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Design of a Hybrid Power System for Electrification of New Talkha Bridge Construction in Egypt.

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Design of a Hybrid Power System for Electrification of New Talkha Bridge Construction in Egypt

تصميم لنظام هجين لتغذية الأحمال الكهربية اللازمة لأعمال إنشاء كوبري طلخا الجديد في مصر

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KEYWORDS:
Hybrid power system, PV, Battery storage, Diesel generator, Fuel consumption, Sizing procedures, Life Cycle Cost, Economic analysis

***الملخص العربي:*- يهدف هذا العمل إلى تقديم تصميم فعال لنظام هجين مستقل عن الشبكة مكون من ألواح الطاقة الشمسية والبطاريات ومولد الديزل. طريقة التصميم المقدمة تتبع خطوات ممنهجة وعملية لتحديد القدرات والسعات للمكونات المطلوبة والمستخدمة في النظام الهجين. تتم الحسابات اعتمادا على مواصفات المكونات المستخدمة بالنظام وكذلك الحمل المطلوب وشدة الاشعاع الشمسي للمنطقة محل الدراسة. بالإضافة إلى أنها تتميز بإمكانية تطبيقها على أي مشروع (حمل كهربي) بصفة عامة سواء كان في المناطق النائية أو القريبة من الشبكة وعلى أثر ذلك تم التطبيق على مشروع إنشاء كوبري طلخا الجديد في مصر. في هذا البحث أيضا تم عمل دراسة اقتصادية لعدة نظم تشغيل لتحديد أيهم الأفضل من حيث التكلفة والكفاءة ومدى التأثير على تلوث البيئة وتشجع نتائج هذا البحث على استخدام نظام الطاقة الشمسية الهجين في المناطق النائية في مصر.**

Abstract— **This paper aims to introduce an effective design of a stand-alone hybrid power system (HPS). The designed system consists of a photovoltaic (PV) array, battery bank and diesel generator. The presented technique proceeds in practical and plausible steps to estimate the rated powers of each component of the HPS. It will be determinant based on the expected loads, characteristics of the used PV module and the meteorological data of the region of installation. Furthermore, it can be applied to design a hybrid power system for electrification of any individual load either in rural or urban areas which are near to the main grid. Thereupon, it is applied on a case study (Constructing of New Talkha Bridge in Egypt). Additionally in this paper, various operational configurations are studied, analyzed economically to ascertain which of them the optimal and appropriate considering cost, reliable and pollutant emissions are. The results of the study encouraged the use of the hybrid PV system in rural areas in Egypt.**

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I INTRODUCTION

RECENTLY, the world has an attention to minimize the dependent on the traditional energy sources and depend on an alternative energy sources. Moreover, the fluctuations in fossil fuel prices in the last decade together with the coming shortage and depletion have heightened concerns over future energy supply security. To this end, advanced energy policies, in many countries, have been based on the development of renewable and sustainable energy resources to be considered as the promising alternative energy sources [1]. Hybrid Power System (HPS) based on photovoltaic (PV) and diesel generator systems is considered as an effective option to electrify rural areas. However, two major limitations exist that prevent widespread adoption: availability of the electricity generated and the cost of the equipment [2].

Egypt is considered as one of the countries which are rich in solar energy available almost all the year. Therefore, the authors decided to make benefits for the construction site

"Talkha Bridge on the Nile" of a construction company in Egypt from the availability of solar resources and depend on PV plants especially with the rising electricity tariffs.

This paper introduces a proposed methodology that employs a techno-economic approach to determine the system design optimized by considering multiple criteria including size, cost, and availability. This approach makes use of a deterministic algorithm to suggest, among a list of commercially available system devices, the optimal number and type of units, ensuring that the total cost of the system is minimized while guaranteeing the availability of the energy [3].

Generally, the steps of hybrid PV system design can be listed as follows;

1. Find the suitable location for the installation site depending on its geographical and meteorological data.
2. Estimate the maximum load demand for the required system.
3. Determine the Size of the PV system components and the battery bank.
4. Define the other available energy sources which could be installed (main grid, diesel generator, battery bank, etc.).
5. Create and examine different configurations by combining the available energy sources.
6. Analyze each suggested scenario Techno-economically.
7. Choose the optimal scenario.

Finally, this paper is organized by the beginning with the design and sizing procedures of the hybrid PV system. Hence, they are applied on the proposed case study. Then, different operational strategies are created among the available energy systems. Finally, an economic analysis based on Life Cycle Cost (LCC) technique is evaluated for each suggested scenario. The optimal configuration is determined according to the appropriate considering cost, reliable and pollutant emissions.

II THE DESIGN PROCEDURES

In this section, each step of the listed design procedures is discussed in details. Generally, the main components of the proposed hybrid PV system are namely PV array, inverter, battery bank, battery charger, diesel generator and the load.

1. Meteorological Data

Collection of meteorological and geographical data is necessary for the PV system. It is required to analyze the available solar energy which could be gained at the selected site. Various sources for such data are available at web sites and/or other programmable software specialist at this field. For example, Solar Med-Atlas of the Mediterranean [4], National Aeronautics and Space Administration (NASA) [5], National Renewable Energy Laboratory (NREL) [6], and/or Google Earth Software.

