

# Economic Analysis of a Grid-Connected Hybrid Renewable System Supplying CIT Center at Mansoura University-Egypt

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**Abstract:** Renewable energy is one of the major inputs for the economic and social development of any country. In case of the developing countries, the renewable energy sector represents a critical importance in increasing electrical energy which requires huge investments to meet them. The Hybrid Renewable Energy System (HRES) provides the consumer with reliable and cheap electricity by reducing the dependence on one renewable source. Therefore optimal combination and sizing design of HRES has a very important role in the use of renewable energy effectively and economically. Egypt has a huge potential for renewable energy sources which encourages the implementation of renewable energy projects. This paper presents an economic analysis of applying a HRES to provide Communication and Information Technology (CIT) Centre in Mansoura University-Egypt, with its needs of electricity. A modified Particle Swarm Optimization (PSO) technique is applied to optimize the capacity sizes of different components of hybrid PV/wind power generation system. A Matlab code is developed to represent the proposed method. The results indicate the optimal configuration and sizing of the proposed HRES. Capital budgeting and economic analysis indicate that HRES is technically feasible and economically viable.

**Key words:** Economic Analysis, Grid connected, Hybrid Renewable system, Particle Swarm Optimization, Wind Turbines, Photovoltaic.

## 1. Introduction.

According to the increase in energy demand, the Egyptian government is struggling to secure energy supplies to meet the needs of economic and social development. The Egyptian government begun to activate the implementation of renewable energy strategy, which aims to increase the contribution of renewable energies to 20% of the total generated power by 2020 [1]. In recent years, the hybrid generation system has become significant because of the complementary characteristics among the new and renewable energy resources. In many regions, when solar and wind resources are combined for power generation, they complement each other by means of daily and seasonal variations. This combination reduces the dependence on one environment parameter thus providing the consumer with reliable, cheap electricity, and is more effective than utilization of single renewable energy source [2]. Hybrid, wind turbine and PV modules, offer greater reliability than any one of them alone

because the energy supply does not depend entirely on one intermittent source. HRES can operate either in grid-connected or stand-alone mode. In case of grid-connected mode, the main priority of the system is to cater the local energy demand and occasionally to feed the grid with surplus energy. In a stand-alone mode, the system supplies a local load independently of the grid utility. When a HRES includes solar or wind energy an auxiliary source of energy (e.g. battery banks, fuel cells, diesel generator or utility grid) is required in order to overcome the stochastic availability of those energies [3]. Sizing and optimal design are very important in order to efficiently and economically utilize HRES. The sizing optimization methods can help to guarantee the lowest investment with a seasonable and full use of the solar and wind resources. However, the energy system sizing procedure and operation control strategies are getting more complex due to the nonlinear components' physical characteristics.

In the past few years, several methods have been used to design HRES. According to their complexity level, these methods can be classified as: analytical methods, software packages and optimization methods.

### • Analytical methods

In these methods, hybrid systems are represented by means of computational models which describe the system size as a function of its feasibility. In [4-6], the authors proposed probabilistic models using statistical approach and in particular convolving the probability density function of power generated from solar and wind systems. A procedure for probabilistic treatment of solar irradiate and wind speed data as a method of evaluating the electric energy generated by both a PV system and a wind energy conversion system was presented in [7]. The method depends on using probability density function to assess the long-term performance of a hybrid PV/wind power system.

### • Software Packages

Recently, commercial software simulation tools are broadly used in performance assessment of HRES. These models are used to simulate the

performance of “hybrid” or “distributed energy resource” systems that typically include one or more renewable sources of electricity combined with a traditional fossil based fuel source. The models include: HOMER, RETScreen, Hybrid2, TRNSYS, and many other software packages [8-9]. The most important one of these tools is the Hybrid Optimization Model for Electric Renewable (HOMER), which was developed by the National Renewable Energy Laboratory (NREL) [10]-[13]. It is public domain software that simulates and optimizes stand-alone and grid-connected power systems with any combination of renewable sources. Also, all costs except fuel handling costs and taxes are included. The main drawback of this software is the “Black Box” code utilization. The HOMER models are based on linear equations, so that it may not represent the renewable energy source characteristics exactly.

#### • Optimization methods

An optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found. With the advent of computers, optimization has become a part of computer-aided design activities. Many researchers have used optimization techniques to minimize the cost of HRES energy production or to maximize the efficiency of the system.

Geem in [14] used an optimization technique called Branch-and-Bound to find the optimal combination of a hybrid PV/wind system based on a complete data-set. That technique does not guarantee global optimum solution. The authors in [15] proposed a decision support system that can be used for hourly energy management of a mix of renewable energy systems, but the method was applied for one day only. In [16], the authors deal with the optimal sizing of PV/wind turbine by adopting different multi criteria decision analysis optimization approaches. But they consider different weighting criteria, so the computational time may be slow. Multi-objective Linear Programming (MOLP) technique was used to determine the optimal mix of renewable energy sources in [17] and [18].

