

Economical and Technical Assessment of Hybrid Renewable Energy Systems for Optimal Performance Applied in Hurghada, Egypt.



Fathy Ghonima, M. Ezzat, T.S. Abdel-Salam

Abstract: This paper deals with economic and technical evaluation of the hybrid power system which is fed six-megawatt load located in a city in Egypt called Hurghada. There is two types of economical evaluation. The first type is Economical evaluation which has two parts, the first part is cost estimation to know the price of generating power of the hybrid system in every season to reveal the lowest and the highest cost of the power unit in every season and The second part is an economic load dispatch for the six-megawatt load to know which hybrid system topology gives the required power at low cost and which topology gives the required power at a higher cost, economic load dispatch made for eight possible hybrid system topologies for four hybrid system units. The technical evaluation made by studying generating reliability indices Loss of Load Probability (LOLP), Loss of Load Expectation, (LOLE) Expected Energy Not Supplied (EENS) in every season of the year to know which season is more reliable to supply power to the load area. Studying generating reliability at the probabilities for generating units to achieve reliability index calculation according to the load duration curve of the load area in one year. The evaluation made by simulation of the hybrid system in MATLAB Simulink in every season and optimize power by using the Genetic Algorithm and Partial Swarm Optimization to ensure economical and technical optimal performance of the hybrid system.

Keywords: Economic load dispatch, Generation system reliability, Levelised cost of energy, solar-wind-diesel-fuel cell hybrid power system,

I. INTRODUCTION

Isolated areas have a great problem to receive power from the Grid as a distribution system suffers from some geographical constraints in isolated areas such as mountains, seas, and desert sands. The hybrid system of Conventional power plants and non-Conventional power plants is suggested to be the solution to this problem.

This paper focuses on the Economical Evaluation hybrid system in Hurghada in the US dollar for the growing interest of micro grid renewable energy sources that demand energy storage power devices [1],[2].

Analysis of the electricity system provides information on cost measures for different technology in the electricity market. There is no economic indicator that allows us to know the different prices between power plants in the hybrid system that make some manufactures, analysis agencies, government ministries in the energy market have approved some economic indicators [3],[4].

Economic indicates the 'Levelised Cost of Energy (LCOE) calculations depend on the temporal characteristics of the electricity price profile also another economic indicator is the "Levelised Cost of Storage" (LCOS) which its calculations depend on economic storage [5]-[7]. Economic indicator compensates for rapid change in load power, the economic indicator is sensitive to changes of varied and depends on the formula of the consideration specified [8]. in this paper the economic evaluation uses economic indicator (LCOE).

Another Economical Evaluation hybrid system in the paper is a short term economic load dispatch for power generating units in the load area in Hurghada.

The hybrid power system is designed to be continuous variation in service for power demand that affects in operation cost of the system. Economic load dispatch is a method to schedule power output of generating units in respect of the load area power demand.

The objective of economic load dispatch is to allocate the optimal power generation from different units at the lowest cost possible, with the system constraints to solve the economic load dispatch problem. Economic load dispatch uses mathematical programming and optimizes techniques, conventional methods include the Newton-Raphson method, Lambda Iteration method, Base Point and Participation Factor method, Gradient method [9]. The economic load dispatch objective function uses an economic indicator called (LCOE) using a stochastic genetic algorithm [10],[11]. Economic load dispatch calculations made for eight possible hybrid power system topology to minimize the overall operation cost.

Technical Evaluation of the hybrid system in this paper is Generating Reliability for hybrid study model. Generating Reliability is classified into two methods categories Monte Carlo simulation and analytical methods.

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* Correspondence Author

Fathy Ghonima, MSc student in Department of Electrical Power & Machine, Faculty of Engineering, Ain Shams University, Cairo, Egypt
Email: fathyghonima2017@gmail.com

M. Ezzat, Assistant Professor in Department of Electrical Power & Machine, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
Email: moh_ezzat@eng.asu.edu.eg

T.S. Abdel-Salam³ Professor in Department of Electrical Power & Machine, Faculty of Engineering, Ain Shams University, Cairo, Egypt
Email: tarekabdelsalam@gmail.com

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Monte Carlo simulation applies to renewable energy generation systems uses the predication techniques to achieve the time series of renewable energy data and integrate the different attributes with the renewable energy unit failure to achieve the system generating capacity adequacy indices [12]-[15].

Analytical methods are a probabilistic approach uses the various approaches for the power output curve of the renewable energy unit to generate the power data in study site relating to the load adjustment approach account to the fluctuation of energy to minimize the utility load and then uses the adjusted load values to calculate the reliability indices associating to the hybrid model with load duration curve within a discrete time frame [16].

In this paper the reliability indices are calculated by analytical methods associated with load duration curve for a year to obtain the generating Reliability indices Loss of Load Probability (LOLP), Loss of Load Expectation, (LOLE) Expected Energy Not Supplied (EENS) which reveal the short term performance of the hybrid power system in the study site.

Paper organization as follows Section I: Introduction, Section II: Structure of the hybrid system and presentation of study site, Section III: Optimization Methods: Genetic Algorithm method and Partial Swarm Optimization method, Section IV: Economical evaluation: cost estimation and economic load dispatch, Section V: Technical evaluation: generating reliability, Section VI: Simulation results system economical evaluation results, technical evaluation results, Section VII: Conclusion.

II. STRUCTURE OF HYBRID SYSTEM AND PRESENTATION OF STUDY SITE

A. Structure Of Hybrid System

A hybrid solar-wind-diesel-fuel cell stack consists of three power generation units and a fuel cell stack for emergency loads may occur in the study area. A schematic diagram of the hybrid system is shown in Figure 1 where solar power (Ps), wind power (PW), Diesel power (Pd), fuel cell stack power (Pfc) and load power (Pg).

