

## Article

# Economic Design of Hybrid Pico-Hydraulic/Photovoltaic Generation System: A Case Study in Egypt

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**Abstract:** Clean and renewable energy sources are the preferable power system generations for the overall world. This research aims to present a very highly integrated, economic, professional, and simple construction, clean and natural resources usage of the renewable hybrid generation system. This research performs analysis, systematic representation, evaluation, and design of the hybrid proposed system—pico-hydraulic from home usage water and photovoltaic (PV)—to generate an optimal renewable generation system using a new professional control system. Applying this proposed technique in Egypt shows that the hybrid system successfully overcame Egypt's energy crisis. Renewable energy will rise to 8.782% by increasing 7.323% (14,408.83 GWh/Y). Besides, this system increases the power supply reliability; it gives an additional emergency supply and reduces the exhausts from other generation stations (e.g., CO<sub>2</sub>). The saving from this hybrid system is very effective for; the residential sector (subscribers), which will be ranged from 9599.298 million EE/10Ys up to 86,393.68 million EE/10Ys that equals 5399.6 million \$, government to use this extra generation energy to reduce the maximum loads from various stations. A practical model has been presented with results to verify the high efficiency of the proposed system that illustrates the effective performance of the used hybrid system.

**Keywords:** renewable energy; hybrid proposed generation system; exhausts; residential; economic strip



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## 1. Introduction

One of the main incentives for economic development is enhancing the electric energy sector, as it plays a significant role in present-day civilization [1]. Due to population growth, human comfort level boosting, and industrialization development, electricity demand is increasing rapidly globally with an annual growth rate of 4% [2]. Therefore, most researchers are interested in how to save or generate electrical power.

### 1.1. Saved Power Literature Overview

The saving in power for all consumed sectors, especially the buildings considered one of the largest energy sectors, about 30–32%, from the total energy productions. For example, the retail sector may reach up to 80% of the energy used [3,4].

These saved methodologies studies apply to traditional homes and smart homes. Generally, smart home technologies have reached a good state of maturity, but these are not found in all countries [5]. Paper [6] refers to some of the smart home projects: the Computer-aided design software for smart home devices (based on cloud computing service project) helps the designer to select the smart home device and build a smart living space (visual stimulation). In addition, in Refs. [6,7], another project called energy saving

depends on using sensors to minimize domestic energy waste according to human habits. One of the earliest projects is Mozer's adaptive control of the US's home environment (ACHE) system. ACHE can use adaptive sensors to control: temperature, heating, and lighting. Authors in [8] introduce energy usage scheduling and management under electric utility to solve the energy management problem and reduce bill cost, peak-to-average ratio, and carbon emission. The model presented in [9] interests saving lighting power by applying an appropriate lighting design system. The saving system introduced in [10] reviews more than 23 power saved researches with different methods/strategies. Other saving researches [11–14] present the various controlled lighting system to give the required illuminance according to the human occupancy/reference to the place activity or by the vehicles traffic density in the street as in [12], illumination sensors as in [13,14] uses sensor-triggered control strategies. Due to the importance of commercial buildings, paper [15] gives a hybrid system to save consumed power at high levels.

### 1.2. Related Works Overview

Most of the world's energy is derived from fossil fuels which cannot supply all the required load demand–depleted and limited– and contributes to high exhausts (traditional generation systems give nearly 75% of total CO<sub>2</sub> emission in the world) [16].

There are many works of the literature on RE generation systems which can conclude generation types (PV, Wind . . . etc.), enhancement production methodologies, etc.

In recent years, many research studies have tried to reach the optimal generation/operation from the very important type (RE)(samples):

- The RE can reduce the exhausts to provide a clean environment through studies [17].
- The optimal production with PV generation requires various methodologies and techniques [18,19].
- Other researchers execute the various combined methods (Hybrid) to reach the optimal production, such as [16,20–22], which are very effective in reaching optimal production with the economy.

From the above sections;

- There is a need to produce additional electrical power from RE to satisfy the unsupplied loads throughout the world,
- The generation of Hybrid RE is a very effective electrical production system w.r.t traditional and single method,
- Most research scope about the advanced methodologies that may be cannot be applied in practical especially the developing countries and with popular human houses.

Therefore, the key contribution of this paper is the development of a comprehensive and actual optimal for generating power from Hybrid Pico-hydraulic/Photovoltaic by effective/simple methodology. This study gives an applied model in the popular home using RE of solar energy and water by the lowest cost and high saving money method as explained in the case study section.

An applicable model is verified in Egypt -as a case study-to show how this proposed technique can effectively increase the RE generation for the government and save money for the consumers.

## 2. Egypt Renewable Energy Scenario

In Egypt, about 95% of the population is served by the electricity grid. The current available capacity is larger than the peak load by only 3% “lower than the internationally advisable margin of 15%”. Thermal plants supply most of the energy, and the remaining demands are supplied by large hydro plants with very low percentages by independent power producers (e.g., wind) [23]. According to [24], 91.43% of total power production is from thermal plants (95.91% from natural gases and 4.09% from heavy oil), hydro plants give 7.27%, wind and solar give 1.91%. According to the duration of the sun's brightness, PV systems be economical or not for smart houses (proposed technique). Some

information about Egypt's renewable energy with solar energy will be introduced in the following paragraphs:

The duration of the sun's brightness is high throughout Egypt, starting from a low level of 3300 h/Y along the northern part of places such as Alexandria to reach the highest level of more than 4000 h/Y in most parts of the country [25,26]. The average daily brightness of the sun ranges between 9.3–10.8 h/D [27]. In the north, it ranges from 6–8 h/D, while it is between 8–10 h/D in the south. The number of hours of sunshine increases in summer to a maximum of 12 h/D in June and July [28,29].

Although Egypt is vast and has abundant solar energy resources, the numbers of meteorological stations are few. Therefore, many methodologies are done to solve this problem [30,31].

There are updated Egyptian studies that focus on how great benefits of PV system in Egypt are to give the maximum output green generation [32], and discuss the quality effects of PV generation outputs (I, V) on the low voltage grid of Electronics Research Institute Egypt [33]. The hybrid systems for various generation and applications types are applied to give the most economic and efficient solution, such as the application of hybrid wind/P.V. energy system for a remote area in Egypt [34] and supply the required loads without any defaults of the grid "DGs" while keeping the distribution network within minimum pollution [35].

### 3. Methodology

The methodology has been selected and developed based on the aim of this case study. The methodology has been based on; designing hydraulic and PV systems, the mathematical calculations of the required power to satisfy decided power, and limiting the home consumer bill to the economic range. It is based on estimating the required power needed from the RE hybrid system to maintain the monthly residential home on the economic strip. This economic strip will be decided from the tariff of the ministry of Egypt electricity. The comparison shall explain that the hybrid system can give the required power by an easy and simple method with minimal cost w.r.t the traditional power supplied by the government. The proposed, tested model will verify the methodology, and this model builds on Figures 1–3. These Figures investigate how can generate the required power from a hybrid system; Figure 1 explains the integrated generation system flowchart (verify the supply power/voltage maintained at a certain level under any circumstances), Figure 2 display the structure of hybrid system components and the perfect places of them, and Figure 3 indicates the logic circuit to fix the power/voltage at the required level.