2. Load Demand Estimation

Estimation of the energy demand of the proposed system is an important step where the design is built upon. It determines the required energy to be produced. It is worth mentioning that many of the systems had previously failed not because the system was installed incorrectly, or that the equipment and components of the system may have failed, but because customers were not aware of the accurate amount of the required energy to be produced. Mainly, the required load characteristics are:

- *Application characteristics*
- *Average expected daily consumption (kWh/day)*
- *The maximum daily load (kW)*

However, the experience of the system designer plays a crucial role in order to infer other basic information (e.g. reliable autonomy factor, solar fraction, energy availability, installation position) that is required to achieve an effective system configuration and suitable component sizes.

3. Selection of System DC Bus Voltage and the Components

Typically, the selection of DC nominal voltage of the designed system ($\mathbf{V}_{DC.\mathrm{sys}}$) is depending on the load type, daily load demand and the input voltage of the used products in the system. In general, the DC voltage ranges are 12, 24, 48, 110, etc. However, some devices with voltage rate above 48V could be unavailable at local markets. Therefore, 48V shall be selected for this designed system.

Otherwise, the selection of system's components depends on many factors such as availability at local market, cost and efficiency. Thus, SunTech PT6P60-250W poly-crystalline PV module, a 12V German Gel valve-regulated lead acid battery with capacity of 200Ah, Steca solar charge controller of model PT-MPPT-5KW and an inverter of model PT-GalaxySolar-5K-48V are selected to be utilized in this work (Appendix A). While, a transformer of 5kVA-48V is selected for three-phase loads.

4. Battery Bank

Lead-acid batteries are selected to be utilized in this design for storing the excess produced energy. Primarily, the main parameter used to characterize the batteries is the depth of discharge (DOD) **[7]**. Generally, sizing of the battery bank capacity depends on different parameters which are clarified by the formula **[8]**;

$$C_{Ah} = \frac{N_{aut} \ x \ E_L}{DOD_{max} \ x \ V_{DC} \ x \ \eta_{bat} \ x \ \eta_{inv}} \quad (1)$$

In which, $\mathbf{C_{Ah}}$ is the required battery bank capacity in (Ah), $\mathbf{N_{aut}}$ is the number of autonomy days, $\mathbf{E_L}$ is the maximum energy demand of the proposed case study in (kWh/day), $\mathbf{DOD_{max}}$ is the maximum depth of charge for the selected battery, $\boldsymbol{\eta_{bat}}$ is the battery efficiency and $\boldsymbol{\eta_{inv}}$ is the inverter efficiency.

Number of series connected batteries per string ($\mathbf{N_{s.bat}}$) can be estimated by;

$$N_{s.bat} = V_{DC} \ x \ V_{selected.bat} \quad (2)$$

While, number of parallel strings of batteries ($\mathbf{N_{p.bat}}$) can be estimated by;

$$N_{p.bat} = C_{Ah} \ x \ C_{selected.bat} \quad (3)$$

5. PV Generator

The solar cell is considered the basic unit of PV system which converts sunlight into electricity. The cells are connected in series or/and parallel to form PV modules and arrays. The PV system can produce the required energy demand with a designed number of connected modules in series and parallel strings. In general, the required peak power should be produced by a PV generator ($\mathbf{P_{PV.Gen}}$) can be calculated using the following equation [9];

$$P_{PV.Gen} = \frac{E_L \; x \; f_{Safety}}{H_{tilt} \; x \; \eta_{PV\,sys}} \; x \; PSI \qquad (4)$$

Where, $\mathbf{H_{tilt}}$ is the average solar irradiation in peak sun hour's incident for specific tilt angle in (kWh/m2/day), $\boldsymbol{f_{safety}}$ is an optional safety factor, PSI is the peak solar intensity at the earth's surface (=1000 W/m2) and $\boldsymbol{\eta_{PV.sys}}$ is the PV system efficiency which can be calculated as [10];

$$\eta_{PV.sys} = \eta_{wires} \; x \; \eta_{MPPT} \; x \; \eta_{bat} \qquad (5)$$

Where, $\boldsymbol{\eta_{wires}}$ is the energy transmission efficiency of wiring system losses due to distances between components of the PV system which in this design is kept above 95% and $\boldsymbol{\eta_{MMPT}}$ is the efficiency of the MPPT charge controllers and/or inverters.