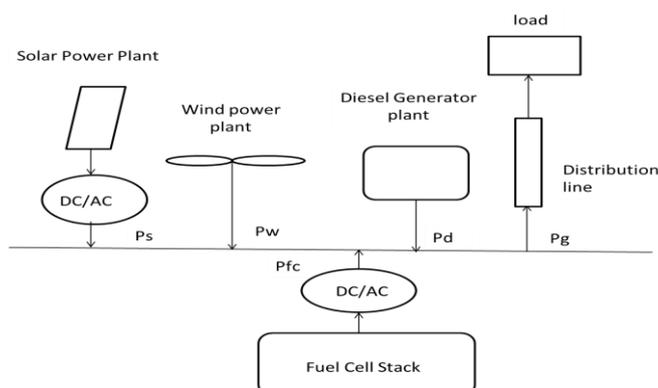


Fig. 1.schematic diagram of the hybrid system.

Solar power output and wind power output are depending on environmental constraints in the study area. Wind power turns a generator to produce electricity. The wind power depends on both the wind speed and the area swept by the turbine blades the total wind power capacity of the wind turbine is 4 megawatts. The solar power plant of

the hybrid system consists of photovoltaic array 200 series modules and 100 parallel strings to supply power to load with total power capacity is 4.23 megawatts. Diesel Generator plant consists of implements a 3-phase synchronous machine modeled in the d-q rotor reference frame. Stator windings are connected to an internal neutral point Diesel Generator is a diesel engine connected with an alternator to generate power Diesel Power Plant of the hybrid system consists of Salient Pole Synchronous Generator used in the hybrid system with the total power capacity of 5.3 megawatts. the Fuel cell has symmetry with battery but fuel cells don't consume power from other power resources in the hybrid system The fuel cell stack block implements the number of fuel cells connect together to increase the output power capacity from the fuel cell.

The fuel cell stack is a Generic hydrogen fuel cell model. The type of cells used in the hybrid system is the Proton Exchange Membrane Fuel Cell (PEMFC). The total capacity of fuel cell stack 120400 watts. The characteristics of the used Photovoltaic Array of the hybrid system is shown in Figure 2. The specifications of the used power equipment of the hybrid system are shown in Table I, Table II, Table III, and Table IV.

Table-I: Diesel Generator Specifications

Nominal power (WATT)	5.3e06
Nominal Voltage(Vrms)	220
Norminal Frequency (Hz)	50
field current(A)	100
Stator Rs(ohm)	0.00076
Stator L1 (H)	1.273e-005
Stator Lmd (H)	0.002145
Stator Lmq (H)	5.204e-005
Field Rf'(ohm)	0.0001576
Field Lld'(H)	8.703e-005

Table-II: Photovoltaic Array Specifications

Maximum power (W)	213.15
Cells per Module (Ncell)	60
Open circuit voltage Voc (V)	36.3
Short circuit current Isc (A)	7.84
Voltage at max power point Vmp (V)	29
Current at max power point (A) Imp	7.35

Table-III: Wind Turbine Specifications

cut-in wind speed (m/s)	2
cut-out wind speed (m/s)	5.826
Rated wind speed (m/s)	5.061
Maximum power (MW)	4

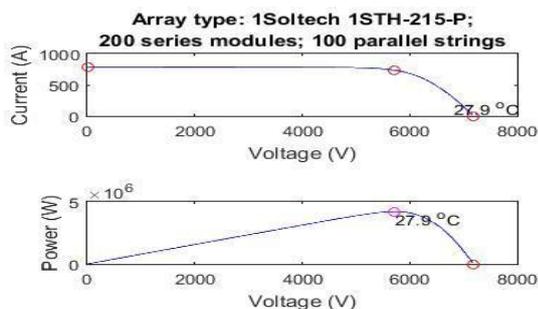


Fig. 2.Characteristics of Photovoltaic Array

Table-IV: Fuel Cell Specifications

Fuel Cell Type	Proton Exchange Membrane Fuel Cell (PEMFC)
Number of Cells	[900]
Stack power [Normal(watt),Maximal(watt)]	[50000 ,120400]
Voltage at 0A and 1A [V_0(V), V_1(V)]	[900 895]
Nominal stack efficiency (%)	55
Nominal Air flow rate [lpm]	2100
Reactants	[Hydrogen and air]
Fuel cell Resistance (ohm)	0.66404
Exchange coefficient [alpha]	0.26402

B. Presentation Of Study Site

The chosen study site is located in Hurghada which is a city in the Red Sea Governorate of Egypt located at Latitude: 27°15.4428' N. Longitude: 33.8129100° E. The Load curve of the study site is shown in Figure 3. The peak load consuming power is 4.33 megawatts. The load duration curve is one of the requirements to obtain generation reliability indices. The load duration curve shows the load performance in the load area in Hurghada during the period of time. The time is in days of one year (365 days) or time percentage (100%) The load duration curve is shown in Figure 10 in the simulation results section.

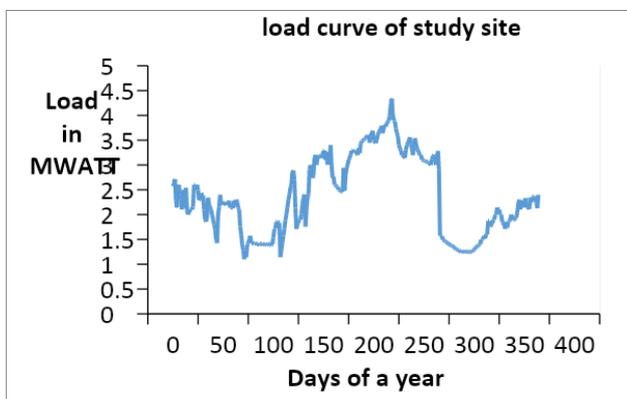


Fig. 3.. load curve of the study area.

C. System Constraints

The Hybrid system has three major constraints first variable is the wind speed, the second variable is solar

radiation and the third variable is the temperature at the study site. The constraints make a change in the energy output of renewable resources every month of the year in the study site is shown in Table V. The calculations are taken on the same day of each month and then calculated the average in every season [17]-[19].