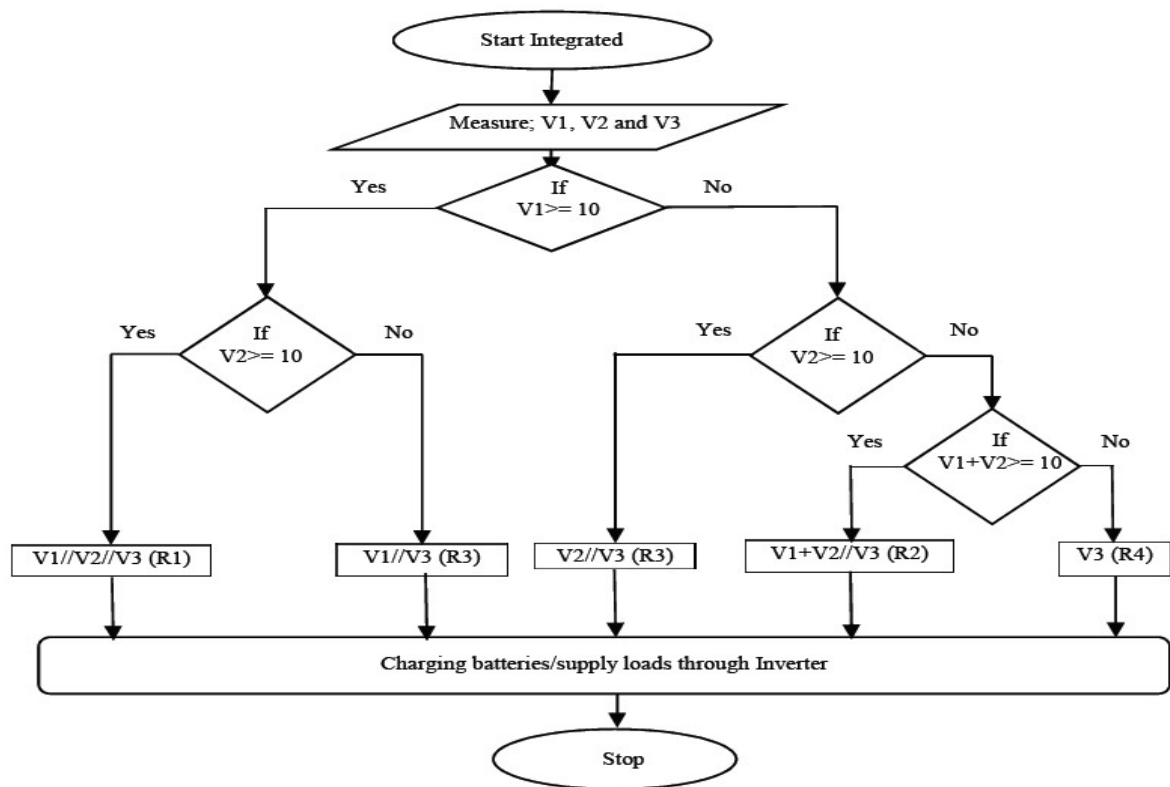


Figure 1. Integrated generation system flowchart.

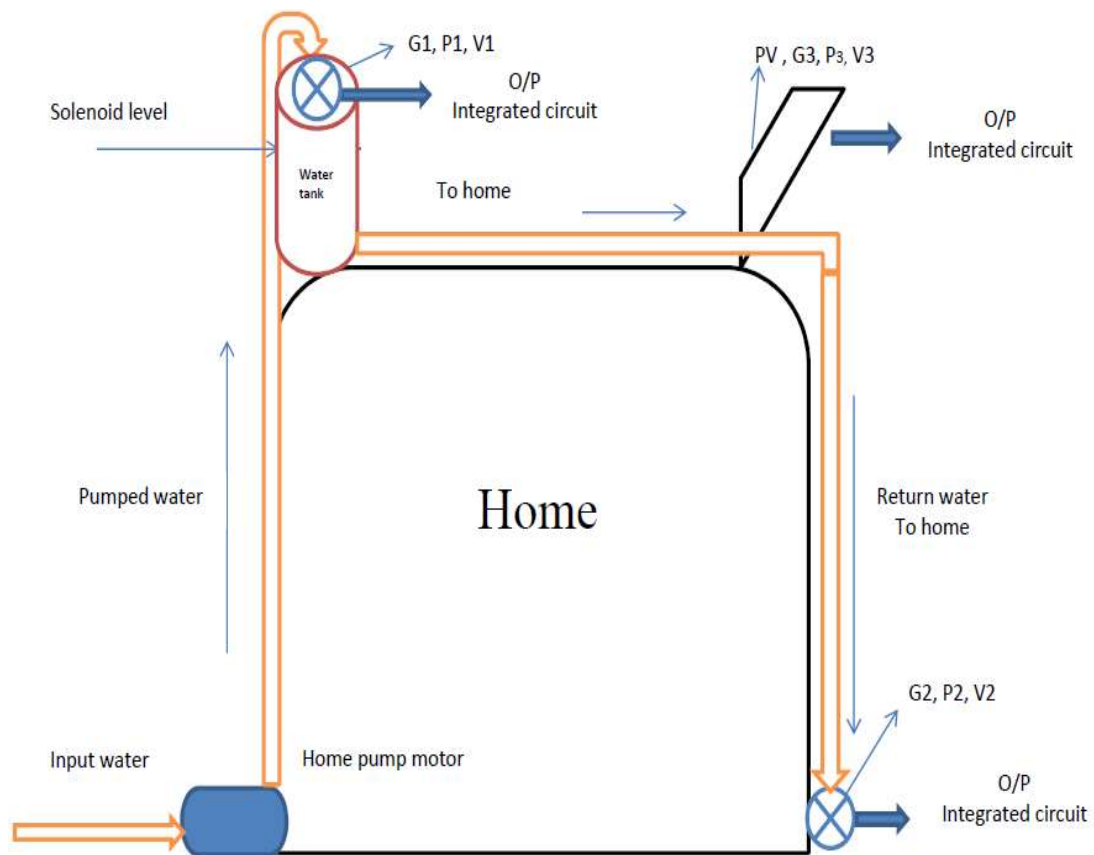


Figure 2. House generation systems places.

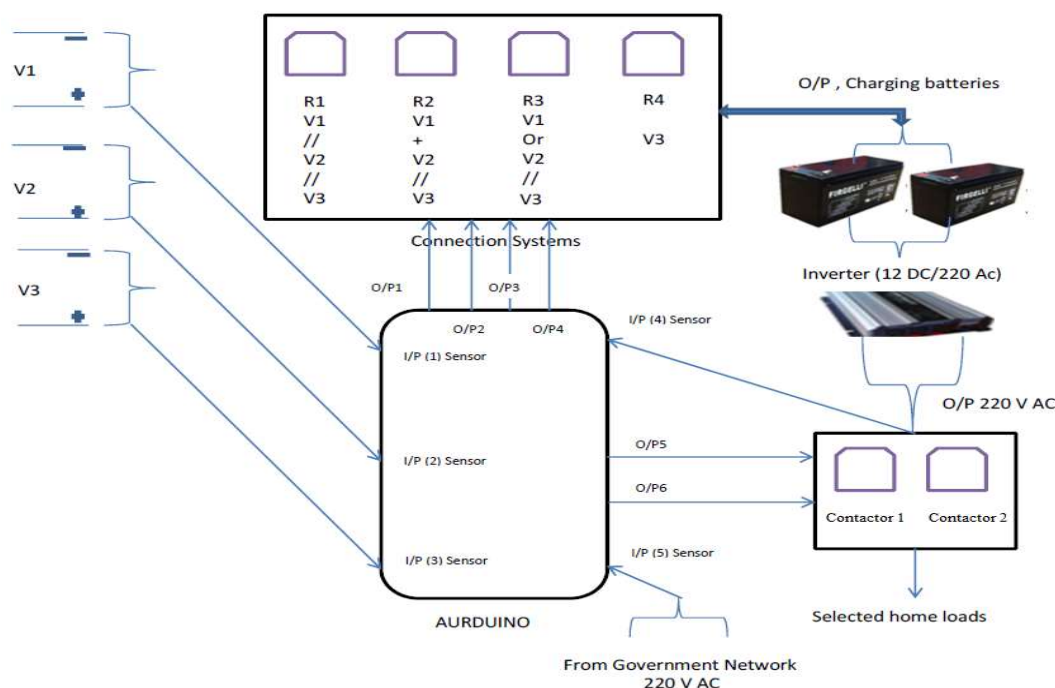


Figure 3. The integrated generated power model.

#### 4. The Hydraulic Electrical Power Generation System

Energy is a critical factor in developing countries; one of these is hydraulic (hydropower) renewable energy, which has the largest renewable resource and multi-advantages w.r.t other generated electrical sources. It plays an essential role in many world regions, with more than 150 countries generating hydroelectric power. For example, it provides about 96 percent of the renewable energy in the United States [36–39]. Therefore, it has added attention to optimize the operation [40] and generate compensatory of other generation types [41,42]. In the hydraulic power stations (Hydropower on a small scale), the electrical energy can be generated by water kinetic energy, which can activate the mechanical turbine's energy [43,44]. Table 1 indicates the hydraulic power generation plant (categories) [45].

Table 1. The hydraulic power plant categories [42,45,46].