In the last years the artificial intelligence (AI) techniques, especially evolutionary techniques, have turned out to be potent methods to solve such kind of optimization problems. In many cases those techniques guarantee the global optimization solution. The authors in [19] used Genetic Algorithm (GA) to determine the optimal sizing of PV resources as grid connected mode in distribution systems with the aim of maximizing net present worth of the system. In [20] the authors have used the classic GA to calculate the optimum system

configuration that can achieve the customers required Loss of Power Supply Probability (LPSP) with a minimum annualized cost of system. But LPSP concept used in [19]-[20] is a statistical parameter based method. Therefore, in a bad resource year, the system may suffer from much higher probability of losing power than the desired value.

HRES optimization problem is a complicated one; it needs a special tool capable of solving it rapidly and effectively. Particle Swarm Optimization technique (PSO) is one of the most promising AI techniques because it is proven to be both very fast and effective when applied to a diverse set of optimization problems [21]. PSO algorithm has been used for optimal design of HRES in [21]-[24]. The authors in [21] and [22] used PSO for optimal sizing of grid-connected micro-grid. Authors proposed a hybrid system consists of renewable sources and battery banks. Reference [23] used PSO for optimal design of PV grid-connected systems. The author formulated the optimization problem simply as it contains PV source only. A PSO algorithm is proposed in [24], to design a renewable sources connected to a grid optimally.

This paper presents a modified PSO based approach for optimal sizing of grid connected HRES for a proposed 20 year period of operation. The approach applies a deterministic algorithm to suggest the optimal number and type of units ensuring that the total investment cost of the system is minimized while guaranteeing the availability of the energy. A Matlab code is developed to represent the proposed approach. The developed code is implemented with a real data to find optimal configurations and sizing of a hybrid PV/wind system capable of supplying the CIT centre in El-Mansoura University, Egypt with its energy requirements. The next section describes in detail the HRES components and its mathematical model.

## 2. Proposed HRES Components Modeling.

The proposed system is a grid connected hybrid (solar/wind) system. A schematic diagram of the proposed is shown in Figure 1. In this mode the utility grid is considered as the backup for the system in case of energy deficit. On other hand, whenever the produced energy is greater than demand, the surplus energy is sent to the grid.

Mathematical modeling of the HRES components is the first step for optimization process. The following subsections present a brief description of the models used for simulating the proposed HERS system.

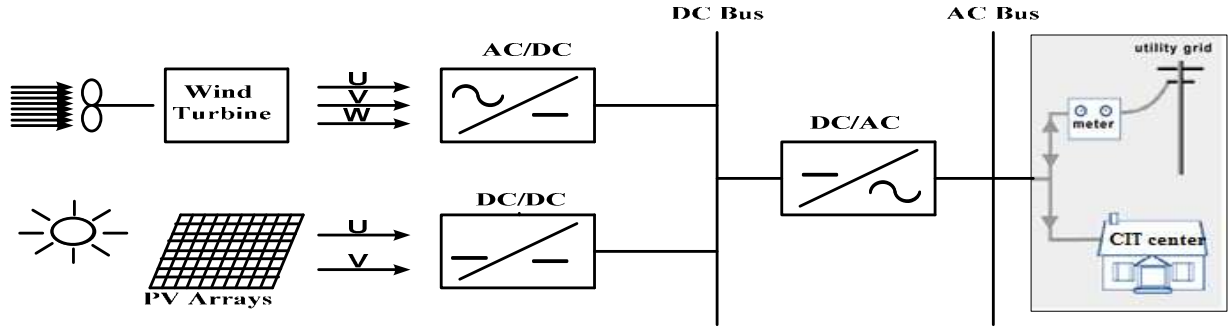


Fig. 1. Block diagram of grid connected hybrid PV/ wind generation unit.

### A. Modeling of Wind Turbine

The most simplified model to simulate the power output of a wind turbine could be evaluated from its power-speed curve [25]. It is important to adjust the measured wind speed to the hub height ( $h$ ). This can be done by using the wind speed data at a reference height ( $h_r$ ) from the database as explained by equation (1) [26]:

$$V(t) = V_r(t) \cdot \left(\frac{h}{h_r}\right)^\gamma \quad (1)$$

Where  $v$  is the wind speed at the desired height  $h$ ;  $v_r$  is the wind speed at a reference height  $h_r$ ; and  $\gamma$  is the wind shear exponent coefficient which varies with pressure, temperature and time of day, ranging from 1/7 to 1/4 [25-26]. In this paper, this coefficient is taken as one-seventh (1/7). The best description for variation of wind velocity is the Probably Density Function (PDF). The PDF indicates the probability that an event will occur between two end points. In this paper, the PDF is taken as a Weibull function which can be defined as [25]:

$$f(x) = \frac{\beta}{\eta} \cdot \left(\frac{x}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{x}{\eta}\right)^\beta} \quad (2)$$

Where:  $\beta$  is the shape factor;  $x$  is the wind velocity; and  $x \geq 0$ ,  $\beta > 1$ ,  $\eta > 0$ .

