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Optimization of microgrids on/off-grid to the electrification of residential load in Saida, Algeria

***Abstract**. This article presents the optimization implemented to give the optimal architecture for a microgrid (MG) with minimum cost. In this framework, three configurations had created using HOMER software. The first MG1 consists of a PV system, wind turbine, and a battery, all of the systems connected to a residential load of 11.2 kWh/d with a peak load demand of 2.11 kW in Saida, Algeria. The second MG2 is the same as MG1 with the addition of a diesel generator. The third MG3 is MG1 connected to the electrical grid. The results show that MG3 is the best configuration, with a TNPC of 14,054$, a COE (Cost Of Energy) of 0.269$/kWh, and a renewable fraction (RF) of 87.9%.*

Streszczenie.** W artykule przedstawiono optymalizację wdrożoną w celu uzyskania optymalnej architektury mikrosieci (MG) przy minimalnych kosztach. W ramach tego projektu stworzono trzy konfiguracje za pomocą oprogramowania HOMER. Pierwszy MG1 składa się z systemu fotowoltaicznego, turbiny wiatrowej i baterii, przy czym wszystkie systemy są podłączone do obciążenia mieszkalnego wynoszącego 11,2 kWh/d przy szczytowym zapotrzebowaniu na obciążenie 2,11 kW w miejscowości Saida w Algierii. Drugi MG2 jest taki sam jak MG1 z dodatkiem generatora diesla. Trzeci MG3 to MG1 podłączony do sieci elektrycznej. Wyniki pokazują, że MG3 jest najlepszą konfiguracją, z TNPC na poziomie 14 054 USD, COE (Koszt Energii) na poziomie 0,269 USD/kWh i frakcją odnawialną (RF) na poziomie 87,9%.* (Optymalizacja mikrosieci on/off-grid do elektryfikacji obciążenia mieszkalnego w Saida, Algieria***)

Keywords: Microgrid, renewable energies, optimization, HOMER.
Słowa kluczowe: Mikrosieć, odnawialne źródła energii, optymalizacja, HOMER.

Introduction

In recent years, the electrical grids have become complex and high [1]. Global energy consumption is closely related to population. The increase in the world's population and the industrial activity of developing countries have led to an explosion in energy needs [2, 3]. Excessive exploitation of fossil resources to satisfy these needs is the cause of the emission of polluting gases, the pollution of which is the origin of global warming and climate change [4]. The transport sector is responsible for almost a third of global CO2 emissions [5].

Unfortunately, renewable energy is not yet to compete with today's large power stations because of their intermittency and fluctuating nature. Therefore, it is essential to use storage systems to ensure the continuity of the energy supply [6]. Today, there is a sharp increase in energy from renewable resources in many countries as wind and solar, with the addition of diesel generators and storage systems. The components combination constitutes a hybrid renewable energy system (HRES) connecting on/off-grid [7].

Another alternative for electricity producers is to encourage the consumer to become a producer and user of energy to meet their needs in both quality and quantity to build a stable and autonomous base-voltage grid. The distribution system operators (DSOs) cannot refuse a decentralized production installation. But they need to establish the connection conditions (cost, installation power, injection point, etc.) by contract with the producer according to the energy laws [8]. The principal aspect of HRES is the optimal design, sizing, and cost of the microgrid (MG) components (Total Net Present Cost, Cost Of Energy, and Operations and Maintenance Cost) [9].

Various simulation techniques, optimization analysis, configurations, and control strategies have been presented in many papers to study the field of HRES. Optimal design for a hybrid microgrid-hydrogen storage facility in Saudi Arabia had investigated by Abdulaziz [10]. Huiru Zhao and Hao Lu performed a stochastic optimization of the operating strategy of a microgrid participating in the day-ahead market considering the energy storage system and demand response [11]. Hak-Ju Lee used PowerFactory software for optimal MG design of PV systems, wind turbine generators, and diesel generators for the electrification of Deokjeok Island in South Korea [12]. The evaluation of the design and optimization of proposed off-grid HRES for different load dispatch strategies had implemented by Fatin Ishraque [13]. Mohammad had performed studies of technical, ecological, and economic aspects for the optimal sizing and energy management of PV/wind/diesel/battery systems using HOMER software [14]. This paper aims to study the techno-economical aspect of microgrids (on-of-grid) to electrify a residential load in Saida, Algeria.

