}}{R_{comp}}\right) \quad (29)$$

INT =a function that returns the integer amount of a real number. The initial capital costs can be estimated from the information given in Table 3.

TABLE 3: COSTS AND OTHER PARAMETERS FOR ECONOMIC ANALYSIS

	unit	PV Solar System	Fuel cell	Electrolyzer	H2 tanks
Capacity	kWh	5.46	5	5	9.81
Life time	years	20	5	5	20
Initial cost	$	15,465	22,427	9800	4770
Replacement cost	$	6,573	15,699	6860	4770
Operation and maintenance cost	$	50	50	20	10

5. FLOWER POLLINATION ALGORITHM

The FPA has been introduced by Xin-She Yang has in 2012, which is a mimic of the pollination method of flowering plants (26, 27, 28). Pollination can be accomplished by self-pollination or cross-pollination. The algorithm has benn illustrated in the following flowchart of Figure 4. Via MatlabTM package, the numerical simulation outputs acquired by the FPA algorithm have been compared to the corresponding results while using the ABC. The parameters of the FPA and ABC algorithms are listed in Table 4.

TABLE 4: PARAMETERS OF THE ABC AND FPA ALGORITHMS

Algorithm	**ABC**	**FPA**
Number of iterations	100	100
Population Size	25	25
Dimension of the search variables	4	4
Probability switch		0.8

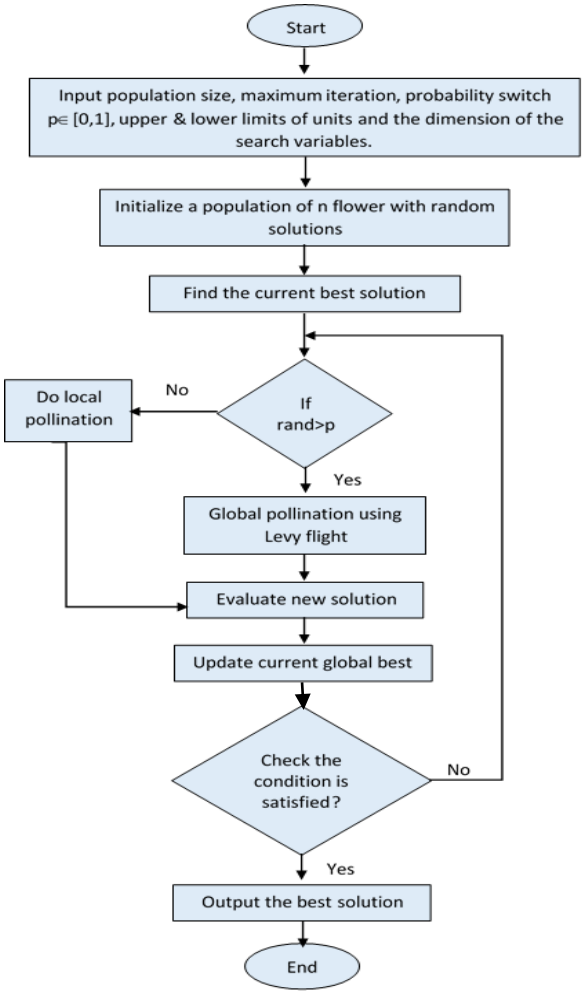

Fig.4: The flowchart of the FPA technique.

6. RESULTS AND DISCUSSIONS

The simulation time step is considered to be one hour and runs data for one year. The obtained outputs from the FPA are taken as a reference for comparison purposes. The peak border of the LPSP = 2% has been considered in this work. The optimal solution obtained for this limit for the two algorithms are shown in Table 5. The optimal solution ranked on the basis of the TNPV. Table 5 indicates that, when the LPSP of 1.69%, the system should be designed to work at a low TNPV of $3,479,022 and the LCOE of 0.708 $/kWh. Again, for this LPSP value, the EXC of the system is to be 3.84%. The results from Table 5 clearly indicate that both FPA and ABC find convergent optimized solutions, but the FPA is satisfactory as compared to the ABC in terms of simulation time and outputs.