Category	Capacity	Application
Large	50–1000 MW	Large cities
Small	1–50 MW	Small cities to towers
Mini	100–1000 kW	Towers
Micro	<100 kW	Rural community
Pico	<5 kW	Individual home

A Pico-hydro system might produce just 2 kW, whereas a large utility-scale hydro system could easily produce hundreds of Megawatts. So that, a 2 kW hydropower system could satisfy the annual electrical energy needs of two average UK homes, whereas a utility-scale 200 MW system could supply 200,000 average UK homes [47]. Many researchers are interested in hydraulic generation energy for very low values, as in [48], which uses the kinetic energy inside the home pipelines to produce about 10 W.

The work suggested in [49] provides updated information on the challenges and innovation trends and emerging hydropower technologies.

#### 4.1. Electric Power Computation

Hydropower on a small scale is one of the most cost-effective energy technologies to be considered for rural electrification in less developed countries. Small hydro technology is extremely robust and is one of the most environmentally benign energy technologies available [37]. The capacity of the hydraulic unit-generated power- and, accordingly, turbine type depends upon some factors; the volume of water discharge, the distance head (water pressure), and the rotational speed of the generator. In general, the theoretical mechanical horsepower can be calculated by [36,37,44]:

$$P_m = \frac{Q \times H}{8.8} \quad (1)$$

where;

$P_m$  is the theoretical mechanical horsepower

$Q$  is the flow rate in cubic feet per second

$H$  is the head in feet.

According to [50], water in motion possesses three forms of energy; kinetic energy due to its velocity, pressure energy due to its pressure, and potential energy due to its height:

$$\text{Kinetic energy} = \frac{V^2}{2} \quad (2)$$

$$\text{Pressure energy} = \frac{P}{\rho} \quad (3)$$

$$\text{Potential energy} = g \times H \quad (4)$$

where:

$V$  is the velocity of flow, m/s

$P$  is the pressure, N/m<sup>2</sup>

$\rho$  is the density of water, kg/m<sup>3</sup>

$H$  is the height of the level of water above some datum level, m

The generated electrical power can be calculated by [39,40,46,50–53]:

$$P_t = Q \times \rho \times g \times H_n \times \eta_t \quad (5)$$

$$H_n = H_g - H_{lo} \quad (6)$$

$$Q = \frac{P_t}{\rho \times g \times H_n \times \eta_t} \quad (7)$$

$$P_{op} = P_t \times \eta_g \quad (8)$$

where (as shown in Figure 4):

$P_t$  is the output from the turbine, W

$Q$  is the flow rate in the pipe, m<sup>3</sup>/s

$G$  is the acceleration of gravity (for water = 9.81), m/s<sup>2</sup>

$H_n$  is the net height, m

$H_g$  is the gross vertical head, m

$H_{lo}$  is the head loss, m

$\eta_t$  is the turbine efficiency

$P_{op}$  is the net output from the generator, W

$\eta_g$  is generator efficiency

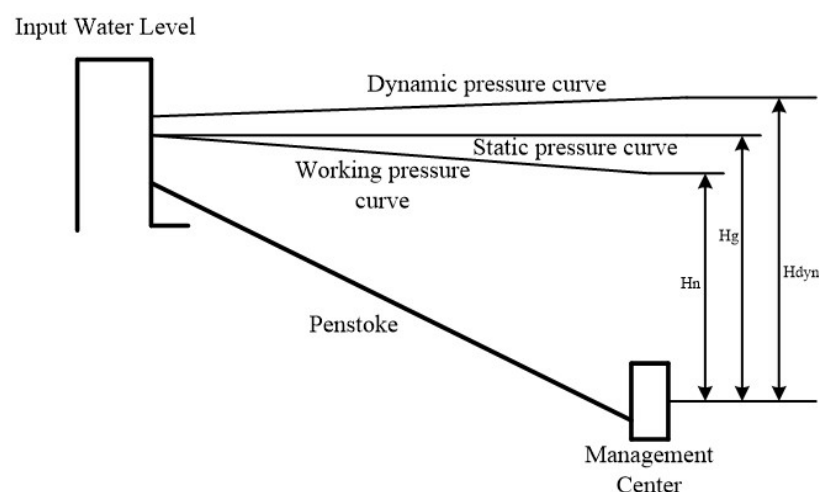


Figure 4. Principle scheme of hydroelectric power system [39].

According to [54], the overall efficiency factor ( $\eta_g \times \eta_t$ ) ranges from 0.5 to 0.7, depending on the capacity and type of system. The specific turbine speed can be calculated by [39]:

$$N_s = \frac{N_t \times \sqrt{Q}}{H_n^{3/4}} \quad (9)$$

where:

$N_s$  is the specific speed of the turbine, rpm

$N_t$  is turbine's rotation speed, rpm

According to [55], the efficiency factors of power stations from the Ministry of Electricity and Energy's annual reports range between 84.9% and 85.6% at the "Aswan Hydraulic station". The velocity head ( $V$ ) equals [39,53]:

$$V = \frac{Q}{\pi r^2} \quad (10)$$

From the above equations, the production of energy depends mainly on parameters [37,45]: The amount of water available " $Q$ ", water loss due to flood spill and friction, the difference in head between upstream intake and downstream outlet, and the efficiency in energy conversion of electromechanical equipment.

#### 4.2. Hydraulic Turbine Classifications

There are two main turbine types: Impulse (e.g., Pelton wheel, Turgo-impulse wheel, Girad turbine) and Reaction (e.g., Fourneyron, Thomson, Francis, etc.). These turbines have their construction, benefits, applications, and appropriate commercial turbine names [50]. In addition, the hydraulic turbine can be classified according to [50–52]: Head and quantity of water, Originator name, Nature of bladed working, The direction of water flow, Turbine shaft axis, and Specific speed. For example, Deriaz turbines can be used up to 300 m. Table 2 gives the recommended turbine types related to water heads [41,50].

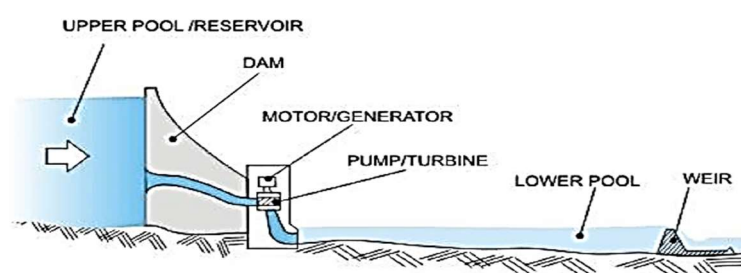
#### 4.3. Pumped Storage

Pumped storage plants are used during off-peak hours to pump water from a lower reservoir into an upper reservoir "storage water" [5,37,56,57]. In the present study, the home water pump is used as pumped storage, but the kinetic water energy will be used in two ways, as explained in the following sections. Figure 5 explains the pumped storage scheme [56].



**Table 2.** Recommended turbine types related to water head [50].

Type of Turbine	Range of Head	Specific Speed in Metric Units
Pelton (1 nozzle)	200 m	10–20
Pelton (2 nozzle)	to	20–40
Pelton (4 nozzle)	2000 m	40–50
Turgo impulse turbine	as above	50–100
Francis (low speed)	15 m	80–120
Francis (medium speed)	to	120–220
Francis (high speed)	300 m	220–350
Francis (express)		350–420
Propeller	5–30 m	310–1000

**Figure 5.** Pumped storage scheme [56].

## 5. PV System

PV system is a very important method for generating power, as referred to in most research for RE resources. This study uses a PV system with normal operation, and the PV required power will be decided through the next sections. This PV generation system will give the supplemental w.r.t hydraulic electrical power. The next sections will show how this proposed low PV generation will increase the sharing of RE sources in Egypt.

## 6. Proposed System

The proposed integration system is a multi-generation system that contains two cooperation systems; Pico-hydro generation, similar to consumed water distributed in houses [48,58] with solar generation system. This proposal will be applied by deciding the required power value, which can save any supplied power system in saved cost levels. Thus, there are two needed values to reach this goal, the first from Pico-hydro generation and the other from PV generation. In the case of, the study applies in the house to maintain its monthly electrical bill to saved level (economic-strip). Therefore, the proposal has the following tasks:

- Decides the powers needed from PV and hydraulic systems (hybrid system) to limit the consumed monthly house bill to certain economical money paid,
- Illustrates the steps, with the mathematical controlled equations and procedures, to verify this goal, and
- Confirms the proposed technique with the actual model.