Area selection

The microgrid proposed is located in Saida, the northwestern region of Algeria. Its geographical coordinates are 34.66 attitudes and 0.333 longitudes. Saida is called the desert gate. This area characterizes by cold, partly cloudy weather in winter and hot, dry weather in summer. The climatic values of the region located at the coordinates of solar radiation and wind speed had obtained by the National Aeronautics and Space Administration (NASA) during this period (from 1 January 2022 to 31 December 2022). The annual average of solar radiation during the mentioned year is 4.9 kWh/m2/d, and an average wind speed of 4.38 m/s at 25m high above the earth's surface. Fig. 1 and Fig. 2 represent the monthly average solar radiation and wind speed, respectively.

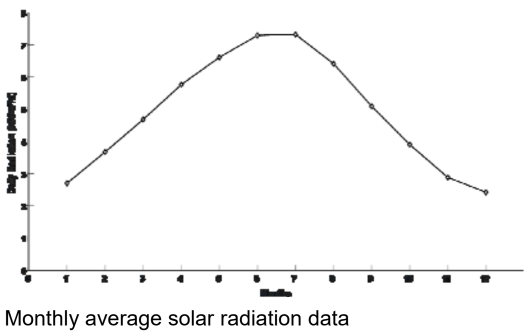


Fig.1. Monthly average solar radiation data

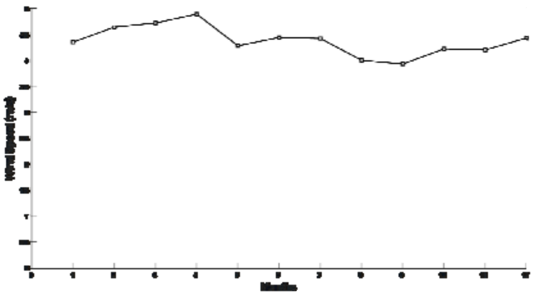


Fig.2. Monthly average wind speed data

The proposed microgrid in the same selected region (Saida, Algeria) allows for electrifying a residential load that varies in one day (24 hours) with an average annual power consumption of 11,26kWh/d. Fig. 3 shows the daily load profile with a peak load demand of 2.11kW.

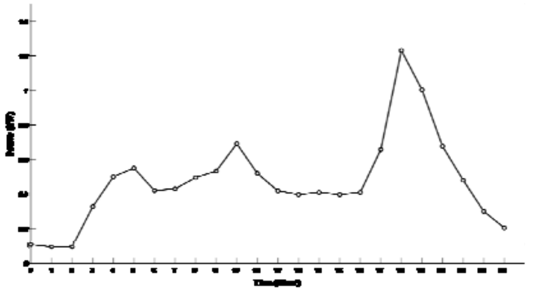


Fig.3. Load profile variation for 24 hours of the day

PV system modelling

PV panels convert solar radiation into electrical energy. The output power of the PV system can be estimated using the following expressions Eq. (1) based on two variables: ambient temperature and solar irradiance [15].

(1) $$P_{PVout}(t) = P_{PVrated} \times f_d \times \frac{G(t)}{10^3}[1+\alpha(T_{cell}(t)-25)]$$

(2) $$T_{cell}(t) = \left[T_a(t) + \frac{NOCT-20}{800} \right] \times G(t)$$

Where P_{PVout} is the rated power of the PV system, $P_{PVrated}$ is the PV rated power, f_d represents derating coefficient (losses induced by the DC nameplate) and G(t) represents the real and standard-test based solar irradiation at time t in terms of W/m^2, *a* is the temperature coefficient. T_{cell}, T_a are is the cell temperature and are the ambient temperature at time t respectively.