TABLE 5: OPTIMAL SIZING OUTPUTS DRAWN FROM THE FPA AND THE ABC

Algorithm	FPA	ABC
LPSP	1.69%	1.92%
EXE	3.84%	3.22%
LCOE	0.708	0.723
TNPC	3,479,022	3,555,807
Total annual cost	**209,051**	**213,665**
Npv	21	20
N_{H2T}	38	39

The FPA predicts 21 solar PV panels, 28 FCs, 60 electrolyzers and 38 H2 storage tanks. Figure 5 illustrates the comparison between the FPA and the ABC convergence for LPSP of 2%. The outputs illustrate the quick convergence of the introduced technique to the optimal arrangement relative to ABC convergence. Lengthy discounted cash flow is illustrated in Figure 6 and 7 shows the assistance of the costs of each equipment to the TNPV of the optimized design.

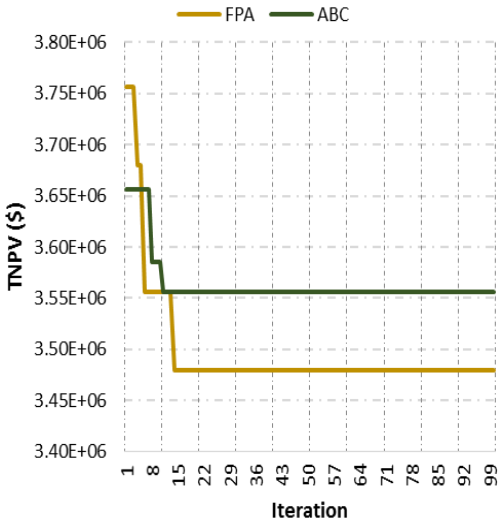

Fig. 5: Comparison of convergence rates for the FPA and the ABC techniques at LPSP=2%.

It is cleared that, the FC system has the highest capital, replacement costs of ($627,956) and ($1,436,470) respectively. Figure 8 shows that the portion of the PV,

the FC, the electrolyzer and the H_2 storage tank annualized costs from the TNPC of the optimized system. Different sensitivity analysis has been behaved to portend the future efficiency of the system. Three variables are assumed: the changing of the initial cost of the FC, the electrolyzer and the H_2 storage tank. Figure 9 shows the effect of the cost variation of the FC system from 50% to 125% of the present cost used in this study on the LCOE. From Fig. 8, the changing of the FC system has the major effect on the LCOE compared than the cost of the electrolyzer and the H_2 storage tank. The LCOE increases from 0.5054 $/kWh to 0.7075 $/kWh for the FC system initial cost of 11213.5 $/unit and of 22427 $/unit respectively. This means that decreasing the FC system initial cost by 50%, the LCOE is reduced to 28.57%. For the same decrease in the initial cost of the electrolyzer and the H_2 storage tank, the LCOE is decreased by 13.13% and 2.63% respectively.