The scale factor  $\eta$  shows how the distribution lies and how it stretched out.

The output energy from the wind turbine, at any wind velocity, can be estimated by using wind turbine power curve which is usually given by manufacturer. For a wind speed profile, the available energy can be calculated as [25]:

$$E_{WT} = (\text{days}) \cdot (\text{hours}) \cdot \sum_{v=1}^{25} P_c f(v, \beta, \eta) \quad (3)$$

Where  $E_{WT}$  is the energy generated by the wind turbine at a specific site (in kWh), the product of days by hours gives the total hours used in simulation,  $P_c$  is the output power of wind turbine (in kW),  $f(v, \beta, \eta)$  is the Weibull probability density function for wind speed  $v$  at a given shape factor  $\beta$  and scale factor  $\eta$ ,  $v_{\min}$  and  $v_{\max}$  are the minimum

and maximum wind speeds. For commercial small wind turbines  $v_{\min}$  and  $v_{\max}$  take values between 0 and 24 m/s [18].

### B. Modeling of PV Module

The PV array performance is simulated by deriving the PV model that represents the maximum output power at any temperature. The used model can predict output power of PV panel at different temperatures and various radiation levels. The proposed mathematical model of a PV panel is deduced using the following equations [25]:

$$P_{PV} = V \cdot I(V) \quad (4)$$

Where:

$$I(V) = \frac{I_x}{1 - e^{-\left(\frac{V}{b}\right)}} \cdot [1 - e^A] \quad (5)$$

$$A = \left(\frac{V}{b \cdot V_x} - \frac{1}{b}\right) \quad (6)$$

$$V_x = s \cdot \frac{E_i}{E_{iN}} \cdot TCV \cdot (T - T_N) + s \cdot V_{\max} - B \quad (7)$$

$$B = s \cdot (V_{\max} - V_{\min}) \cdot e^C \quad (8)$$

$$C = \left(\frac{E_i}{E_{iN}} \cdot \ln \left[ \frac{V_{\max} - V_{oc}}{V_{\max} - V_{\min}} \right] \right) \quad (9)$$

$$I_x = p \cdot \frac{E_i}{E_{iN}} \cdot [I_{sc} + TCI \cdot (T - T_N)] \quad (10)$$

Where

- $P_{PV}$  output power of the PV panel (W),
- $I(V)$  output current of the PV panel at a specific output voltage (A),
- $V$  output voltage of the PV panel (V),
- $b$  characteristic constant based on I-V curve, its value ranges from 0.01 to 0.18 [16].
- $SR_i$  solar radiation impinging the cell ( $\text{W/m}^2$ ),
- $SR_{iN}$  solar radiation at Standard Test Condition (STC) ( $=1000 \text{ W/m}^2$ ),
- $t_N$  temperature at STC ( $= 25^\circ \text{C}$ ),
- $I_{sc}$  short circuit current at STC (A),
- $V_{oc}$  open circuit voltage at STC (V),
- $V_{\max}$  open circuit voltage at  $25^\circ \text{C}$  and  $1200 \text{ W/m}^2$  (V),
- $V_{\min}$  open circuit voltage at  $25^\circ \text{C}$  and  $200 \text{ W/m}^2$  (V),
- $t$  temperature of PV panel ( $^\circ \text{C}$ ),
- $T_{CI}$  temperature coefficient of  $I_{sc}$  ( $\text{A}/^\circ \text{C}$ ),

$T_{CV}$	temperature coefficient of $V_{oc}$ ( $V/^{\circ}C$ ),
$I_x$	short circuit current at any solar radiation and panel temperature (A),
$V_x$	open circuit voltage at any solar radiation and panel temperature (V),
$s$	number of PV panels in series,
$p$	number of PV panels in parallel.

The following equation is used to calculate the annual energy of PV arrays at a specific site with a given solar radiation.

$$E_{PV} = P(SR_x) \cdot (Solar\ Window) \cdot (365) \quad (11)$$

Where  $E_{PV}$  is the annual production of PV energy,  $SW$  (*Solar Window*) is the total hours the sun hits the PV modules at an average hourly solar radiation, and  $P(SR_x)$  is the PV module output power at an average hourly solar radiation  $SR_x$ .

### C. PV Controller

The PV controller works as a voltage regulator. There are five different types of PV controllers: shunt controller, single-stage series controllers, diversion controller, pulse width modulation (PWM) controller and maximum power point tracking (MPPT) controllers. In this paper the MPPT controller is used as a PV controller. This controller tracks the maximum power point of the array

throughout the day to deliver the maximum available solar energy to the system [18].

### D. Inverter

Inverters are available in three different categories: grid-tied battery-less, grid tied with battery back-up and stand-alone inverters. Currently the grid tied battery-less inverters are the most popular ones. These inverters are connected directly to the public utility, using the utility power as a storage battery. When the sun is shining or the wind is blowing, the load is supplied by the PV or wind turbine via the inverter. Whenever the produced energy is greater than demand, the excess energy is sold to the utility.