Wind turbine modelling

Wind power is a renewable energy source that converts the kinetic energy of wind into electrical energy. The power output of a wind turbine is determined using the following equations [16].

(3) $$P_{WT}(t) = 0 \;\; if\, V_{cut\_in} < 0 \, or \, V_{cut\_out} > 0$$

$$P_{WT}(t) = V^3 \left(\frac{P_r}{V_r^3 - V_{cut\_in}^3} \right) - P_r \left(\frac{V_{cut\_in}^3}{V_r^3 - V_{cut\_in}^3} \right)$$

(4) $$if\, V_{cut\_in} \le V < V_{rated}$$

(5) $$P_{WT}(t) = P_r \;\; if\, V_{rated} \le V \le V_{cut\_out}$$

where P_{WT} is the rated power (*k*W), V is the wind speed (m/s). V_{cut_in}, V_{cut_out}, V_r represent cut in, and cut-out and rated wind speed of WT respectively (usually the manufacturer set these values).

Diesel generator modelling

Diesel generators are the backbone of microgrid operations, ensuring the efficiency of the microgrid by providing a steady source of power in times of need. The power output depends on the fuel consumption of the diesel generator at time t is calculated by the following equation Eq. 6 [17].

(6) $$F_{cons}(t) = \alpha P_{DG}(t) + \beta P_r$$

Where F_{cons} is the generator fuel consumption (*L*/*h*), P_r is the nominal power generated by DG (*k*W) at each hour (t), P_{DG} is the output power of diesel. The constant α and β represent the fuel consumption coefficients (*L*/*k*W*h*), in the present study are taken as 0,246 and 0.8415.

Storage system modelling

A battery system is a fundamental unit that ensures the supply of the load when the power generated from renewable energy sources is insufficient, restitution during peak demand, and while the energy resources work with a slower response (WT). The system's battery capacity C_b has obtained using the formula expressed such as [18]:

(7) $$C_B = \frac{P_l \times AD}{k_b \times k_{inv} \times DOD}$$

Where P_l is the energy demand, AD represents the autonomy period and DOD is the depth discharge of the battery. k_b, k_{inv} are battery and inverter efficiencies respectively.

production and absorption of battery system during the time (t) described as follows [19].

(8) $$P_b(t) = \left(P_{PV}(t) + P_{WT}(t) \right) - \frac{P_l}{k_{inv}}$$

Where P_b, P_{PV} and P_{WT} are energy power produced from battery, PV systems and WT.

(9) $$if\; P_b > 0 \Rightarrow \; P_t(t) > P_l(t)$$

(10) $$if\; P_b < 0 \Rightarrow \; P_t(t) < P_l(t)$$

(11) $$if\; P_b = 0 \Rightarrow \; P_t(t) = P_l(t)$$

Where P_l is load power demand, P_t represent the sum of power from renewable energies $P_t(t) = P_{PV}(t) + P_{WT}(t)$.

The performance battery can be affects by the state of charge of a battery (SOC) in the charge and discharge. The SOC can be determined using the following equation [20].

- Charging process, if $P_t(t) > P_l(t)$

(12) $$SOC(t) = SOC(t-1)(1-\sigma) + \left(P_t(t) - \frac{P_l(t)}{k_{inv}} \right) \times k_b$$

- Charging process, if $P_t(t) < P_l(t)$

(13) $SOC(t) = SOC(t-1)(1-\sigma) + \left(\frac{P_l(t)}{k_{inv}} - P_t(t) \right) \times k_b$

Where $SOC(t)$ and $SOC(t-1)$ represent the battery charge state at times *t* and (*t*-1) respectively.

Converter modelling

The inverter converts the electrical energy from direct current (DC) to alternating current (AC). The efficiency of the converter had evaluated as follows [21].