Typically, the rated output power of a PV module (P_{STC}) is affected by losses factors (as temperature, dust, dirt, etc.). As a result, its power rating is reduced to a de-rated output power which is given by [10];

$$P_{mod} = P_{STC} \; x \; f_{temp} \; x \; f_{dirt} \; x \; f_{toler} \qquad (6)$$

Where, $\boldsymbol{f_{toler}}$ is a tolerance value given by the manufacturer (varies from manufacture to another), $\boldsymbol{f_{dirt}}$ is derating factor due to the dust and dirt that could be stacked on the surface of the module (usually an acceptable value of 5% is taken), $\boldsymbol{f_{temp}}$ is temperature de-rating factor which can be calculated by [11];

$$f_{temp} = 1 + [\, \gamma \, (T_{eff} - T_{STC})] \qquad (7)$$

Where, $\boldsymbol{\gamma}$ is power temperature coefficient in (%/oC) given by the manufacturer (Appendix A), TSTC is the cell temperature at standard test condition (STC) which is usually 25oC, $\mathbf{T_{eff}}$ is the effective average cell temperature in (oC) which can be calculated as follows;

$$T_{eff} = T_{amb} + 25^{o}C \qquad (8)$$

Where, $\mathbf{T_{amb}}$ is the daily ambient cell temperature in (^{o}C).

Number of series connected modules per string (Ns.mod) can be estimated by;

$$N_{s.mod} = V_{DC} \; / \; V_{mp} \qquad (9)$$

Where, $\mathbf{V_{mp}}$ is the voltage of the selected module at the maximum power point (Appendix I).

While the number of modules in parallel ($\mathbf{N_{p.mod}}$) can be estimated by;

$$N_{p.mod} = \frac{P_{PV.Gen}}{N_{S.mod} \; x \; P_{mod}} \qquad (10)$$

Thus, the total required number of modules ($\mathbf{N_{mod}}$) can be calculated as follows;

$$N_{mod} = N_{s.mod} \; x \; N_{p.mod} \qquad (11)$$

6. Battery Charge Controller

The charge controller device is strongly required as it provides safety charging for batteries by managing the charging and discharging process in addition to it saves the batteries lifetime. It should match the voltage of both installed PV array and batteries. Basically, the controller has to be capable of carrying the short circuit current of the array. The rated current of battery charger controllers ($\mathbf{I_{chrgs}}$) is estimated by following formula **[12]**;

$$I_{chrgs} = N_{P.mod} \; x \; I_{sc} \; x \; f_{Safety} \qquad (12)$$

Where, $\mathbf{I_{sc}}$ is the short-circuit current of the selected PV module (Appendix A).

The required number of charger controllers ($\mathbf{N_{chrgs}}$) can be calculated also by;

$$N_{chrgs} = I_{chrgs} \; / \; I_{selected.chrg} \qquad (13)$$

7. Inverter

The inverter is sized based on calculation of the actual power drawn by the appliances which will run at the same time. It should be capable of handling the maximum expected power of these appliances. Also, starting current of large motors (if exist) should be taken into account. The input voltage of the inverter has to be matched with the selected DC bus voltage while its output should be compatible with the operating voltage of the used appliances. Other factors such as the power and safety factor for system expansion should be taken into account. The total rated power of the required inverter ($\mathbf{S_{inv}}$) can be estimated based on the following formula;

$$S_{inv} = \frac{(P_{RS} + P_{LSC})}{p.f} \; x \; f_{Safety} \qquad (14)$$

Where, $\mathbf{P_{RS}}$ is the power rating of appliances which run simultaneously, $\mathbf{P_{LSC}}$ is the estimated rating power of large surge current appliances and $\boldsymbol{p.f}$ is the power factor.

8. Diesel Generator

Utilizing diesel generator in a combination with the PV system helps in improving the performance of the hybrid system (e.g. high energy availability, optimized battery size and operating lifetime and ensures high power reliability). Additionally, it has low investment cost. However, integrating a back-up generator with the stand-alone PV systems goes along with air pollution, noise and continuous dependence on fuel delivery. In some places, the fuel delivery is problematic and can increase operating costs to very high levels. Therefore, sizing of the back-up generator is always case specific, and requires a careful study of the application, including many technical, geographical and financial conditions **[13]**. Generally, the rated power of the diesel generator must be;

- Equal to the daily maximum expected peak load,
- Greater than the daily average load or
- Matches a specific critical load.