Due to the present highly consumed home energy, the electrical strip “residential/commercial” can easily change from economical to investment (expensive). Therefore, with simple and professional techniques (Figures 1–3), the proposed methodology will overcome this challenge to limit the home strip “segment” to the economic one. The following section illustrates the proposed integrated system: the mathematical calculations, the various components, the complete design, the practical model with its application, and the cost analysis.



### 6.1. Pico-Hydro Generation System

The study determines the feasibility and achievability of the proposed Pico-hydro system through the following:

#### 6.1.1. Power Determination

In this study, there are some assumptions:

- The daily consumed power for each family home person is denoted by ( $P_p$ , W/day),
- The number of family persons is ( $n$ ),
- The actual total family persons daily consumed power is ( $P_T = n * P_p$ , W/day),
- The consumed water/person is denoted by ( $Q_p$ , L/day),
- The total consumed water for all family persons is ( $Q_T = n * Q_p$ , L/day), and
- The total consumed power for all family persons must be limited to economic value denoted by ( $P_{ec}$ , W/day).

From the above assumptions and the hybrid system data: the required generation value for the bill to be economical is:

$$P_{req} = P_T - P_{ec} \quad (11)$$

Suppose that;  $Q = Q_T$ ,  $\rho$ ,  $g$  and  $P_{req}$  are known, and others will be decided. There are two-generation units in the proposed systems: One of them is fixed in the outlet of the pumped pipe motor “inside the water home tank”, which depends on the motor pump water pressure without any friction or loss ( $P_1$ ), and the other is fixed in the way pipe supply water from the tank to daily home consumed waters “laundry, cook and bathe”, it has kinetic energy that depends on the head of fall water ( $H_n$ ).

From [58], the relation between the head ( $H_n$ ), m” and the pressure ( $P_w$ , psi) is:

$$H_n = 0.704 \times P_w \quad (12)$$

Therefore, the power generation from the first unit “ $P_1$ ” can be calculated by:

$$P_1 = 0.704 \times P_w \times Q_T \times g \times \rho \times \eta_t \times \eta_g \quad (13)$$

However, the second “water return way” has generation value “ $P_2$ ”, it can be calculated by:

$$P_2 = Q_T \times H_n \times g \times \rho \times \eta_t \times \eta_g \quad (14)$$

#### 6.1.2. The Used Equation Parameters

There are important parameters, which can be calculated with high accuracy: The decided turbine and generators’ efficiencies, which are based on the used percentages in [58], as shown in Figure 4, the gross head ( $H_g$ ) and the head loss ( $H_{lo}$ ) in the water tank (Figure 4) depend on; type, diameter, length of the pipe tank, and the number of bends or elbows, the water flow rate ( $Q$ ) can be calculated by the same method (bucket method) in [58], and turbine type; the used turbine type depends on its place and generation power limits. In this study, the used turbine is impulse type. According to many concerns presented in [58] permanent magnet DC generator is used. The calculated quantity of pumped water by motor [59]:

$$whp = \frac{gpm \times TDH \text{ (ft)}}{3960} \quad (15)$$

Due to the pumped water (motor) does not give the full efficiency [45], equation (15) will be divided by 0.8 [59] for small electric motors", Equation (15) will be:

$$\text{whp} = \frac{\text{gpm} \times \text{TDH (ft)}}{3960 \times 0.8} \quad (16)$$

where:

TDH is the total dynamic head in feet

Gpm is the pumping rate in gallons per minute, and

Whp is the water horsepower.

## 6.2. Solar Energy System

Due to the decrease in traditional energy resources, the world energy generated systems are interested in renewable energy resources to ensure energy security and strengthen/maintain the environment without polluting "green energy" [60,61]. Some of the most interesting recent researches and studies are solar energy (photovoltaic "PV"), which is an environmentally friendly power generation source [62–64]. Many researchers have paid attention to getting the maximum generation energy from PV/PVT/PV-PVT-CR/CPV with other supplementary systems [65–70] to give the required residential loads depending on the net-metered load data and system install data [71]. The generation with this PV system be denoted by ( $P_s$ ).

This proposed hybrid system has standard generation powers in the market and purchasing power ( $P_2$ ) according to the following equation:

$$P_{\text{req}} = P_1 + P_2 + P_s \quad (17)$$

Therefore, if the Pic-hydro generation power ( $P_1 + P_2$ ) is sufficient to limit the segment to its economic value; there is no need to add solar generation power " $(P_s)$ ".

## 6.3. The Proposed Integrated System

The proposed system can be explained through:

- The flowchart in Figure 1 shows the proposed technique integrated procedures (programming), which indicates the maintained supply outputs voltages and power to charge the battery/selected loads under various circumstances,
- The proposed pico-hydraulic and PV model is displayed in Figure 2; the compound system contains two pico-hydraulic and one PV generation unit to supply the required power ( $P_{\text{req}}$ ), and
- The integrated system shown in Figure 3 contains three-generation outputs units ( $P_1$ ,  $P_2$ , and  $P_3/P_s$ ), the Arduino program circuits, different relays operations ( $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$ ), charging circuit to storage energy battery/s, inverter to convert DC/AC voltage and selected loads contractors, this system is responsible for maintaining the supply voltage/power to batteries/loads under different cases.

This study investigates a very effective, simple, economic, and handled model. Therefore, the main contributions of this study are:

- Explaining the benefits by using the daily natural resources for generating electrical energy;
- Maintaining the supply voltage/power from the proposed circuit by a new simple and professional control system for certain values (a proposed technique in Figures 1 and 3);
- Applying the proposed integrated circuit (Figure 2 and Figure 13);
- Limiting the consumed electrical energy bill to a certain acceptable economic strip level by hybrid generation system;
- Executing high savings in energy and money and helping the environment to get rid of toxic exhausts such as  $\text{CO}_2$ ; and

- Verifying the proposed system by actual case study in Egypt.

## 7. Design the Proposed System with Actual Case Study

In this paper, the proposed methodology will be implemented by an actual case study in Egypt. According to Figure 6 ([72], last report 2017–2018),

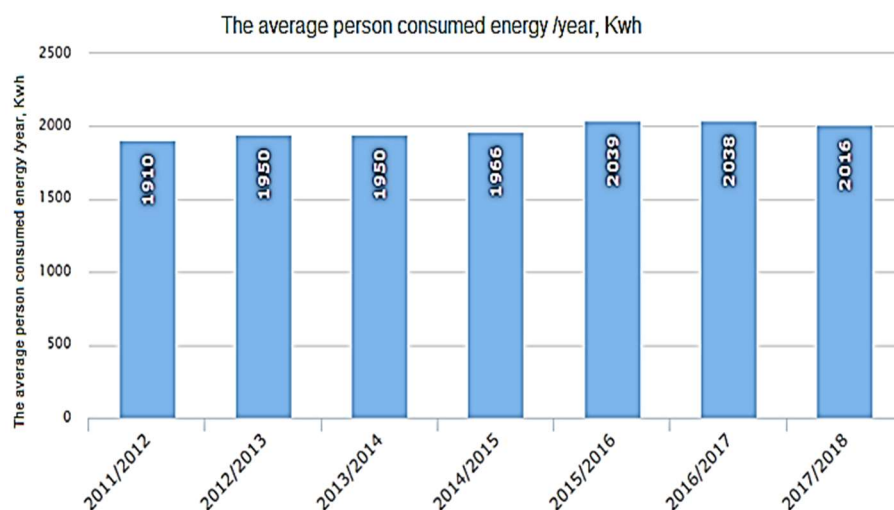


Figure 6. The average person consumed energy /year, kWh [72].

- The annual consumed energy for each Egyptian person is 2016 kWh/Y “the average person daily consumed energy is 5.5232 kWh, Figure 6”.
- The economic strip up to 650 kWh/M–0.9 E£/kWh(EGP)- but investment one from 651 kWh/M with 1.35 E£/kWh- which can be described in Figure 7 [73].
- Based on the report in [74], the average person daily consumed water is 300 Liters.

Household uses			Commercial uses		
Consumption brackets (KWh/ month)	Pt./KWh	Customer service EGP/ customer-month	Consumption brackets (KWh/ month)	Pt./KWh	Customer service EGP/ customer-month
0-50	22.0	1	0-100	55	5
51-100	30.0	2	0-250	100	15
0-200	36.0	6	0-600	115	20
201-350	70.0	11	601-1000	145	25
351-650	90.0	15	0-more than 1000	150	40
651-1000	135.0	25	Read by Zero	-	9
0 - more than 1000	145.0	40			
Read by Zero	-	9			

Figure 7. The electricity sales tariff (2017–2018) [72,73].