Table-V: Variation of temperature, wind speed and solar radiation at the Study site

MONTH	Temperature (°C)	Wind Speed (m/s)	Solar Radiation (W/m2)
January	20.6	4.917	200
February	21.7	5.543	250
March	24.1	5.588	300
April	27.8	5.140	320
May	30.6	5.856	340
June	32.8	6.482	350
July	33.3	6.07	332
August	33.9	6.169	308
September	31.7	6.795	270
October	29.4	5.722	220
November	26.7	4.962	180
December	22.2	5.275	171

III. OPTIMIZATION METHODS

Optimization power for cost estimation and economic load dispatch of the system is made for every season of the year by using LCOE as fitness function and constraints of power in every power resources in season is taken from the simulation that made by MATLAB Simulink of the hybrid system model in the study area. Optimization is using two methods. Genetic Algorithm and Partial Swarm Optimization.

A. Genetic Algorithm

This method solution is randomly generated to form an initial population, then evaluate solutions to reproduction solutions to achieve the best solution.

The following Table VI represents the simulation optimization parameters and Figure 4 shows the Genetic Algorithm: (GA) flowchart of optimal sequences [20].

Table-VI: Genetic Algorithm: (GA) optimization parameters

Parameters of GA method	
Population size	50
Number of iterations	100
Selection tournament size	2
Constant tolerance	1e-3
Function tolerance	1e-4
Crossover ratio	1.0
Crossover fraction	0.8

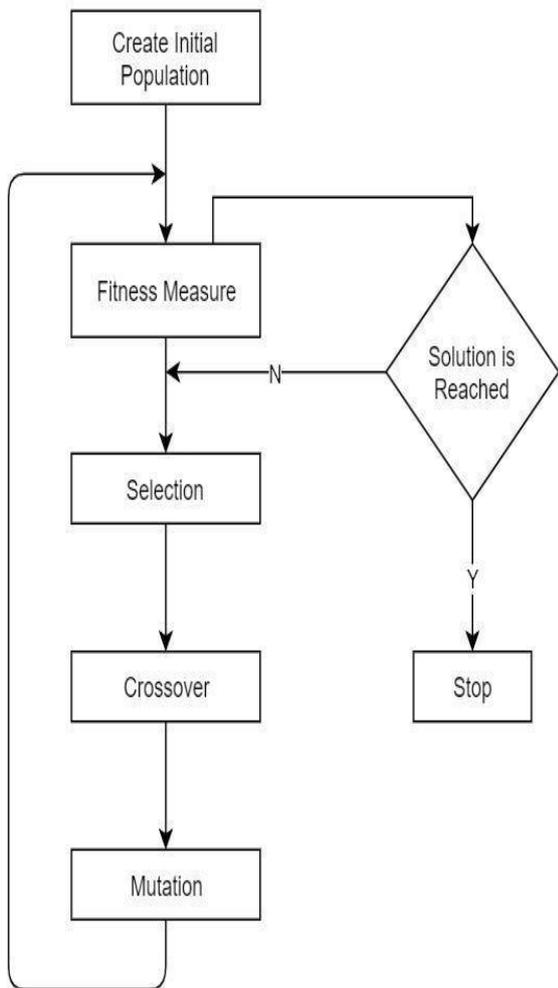


Fig. 4. flowchart of optimization with Genetic Algorithm

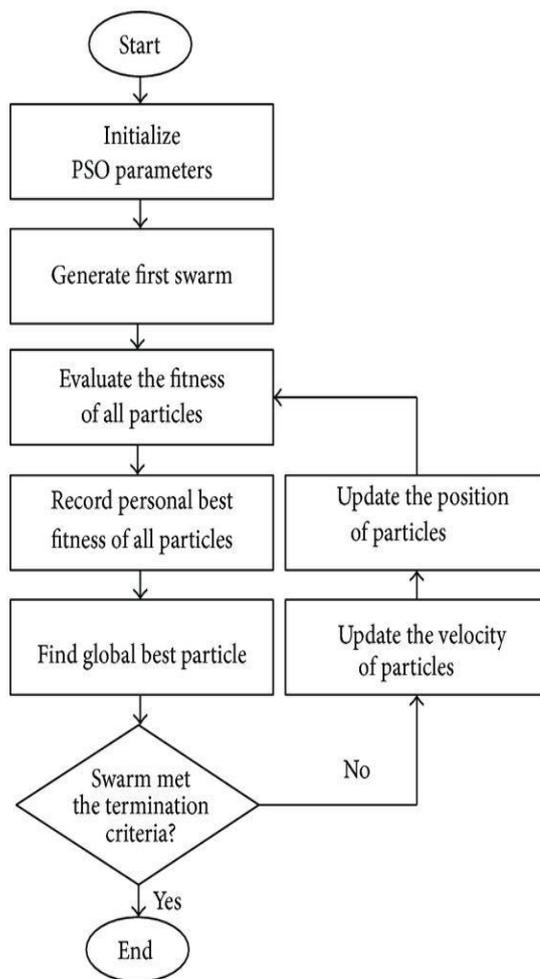


Fig. 5. The flow chart of partial swarm optimization

B. Partial Swarm Optimization

This technique depends on two important factors to determine the required optimization, the first factor is particle velocities (Vij). The second factor is particle positions (xij) [20] to achieve the best solution (P best) as the best value gives the global best (g best). Table VII represents the simulation optimization parameters. The PSO method flowchart of optimal sequences is shown in Figure 5.

Table-VII: Partial Swarm Optimization (PSO) optimization parameters

Parameters of PSO method	
C1	1.2
C2	0.012
W	0.0004
Population size	50
Max iterations	10000

IV. ECONOMICAL EVALUATION

A. Problem Formulation

The cost function for cost estimation and the Economic load dispatch is using an economic indicator (LCOE) as an objective cost function. The cost function is based on the power resource cost such as the capital cost, the operation & maintenance cost, the fuel cost, the discount rate and the lifetime of power equipment. LCOE measures by US dollars per kilowatt power. The formula for calculating LCOE is represented in equation 1 [6] [21].

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad (1)$$

Where n = the economic average lifetime of electricity generation; It = the investment cost in the year t; Mt = the operations and maintenance cost for a year t; Ft = the fuel cost for a year t; Et = the electricity generation for a year t; (1+r)t = the discount rate for a year t.