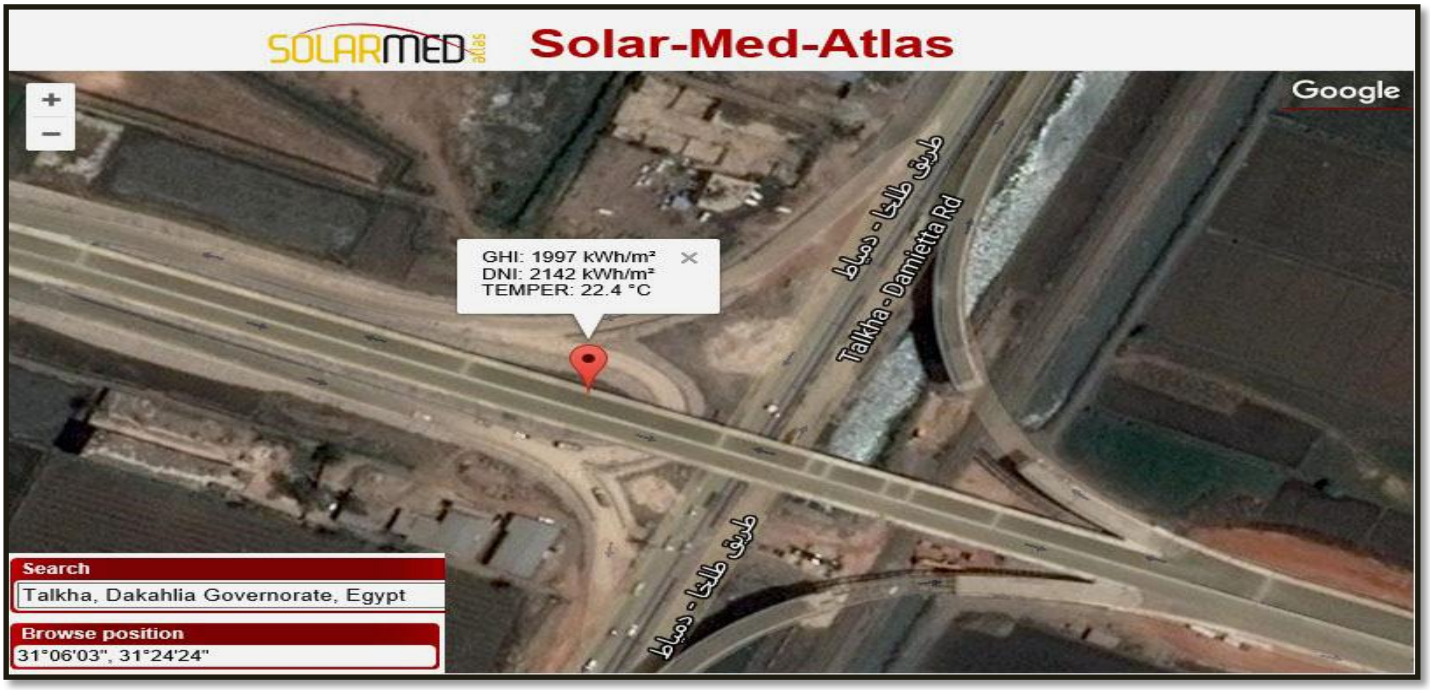

Fig.1 Study area location by [4]

III CASE STUDY

Constructing of New Talkha Bridge project in Egypt is taken as a case study in this work.

A) *Geographical and Meteorological Data*

The project is located in the Delta region of Egypt specifically at Talkha - Damietta Rd, Talkha City at Dakahlia Governorate. By [4-6], the study area is at latitude of 31.06° and longitude of 31.24° (Fig. 1), and the annual average solar radiation incident on a horizontal surface in this region is 5.51kWh/m2/day.

B) *Load Estimation*

The electrical appliances are single and three-phase AC loads as shown in Table 1. In particular, they can be categorized to:

1. Construction site.
2. Work staff's offices.
3. Staff's housing units.
4. Desalination unit

According to Table 1 and Fig.2, the maximum load demand and daily energy consumption (EL) at hot season are found as 90kW and a 559kWh/day respectively. Therefore, the HPS should be designed to meet the energy demand.

TABLE.1
MAXIMUM DAILY ENERGY CONSUMPTION

Electrical AC load or Appliance	No. of Units	Rated power (Watt)	Adjusted factor for AC loads	Adjusted Watta (Watt)	Usage hours (h/day)		Energy consumed (kWh)		Comment	Duty factor
					Wet season	Dry season	Wet season	Dry season		
15 Offices + Mosque										
Lighting	272	18	0.8	6120	6	6	25.7	25.7	only 60-80 % used	0.7
Air Conditioner (2.25 hp)	10	1700	0.8	21250	0	4	0	68	80% avg. usage	0.8
Electric Fan	15	50	0.8	937.5	0	6	0	3.385		0.6
Computer	8	150	0.8	1500	6	6	6.75	6.75		0.75
Printers & scanners	5	50	0.8	313	2	2	0.47	0.47	70% avg. usage	0.75
Paper Sheeting Machine	1	1500	0.8	1875	1	1	1.9	1.9		1
Central Telephone	1	200	0.8	250	2	2	0.5	0.5		1
Wireless Communication Device	4	100	0.8	500	2	2	1	1		1
Refrigerator (16 cu.ft)	1	150	0.8	188	6	6	1.125	1.125		1
Electric Kettle	2	1000	0.8	2500	3	3	7.5	7.5		1
Motor (0.5 hp)	1	375	0.8	468.85	2	2	0.94	0.94		1
Working Site										
Night Lighting	10	400	0.8	5000	10	10	50	50		1
Angle grinders power tools	4	850	0.8	4250	4	4	17	17		1
Hammer drill power tool	2	1000	0.8	2500	4	4	10	10		1
Circular saw	2	1600	0.8	4000	4	4	16	16		1
Wood eater	1	500	0.8	625	2	2	1.25	1.25		1
Air compressor (3 hp)	1	2238	0.8	2797.5	1	1	2.8	2.8		1
Car tires welding device	1	200	0.8	250	1	1	0.25	0.25		1
3-ph Arc welding machine	2	24000	0.8	60000	4	4	1446	144	60%duty cycle	0.5
3-ph injection machine (3hp)	1	3876	0.8	2797.5	4	4	11.2	11.2		1
3-ph Cast iron bender (3hp)	2	2238	0.8	5590	4	4	22.4	22.4		1
3-ph Cast iron cutter (3hp)	1	2238	0.8	2797.5	1	1	2.8	2.8		1
Laboratory Equipment										
• Heater	1	2000	0.8	2500	2	2	5	5		1
•Vibrating sieve equipment	1	600	0.8	750	2	2	1.5	1.5		1
• Determine CBR	1	400	0.8	500	2	2	1	1		1
• CBR blocks breaker	1	800	0.8	750	2	2	2	2		1
Staff Housing Units										
Lighting	75	26	0.8	2437.5	8	8	14.6	14.6	70% average usage usage 75%	0.75
TVs & Satellite TV decoder	12	150	0.8	2250	6	6	13.5	13.5		1
Electric Fan	20	50	0.8	1250	0	8	0	10		1
Washing Machine	1	1500	0.8	1875	1	1	1.9	1.9		1
Smoothing iron	1	1000	0.8	1250	1	1	1.25	1.25		1
Refrigerator (16 cu.ft)	2	150	0.8	375	6	6	2.25	2.25		1
Electric Kettle	2	1000	0.8	2500	4	3	10	7.5		1
Blender	1	200	0.8	250	1	1	0.25	0.25		1
Motor (0.5 hp)	2	373	0.8	932.5	3	3	2.8	2.8		1
Power sockets	8	50	0.8	500	3	3	1.5	1.5		1
Water Heater	1	2000	0.8	2500	4	0	10	0		1
Desalination Unit (10-15m3)	1	5500	0.8	6875	18	18	99	99	60-80person usage	1
Total Energy Consumption								559		