The grid-tied with battery backup inverters are more complex than battery-less grid-tied inverters because they need to sell power to the grid, supply power to backed-up loads during outages, and charge batteries from the grid, PV or wind turbine after an outage. These inverters need to have features similar to both a battery-less grid-tied inverter when selling power to the utility, and to a stand-alone inverter when feeding the back-up loads during outages [18]. In this paper, the grid-tied with battery backup inverter is used. A schematic diagram of the grid-tied battery-less and grid tied with battery back-up inverters is shown in Figure 2.

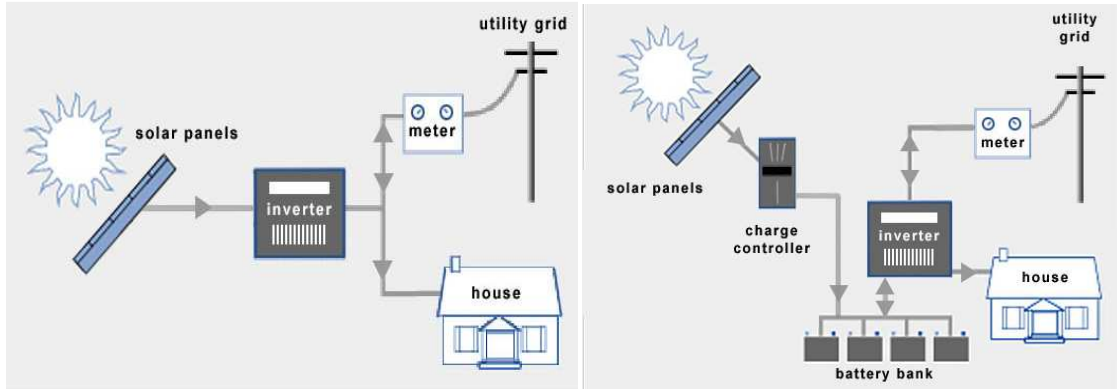


Fig. 2. Schematic diagram of grid-tied battery-less and grid tied with battery back-up inverters.

### 3. Design Model of the Proposed System.

The objective of the economic analysis can be viewed as the determination of the least cost configuration for meeting the energy needs, considering different HRES components. The objective function in this paper is to minimize the system Total Investment Cost (TIC) through the system lifetime ( $T_{lifetime}$ ). The unknown variables (defined in the next paragraph) are ( $N_{PV}$ ,  $N_{WT}$ ,  $N_{IN}$ ,  $N_{CON}$ ). These variables represent the number of equipments (considering different types of each component) needed to supply the load at minimum

cost. The objective function of the TIC of a hybrid PV/wind grid-connected system can be formulated mathematically as follows:

**Minimize:**

$$TIC = \sum_{i=1}^{n_{pv}} (C_{PV} N_{PV}) + \sum_{j=1}^{n_{wt}} (C_{WT} N_{WT}) + \sum_{g=1}^{n_{inv}} (C_{IN} N_{IN}) + \sum_{k=1}^{n_{con}} (C_{CON} N_{CON}) + C_u E_u + C_L E_L \quad (12)$$

Where:  $C_{PV}$ ,  $C_{WT}$ ,  $C_{IN}$ , and  $C_{CON}$  are total investment costs of a PV module, a wind turbine, an inverter, a controller respectively.



$N_{PV}$ ,  $N_{WT}$ ,  $N_{IN}$ , and  $N_{CON}$  are number of PV modules, wind turbines, inverter units, and controllers units respectively.

$C_U$  is the cost of purchased energy from utility (\$/kWh),  $C_L$  is the cost of energy sold to the utility (\$/kWh),

$E_U$  is the annual purchased energy from utility (kWh/year),  $E_L$  is the annual energy sold to the utility (kWh/year).

The total investment costs for each component includes; capital cost ( $C_{cap}$ ), installation cost ( $C_{ins}$ ), annual operation and maintenance cost ( $C_{O\&M}$ ), and replacement cost ( $C_{rep}$ ) throughout the system lifetime.

$$C_{PV} = C_{cap\_pv} + C_{ins\_pv} + T_{lifetime} \times C_{O\&M\_pv} + N_{R\_pv} \times C_{rep\_pv} \quad (13)$$

$$C_{WT} = C_{cap\_wt} + C_{ins\_wt} + T_{lifetime} \times C_{O\&M\_wt} + N_{R\_wt} \times C_{rep\_wt} \quad (14)$$

$$C_{INV} = C_{cap\_inv} + C_{ins\_inv} + T_{lifetime} \times C_{O\&M\_inv} + N_{R\_inv} \times C_{rep\_inv} \quad (15)$$

$$C_{CON} = C_{cap\_con} + C_{ins\_con} + T_{lifetime} \times C_{O\&M\_con} + N_{R\_con} \times C_{rep\_con} \quad (16)$$

Where  $N_R$  is the number of component replacements through the lifetime period.