Cost estimation depends on LCOE cost function elements as follows the definition of each cost element.

- [1] Investment cost: (It): investment cost is the price of setting up equipment and the price of purchase power resource equipment for the hybrid system.
- [2] Operation and Maintenance cost: (Mt): O&M cost of operating power resource equipment and maintenance. The O&M cost is estimated equal to 20 to 25 % of the cost of equipment.
- [3] Fuel cost: (Ft): Fuel cost is the price of fuel used to operate diesel generation. Fuel cost is depending on the amount of power required from the diesel generator as more power uses more litters of fuel in the study area. Fuel consumption of diesel generating is set for 0.3 litter/kilowatt-hour and the cost of fuel is 0.87 \$ per litter.
- [4] Discount rate (r): Discount rate is the price of the equipment at the end of its useful lifetime at a discount rate is depending on the life of the equipment and depreciates value is equal to 0.3.
- [5] Equipment lifetime (n): Equipment lifetime is the number of years that the equipment of the hybrid system gives high performance to supply power.

B. Cost Estimation Methodology

Table VIII shows the Technology characteristics of cost function LCOE that used to calculate cost estimates for each power equipment used in the hybrid system. Technology characteristics include the Investment Cost (\$/m²), The Operation and Maintenance Cost (\$/m²), the Fuel cost (\$/Litter), the Interest Cost (\$/m²) and the Lifetime of System unit (years).

Table-VIII: The technology characteristics of LCOE cost function for each power equipment

System unit	Investment Cost (\$/m ²)	O&M Cost (\$/m ²)	Fuel cost (\$/L)	Interest Cost (\$/m ²)	Life time of System unit (years)
PV Array	600	4	0	9.5	20
Wind Turbine	160	30	0	5	20
Diesel Generator	240000	0.015	0.87	2.42	10
FUEL CELL	250	45	0	3.5	10

The high cost of the investment cost for diesel generator and the lowest cost for the wind turbine, the highest cost of the Operation and Maintenance cost for fuel cell and the lowest cost for diesel generator, The fuel cost only for diesel generator, The high cost of the interest cost for photovoltaic array and the lowest cost for diesel generator and The lifetime is 20 years for photovoltaic and also for wind turbine and 10 years for diesel generator and fuel cell.

C. Economic Load Dispatch

The economic load dispatch is critical for power system operation and control at a constant frequency. The load economic dispatch important to reveal the required power from each power resource to satisfy the need for power for the load at the lowest cost [22]-[24].the study cases of

hybrid system topology represent in table IX. The hybrid system has varied power options such as wind power, solar power, diesel power plant and fuel cell stack to supply the required power to study area. The main aim of this work is to optimize the lowest cost to supply power to the load area. The optimization used in load economic dispatch is the Genetic algorithm is shown in Figure 6. The possible topologies of the hybrid system to supply the power to the six-megawatt load represented in table IX.

The Economic load dispatch optimizes generation cost, according to units of a hybrid system (PV array, Wind turbine, Diesel generator, Fuel cell). The economic load dispatch is using a Genetic algorithm to obtain LCOE to every topology of the hybrid power system to suffice the required power to the load area. The power constraints are taken from system simulation by MATLAB Simulink.

At every study location changes the operating cost of hybrid system topology according to the environmental constraints in the study area .the economic load dispatch measures the cost of every hybrid system topology to help the designer of the hybrid power system to find the cheapest topology of the hybrid power system.

Power output from the wind power plant, solar power plant, and diesel generator plant is depending on quality and inequality constraints.

- (i) Equality and Inequality Constraints: Active power balance equation

The power balance of equality constraints should be applied. The total generated power must be the same as the total demand load plus the total loss of transmission lines [6].

- (ii) Minimum and maximum power limits

The generated output of each generation unit should be between the maximum and minimum bounties. The corresponding inequality constraints for each generation unit of the hybrid system for photovoltaic $0 \text{ MW} < P < 4.263 \text{ MW}$, for diesel generator $0 \text{ MW} < P < 5.333 \text{ MW}$, for wind turbine $0 \text{ MW} < P < 4 \text{ MW}$ and for fuel cell stack $0 \text{ MW} < P < 120400 \text{ W}$.

Table-IX: Economic load Dispatch (ELD) study system topology

CASE NUMBER	SYSTEM TOPOLOGY
CASE ONE	PV+WT+DG
CASE TWO	PV+WT
CASE THREE	PV+DG
CASE FOUR	WT+DG
CASE FIVE	PV+WT+DG+FUELCELL
CASE SIX	PV+WT+FUELCELL
CASE SEVEN	PV+DG+FUELCELL
CASE EIGHT	WT+DG+FUELCELL