(14) $$k_{cnv} = \frac{P_l}{P_t}$$

Where P_l and P_t are the output and input power from/to converter respectively.

Economic parameters of hybrid microgrid

The technical specifications and economics for each component used in this study have listed in table 1. The economic feasibility of HRES in a power system can be determined using this technical and financial information [22].

Table 1. Technical and cost parameters of the proposed MG system

component	parameters	value
Solar PV	Rated power (kW)	1
	Capital cost ($/kW)	1600
	O & M cost ($/yr)	32
	Lifetime (year)	20
Wind turbine	Rated power (kW)	1
	Capital cost ($/kW)	1500
	O & M cost ($/yr)	32
	Lifetime (year)	25
Diesel generator	Rated power (kW)	1
	Capital cost ($/kW)	800
	O & M cost ($/hr)	0.02
	Lifetime (hour)	15000
Battery	Rated power (kW)	1
	Capital cost ($/kW)	180
	O & M cost ($/yr)	3.6
	Lifetime (year)	5
Converter	Rated power (kW)	1
	Capital cost ($/kW)	500
	O & M cost ($/yr)	10
	Efficiently	95
	Lifetime (year)	15

First scenario

Fig. 4 shows a schematic representation of the proposed MG1, including the PV module, the wind turbine, and the battery bank. A bi-directional converter ensures the transfer of energy from the DC bus to the AC bus to satisfy the load demand or to recharge the battery.

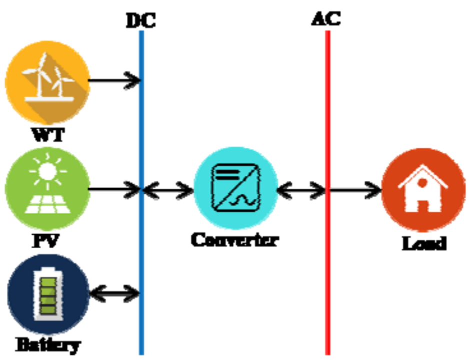


Fig.4. Schematic of MG1

After the simulation with HOMER software, the optimal size of each component for MG1 was determined as follows in table 2.

Table 2. The optimal size of the MG1 component

Component	Power rated (kW)
PV system	4
Wind turbine	1
Number of batteries in parallel	12

The monthly average electric production (PV system and wind turbine) illustrates in Fig. 5.

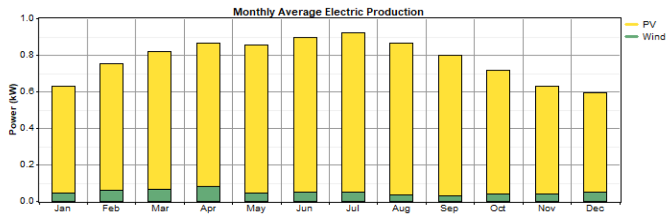


Fig.5. Monthly average electric production of MG1

The annual production curve of the PV system and the wind turbine with the load consumption have shown in Fig. 6.

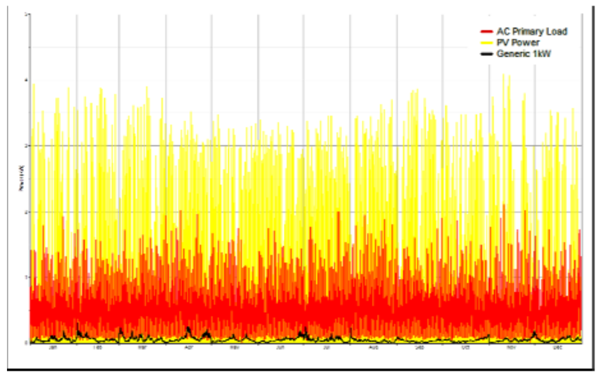


Fig.6. Annual electric production and AC primary load power

Table 3 shows the annual energy values of the generation sources and the load.