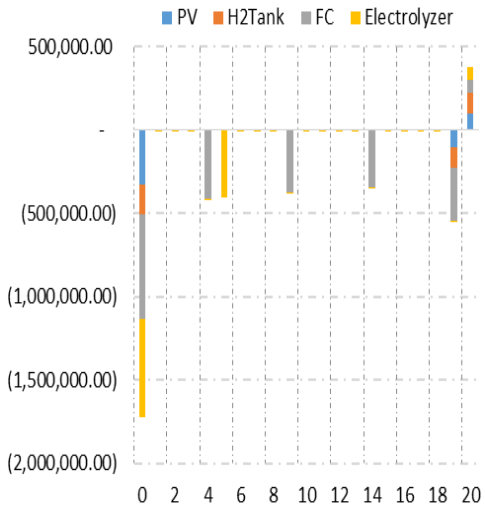

Fig. 6: The discounted cash flow of the optimized system

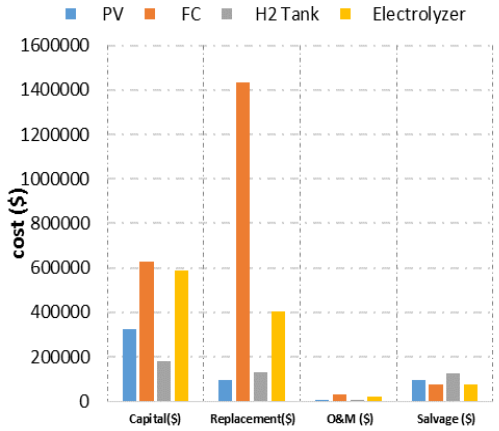

Fig. 7: The breakdown of the TNPC of the optimum HPBRS components

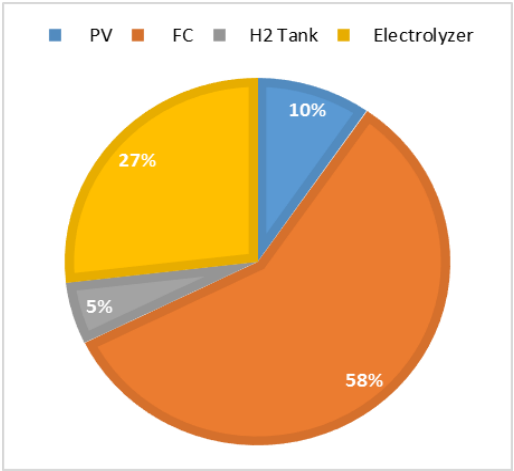

Fig. 8: The percentage of the optimized system components annualized costs in the TNPV

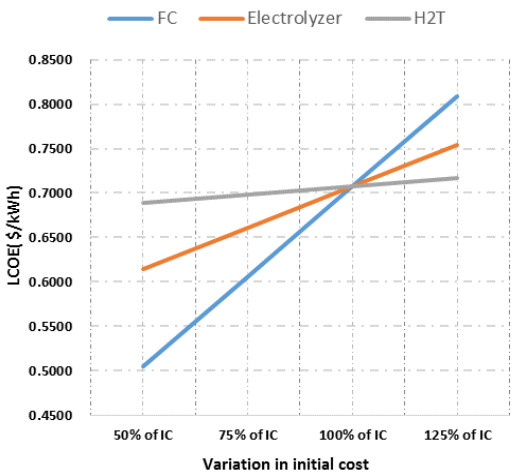

Fig. 9: Impact of the changing of the FC, electrolyzer and H_2 tank cost on the LCOE of the system

7. CONCLUSION

This paper introduces an effective technique to design an island micro-grid based on PV and FC. The proposed design optimizes the size of each device including a reliable power feeding depending on the LPSP, and reducing the TNPV of the system. The main contribution of the proposed design is the implementation of the FPA, which proved to show superior performance when compared to the ABC algorithm. A sensitivity analyses has been done assuming the changing in the cost of the FC, the electrolyzer and the H_2 storage tank. These chosen parameters are highly influence the development decisions, as their changing will affect the long-range sustainability of the system. The introduced design is utilized as a tool to prove its economic, ecological and social effort in covering the existing and the future energy needs.

NOMENCLATURE

Am	Area of a single module (m2)
ABC	Artificial Bee Colony
BOS	Balance Of System
CI	System components initial capital cost ($)
CO&M	Operation and maintenance costs ($)
CR	System components replacement cost ($)
CRF	Capital Recovery Factor
Df	Photovoltaic derating factor (0.8)
SEC	Saudi Electricity Company
EXC	Percentage of the Excess Energy
Eh2	The energy of hydrogen stored in the tank
Eh2-max	The maximum energy of H2 stored in the tank
Eh2-min	The minimum energy of H2 stored in the tank
FPA	Flower Pollination Algorithm
GHG	Greenhouse Gases
G	Global irradiance fallen on the titled plane (kW/m2)
Gref	Solar irradiation at base conditions (1 kW/m2)
GA	Genetic Algorithm
H2	Hydrogen chemical symbol
NH2T	Number of H2 storage tanks
i	Interest rate
If	Inflation rate
Ireal	Real interest rate
KT	Maximum power temperature coefficient
LCOE	Levelized Cost Of Energy
LHV	Lower Heating Value
LPSP	Loss of Power Supply Probability
NOCT	Normal Operating Cell Temperature
NPV	Number of PV modules
P_{elz-T}	The transferred power from the electrolyzer to the H2 tank
Psurp-elz	The transferred power to the electrolyzer
P	Generator operating power (kW)
PPV	Photovoltaic output power (kW)
Prated	Rated module output (kW)
Pre	Power generated by the proposed system at hour t
PEM	Proton Exchange Membrane
PPA	Power Purchase Agreements
PSO	Particle Swarm Optimization
Rcomp	Component life time (year)
Rproj	Project life time (year)