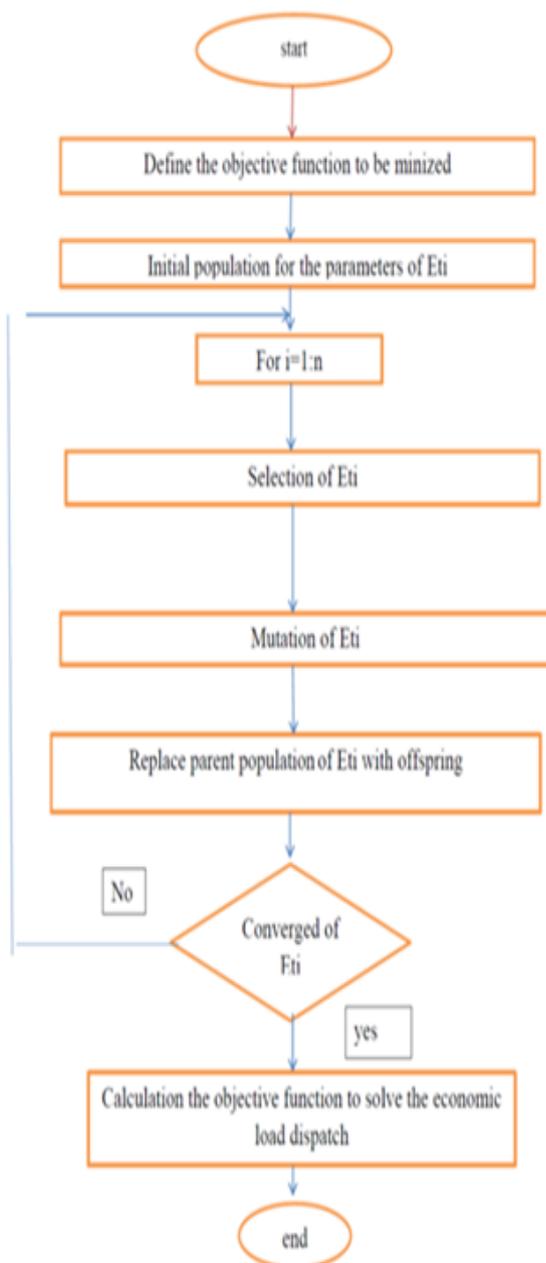


Fig. 6. flow chart of Economic load Dispatch (ELD)

V. TECHNICAL EVALUATION

A. Generating Reliability

The objective of the generation reliability study is to measure the successful performance of a hybrid power system in every season of the year on the basis of generating unit component failure information and system topology that scheduled to serve the load.

The reliability has many Forms generation, transmission, and distribution of electricity. Generation system reliability reveals for the planner of hybrid power systems the prediction of increasing system capacity. Reliability increases the confidence that the total generation units are able to give adequate power when the load area needed.

The Indices of reliability are a probabilistic estimation of the ability of a particular generating topology to supply the load demand.

Reliability indices are sensitive to basic factors such as unit size and unit availability in every season of the year in a selected site [25].

B. Availability And Forced Outage Rate

The probabilistic approach of power system reliability analysis reveals the system as a stochastic process evolving over time. At any moment the system may change from one state to another because of events such as component outages or planned maintenance corresponding to a pair of states (ON, OFF), there is a conditional probability of transition from the state ON to the state OFF [26]. The instantaneous availability $A(t)$ and steady-state availability $A(\infty)$ operating at any time t represented in equation 2. The probability calculations methodology for the study hybrid system is shown in Table X.

$A(t) = \text{Prob}(\text{available at time } t)$ that results

$$A(\infty) = A(t) \quad (2)$$

Unit availability is the interruption of unit service, the outage of the unit has two types. The first type of unit availability is the forced outage of the emergency conditions to take the unit out of service immediately, the second type of unit availability is the outage schedule that the unit is deliberately being taken out of service for preventive maintenance or repair. The failure rate, the repair time, unavailability of the power unit is also known conventionally as “forced outage rate” (FOR) although the value is a rate. FOR depends on the number of hours that the generation unit working and the number of hours that the generation unit shut down for maintenance [25].

The forced outage rate (FOR) is calculated by equation 3.

$$FOR = \frac{\text{Forced outage hours}}{\text{In service hours} + \text{Forced outage hours}} \quad (3)$$

Table-X: Probability calculation methodology for reliability indices used in hybrid system

PROBABILITY CASES	State	PV Array	Wind Turbine	Diesel Generator
CASE NO 1	ALL ON	ON	ON	ON
CASE NO 2	ONE UNIT FAILED	OFF	ON	ON
CASE NO 3		ON	OFF	ON
CASE NO 4		ON	ON	OFF
CASE NO 5	TWO UNITS FAILED	OFF	OFF	ON
CASE NO 6		ON	OFF	OFF
CASE NO 7		OFF	ON	OFF
CASE NO 8	ALL OFF	OFF	OFF	OFF

C. Loss Of Load Probability (Lolp)

It is the basic probabilistic reliability index for generating reliability [25]. It is defined as the probability of the load will exceed the available generation by using the percentage load duration curve for the selected load area in Hurghada load curve is shown in Figure 3.

According to load duration shown in Figure 7 by using the system remaining capacity to map onto the load duration curve and the corresponding time percentage it can be obtained, during the load exceeds the generation capacity [26],[28]. LOLP is used to measure the loss of load risk where Q_j is the outage of the system, R_j is the probability of outage t_j is the number of days. The formula of LOLP calculation by equation 4 also for time percentage the formula of LOLP calculation by equation 5 [28].

$$LOLP = \sum_j P_j t_j \quad (4)$$

Where P_i is the generating system probability, t_i is the time

$$LOLP_{gh} = \sum_{i=1}^N \frac{P_i \times t_i}{100} \quad (5)$$

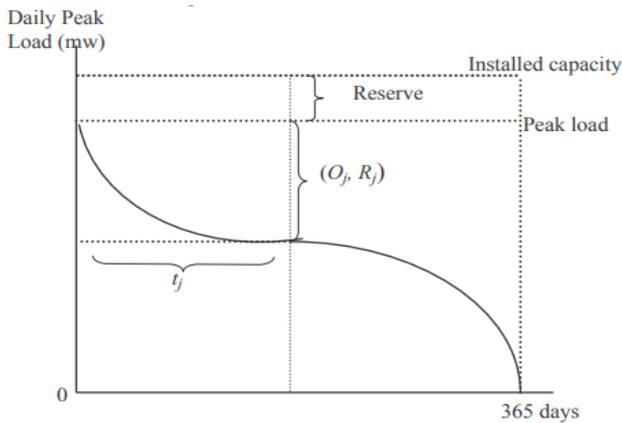


Fig. 7. Estimation of (LOLP) by load duration curve

D. Loss Of Load Expectation (Lole)

It is a probabilistic reliability index similar to the LOLP. It is defined as the average number of days (or hours) in which the daily peak load is expected to exceed the available capacity of the power system. The number of days (or hours) that not to suffice the need for power from the available generation units. The number of days of winter is (90 days), for spring is (92 days), for summer is (92 days), for autumn is (91 days). The formula to calculate LOLE in equation 6.

$$LOLE = \frac{LOLP}{(NUMBER OF DAYS) OR (NUMBER OF HOURS)} \quad (6)$$

E. Expected Energy Not Supplied (Eens)

It is a basic probabilistic reliability index for generating reliability. EENS is used to measure the energy loss risk from the power generating unit by using the load duration curve of the load area as shown in Figure 7. The loss of energy E_i when the power resource is more than the need for the load.