Table 3. The annual production and consumption power

	Component	Power (kWh/yr)	Percentage (%)
Production	PV system	6378	0.93
	Wind turbine	447	0.07
Consumption	AC load primary	4088	1.00

The optimized values of the first configuration PV/WT/Battery are an TNPC of 15,400$, a COE of 0.295$/kWh, and an operating cost of 340$/yr. The system produces excess electricity of 1932 kWh/yr (28.3%) with a 100% renewable fraction.

Second scenario

The proposed MG2 illustrated in Fig. 7 is the same as the past scenario with the addition of a diesel generator.

Table 4 illustrates the optimal values of each element of this configuration.

Table 4. The optimal size of the MG2 component

Component	Power rated (kW)
PV system	2
Wind turbine	2
Diesel generator	1
Number of batteries in parallel	5

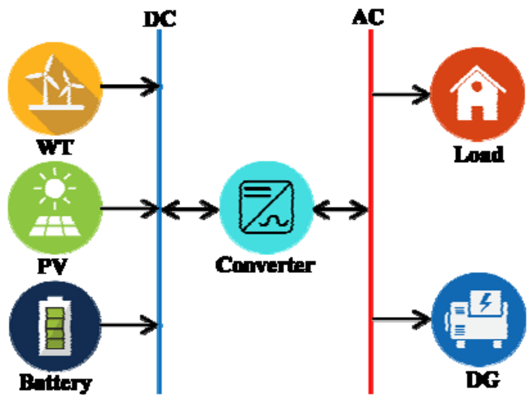


Fig.7. Schematic of MG2

The monthly average of production sources such as PV system, wind turbine, and diesel generator has represented in Fig. 8.

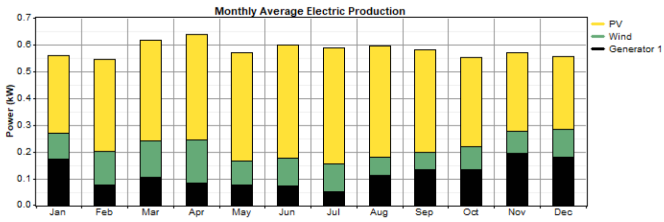


Fig.8. Monthly average electric production of MG2

The annual curves of production sources (PV system, wind turbine, and diesel generator) and consumption (residential load) have shown in Fig. 9.

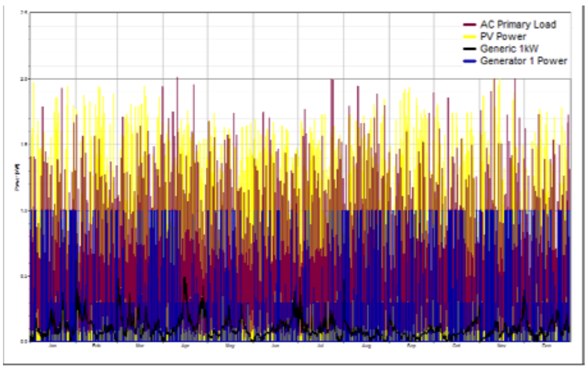


Fig.9. Annual electric production and consumption power

The production-consumption values have listed in table 5.

Table 5. The annual production and consumption power

	Component	Power (kWh/yr)	Percentage (%)
Production	PV system	3189	0.63
	Wind turbine	895	0.18
	Diesel generator	1011	0.20
Consumption	AC load primary	4088	1.00

The results optimized for the second configuration PV/WT/DG/BATTERY have observed that the TNPC, COE, and Operating costs are 15,340$, 0.294$/kWh, and 543$/yr successively. This system has excess energy of 276 kWh/yr (5.41%) and a renewable fraction of 80.2%.

Third scenario

The third MG3 configuration is MG1 on-grid. Using HOMER, optimal sizing results of this configuration have presented in table 6.