There are also a number of constraints incorporated into the model to restrict the set of feasible solutions. The first constraint regards to the energy balance; the total annual generated energy (kWh/year) must meet or exceed the annual effective energy consumption. The annual effective energy consumption is the annual energy consumption of the load divided by the overall system efficiency.

The overall system efficiency can be calculated as:

$$\eta = \eta_{INV} \times \eta_{CON} \times \eta_{WIREs} \quad (17)$$

$$L_{eff} \leq \sum_i E_{PV} N_{PV} + \sum_j E_{WT} N_{WT} + \sum_u E_u \quad (18)$$

$$L_{eff} = \frac{E_{load}}{\eta} \quad (19)$$

The second constraint regards to the sizing of inverters, it must meet or exceed the maximum power of PVs and wind turbines system.

$$\sum_g P_{IN} N_{IN} \geq P_{max} \quad (20)$$

The third constraint regards to the controllers size which must meet or exceed the maximum power of PVs under STC.

$$\sum_k P_{CON} N_{CON} \geq P_{PV_{max}} \quad (21)$$

Where:

$L_{eff}$  Effective energy consumption, (kWh/year)

$E_{load}$  Annual load energy consumption, (kWh/year)

$E_{PV}$  Annual generated energy by PV modules, (kWh/year)

$E_{WT}$  Annual generated energy by wind turbines, (kWh/year)

$P_{IN}$  Maximum output power of inverter, (W)

$P_{CON}$  Maximum output power of controller, (W)

$P_{max}$  Maximum generated power by HRES, (W)

$P_{PV_{max}}$  PV maximum power at STC, (kW)

A modified PSO technique is applied to achieve the optimal configurations and sizing of the HRES that efficiently supply the load while satisfying different economic and operational constraints.

### 3. Proposed Modified PSO Technique

The authors in a previous paper [27] proposed a general PSO modification for electrical applications. The values of the initial vectors and PSO parameters should be determined according to the nature of the problem to be solved. Authors proposed a method to determine the optimal PSO initial vectors and parameters to make PSO faster, performable, and accurate. The computational procedure of the proposed modified PSO method for optimal sizing of HRES is discussed as follows:

The input data are the meteorological data, the unit prices of the projected hybrid system components including installation and maintenance costs, predefined constraints, fitness function and the values of specific PSO parameters. The PSO parameters are selected as: maximum iteration number = 100, number of particles = 100 and weight factor = 0.95. The computational procedure of the proposed modified PSO method for optimal sizing of HRES is shown in Figure 3. A Matlab code is developed to represent the proposed approach. This code is divided into 3 modules as shown in Figure 4. The first module calculates the annual energy generated by any given wind turbine based on the mathematical model illustrated in section 2.1. The module uses the combination of Weibull and wind turbines power curve. The input data for that module are: the wind turbines power curves, tower height and the wind speed resource at hub height. The second module calculates the annual energy generated by a given PV based on the mathematical model illustrated in section 2.2. The input data for the module are: the temperature and the irradiance levels. The third module is the modified PSO initialization data; all the previous results are the inputs to this module. This module calculates the optimal number of HRES components based on minimum total investment cost for all components.

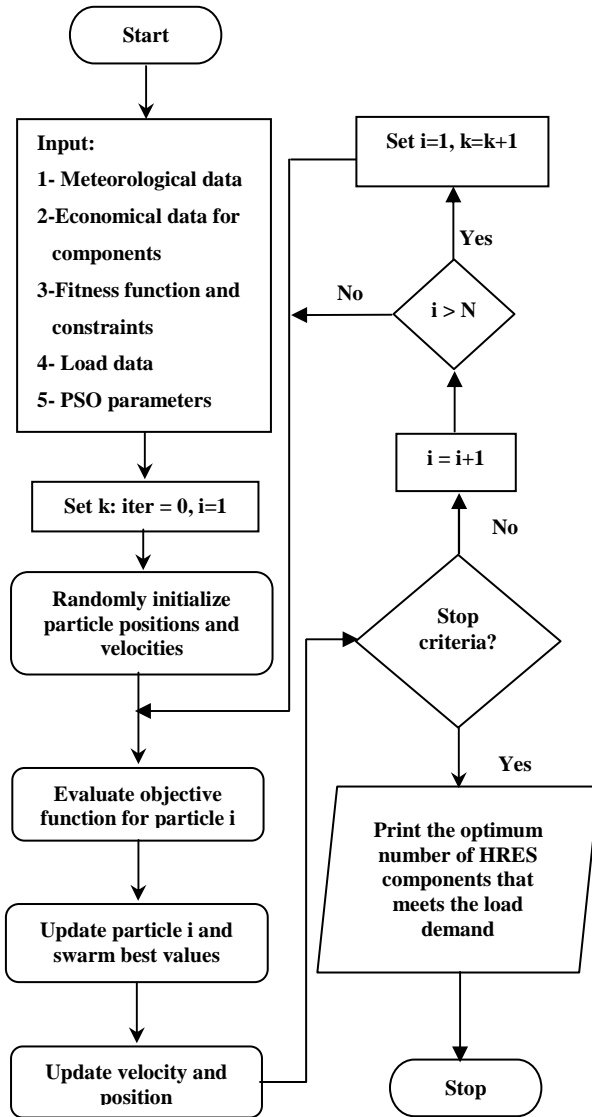


Fig. 3. Proposed PSO method flowchart

## 5. Capital Budgeting and Economic Analysis

Capital budgeting is a long term planning for replacement of an old inefficient equipment and/or additional equipment or physical plant when growing business conditions warrant. Capital budgeting involves setting aside moneys each year for large investments that might need to be made [28]. In this paper the Net Present Value (NPV) method is used in capital budgeting to analyze the profitability of the investment in hybrid energy system. NPV is calculated over one year interval. It compares the present value of money today to the present value of money in the future, taking inflation and returns into account.