These data will help to; decide the limited economical strip, calculate the required generation power from the proposed technique and the actual generation systems (designs and values). Therefore, this proposed system limits the strip to an economic one (saving power and money).

### 7.1. Consumed Energy

Based on the given above data about Egyptian person consumed energy /water and by supposing; the family contains five persons, and the house has two floors, then:

- The total power consumed ( $P_T$ ) is  $(5.523 \times 5 = 27.616 \text{ kWh/D and } 828.48 \text{ kWh/M})$ ,

- The total consumed water/day is  $(300 \times 5 = 1500 \text{ L "1.5 m}^3\text{"})$ ,
- The economic strip is up to 650 kWh/M, which means the monthly needed generation power from the proposed system will be  $828.68 - 650 = 178.68 \text{ kWh/M}$ ,
- The proposed technique should generate the remainder value  $(27.616 - 21.66 = 5.956 \text{ kWh/D})$ .

## 7.2. The Required Generation

The required generation power ( $P_{\text{req}}$ ) is 5.956 kWh/D (178.68 kWh/M) to limit the strip to the economic level. Therefore, the two proposed generation turbines must give this required power ( $P_{\text{req}}$ ) with or without PV system according to the following descriptions and submissions:

- The supply pipe diameter is  $\frac{3}{4}$  inch with electrical motor power equals 0.75 hp, and the motor pump pressure is 5 bar ( $5 \times 14.50378 = 72.5189 \text{ Psi}$ ) [75,76];
- The net head of the water tank to the second pump is 7 m (G2 in Figure 2);
- The total turbine-generator efficiency is 0.8 and Q will have 0.018, 0.026 and  $0.045 \text{ m}^3/\text{min}$  (average  $(0.018 + 0.026 + 0.045)/3 = 0.0296/60 = 0.000493 \text{ m}^3/\text{s}$ ) [77].

The generated power from these turbines are:

### 7.2.1. The First Generation Turbine ( $P_1$ )

- The total high is 7 m (1 m = 3.38 ft)
- According to [78], one gallon per minute =  $5.45099 \text{ m}^3/\text{day}$  ( $0.227124 \text{ m}^3/\text{h} = 3.7854 \times 10^{-3} \text{ m}^3/\text{min}$ ):

According to the above data and Equation (16):

$$0.75 = \frac{Q \times 7 \times 3.38}{3960 \times 0.8}$$

$$Q = 100.422 \text{ g.p.m} = 22.80 \text{ m}^3/\text{h} = 0.38 \text{ m}^3/\text{min} = 0.00633 \text{ m}^3/\text{s}$$

Note; this motor (0.75 hp) will fill the family tank ( $1.5 \text{ m}^3$ ) through 0.06578 h ( $1.5/22.8$ ).

According to the above data and Equations (13) and (14),  $P_1$  has two values:

- $P_1 = 0.000493 \times 9.81 \times 1000 \times 0.8 \times 0.704 \times 72.5189 = 197.528 \text{ W}$ , or
- $P_1 = 0.00633 \times 9.81 \times 1000 \times 0.8 \times 0.704 \times 72.5189 \times 0.06578 = 166.92 \text{ W}$ .

### 7.2.2. The Second Generation Turbine ( $P_2$ )

By the same data and equations,  $P_2$  has two values:

- $P_2 = 0.000493 \times 9.81 \times 1000 \times 0.8 \times 7 = 27.083 \text{ W}$ , or
- $P_2 = 0.00633 \times 9.81 \times 1000 \times 0.8 \times 7 \times 0.06578 = 22.89 \text{ W}$ .

Note that: this hydraulic generation system ( $P_1$  and  $P_2$ ) does not affect the water flow rate (quantity and pressure).

### 7.2.3. The Third Generation Turbine ( $P_s$ )

The generations with two pico-hydraulic cannot supply the required power ( $P_{\text{req}}$ ); therefore PV system should supply power ( $P_{\text{req}} - (P_1 + P_2)$ ).

From the above calculations and given data:

- The home water motor will fill the tank by 3.157 min,
- The first generation unit ( $P_1$ ) will give from 167 to 198 W during motor (3.94 min) operations (average = 182.5 W),
- The second-generation unit ( $P_2$ ) will give from 23 to 27 W during serviced water homework times (average = 25 w), and
- The total average generation by pico-hydraulic units are 207.5 W/D, and the PV system should supply the remaining required power ( $5956 - 207.5 = 5.7485 \text{ kW/D}$ ).

Summary:

- The pico-hydraulic proposed system will give a very low percentage ( $\approx 4\%$ ) of the required power;
- PV system will supply a huge amount of daily-required power ( $\approx 96\%$ );
- The daily consumed power –5 persons- is 27,616 W, which means that; the average consumed power through one hour =  $27,616/24 = 1150.66$  W (pico-hydraulic generation units give 18 % of total consumed home power through one hour);
- The advantages of using the pico-hydraulic generation system are:
  1. Supply the emergency loads;
  2. High benefits usage of the home waters (supplied and wasted);
  3. Give green energy without any exhaust;
  4. It is a basic theory to be used in large wide in the high and extended buildings to give more supplied power;
  5. Applies for irrigation and sewage pumps systems (very high capacity pumped waters) to give high power.

All the given and calculated data are tabulated in Table 3.

**Table 3.** The given and calculated data.

Item	Value	Item	Value
Water motor, hp	0.75	$P_{\text{req}}/\text{day}$ , kW	5.956
Net head, $H_n$ , m	7	$P_1 + P_2/\text{day}$ , W	207.5
$Q/\text{day}$ , m <sup>3</sup>	1.5	$P_3/\text{day}$ , W	5748.5
Person power/day, kW	5.523	%Pico-hydraulic shared/day	4 %
5 Persons power/day, Kw	27.616	%Pico-hydraulic shared/one hour	18 %

Table 4 explains the renewable generation by solar systems related to the total generation of energy in Egypt through 2013–2018 ([74], reports from 2013 to 2018).

**Table 4.** Total sold energy on all voltages classified according to uses GWh (2013–2018) [72,73].

Generation Type/Years		2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018
Total, GWh		164,628	168,050	174,875	186,320	189,550	196,760
Renewable	Total	1497	1446	1558	2225.5	2780	2871
	%	0.909	0.860	0.890	1.194	1.466	1.459
	Solar	237	114	0	167.5	580	537
	%	0.1439	0.067	0	0.089	0.305	0.2729
Hydraulic	Wind,	1260	1332	1558	2058	2200	2334
	Gen.	13,121	13,352	13,822	13,545	12,850	12,726
	%	7.97	7.945	7.90	7.269	6.779	6.467

From the above discussion and Table 4, it can be noted that:

- Egypt has a high ability to generate energy with solar systems, and
- The generated solar energy is very low related to the total generation energies from various generation stations (does not reach 0.28%).

Therefore, this study will remedy raising the percentage share of renewable (lower than 1.5%) energy.

### 7.3. Costs Analysis

This section presents the economical dispatch of the proposed technique with hybrid method “pico-hydraulic and PV” related to the traditional government methods:

### 7.3.1. PV System

The solar energy system (PV) is now one of the most renewable energy sources, all the information about; how the system is used, the components and their prices, etc., can get easily.

According to the above section/subsections and their references:

- The needed power from PV is 5.7485 kW/D, and
- The minimum times of daily brightness of the sun range 6–8 h/day (average 7 h).

Therefore, the required installed PV rating is one kW/h with its other cooperating components.

### 7.3.2. Pico-Hydraulic System

According to Table 3, the DC water generators (pico-hydraulic) rating is 207.5 W. Then, the required components and their prices for the hybrid systems (PV and hydraulic) are shown in Table 5, while Table 6 explains the development of the tariff from 2012/2013–2017/2018 (% incrementation) [72,73].

**Table 5.** The required components and their prices “\$” for hybrid system [79–82].

Types	Costs, \$/Gen	PV	Hydraulic
Solar cell	Price, \$/W		0.28
	Costs 1000 W, \$		280
DC generator	Price (190 W), \$	245	
	Price (20 W), \$	25.8	
Arduino	Price, \$	33	
PCB	Price, \$	25	
Relays	Price, \$	3	
	Price (5), \$	15	
Voltage sensors	Price, \$	3	
	Price (2), \$	6	
Batteries	Price(1200 W), \$	289	
Inverter	Price(2000 W), \$	109	
Accessories and labor	Price, \$	200	
Total costs, \$		1227.8	

Figures 8 and 9 illustrate the tariff incrementations through 5 years for residential and commercial (2013/2014–2017/2018). By using Excel tool to generate the function of each incrementation (e.g.,  $y = 4.7275x^2 + 14.723x + 77.062$  for the first incrementation curve of residential (strip 351–650).