c) Battery Bank Capacity

The battery bank is designed to operate for only 10 hours/day as an autonomy day (N_{aut}) with an efficiency of 85% a value of 0.65 as the DOD (as a worst case). Based on (1), the battery bank capacity is estimated as;

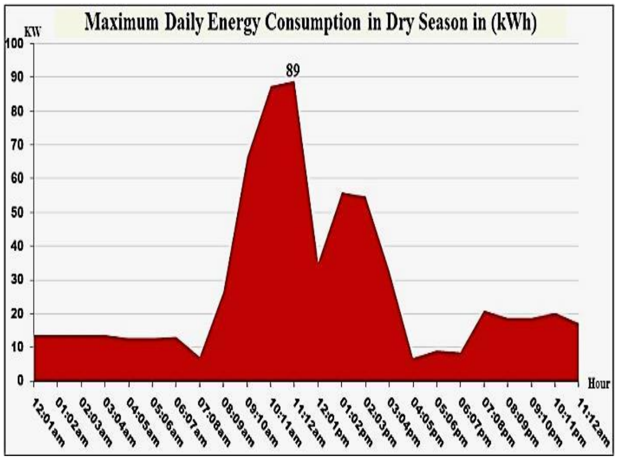

Fig.2 Maximum daily load demand profile

$$C_{Ah} = \frac{(10/24) \text{ x } 559 \text{ (kWh/day)}}{0.65 \text{ x } 48\text{(V)} \text{ x } 0.85 \text{ x } 0.93}$$
$$\approx 9444\ Ah$$

The number of series and parallel batteries can be calculated by using (2) and (3) as follows;

$$N_{S.bat} = 48\ /\ 12\ =\ 4$$
$$N_{P.bat} = 9444\ /\ 200\ \approx\ 48$$

Therefore, the required number of batteries would be 192.

d) PV Generator

Based on (4), the required peak power of the PV generator is;

$$P_{PV.Gen} = \frac{559 \left(\frac{kWh}{day}\right) x\ 1 \left(\frac{kW}{m^2}\right)}{5.51 \left(\frac{\frac{kWh}{m^2}}{day}\right) x\ 0.713}$$
$$\approx 143\ kWp$$

Using (9), the number of series modules per string is;

$$N_{S.mod} = 48\ /\ 30.5\ =\ 1.57$$

Therefore, the required modules to be connected in series are 2.

While, the number of parallel modules in strings can be estimated by (10) as follows;

$$N_{P.mod} = \frac{143\ (kWp)}{2\ x\ 203.75\ (W)} = 351$$

Thus, 352 modules are required to be connected in parallel strings. Therefore, the total required modules in the PV system would be 704.

E) Charge Controller

Using (12), the rated current required by the charge controllers is;

$$I_{chrgs} = 352\ x\ 8.67\ (A) \approx\ 3052\ A$$

Therefore, the total required number of charge controllers can be given by (13) as follows;

$$N_{chrgs} = 3052\ /\ 60\ (A) \approx\ 51$$

F) Inverter

Based on (14), the total required power rating by the inverters is 112.5 kVA for supplying 90kW single-phase appliances at a power factor of 0.8. While, the three-phase appliances of 60kW are electrified by 15 transformers with total power rating of 75 kVA.