The following items are used in the capital budgeting analysis:

1. Inflation rate: it reflects the raise in the prices paid for equipments every year. The inflation rate affects the operation and maintenance cost.
2. Interest rate: it represents the interest a lender charges on borrowed money.
3. Energy escalation rate: it reflects the annual change in the utility energy cost. This value is estimated based on historical data. Table 1 shows the energy escalation rate in Egypt in the last 7 years [29].

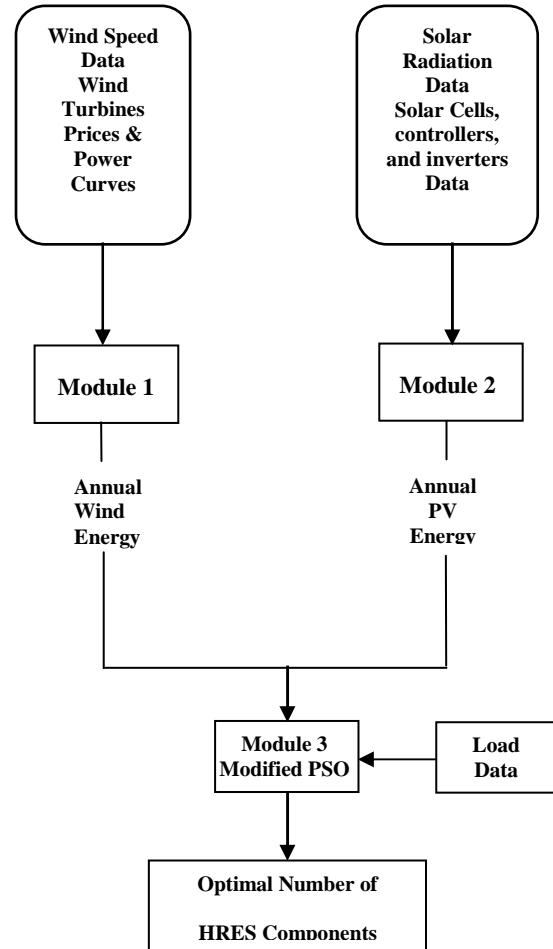


Fig. 4. Modules of the proposed method.

Table 1: Electricity tariffs evolution for Mansoura University in the last 7 years.

Year	Tariff (\$/ kWh)
2007	0.03
2008	0.035
2009	0.04
2010	0.05
2011	0.06
2012	0.07
2013	0.08

Net present value can be calculated as follows [28]:

$$NPV = \sum_{y=1}^{20} \frac{C_{cash}}{(1+i)^y} \quad (22)$$

$$C_{cash} = C_{in} - C_{out} \quad (23)$$

Where:

$C_{cash}$ : the cash flow in (\$),

$C_{in}$ : the income in (\$),

$C_{out}$ : the expenditures in (\$)

$i$ : interest rate.

$y$ : the year number

The project is profitable if the  $NPV > 0$  and the payback period can be calculated as:

$$T_{back} = \frac{TIC}{\left( \frac{\sum_{y=1}^{20} C_{cash}}{20} \right)} \quad (24)$$

A Matlab code is developed to represent the proposed method. The developed code is validated by applying it to design a system that has been designed using HOMER software in a published paper. The results show similar results with a lower cost for the proposed system [25].

## 6. Numerical Analysis

Mansoura University intends to use renewable energy for load electrification. Communication and Information Technology (CIT) center develops and automates the performance of the university's administrative affairs, education, and research. The center was chosen to establish a HRES to feed a part of its needs of electricity. In this paper a modified PSO based approach is applied with a real data to find optimal configurations and sizing of a hybrid PV/wind system capable of supplying the CIT center with its energy requirements.

### A. Input data

Table 2 shows the monthly electrical load requirements of a CIT center, with a peak load of 68 kW. The monthly average wind speed and the solar radiation are obtained from NASA surface meteorology and solar energy [30]. Table 3 shows the monthly averaged insolation incident on a horizontal surface and the monthly averaged wind speed at 50 m above the surface of the earth. In this paper the wind towers are taken with a height of 20 meters, so that the measured wind speed values have to be modified. Table 4 shows the average efficiency for inverter, controllers, batteries and wires used in this study. Other data for the HRES components are given from [31]-[32].