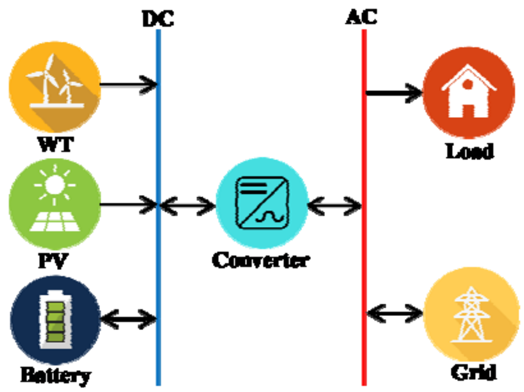


Fig.10. Schematic of MG3

Table 6. The optimal size of the MG3 component

Component	Power rated (kW)
PV system	4
Wind turbine	1
Grid	1000
Number of batteries in parallel	5

Fig. 11 displays the monthly average power production PV system and wind turbine.

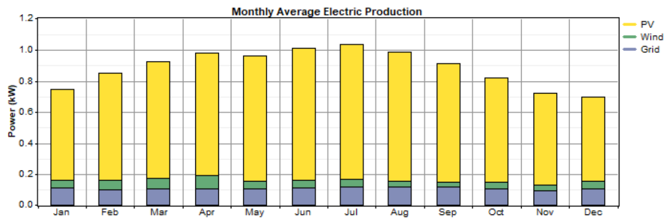


Fig.11. Monthly average electric production of MG3

Fig. 9 represents the graph of the energetic variation during one year of the production sources and the consumption. On the other side, table 7 mentions the annual energy results for each component.

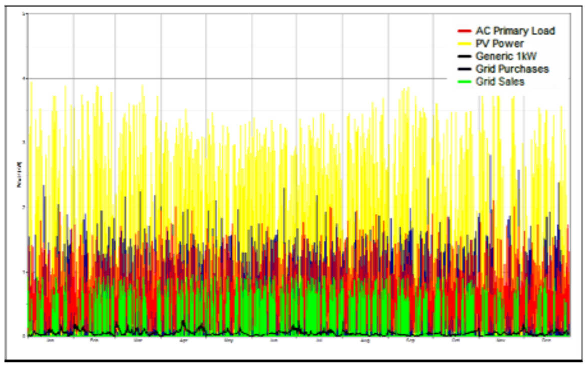


Fig.12. Annual electric production and consumption power

Table 7. The annual production and consumption power

	Component	Power (kWh/yr)	Percentage (%)
Production	PV system	6378	0.82
	Wind turbine	447	0.02
	Grid purchases	936	0.12
Consumption	AC load primary	4088	1.00
	Grid sales	1205	0.23

The MG3 optimization results show that the TNPC has a value of 14,054$, a COE of 0.269$/kWh, and an operating cost of 344$/yr. The simulation indicates that the system provides excessive energy of 1395kWh/yr (18%) with a renewable fraction of 87.9%.

Analyse and discussion

Due to the area nature selected in this study, the results show that the power generated by the PV system in the three MGs had used primarily to supply the residential load. We notice that the annual energy of the PV system generated by MG1 (6378kWh/yr) and MG3 (6378kWh/yr) are equal and higher than MG2 (3189kWh/yr).

The simulation results from HOMER had reported in Table 8. The comparative analysis in Fig. 13 shows that MG2 had low TNPC and COE with a value of 14,054$ and 0.269$/kWh, respectively. The excess of energy produced by MG2 (276kWh/yr) is the lowest of the two other MGs. MG1 generates the highest energy excess with a power of 1932kWh/yr.