Therefore, the required number of single-phase inverters and three-phase transformers is 23 and 15, respectively.

G) Diesel Generator

Two diesel generators are selected for the proposed hybrid power system with the same specifications (TEMPSET, 103kVA, 380/220V).

TABLE.2
SIZING PROCEDURE RESULTS

System Component	*Description of System Component*	*Sizing Result*	*Total Price (EGP)*	*Specification*
Load Demand	Maximum Load Estimated	559 kWh/day, 90kW	-	(1-φ) & (3- φ) AC loads
DC Bus Voltage	Common DC Bus Collector	48 VDC	-	DC Voltage
Battery Bank	Battery Bank Capacity	9600Ah	576000	Gel valve regulated lead acid battery 12V, 200Ah
	Batteries in series	4		
	Batteries in parallel	48		
	Total Batteries	192		
PV Generator	PV Peak power	143kWp	1056000	SL6P60-250W, Ploy-crystalline
	Modules in series	2		
	Modules in parallel	352		
	Total PV Modules	704		
Charge Controller	Chargers Capacity	3052A	142800	Steca PT-MPPT 3kW, 60A
	Total Chargers	51		
(1-φ) *Inverter*	Total Power Rating	115kVA	161000	PTGalaxy Solar 5kVA/48V
	No. of Inverters	23		
(3-φ) *Transformer*	Total Power Rating	75kVA	147000	5kVA, 220/380V
	No. of Transformers	15		
Diesel Generator	Power Rating	103kVA	320000	TEMPSET, 380/220V,157A
	Total Generators	2		

IV SUGGESTED OPERATION SCENARIOS

The previous results of sizing procedures are listed and summarized in table 2. It includes the prices of selected components according to a typical financial offer presented by Egyptian company which is specialized in this field.

Moreover, different operation configurations are suggested to provide more options to power up the proposed load. The configurations are created based on different combination of the available energy sources. Typical sizing and cost analysis are conducted for the suggested configurations **[7]**. Four operational scenarios are created and analyzed economically in this section.

Typically, the optimum sizing process is verified by carrying out an appropriate sensitivity analysis **[14]** in the Egyptian Pound (EGP). Additionally, an economic comparison is applied based on the unit electrical cost (kWh) for both terms; the suggested scenarios and each power source individually. The fixed costs (resulted by the costs incurred at the beginning of the project) and the annual running costs are also included in the comparison.

A)Scenario A; Main Grid and Diesel Generator

This scenario represents the current operation strategy, where the proposed load is supplied via the main grid and two diesel generators with power rating of 100kVA/unit. According to reality, the capital cost required for connection to the grid was only 150000EGP. But, it's worst mentioning that the tariff of the unit electrical has increased in the last few years from 0.32EGP/kWh to 0.86EGP/kWh for the commercial contracting condition. Nowadays, the Egyptian government is shrinking the subsidization for the petroleum products. Thus, the frequent power bills expend about 100000EGP/year plus to an annual regular maintenance of 15000EGP.

On the other side, the capital cost of the both diesel generators and the auxiliaries was 340000EGP, while the running cost has recorded a high value due to the rise of fuel prices up to 1.8EGP/liter. For the utilized generator, the fuel consumption rate at 100%, 75% and 25% of load are 22.3, 16.9 and 8.3 Liters/h, respectively **[15]**. Usually, generator 2 operates for 7 h/day at a 75% of load while the other operates for 8 h/week as a backup system. Also, it assumed that only one generator will be needed for the night time usage is about 12 h/week at a 25% of load.

On the light of previous data, the total annual running costs resulted by utilizing diesel generators can be estimated as 143000EGP including cost of the fuel consumption, fuel transport, losses and regular maintenance (5% of the capital cost).

Finally, the capital and annual running costs incurred in this scenario are 490000EGP and 258000EGP, respectively.

B)Scenario B; Diesel Generators

It is assumed that the diesel generators are the sole energy source. Indeed, the operation hours of generators will be increased. Therefore, one generator is assumed to run for 8 h/day and 12 h/night while the other is used to be operated for 7 h/day.

Thus, the total fixed and annual running costs incurred in this scenario can be evaluated as 340000EGP and 304250EGP, respectively.

C)Scenario C; Hybrid PV/Diesel Generator System

A combination of a hybrid PV/diesel generator system is assumed to supply the proposed load. From table 2, the initial cost of the PV system's components can be simply calculated by 1506800EGP. Other expenses will be considered into the capital cost as the transport and shipping cost (6% of initial cost) and the installation cost of 150000EGP (10% of initial cost).

Moreover, the annual regular maintenance (1-2% of initial cost) and the losses cost (5% of total electricity generated cost) are representing the annual running cost. Thus, the capital and annual running cost of the PV system are 1746800 and 33000 EGP, respectively.

On the other side, a diesel generator must be existed for the emergency and the night time usage. It is supposed to be operated for 12h/week at daytime and 12 hours every night. The usage of the generator 2 at the eastern side of the proposed study area would be taken into account also. Therefore, the annual running cost of the diesel generators can be estimated as 208750EGP.