When g available first-generation unit and h available second operating generation unit within different output power can be denoted by the area in Figure 7 [25],[29].

The formula to calculate EENS represented in equation 7.

$$EENS_{gh} = \sum_{i=1}^N P_i E_i \quad (7)$$

Where P_i the generating system probability, N the number of units of power source, E_i the loss of energy.

VI. SIMULATION RESULTS

A. Economical Evaluation Results

1) Cost Estimation

Cost estimation is simulated using the MATLAB SIMULINK. The cost optimization is made by the GA and PSO methods for each one of the hybrid power systems and total hybrid power systems in winter, spring, summer, and autumn at the study site in Hurghada. The cost currency is US dollars.

In table XI shows the calculations for LCOE of the system by using both partial swarm optimization and Genetic algorithm for optimizing cost in (winter, spring, and summer, autumn).

Table-XI: Cost estimation Results by GA and PSO methods

Method	WINTER		SPRING		SUMMER		AUTUMN	
	GA	PSO	GA	PSO	GA	PSO	GA	PSO
PV (LCOE)	0.221	0.224	0.241	0.236	0.247	0.242	0.243	0.239
WT (LCOE)	1.737	1.719	2.335	2.295	1.857	1.824	2.114	2.080
DG (LCOE)	8.059	8.001	8.412	8.372	8.762	8.730	8.061	8.008
FC (LCOE)	0.101	0.100	0.103	0.101	0.105	0.103	0.103	0.102
Total System (LCOE) [PV+WT+DG+FUEL CELL]	10.120	10.045	11.092	11.006	10.972	10.901	10.523	10.430

Table XI results show that Photovoltaic array LCOE is the high cost in summer (0.2471 USD) and the lowest cost in winter (0.2218 USD), Wind turbine LCOE is the highest in the spring (2.3354 USD) and the lowest in winter (1.7376 USD), Diesel generator LCOE is the high cost in summer (8.7626 USD) and the lowest cost in winter (8.0594 USD). Fuel cell LCOE is the high cost in summer (0.1054 USD) and the lowest cost in winter (0.1014 USD) and for Total system (PV+WT+DG+fuel cell) LCOE is the high cost in the spring (11.0924 USD) and the lowest cost in winter (10.120 USD).

2) Economic Load Dispatch

Load economic dispatch is simulated using the MATLAB simulink for hybrid power system from (PV, WT, DG, and FUEL CELL) is feeding load area of 6 megawatts.

In the following figures (8), (9) show Comparison between the load economic dispatch of three power generation units (photovoltaic array, wind turbine, diesel generator) and fuel cell stack in eight possible topologies four cases without using fuel cell stack and four cases with using fuel cell stack.

(i) Eld Without Using Fuel Cell Stack

In figure 8 Shows the four study cases of load economic dispatch for hybrid system topologies without using a fuel cell stack :case one (PV+WT+DG),case two (PV+WT),case three (PV+DG),case four (WT+DG). In Figure 8 chart the vertical axis represents the total cost of the hybrid power system in US dollars and the horizontal axis represents the study site total power demand in megawatts. From the results of the economic load dispatch without fuel cell stack in Figure 8 reveals that the cheapest cost for hybrid system topology is the case two (PV+WT), The expensive cost for hybrid system topology is case three (PV+DG).

For optimal economic hybrid system strategy is using a hybrid system topology (PV+WT) for the best operating cost saving.

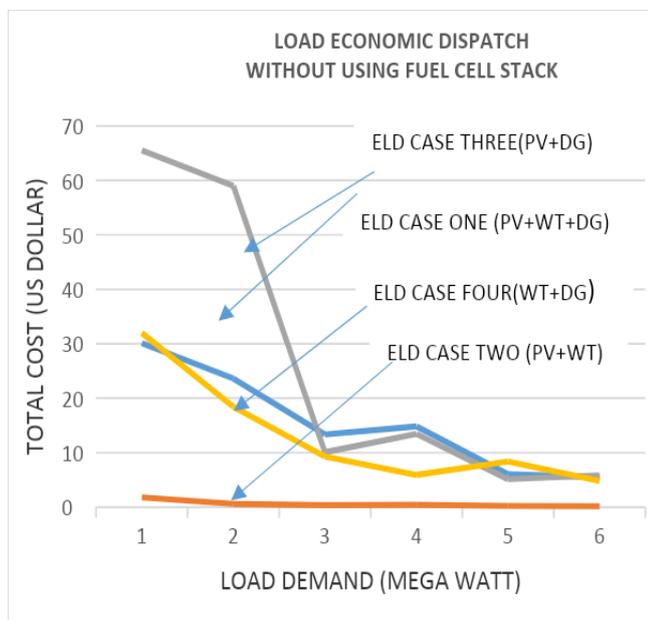


Fig. 8.load economic dispatch without using a fuel cell stack

(ii) Eld With Using Fuel Cell Stack

In figure 9 Shows the four study cases of load economic dispatch for hybrid system topologies without using a fuel cell stack: case five (PV+WT+DG+FUEL CELL), case six (PV+WT+FUEL CELL), case seven (PV+DG+FUEL CELL), case eight (WT+DG+FUEL CELL). In Figure 9 chart the vertical axis represents the total cost of the hybrid power system in US dollars and the horizontal axis represents the study site total power demand in megawatts.