Table 5 shows the rates, cost of purchased energy [29], and annual saved money used for the economic

analysis. In this study the life time for wind turbines, PVs, controllers, and inverters is taken as 20 years.

Table 2: CIT center monthly electrical load requirement

Appliance	kWh/month
Server	240
Computer	261
Lighting	84
Central air-condition	40
Office air-condition	68
Refrigerator	9.6
TV	0.6
Heater	0.24

Table 3: Monthly averaged wind speed and insulation incident on a horizontal surface for Mansoura city

Month	22-year average solar radiation (kWh/m <sup>2</sup> /day)	10-year average wind speed (m/s) at 50 m height
Jan	3.04	5.61
Feb	3.84	5.94
Mar	5.14	5.72
Apr	6.49	5.19
May	7.44	5.04
Jun	8.10	4.9
Jul	7.78	5.01
Aug	7.19	5.09
Sep	6.19	5.17
Oct	4.66	5.18
Nov	3.42	5
Dec	2.74	5.49

Table 4: Average efficiency of hybrid system components

Inverter	0.97
Controller	0.97
Wires	0.96

Table 5: Economic rates for CIT center.

Energy Escalation Rate	10 %
Inflation Rate	6%
Utility KWh Rate	\$ 0.08
Load kWh Rate	\$ 0.1

A Matlab code is implemented for different commercial types of wind turbines and PV modules. Table 6 shows the annual energy output in kWh for different commercial types of wind turbines and PV modules. Figure 5 shows the power curve, and total annual energy output for each turbine. Whereas, Figure 6 shows the P-V and I-V curves for each PV module.

Table 6: Annual energy output for commercial types of wind turbines and PV modules

<b>Wind Turbines</b>	
Product	Energy Generated (kWh/year)
SouthWest (Air X)	506.27
SouthWest (Whisper 100)	1411.16
SouthWest (Whisper 200)	2952.03
SouthWest (Whisper 500)	8852.62
SouthWest (Skystream 3.7)	5393.74
Aeromax Engineering(Lakota)	1633.15
Bergey (BWC 1500)	3177.76
Bergey (BWC XL.1)	2643.78
Bergey (BWC Excel-R)	15580.78
Bornay (Inclin 250)	854.43
Bornay (Inclin 600)	1680.67
Bornay (Inclin 1500)	5371.67
Bornay (Inclin 3000)	10059.92
Bornay (Inclin 6000)	21250.96
Abundant Renewable (ARE110)	6103.25
Abundant Renewable (ARE442)	27206.12
Kestrel Wind (600)	1085.51
Kestrel Wind (800)	1878.78
Kestrel Wind (1000)	3734.14
Kestrel Wind (3000)	5866.09
Solacity (Eoltec)	13806.2
<b>PV Modules</b>	
Sharp ND-250QCS	489.31
Hyundai HiS-255MG	483.22
Lightway	478.12
Trina TSM-PA05	474.4
Solartech SPM135P	251.85
CSI CS6P-235PX	468.36
CSI CS6X-280P	564.95
CSI CS6X-285P	574.49
Canadian Solar -250P	495.06
CSI CS 6X-295P	593.07
Canadian Solar -300P	602.1
Canadian Solar-255M	503.34
Hyundai HiS-260MG	491.92

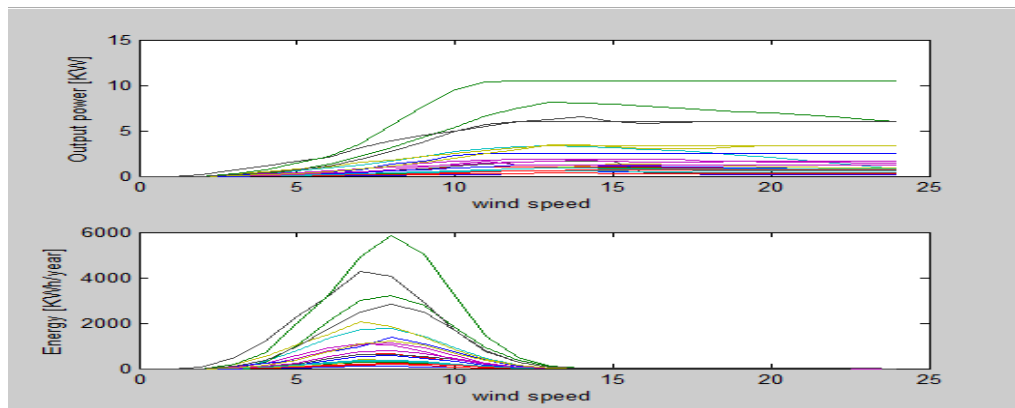


Fig. 5. Wind turbine power curves and energy outputs.