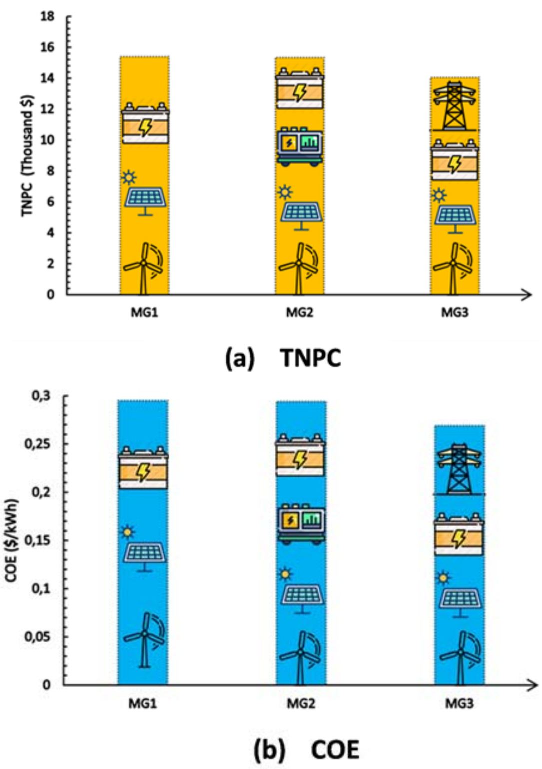
For the environmental side, the resulting CO_2 emission from MG1 is zero because the energies had generated by purely net sources (PV/WT) with a renewable factor of 100%. The other two systems use polluting sources (diesel generator, grid). The result shows that MG3 minimizes CO_2 emissions while MG2 releases a quantity of CO_2 emissions of 950kg/yr.

Table 8. The comparative analysis

	Scenario 1 (MG1)	Scenario 2 (MG2)	Scenario 3 (MG3)
TNPC ($)	15,400	15,340	14,054
COE ($/kWh)	0.295	0.294	0.269
Excess energy (kWh/yr)	1932	276	1395
Renewable factor (%)	100	80.2	87.9
CO_2 emissions (Kg/yr)	0	950	-170

Conclusion

The new electricity challenges supply is at the heart of many technological, financial and political debates. To ensure a stable and healthy future for tomorrow's grids, it seems essential to renew the current infrastructure and make it more intelligent. The fruit of this work is to study the technical-economic aspect of microgrids, which is why we created Three MG.



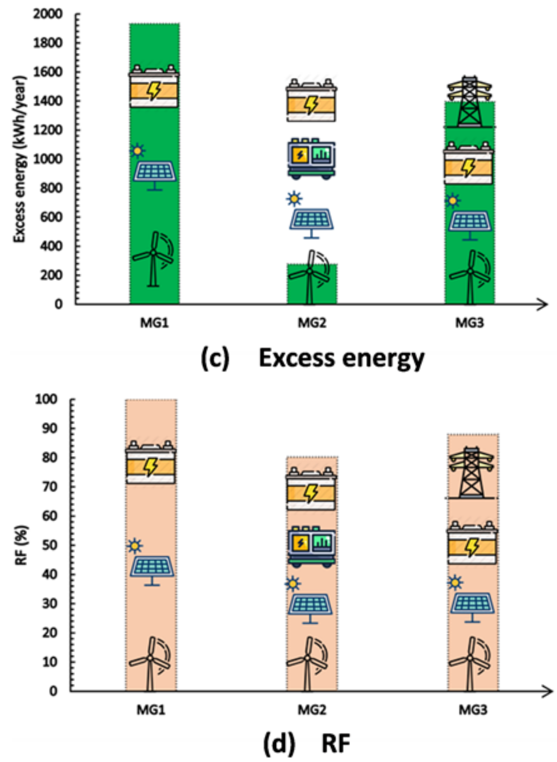


Fig.13. Summary of system parameter comparisons: (a) TNPC, (b) COE, (c) excess energy, (d) renewable fraction

The result shows that the optimal microgrid in sizing and cost is MG3 which has connected to a grid with a low TNPC of 14,054$, a COE of 0.269$/kWh, the PV production is 82%, minimization of CO_2 emission with a value of 170kg/yr. The consumer can sell 1205kWh/yr of energy to the grid and an energy purchase of 936kWh/yr for use during the peak load demands.

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