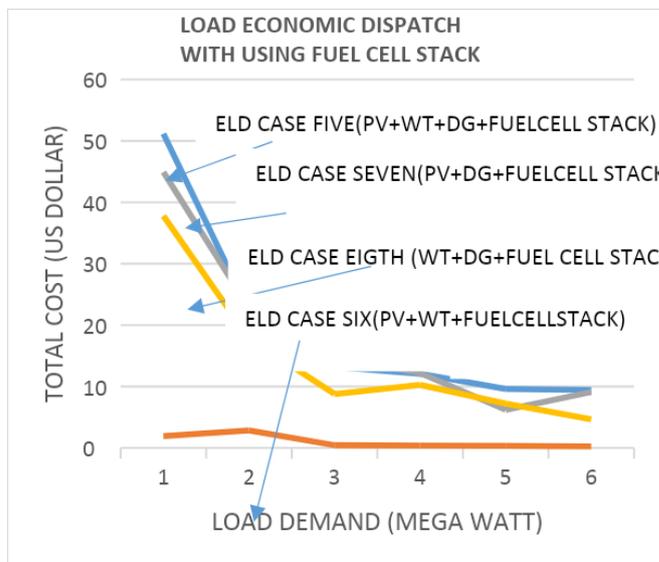


Fig. 9.load economic dispatch with using a fuel cell stack

From the results of the economic load dispatch with fuel cell stack in Figure 9 reveals that the cheapest cost for hybrid system topology is case six (PV+WT+FUEL CELL), The expensive cost for hybrid system topology is case five (PV+WT+DG+FUEL CELL).

For optimal economic hybrid system strategy is using a hybrid system topology (PV+WT+FUEL CELL) for the best operating cost saving.

Using Partial swarm optimization and Genetic Algorithm method in economic evaluation appears many merits and demerits in the two methods in optimization as shown in Table XII.

Table-XII: GA and PSO methods Comparison from economical evaluation

Genetic Algorithm (GA)	Partial swarm optimization (PSO)
<p>Merits</p> <p>1-GAs are flexible, widely applicable in the optimization process.</p> <p>2-GA can optimize a lot of parallel measures simultaneously (multi-objective)</p> <p>3-Operators can be customized to take advantage of regularities or constraints in a particular domain to improve the speed or quality of convergence.</p>	<p>Merits</p> <p>1-Insensitive to scaling of design variables.</p> <p>2- Simple implementation and Easily parallelized for concurrent processing.</p> <p>3-PSO is very few algorithm parameters and derivatives free.</p> <p>4-PSO is a very efficient global search algorithm.</p>
<p>Demerits</p> <p>1-Abstractions about the problem itself, such as mathematical simplifications can't be used.</p> <p>2-Difficult to predict how long convergence will take randomness in the process means this might vary widely.</p>	<p>Demerits</p> <p>1- Fast tendency and premature convergence in mid optimum points.</p> <p>2-Slow convergence in a refined search stage.</p>

Technical Evaluation Results

3) Generating Reliability Results

A technical evaluation is made to test a hybrid system that contains three generating companies in every season of one year by using the analytical method. The power generating probability changes according to different cases are shown in Table X.

The load duration curve of the study site and the force outage rate of power equipment have a direct effect on the calculation of the reliability index. Figure 10 shows the percentage load duration curve of the study site

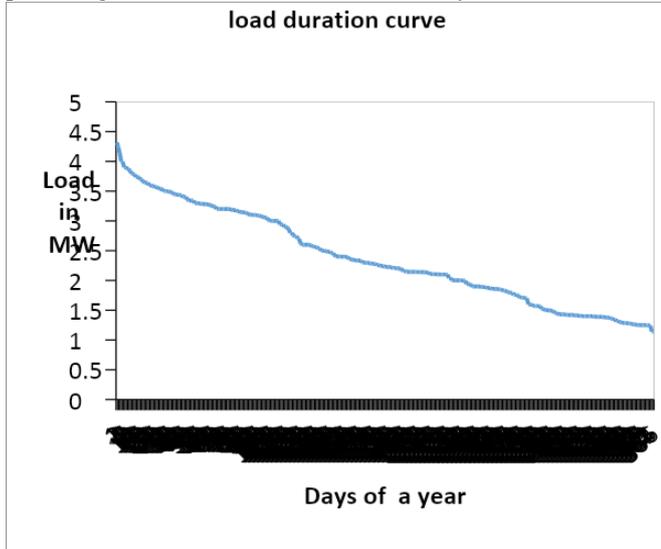


Fig. 10. Load duration curve of study area

Table XIV shows the Forced Outage Rate (FOR) for power resources in every season. FOR calculations according to the number working hours of the power unit (hours in service) and the number of hours of power unit shut down (force outage hours).

Table-XIV: Force outage rate (FOR) in every season

SEASON	WINTER	SPRING	SUMMER	AUTUMN
(FOR) Photovoltaic array	0.20	0.78	0.80	0.40
(FOR) Wind Turbine	0.30	0.45	0.75	0.65
(FOR) Diesel Generator	0.04	0.02	0.05	0.02

For Calculating reliability index at the first determine generating system probability in every season to calculate the LOLP reliability index, LOLE reliability index and EENS reliability index by applying equation (4), (6),(7) with using the percentage load duration curve in Figure 10.

Table XIII shows the generating system probability. In table XIII abbreviations probability (P), Capacity Outage (C Out), Capacity In (C In), Load loss (LL) Megawatt (MW) Winter (WIN) Spring (SPR), Summer (SUM) and Autumn (AUT)

Table-XIII: Results of generating system probability in every season

case	P WIN	P SPR	P SUM	P AUT	C OUT MW	C IN MW	LL MW
NO 1	0.5376	0.11858	0.0475	0.2058	13.596	0	0
NO 2	0.1344	0.42042	0.19	0.1372	9.333	4	0
NO 3	0.2304	0.09702	0.1425	0.3822	9.596	4.263	0
NO 4	0.0224	2.42E-03	2.5E-03	4.2E-03	8.263	5.333	0
NO 5	0.0576	0.34398	0.57	0.2548	5.333	8.263	0.667
NO 6	9.6E-03	1.98E-03	7.5E-03	7.8E-03	4.263	9.596	1.737
NO 7	5.6E-03	8.58E-03	0.01	2.8E-03	4	9.333	2
NO 8	2.4E-03	7.02E-03	0.03	5.2E-03	0	13.596	6
SUM OF P	$\Sigma=1$	$\Sigma=1$	$\Sigma=1$	$\Sigma=1$			

Loss of Load Probability reliability index, Loss of Load Expectation reliability index and Expected Energy Not Supplied reliability index of the hybrid system at load study area are shown in charts in Figure 11, Figure 12 and Figure 13.