Where:

y is the percentage incrementation (%) related to 2013–2014 and x is the number of year (i.e., 2013–2014 = 1, 2014–2015 = 2...etc.).

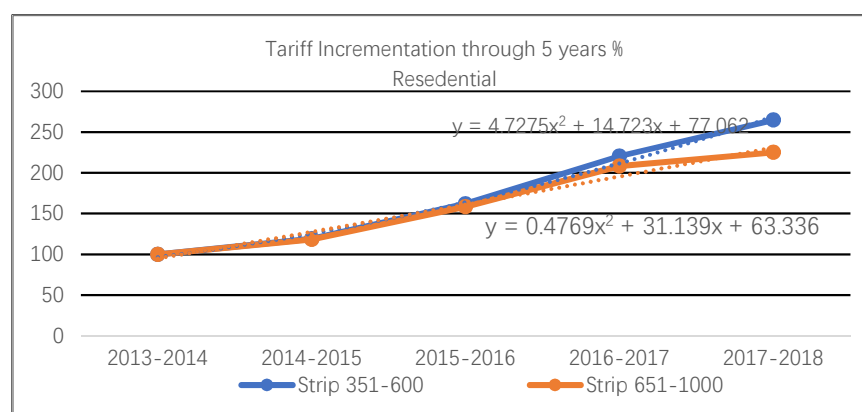
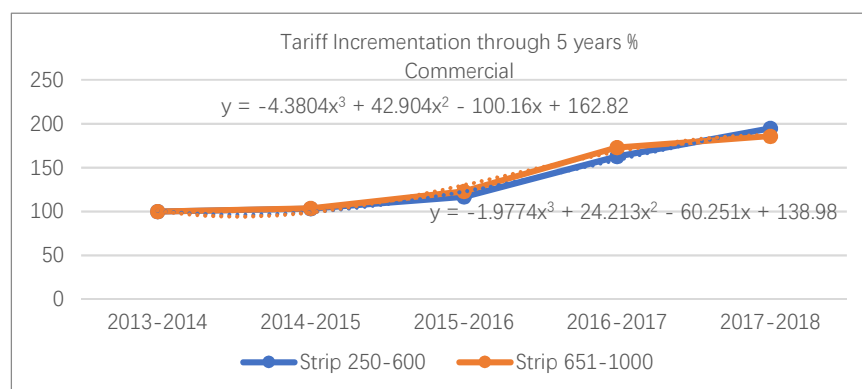
### 7.3.3. Economic Analysis of Project

According to [79–83]:

- The guarantee for PV cells is not less than 20 years;
- The guarantee for the inverter is not less than ten years;
- The guarantee for batteries is about two years; and
- The guarantee for the DC generation units is from 8–12 years and other accessories.

**Table 6.** Development of Egyptian Ministry of electricity tariff, E£/kWh (2013–2018) (increasing related to 2013–2014 for each range) [72,73].

Years		2013–2014		2014–2015		2015–2016		2016–2017		2017–2018	
Buildings	Strips	Resid.	Comm.	Resid.	Comm.	Resid.	Comm.	Resid.	Comm.	Resid.	Comm.
Resid.	351–650	0.34	-	0.405	-	0.55	-	0.75	-	0.9	-
	% Increasing	100	-	119.117	-	161.76	-	220.588	-	264.705	-
	651–1000	0.6	-	0.71	-	0.95	-	1.25	-	1.35	-
	% Increasing	100	-	118.33	-	158.33	-	208.333	-	225	-
Commercial	251–600	-	0.59	-	0.61	-	0.69	-	0.96	-	1.15
	% Increasing	-	100	-	103.389	-	116.949	-	162.711	-	194.915
	601–1000	-	0.78	-	0.81	-	0.96	-	1.35	-	1.45
	% Increasing	-	100	-	103.845	-	123.076	-	173.076	-	185.897

**Figure 8.** Percentages incrementations in case of residential loads.**Figure 9.** Percentage incrementations in case of commercial loads.

According to the above data about components guarantee and the new control system (Figure 3), the project will still be efficient for ten years. Therefore, the total project costs (adding the replacing batteries four times through ten years, battery guarantee two years only) equal  $1227.8 + 4 \times 289 = \$2383.8 \approx 38140.8$  E£, with a rate of change  $\$1 = 16$  E£.

From the above: The yearly project cost is  $\$238.38 \approx 3814.08$  E£, and the monthly project cost is  $19.865 \approx 317.84$  E£.

#### 7.4. Project for Residential Loads

This section explains the benefits of the proposed hybrid system supplied energy w.r.t the supplied energy with government electricity.



According to the above sections, the proposed methodology interests the strip from 651–1000 kWh, the investment strip “350–650 is economic strip”. From Figure 8, the controlled function for Egyptian tariff incrementations is nearly decided by (Excel facilities functions):

$$y = 0.4769 x^2 + 31.139 x + 63.336 \quad (18)$$

Note that:

- Reference [74] has reported up to 2017–2018,
- The required energy from a hybrid system according to the above sections is 178.493 kWh/M to limit the strip within the economic level,
- This value will be calculated by; using the Egyptian tariff (strip 651–1000) and by the hybrid system to explain its savings,
- By using Equation (18) to decide the percentage incrementations for ten years from 2017–2018, Table 7 and the corresponding Figure 10 show the saving energy and money by using the proposed hybrid system for 10 years project lifetime (basis tariff is 2017–2018),
- $y$  is the percentage incrementations and  $x$  is the number of year/s (e.g.,  $x = 5$  for 2017–2018,  $x = 6$  for 2018–2019...etc.),
- Using Table 6 and Equation (18):

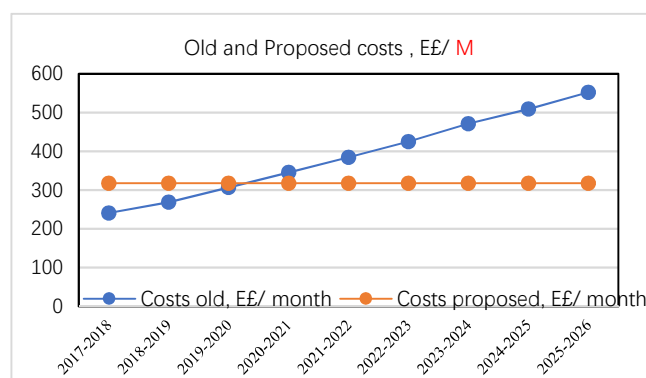
Equation (18) has percentage error =  $2.646 \approx 3\%$  (e.g., for 2017–2018  $y = 225$  as actual value (from Table 6), but by Equation (18);  $y = 230.95$ ), the highest percentage error =  $6.14 \approx 6\%$  for: 2016–2017 ( $y = 208.333$ , by Equation (18)  $y = 195.5224$ ),

- Table 7 values are derived from Equation (19) after multiplying Equation (18) by 0.94 (error of 0.06):

$$y = (0.4769x^2 + 31.139x + 63.336) \times 0.94 \quad (19)$$

**Table 7.** Incriminations, strip costs, and % savings for each family (5 persons) with proposed methodology through 10 years for residential loads “from 2017/2018 to 2026/2027”.