Finally, the total capital and annual running costs resulted by this scenario are about 2087000EGP and 241750EGP, respectively.

D) Scenario D; Hybrid PV/batteries/Diesel Generator

For more variety, this scenario is created and analyzed economically. The battery bank is utilized instead of diesel generator 1. The purchase cost of the hybrid PV/battery system is estimated as 2082800EGP. Thereby, the capital cost would be 2407800EGP, while the running cost is 53000 EGP/year.

On the other side, the fixed cost of diesel generator is evaluated as 170000EGP while the annual running cost is estimated by about 120000EGP.

Finally, the capital and annual running costs incurred in this scenario are 2577800EGP and 173000EGP, respectively.

V ECONOMIC EVALUATION

In this context, the primary objective of the present study is to determine the optimum dimensions of a stand-alone PV-diesel system, under the restriction of minimum long-term electricity generation cost, and accordingly obtain a comparison of different suggested scenarios. For this purpose, the developed methodology is applied with results obtained being rather encouraging for the implementation of the proposed optimal solution [16].

The available energy systems are categorized into the main grid (system A), hybrid PV/battery (system B), PV (system C) and diesel generators (system D). Table 3 presents an economical evaluation based on the unit electrical cost (¢kWh) for each configuration dependent on the expected life cycle of the study.

The life cycle cost (LCC) of any system is the total present worth (PW) estimation of the major economic values. The LCC of the proposed hybrid PV system can be given by [8];

$$LCC = ₡_{Purch} + ₡_{inst} + ₡_{BnPW} + ₡_{MPW} - ₡_{Salv} \tag{15}$$

In which, ¢Purch is the cost of purchasing PV system's components (e.g. modules, batteries, chargers, inverters, transformers), ¢inst is the installation cost, ¢BnPW is the present worth's value of the nth extra group of batteries which should be frequently replaced at the end of their lifetime, ¢salv is the salvage value of the system at the end of expected lifetime of the system (about 10% of initial cost) and ¢MPW is the present worth value of the maintenance cost which can be calculated by the multiplying of the annual maintenance (M/yr) cost, (2% of purchase cost) by the present worth factor below [17];

$$PW = \sum_{n=1}^{25} \frac{(1+i)^{n-1}}{(1+d)^{n}} \quad (16)$$

In which, i is the inflation rate, d is the interest or discount rate and n is the lifetime of the entire system which is considered as 25 years. In Egypt, i and d are 10.098% and 9.75%, respectively [18].

Likewise, the present worth's value of the n^{th} extra group of batteries which would be replaced can be given by [17];

$$₵_{\text{BnPW}} = \text{PW x } ₵_{\text{Bat}} \quad (17)$$

Finally, the unit electrical cost of 1 kWh ($₵_{kWh}$) can be determined as follows;

$$₵_{kWh} = \frac{LCC}{365 \; x \; n \; x \; E_L} \quad (18)$$

VI DISCUSSION

This paper provides sizing of a hybrid PV system based on a typical load of this case study (Construction of the New Talkha Bridge Project). The current operational strategy is defined and analyzed according to the reality. However, the sizing of the hybrid PV system was built upon the maximum load demand to provide the reliability. Furthermore, more configurations were created to unlearn more options for operational strategies. All components, including the PV array, single-phase inverters, three-phase transformers, batteries and charge controllers are sized and listed in table 2. The financial analysis of the sizing results is based on an actual offer presented by an Egyptian company specialized in this field (Table 2).

Table 3 categorizes the available energy sources; the main grid, the hybrid PV/battery, PV only and diesel generators into systems A, B, C and D, respectively. Each energy source and the suggested configurations are economically evaluated based on the life cycle cost (LCC) technique. The economic analysis included also the capital cost and the unit electrical cost **($₵_{kWh}$)**.

It was clarified by table 3 that the unit electrical cost of system A **($₵_{kWh\text{-}A}$)** is 0.97 EGP/kWh. While applying systems B, C and D recorded values of 1.21, 0.48 and 1.73 EGP/kWh, respectively.

The lowest value of $₵_{kWh\text{-}C}$ refers that it is the optimal system, but the PV system must to be combined with another energy source as it cannot supply the load at night time or/and at cloudy days. Therefore, system A would be the optimum solution, but it has a high running cost. In addition to the government intends to eliminate the subsidization from the conventional energy sector. Also, the main grid connection might be not available at some construction sites (work nature), beside that the customer has no control on power supplying or/and interrupting.

For system B, it involves a battery storage system to overcome the reliability problem of system C. Despite of the high initial cost and periodic replacement groups of batteries, system B recording a value of 1.21EGP/kWh. This is considered as a reliable system and more optimal than applying the diesel generators as system D.