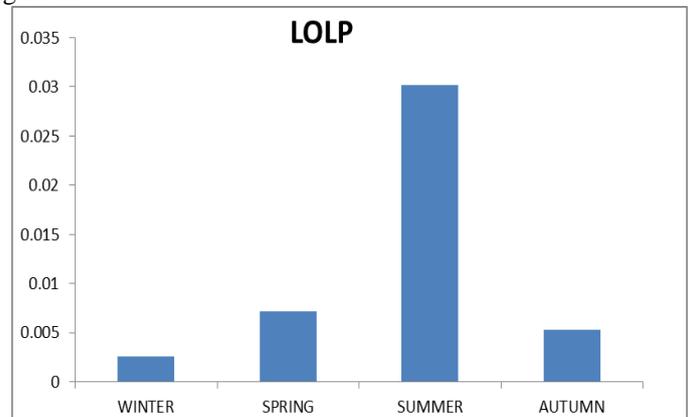


Fig. 11. Loss of Load Probability Results

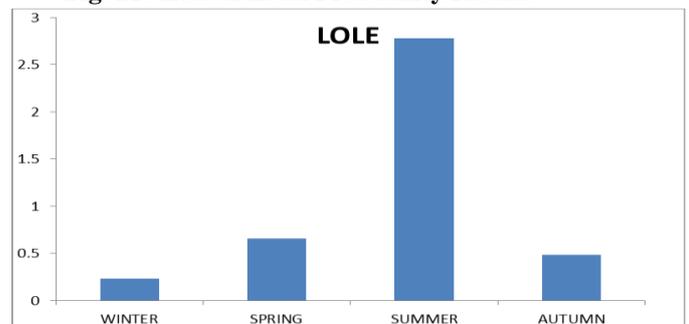


Fig. 12. Loss of Load Expectation Results

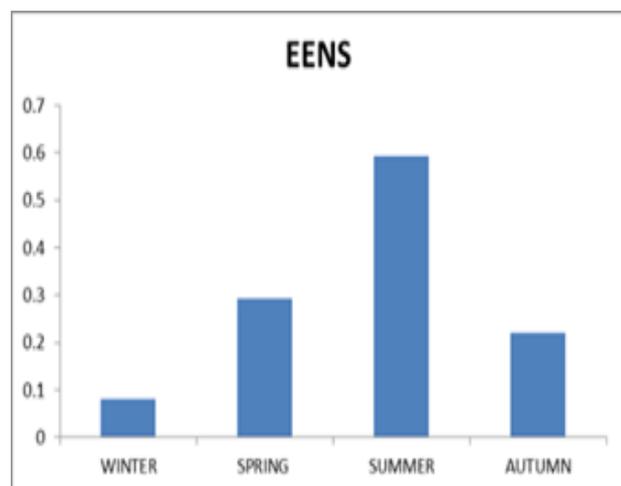


Fig. 13. ..Expected Energy Not Supplied Results

The results show that Loss of Load Probability has the highest value in summer by (0.030199) and the lowest value in winter by (0.002556) the Loss of Load Expectation has the highest value in summer by (2.778274) and the lowest value in winter by (0.230005). The Expected Energy Not Supplied has the highest value in the summer of (0.593218) and the lowest value in winter by (0.080694). Results show that a hybrid system is more reliable, highly effective in winter as LOLP, LOLE and EENS have the lowest values in winter and the hybrid system is less reliable in summer.

VII. CONCLUSION

Economical and Technical evaluation made recommendations for hybrid system operators and designers to forecast the size of power equipment. An economical evaluation has two parts (cost estimation) and (Economical load dispatch). Cost estimation gives recommendations reveal that the total hybrid system cost has the highest cost in (March, April, May) by almost 11.0924 \$/kilowatt and the total hybrid system cost has the lowest cost in (December, January, February) by almost 10.120 \$/kilowatt. Economical load dispatch gives recommendations for hybrid system topology (without the fuel cell stack) reveals that the cheapest hybrid system topology is (photovoltaic array with a wind turbine) and the most expensive hybrid system topology is (photovoltaic array with diesel generator), Economical load dispatch gives recommendations for hybrid system topology (with the fuel cell stack) reveals that the cheapest topology is (photovoltaic array, wind turbine, fuel cell stack) and the most expensive topology is (photovoltaic array, wind turbine, diesel generator, fuel cell stack).

Technical evaluation is (Generation reliability) for every season of a year in the study area made by analytical methods associated with a load duration curve in the study area in a year and the force outage ratio (FOR) of generation units in the system for preventive maintenance or repair. Generation reliability gives recommendations that the system is less reliable in (June, July, August) and the system is more reliable in (December, January, February).

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AUTHORS PROFILE



Fathy Ghonima, received his B.Sc from Faculty of Engineering Electrical Power and Machines Department, Assuit University, Assuit, Egypt in 2010. He is working now as Maintenance Engineer in Cairo.



M. Ezzat, Got his B.Sc., M.Sc., and Ph.D from Ain Shams University, Cairo, Egypt on 2001, 2007, and 2012 respectively. He is working now as an associate professor in Electrical Power and Machines Department, Ain Shams University. He has many publications in international conferences as well as international journals. Supervised many Ph.D and M.Sc theses in the areas of Power System Protection, Energy and Renewable Energy. His Fields of Interests lie in Power System Analysis, Planning, protection and Renewable Energy.



T.S. Abdel-Salam, received his B.Sc. and M.Sc. from Ain Shams University, Cairo, Egypt on 1980 and 1986 respectively. Got his Ph.D. degree from University of Windsor, CANADA in the area of power loss reduction on Distribution Systems. Participated in many paper refereeing, nationally and internationally and he is a member of technical committee in many conferences and international periodicals. He has more than 55 publications in local and international conferences, local and international periodicals. Supervised many Ph.D. and Master theses in the areas of Power Systems, EMF exposure and renewable energy. Working as a consultant Engineer for many Electrical Installation projects. Currently, he works as a head of Renewable Energy Department in the Faculty of Energy and Environmental Engineering, British University in Egypt (BUE).