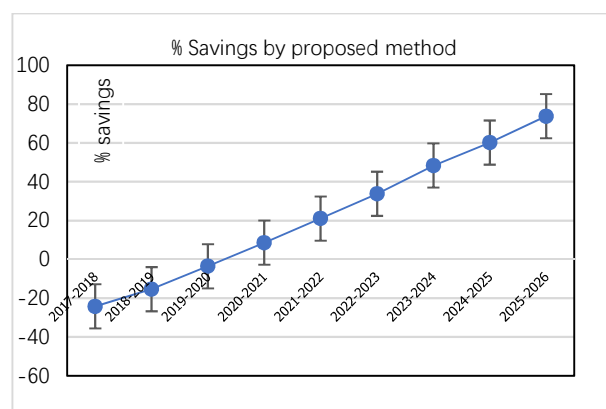
Years	2017– 2018 $x = 5$	2018– 2019 $x = 6$	2019– 2020 $x = 7$	2020– 2021 $x = 8$	2021– 2022, 2022, $x = 9$	2022– 2023 $x = 10$	2023– 2024 $x = 11$	2024– 2025 $x = 12$	2025– 2026 $x = 13$	2026– 2027 $x = 14$
% Incremen.	225	251.298	286.396	322.391	359.28	397.07	435.755	475.33	515.81	557.189
Tariff, 0.6 E£ (basic)	1.35	1.507	1.718	1.934	2.155	2.382	2.614	2.852	3.094	3.343
Cost, 78.493 E£/M	240.965	268.988	306.65	345.205	384.65	425.170	471.507	509.06	552.257	596.702
Costs, E£/10Y “Old sys.”	2891.58	3227.85	3679.8	4142.46	4615.8	5102.04	5658.08	6108.72	6627.08	7160.42
Total costs, E£/10Y “Old sys.” 49,213.855										
Total costs, E£/10Y “Proposed sys.” 38,140.8										
% Total money-saving, E£/10Y	29.03%, = 11,073.055 E£/10 years									
% Savings w.r.t 814.08/Y	−24.186	−15.369	−3.52	8.60	21.02	33.708	48.347	60.162	73.75	87.73



**Figure 10.** Comparison between the old and proposed hybrid system costs/month for residential “from 2017/2018 to 2026/2027”.

Table 7 indicates the comparison between the family consumed energy costs using; the calculations by traditional generation sources and the proposed system through 10 years.

General notes: The total percentage saving money by the proposed system for residential loads is 29.03% related to the traditional supply (for ten years, Table 7), the proposed hybrid system gives the lowest monthly costs instead of the traditional system after the first three years (starts from 2020–2021, Figure 10), and the percentages saving effective values present after the first three years (starts from 2020–2021, Figure 11).



**Figure 11.** Percentage savings of proposed hybrid system for residential “from year 2017/2018 to year 2026/2027”.

### Contributions of the Hybrid System

From the above sections:

- The proposed system gives  $(27.616 - 21.66 = 5.956 \text{ kWh/D})$ , which equals 21.567 % of the total residential loads (family with five persons);
- This system will succeed to give the same percentage for all the residential application loads (from Table 8 = 66,809 GWh); then
- The given generated energy from the proposed hybrid system is 14408.83 GWh/years)  $(0.21567 \times 66089 \text{ GWh})$ .

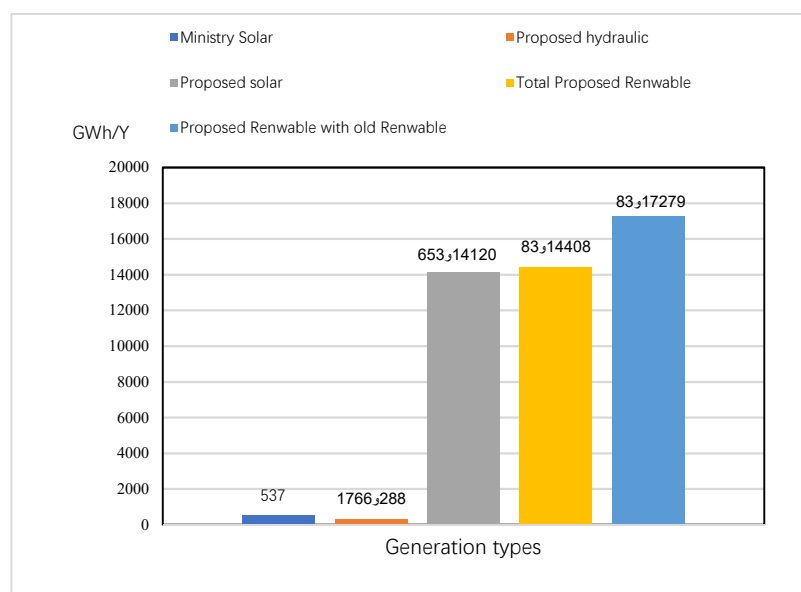
**Table 8.** Contributions of the proposed hybrid system in various generation/loads types.

System Types/Items	Traditional System						Proposed Hybrid System					
Generation Systems	Total Generations, GWh		Residential Loads, GWh		Renewable, GWh (Solar)		Total Generations, GWh		Residential Loads, GWh		Renewable, GWh	
Generation Types	By Minis.	By Prop.	By Minis.	By Prop.	By Minis.	By Prop.	By Minist.	By Prop.	By Minis.	By Prop.	By Minis.	By Prop.
Energy values, GWh	196,760	-	66,809	-	537	-	182,351.17	14,408.83	52,400.16	14,408.83	537	14,408.83
Energy Percentages, %	100	-	33.954	-	0.2729	-	92.676	7.323	78.432	21.5671	0.2729	7.323
Total percentage without wind, %						0.2729						7.5959
Total percentage with wind, %						1.4591						8.782

This proposed hybrid system positively affects renewable generation systems, as shown in Figures 10 and 11. Table 8 explains the contributions of the proposed system to increase by effective values of the renewable and total development generation stations in Egypt.

Notices from Tables 7 and 8:

- The renewable ministry systems solar generation contributes only 537 GWh/Y, which equals 0.2729% of the total developed generated energies;
- The proposed hybrid system will raise the contribution of the renewable (proposed + old solar) to be 14,945.83 (537 + 14,408.83), which equals 7.5959% of the total developed generated energies and leads to reduce the generations of other sources (e.g., steam by the same 7.5959% values, decreasing in CO<sub>2</sub> exhausts);
- The proposed and wind energies will share 8.782 % (17,279.83 GWh/Y) of the total developed generation energies.
- According to Tables 3 and 7, the proposed hybrid system has two generations systems (Figure 12):
  1. Pic-hydraulic system: it contributes by 288.1766 GWh/Y (2 % of 14,408.83), which has a percentage of 0.14646 % of the total developed generated energies “half the sharing percentage of the traditional solar system”, and
  2. The solar system contributes by 14,120.653 GWh/Y (98% of 14,408.83), which has a percentage of 7.1765 from the total developed generated energies (26.29 times the sharing percentage of the traditional solar system of the ministry).
- The generation stations can reduce the total outputs to be 182,351.17 GWh/Y, which is 92.677% of the old total developed generated energies (7.323% reduction);
- By using the savings from Table 6, the percentage saving money by the hybrid proposed system is 29.03% related to the traditional system (return to subscribers);
- From Table 8, the proposed system gives 14,408.83 GWh/Y, by using Table 7 for tariff cost from 2017–2027 (ten years) E£/kWh:
  1. The total costs of 14,408.83 GWh through 10 years equal  $14,408.83 \times (1.35 + 1.057 + 1.718 + 1.934 + 2.155 + 2.382 + 2.614 + 2.852 + 3.094 + 3.343) = 330,668.2397$  million E£/10Ys (20,666.76 million \$ with rate of change \$ = 16 E£)
  2. The return residential subscribes savings in money through ten years =  $330,668.2397 \times 0.2903 = 95,992.9899$  million E£/10Ys (5999.5618 million \$)
- The proposed system will reduce the exhaust from steam stations' (CO<sub>2</sub>) by 7.3%, which leads to a higher clean environment.
- Figure 12 explains the effectiveness of the proposed hybrid system on the renewable generation Egyptian systems (2017–2018).



**Figure 12.** The effectiveness of the proposed hybrid system on the Renewable Egyptian generation systems.

Note that the above residential building generation (14,408.83) by supposing all the buildings are private without public ones. Therefore, if the private will be taken as percentages related to public buildings, the generations and savings—with applied this proposed system—will be shown in Table 9:

**Table 9.** The generations and saved money with different private residential percentages w.r.t all residential buildings (loads) through 10 years (2017–2027).