Rrem	Remaining life of the equipment at the finish of the project lifetime (year)
Rrep	Duration of replacement cost (year)
S	System component salvage value ($)
SEC	Saudi Electricity Company
SOC	State Of Charge
TAC	Total Annual Cost
Tamb	Ambient temperature (°C)
TNPV	Total Net Present Value
Tc	Photovoltaic cell temperature (°C)
Tref	Reference condition temperature (°C)
Ul	Coefficient of overall heat loss (w/m2/°C)
τ	Photovoltaic cell transmittance coefficient
η_{elz}	Efficiency of the electrolyzer
α	Absorption coefficient of the photovoltaic cells
ηinv	Efficiency of the inverter

REFERENCES

[1] C. L. Azimoh, P. Klintenberg, F. Wallin, B. Karlsson, and C. Mbohwa, "Electricity for development: Mini-grid solution for rural electrification in South Africa," Energy Convers. Manag., vol. 110, pp. 268–277, 2016.

[2] A. Giwa, A. Alabi, A. Yusuf, and T. Olukan, "A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria," Renew. Sustain. Energy Rev., vol. 69, pp. 620–641, Mar. 2017.

[3] S. Barakat, M. M. Samy, M. B. Eteiba, and W. I. Wahba, ". Optimization of an Off-Grid PV/Biomass Hybrid System with Different Battery Technologies. Volume 40, July 2018, Pages 713-727, https://doi.org/10.1016/j.scs.2018.01.012. 2018.

[4] S. Singh, M. Singh, and S. C. Kaushik, "Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system," Energy Convers. Manag., vol. 128, pp. 178–190, Nov. 2016

[5] C. M. I. Hussain, B. Norton, and A. Duffy, "Technological assessment of different solar-biomass systems for hybrid power generation in Europe," Renew. Sustain. Energy Rev., vol. 68, pp. 1115–1129, Feb. 2017.

[6] M. Kalantar and S. M. Mousavi G., "Dynamic behavior of a stand-alone hybrid power generation system of wind turbine, microturbine, solar array and battery storage," Appl. Energy, vol. 87, no. 10, pp. 3051–3064, 2010.

[7] E. Koutroulis, D. Kolokotsa, A. Potirakis, and K. Kalaitzakis, "Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms," Sol. energy, vol. 80, no. 9, pp. 1072–1088, 2006.

[8] P. Paliwal, N. P. Patidar, and R. K. Nema, "Determination of reliability constrained optimal resource mix for an autonomous hybrid power system using Particle Swarm Optimization," Renew. Energy, vol. 63, pp. 194–204, Mar. 2014.

[9] M. Sharafi and T. Y. ELMekkawy, "Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach," Renew. Energy, vol. 68, pp. 67–79, Aug. 2014.

[10] M. Tahani, N. Babayan, and A. Pouyaei, "Optimization of PV/Wind/Battery stand-alone system, using hybrid FPA/SA algorithm and CFD simulation, case study: Tehran," Energy Convers. Manag., vol. 106, pp. 644–659, Dec. 2015.

[11] E. S. Oda, A. A. Abdelsalam, M. N. Abdel-Wahab, and M. M. El-Saadawi, "Distributed generations planning using flower pollination algorithm for enhancing distribution system voltage stability," Ain Shams Eng. J., Dec. 2015.

[12] D. F. Alam, D. A. Yousri, and M. B. Eteiba, "Flower pollination algorithm based solar PV parameter estimation," Energy Convers. Manag., vol. 101, pp. 410–422, 2015.