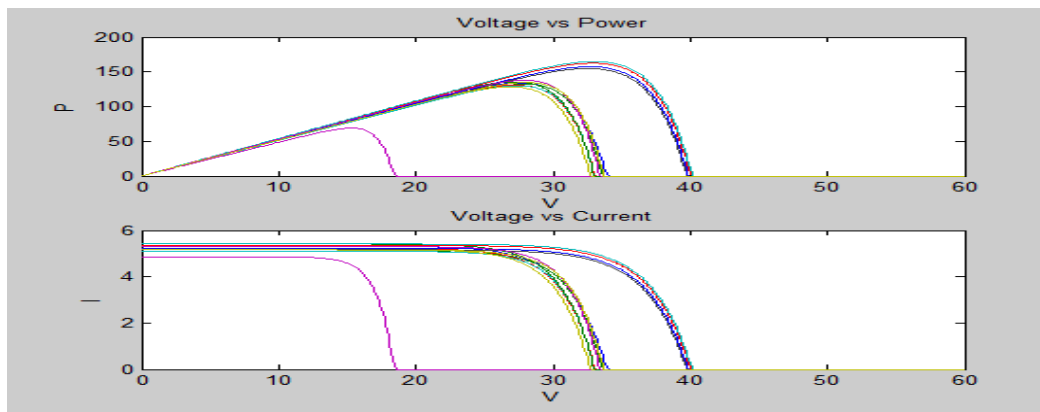


Fig. 6. P-V and I-V curves for different PV modules.

### B. Optimization using modified PSO technique

With the above calculated data, the optimization can be performed. The lower and upper bounds for each unknown variable in this module must be specified. According to the available land area, these bounds are taken as: 0 to 1 for the wind turbines, 0 to 60 for the solar modules, 0 to 5 for the controllers and 0 to 5 for the inverters. Total system efficiency is found as 90 %. The optimization results are shown in Table 7. The results detect the optimum combination of equipments needed to supply the energy needs at minimum possible cost.

### C. Economic analysis

Economic analysis for a time period of 20 year is then performed. Table 8 shows the results of economic analysis and the net present value for CIT center by applying the proposed optimization method. Since the net present value is positive, the proposed HRES system is considered as a good investment. The system payback period is 8 years, i.e. it can return the installation investment in only 8 years.

Table 7: Optimization results for CIT center.

Type	Manufacture equipment	Quantity	
Wind Turbines	SouthWest (Skystream 3.7)	1	
Photovoltaics	Lightway 235w	5	
Inverter	Schneider Electric (XW4024)	1	
Controller	Schneider Electric (XW-MPPT-60)	1	
Total Investment Cost = \$ 10593.5			
Total generated power			
Type	Manufacture equipment	Rated capacity, Watt	Total annual generated energy (kWh/year)
WT	SouthWest	1800	5393.7
PV	Lightway	235	2390.6
System annual generated energy =7784.33kWh			
Load annual consumed energy=7333.33 kWh			
System Annual Available Energy for Sale to Utility=451 kWh			

Table 8: Economic analysis for CIT center.

Year	Expense	Income		Cash Flow \$	Present Value \$
	Yearly Payment	Saved Money	Utility Sell		
1	-529.7	622.75	45.1	138.15	129.1121
2	-529.7	685.025	45.1	200.425	175.059
3	-529.7	753.5275	45.1	268.9275	219.5249
4	-529.7	828.8803	45.1	344.2803	262.6498
5	-529.7	911.7683	45.1	427.1683	304.5651
6	-529.7	1002.945	45.1	518.345	345.3952
7	-529.7	1103.24	45.1	618.64	385.2579
8	-529.7	1213.564	45.1	728.964	424.2637
9	-529.7	1334.92	45.1	850.32	462.5177
10	-529.7	1468.412	45.1	983.812	500.1201
11	-529.7	1615.253	45.1	1130.653	537.1651
12	-529.7	1776.778	45.1	1292.178	573.7425
13	-529.7	1954.456	45.1	1469.856	609.938
14	-529.7	2149.902	45.1	1665.302	645.8328
15	-529.7	2364.892	45.1	1880.292	681.5044
16	-529.7	2601.381	45.1	2116.781	717.027
17	-529.7	2861.519	45.1	2376.919	752.4717
18	-529.7	3147.671	45.1	2663.071	787.9066
19	-529.7	3462.439	45.1	2977.839	823.3973
20	-529.7	3808.682	45.1	3324.082	859.006
<b>Net Present Value = 10196.46</b>					
<b>Payback period in 8 year</b>					

## 8. Conclusion

Egypt has a huge potential for renewable energy sources, particularly wind power as well as the enjoyment of high solar radiation. In this paper the main system components of a small-scale hybrid wind-photovoltaic system installation were analytically modeled and investigated for CIT center at Mansoura University-Egypt. The paper presented a general computerized economic assessment procedure used in the preliminary evaluation of the technical feasibility and financial viability of potential HRES installations.

The optimization problem is solved using modified PSO technique. The proposed modified PSO technique has the ability to attain the global optimum with relative computational simplicity compared to conventional optimization methods, such as HOMER software. A Matlab PSO code is developed to represent the proposed method. Then, an economic analysis is presented to demonstrate the feasibility of the project. The results prove that the

grid-connected HRES project is a profitable investment for Mansoura University.

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