Percentages %	Generations, GWh	Ct = Costs for 10 Years Million E£/\$ × 22.949 (Table 8)	Saving Money Million E£/\$, Ct × 0.2903
10	1440.883	33,066.82/2066.676	9599.298/599.956
20	2881.766	66,133.64/4133.35	19,198.595/1199.91
30	4322.649	99,200.46/6200.02	28,797.89/1799.868
40	5763.532	132,267.28/8266.705	38,397.19/2399.8244
50	7204.415	165,334.1/10,333.38	47,996.489/2999.78
60	8645.298	198,400.9/12,400.05	57,595.78/3599.73
70	10,086.181	231,467.74/14,466.73	67,195.08/4199.69
80	11,527.06	264,534.56/16,533.41	76,794.38/4799.64
90	12,967.947	297,601/18,600	86,393.68/5399.6

## 8. The Hybrid Generation System

As discussed in the previous sections, the hybrid system contains two generation systems: Pico-hydraulic and solar (PV). These two generated systems are used with an integrated system to maintain the continuity of supplying voltage to inverter/batteries “Figures 2 and 3”. This proposed integrated system has the following advantages: It gives the accepted voltage range to inverter/batteries “continuously” from PV and/Pico-hydraulic units according to Figure 1, the system must be effective in power generation and money savings for success. It can be used as an emergency power supply in case of shutdown of the ministry power supply directly or from charged batteries, and it is very easy to install, and it uses natural resources (solar and water) to generate high economic and clean energy.

### Applicable Model

Figure 13 displays the full integrated circuit details used to verify the hybrid generation system operation and efficiency (the model was executed in the electrical power laboratory, faculty of engineering, Kafrelsheikh University). The proposed system model has been tested and checked with various states according to the flowchart in Figure 1. Its operations were accurate and very easy to work, similarly to the methodology displayed in Figure 3.

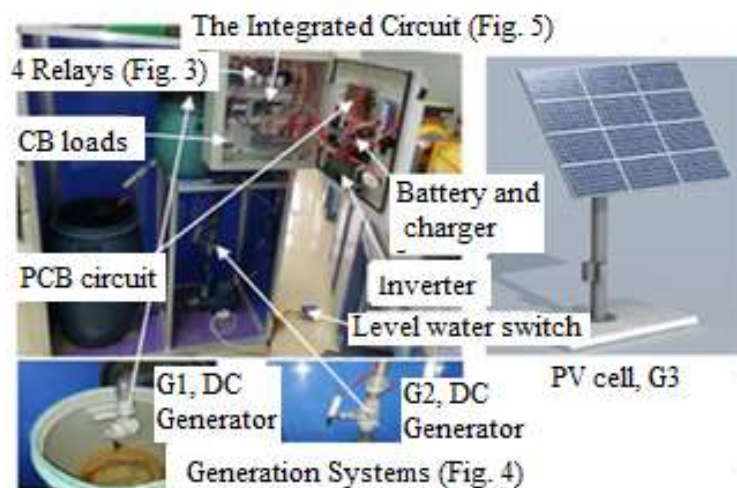


Figure 13. The practical integrated model of the hybrid generation system.

There are actual results from the practical model (Table 10):

Table 10. Different output values from three-generation systems.

Cases	Pump 1 *			Pump 2 *			PV **			Total O/P		
	V, V	I, A	P1, W	V, V	I, A	P2, W	V, V	I, A	P3, W	V, V	I, A	PT W
1	12	0.83	10	-	-	-	-	-	-	12	0.83	10
2	-	-	-	10	0.8	8	-	-	-	10	0.8	8
3	-	-	-	-	-	-	12	8.3	100	12	8.3	100
4	12	0.83	10	-	-	-	12	8.3	100	12	9.1	109.95
5	-	-	-	10	0.8	8	12	8.3	100	11	9.1	108
6	12	0.83	10	5.6	0.44	2.46	-	-	-	12	0.83	10
7	8	0.66	5.28	4.2	0.336	1.4	-	-	-	12.2	0.996	6.6

\* Pump power 10 W, \*\* PV used is 100 W.

Note that: This proposed model has been tested with two DC generators (10 W each) to verify the success of operations.

## 9. Conclusions and Policy Implications

This study numerically investigates hybrid Pico-hydraulic and PV systems using the proposed model (integrated system). The proposed hybrid system discusses the renewable energy challenge, the actual existing data for the world and Egypt as an application case study, the generation and consumption according to verified references, and the cost analysis of the proposed system related to the traditional generation systems. The proposed hybrid system has much potential (advantages); simple, reliable, efficient and improving the operational performance of renewable energy systems. Furthermore, the mathematical equations, calculations, discussions, and practical models were drawn (positive impacts):

- Continuous supply allowable charging voltages to inverter/batteries by this intelligent circuit (whether the outputs voltages from water/solar in its ranges/levels or not).
- Emergency supply system home loads can be supplied.

- Increase the contribution of renewable energy by the solar system from 0.273% to 7.595% of the total different installed generation stations in Egypt.
- Saves a lot of money for residential users (subscribers); each family can save 11,073 E£/10 Y (\$296.06) through service lifetimes of application of this proposed system related to supplying the same loads by the government system.
- On a large scale, according to Table 9, the savings in money in the residential subscriptions sector (through ten years) ranged from 9599.298 million E£/10Ys (lowest percentage, 10%) up to 86,393.68 million E£/10Ys = 5399.6 million \$ (percentage 90%).
- Uses the daily human usage water in the home to give 288.1766 GWh/Y (2% of 14,408.83), which has a percentage of 0.14646% of the total developed generated energies (half the sharing percentage of the total updated traditional solar system in Egypt through 2017–2018).
- Uses solar energy (nature resource) to give 14,120.653 GWh/Y (98% of 14,408.83), which has a percentage of 7.1765% of the total developed generated energies (26.29 times the sharing percentage of the traditional solar system in Egypt through 2017–2018).
- Help the Egyptian electrical ministry to reduce the energy outputs from its generation stations to be 182,351.17 GWh/Y. This reduction is 7.323% of the total developed supplied energy, which increases the service lifetime of ministry generation stations (decreasing their maximum loads) and gives the government a chance to install new projects to use this extra generation energy.
- Increase the system power quality.
- For environmental impact, it reduces the exhaust from steam stations' (CO<sub>2</sub> (by 7.3%), which equals the added by the proposed system), which leads to a higher clean environment.
- Some of the houses are individuals (e.g., Villa), which has its green land around it. This green land takes about half the quantity of water house; this means the generation of pico-hydraulic may share with another percentage value added to the previous percentage.
- It can be applied to all residential and commercial buildings to save users and the government more.

But, there are limitations on the application of this proposed system: needs the source of hydraulic system (water tank) and solar sources to give all the above benefits. The output voltages and energy are still in low ranges, with interest on the cost and maintenance fee for the pico-hydro power generator and the decline of photovoltaic cell performance. There is a reduction in the saved by this study may be limited to a very percentage (maybe less than 0.05% from 7.3%). In addition, there is no support by governments to apply this model.

In future research, authors will try to overcome these drawbacks by:

- This proposed study must be supported by governments by giving bonuses on the bill, and reducing the cost by not applying tax and customs on the products used in the application to consumers in a residential and commercial building, and
- Try to apply this model for large scales (e.g., irrigation projects).

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## Nomenclature

### Abbreviations

ACHE	Adaptive control of the home environment
PV.	Photo-voltaic
PVT	Photovoltaic thermal
PVT-CR	Photothermic–radiative cooling
CPV	Concentrator Photovoltaic
RE	Renewable Energy

### Symbols

$P_m$	Theoretical mechanical horsepower
$Q$	The flow rate in cubic feet per second
$V$	The velocity of flow, m/s
$P$	Pressure, N/m <sup>2</sup>
$\rho$	The density of water, kg/m <sup>3</sup>
$P_t$	The output from the turbine, W
$Q$	The flow rate in the pipe (m <sup>3</sup> /s)
$G$	Acceleration of gravity (for water = 9.81 m/s <sup>2</sup> )
$H_n$	The net height, m
$H_g$	Gross vertical head, m
$H_{lo}$	Head loss, m
$\eta_t$	Turbine efficiency
$P_{op}$	The net output from the generator, W
$\eta_g$	Generator efficiency
$N_s$	The specific speed of the turbine, rpm
$N_t$	Turbine's rotation speed (rpm)
$P_p$	Daily consumed power for each family home person is denoted by, KWh
$N$	Number of family persons
$P_T$	The actual total family persons daily consumed power, KWh
$Q_p$	Consumed water/family person, m <sup>3</sup>
$Q_T$	Total consumed water for all family persons, m <sup>3</sup>
$P_{ec}$	Total consumed power for all family persons must be Limited to economic value, and it is denoted by, KWh
$P_w$	The pressure, psi
TDH	Total dynamic head, feet
Gpm	Pumping rate in gallons per minute
Whp	Gpm
$P_s$	Additional solar generation power, KW h
E£	Egyptian pound

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