[13] H. A. M. Fathi, E. Beshr, and M. B. Eteiba, "Multi-Objective optimization of islanded microgrids," Electrical, Computer and Communication Technologies (ICECCT), 2015 IEEE International Conference on, 2015, pp. 1–7.

[14] M. M. Samy, S. Barakat. H. H. Sarhan and, S. A. Al-Ghamdi. " A Hybrid PV-Biomass Generation Based Micro-Grid for the

Irrigation System of a Major Land Reclamation Project in Kingdom of Saudi Arabia (KSA) - Case Study of Albaha Area" Proceeding of the 18th IEEE International Conference on Environment and Electrical Engineering, Palrmo, Italy June 12 –15, 2018.

[15] V. Dash and P. Bajpai, "Power management control strategy for a stand-alone solar photovoltaic-fuel cell--battery hybrid system," Sustain. Energy Technol. Assessments, vol. 9, pp. 68–80, 2015.

[16] S. Saravanan and S. Thangavel, "Instantaneous reference current scheme based power management system for a solar/wind/fuel cell fed hybrid power supply," Int. J. Electr. Power Energy Syst., vol. 55, pp. 155–170, 2014.

[17] P.C. Chen, "Configuration of solar-hydrogen mild hybrid fuel cell power systems for electric vehicles," J. Power Sources, vol. 201, pp. 243–252, 2012.

[18] D. Bezmalinović, F. Barbir, and I. Tolj, "Techno-economic analysis of PEM fuel cells role in photovoltaic-based systems for the remote base stations," Int. J. Hydrogen Energy, vol. 38, no. 1, pp. 417–425, 2013.

[19] H. Chiroma, N. L. M. Shuib, S. A. Muaz, A. I. Abubakar, L. B. Ila, and J. Z. Maitama, "A review of the applications of bio-inspired Flower Pollination Algorithm," Procedia Comput. Sci., vol. 62, no. Scse, pp. 435–441, 2015.

[20] M. S. Ismail, M. Moghavvemi, and T. M. I. Mahlia, "Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate," Energy Convers. Manag., vol. 69, pp. 163–173, 2013.

[21] R. S. Garcia and D. Weisser, "A wind--diesel system with hydrogen storage: Joint optimisation of design and dispatch," Renew. energy, vol. 31, no. 14, pp. 2296–2320, 2006.

[22] S. Barakat, M. M. Samy, M. B. Eteiba, and W. I. Wahba, "Viability study of grid connected PV/Wind/Biomass hybrid energy system for a small village in Egypt," in Power Systems Conference (MEPCON), 2016 Eighteenth International Middle East, 2016, pp. 46–51.

[23] S. Barakat, M. M. Samy, M. B. Eteiba, and W. I. Wahba, "Feasibility Study of Grid Connected PV-Biomass Integrated Energy System in Egypt," Int. J. Emerg. Electr. Power Syst., vol. 17, no. 5, 2016.

[24] H. Yang, W. Zhou, L. Lu, and Z. Fang, "Optimal sizing method for stand-alone hybrid solar--wind system with LPSP technology by using genetic algorithm," Sol. energy, vol. 82, no. 4, pp. 354–367, 2008.

[25] B. Leland, and Anthony Tarquin "Engineering economy," 7th edition 2012.

[26] M. M. Samy, Shimaa Barakat and H. S. Ramadan, "A Flower Pollination Optimization Algorithm for an Off-Grid PV-Fuel Cell Hybrid Renewable System," Accpted for publication on the International Journal of Hydrogen Energy (IJHE), 24 May, 2018.

[27] Nahar Alshammar, M. M.Samy and Johnson Asumadu "Optimal Economic Analysis Study for Renewable Energy Systems to Electrify Remote Region in Kingdom of Saudi Arabia", Proceeding of the 20th IEEE Middle East Power Systems Conference (MEPCON), Cairo, Egypt, Dec 18 –20, 2018.

[28] X.-S. Yang, "Flower pollination algorithm for global optimization," in International Conference on Unconventional Computing and Natural Computation, 2012, pp. 240–249.