Table 3 provides the unit electrical cost resulted by available sources combinations. It is concluded that kWh cost resulted by the hybrid PV/diesel generator system was 1.48EGP/kWh. While the combination between the main grid and the generators recorded a higher value of 1.79EGP/kWh. Even the configuration of a main grid/PV/battery hybrid system has recorded a value of 1.19EGP/kWh. It can say that the optimal configuration for this case study is the main grid/PV system with the optimum value of 0.82EGP/kWh. However, this paper aims to provide an optimal configuration that could be applied for any consumer especially at remote areas, so it is recommended that system B would be the optimal configuration providing an efficient, reliable and economic power system. From the economic view, it was deduced via the practical calculations that the hybrid PV/battery system is more economical than utilizing diesel generators.

Furthermore, PV and other green energy sources are dependent systems providing a clean and permanent energy which rely beyond the control of its owner not liable for prices fluctuations or other squeezes. It worst to mention that the PV systems can be as a financial projects by selling the extra produced energy backward to the national electrical network by the highest tariff for the unit electrical, in case of connecting to the grid under its terms and conditions

TABLE.3
Sample of calculation results of the developed program

Load Sharing (%) Concept

A	B	C	D	¢A-Cap	¢A-An.Run	¢A-kWh	¢B-Cap	¢B-An.Run	¢B-kWh	¢C-Cap	¢C-An.Run	¢C-kWh	¢D-Cap	¢D-An.Run	¢D-kWh	¢kWh
100%	—	—	—	150000	167989	0.97	—	—	—	—	—	—	—	—	—	0.97
—	100%	—	—	—	—	—	2516558	28318	1.21	—	—	—	—	—	—	1.21
—	—	100%	—	—	—	—	—	—	—	1744408	33126	0.48	—	—	—	0.48
—	—	—	100%	—	—	—	—	—	—	—	—	—	340000	273087	1.73	1.73
75%	—	—	25%	150000	131934	0.77	—	—	—	—	—	—	340000	134228	0.97	1.74
50%	—	—	50%	150000	95878	0.57	—	—	—	—	—	—	340000	180514	1.23	1.79
—	—	50%	50%	—	—	—	—	—	—	888792	10749	0.25	340000	180514	1.23	1.48
50%	—	25%	25%	150000	95878	0.57	—	—	—	446136	6945	0.13	340000	134228	0.97	1.68
50%	50%	—	—	150000	95878	0.57	1275582	16554	0.62	—	—	—	—	—	—	1.19
50%	—	50%	—	150000	95878	0.57	—	—	—	888792	10749	0. 25	—	—	—	0.82
25%	—	50%	25%	150000	59823	0.37	—	—	—	888792	10749	0. 25	340000	134228	0.97	1.59

V CONCLUSION

In this paper, general sizing procedures for a hybrid PV system are introduced and applied for a typical load of Construction Talkha Bridge project in Egypt. The achieved results show that a 143kWp PV generator capacity is capable to electrify the considered load demand of 559kWh/day. The required storage system is consisting of 232 batteries which are designed to supply the system for a 10hours. Other components as 51 chargers, 23 inverters, 15 three-phase transformers and 2 diesel generators (380/220V, 103kVA) are required for the proposed system. Different operation scenarios are created based on the combination of the available energy sources (main grid, diesel generator, PV and the battery bank) providing a multi-configuration options for variable conditions. An economic evaluation of each energy source individually and the suggested scenarios is introduced based on the maximum (worst) case, including the economic parameters; the capital cost (¢Cap), annual running cost (¢An.Run) and the unit electrical cost (¢kWh).

It was concluded that the minimum unit electrical cost resulted by utilizing the main grid (without the government subsidization) is 0.97 EGP. While utilizing the PV system with and without batteries recorded 1.21 and 0.48EGP/kWh, respectively. Obviously, utilizing only diesel generators as a relegated option as it recorded the highest value of 1.74EGP/kWh beside to the demerit of permanent fuel supplying. Typically, the main grid connection is not available at almost all rural areas; in addition to the government subsidization for petroleum products will be restricted. Thence, according to the practical calculation and the main objective of this work, it was deduced that the hybrid PV/battery system is the optimal configuration which provides the reliability, permanent and clean energy source.

APPENDICES

***Appendix A*; Products datasheet**

TABLE 4
.A1 POLY-CRYSTALLINE PV MODULE PT6P60-250W ELECTRICAL CHARACTERISTICS

Maximum Power at (STC), P_{Max}	250 W
Power Tolerance	±5 W
Optimum Operating Voltage, Vmp	30.5 V
Optimum Operating Current, Imp	8.21 A
Open Circuit Voltage, V_{OC}	37.6 V
Short Circuit Current, I_{SC}	8.67 A
P_{Max} Temperature Coefficient, γ	-0.44 %/^{o}C
V_{OC} Temperature Coefficient, β	-0.30 %/^{o}C
I_{SC} Temperature Coefficient, α	+0.05 %/^{o}C
Operating Temperature, Top	-40~+ 85^{o}C
NOCT	45±2 ^{o}C
Maximum System Voltage	1000 VDC
No. Of Cells	60pcs (6x10)
Dimension of Module	(1640x992x40mm)

** STC: Standard Test Condition at 1000W/m^2,AM1.5 and 25^{o}C*
** NOCT: Normal Operating Cell Temperature*

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