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The Impact of PV Power Plants Implementation on Electricity Cost and Shadow Price Minimization

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Abstract: The increase reliance on competitive electricity market has led to widespread research to reallocate energy sources and minimize the price of energy and the services related to it. The main issues that faces the design of any energy market, is thehigh cost of generation and the high shadow pricesthat highly impacts the consumers.Also,achieving the supply-demand balance and minimization of the transmission congestion is a vital goal while planning. In this paper, a transparent and open competitive market is attained. In order to control the electricity market and reduce the market clearing price, this study proposed introducing renewable energy power plants which has lower electricity generation cost in comparison with the conventional power plants.Minimization of the shadow price is achieved by dividing the electricity grid into multiple regions. Every region has a different shadow price depending on the load demand and the power plants available to supply the demand at this region. Where,the market clearing price of each region is set as the price of generation of the highest power plant sharing in supplying the load demand at this region. This methodology is applied on the Egyptian unified power network.Sizing and allocation of the renewable energy power plantsis studied carefully from the technical and economical point of view to maximize the benefit and minimize the overall cost function and shadow price.

Keywords: Economic Feasibility Study, Electricity Cost Minimization, Optimal Power Flow, Shadow Price,PV Power Plants.

I. INTRODUCTION

Afive-year subsidy removal plan of the electricity prices in Egypt was launched in July 2014 [1] aiming at attracting investments in the electricity sector. Nevertheless,conventional power plants have been used as a primary source of energy to supply the rapid increase of the energy consumption[1].

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However, greenhouse gases are emitted from fossil fuels.These gaseshave a negative impact on the future generation and the environment, and it is also considered as expensive way for generating electrical energy[1]. In order to fulfill the load demand at low price, other energy resourcesare required to overcome this problem. Renewable energy resources are considered as an effective solution within this regard.

Investment in solar energy are increasing daily[2]. Investors inPhotovoltaic (PV) power plants require detailed economic feasibility studies from the installing companies.However, all studies are not satisfactory and very simple as it misses the calculation of the payback period in a professional way[2].

Forecasting of solar radiation is important while modeling solar energy generation and must be studied in detail.

From this point of view, many techniques and methods were employed to estimate the solar radiation. Solar radiation was forecasted using artificial intelligence techniques[3]. Neural networks were trained using local weather measurements of different cases and gathered parameters from the past[3]. While in [4], the authors improved the accuracy rate of forecasting using data from the satellites. In[5], development of a new method called CIADCast is performed, which is used for short term forecasting of solar radiation

In the present study, solar energy generation is modeled by determining the hourly solar radiation values throughout the year since the sun is the main source of the PV power plants[2]. Many technical details are considered while modeling the amount of solar energy generated from the PV panels[2]. Technical details include the optimum angle of declination of the PV panel, the optimum collector angleof the PV panel. The location of the PVpower plant, the duration of the sunlight is taken into consideration[2]. Also, the average solar radiation incoming on a horizontal plane and the empirical constants for climate conditions, such as pressure, weather and humidity is well-thought-out[2].The average solar radiation and the solar radiation angle factor which differs according to the panel location on the hemisphere is studied as well[2].

The expected performance of PV power plants including average daily energy,the operation time and the downtime are presented in this study. These data are considered as an important parameter while determining the payback period of investment. Obtaining these values, allowed this study to make a serious analysis in planning PV power plants installation.

II. DATA IMPLEMENTATION OF THE EGYPTIAN ELECTRICITY UNIFIED POWER NETWORK

Egyptian unified power network data collection was one of the main obstacles in solving the present case study. Different resources were used to get the generation data, load demand data, transmission line data, transmission line topology, and the grid topology.

The generation data was taken from the Egyptian electricity holding company annual report[6]. It shows detailed data of the 6 generation companies and the 77 power plants affiliated to it. The percentage of investment[7] and the population distribution [8] at each node is used to determine the load demand at each node. Technical properties of the 1590 Lapwing Aluminum Conductor Steel Reinforced ACSR [9] is used to determine the transmission line capacity. GeographicInformation System (GIS)[10] showed the voltage rating of each line.

Open street maps [11] were used to estimate the node location and branches connecting these nodes as shown in Fig. 1. The length of the transmission lines was estimated using the latitude and longitude of each bus.

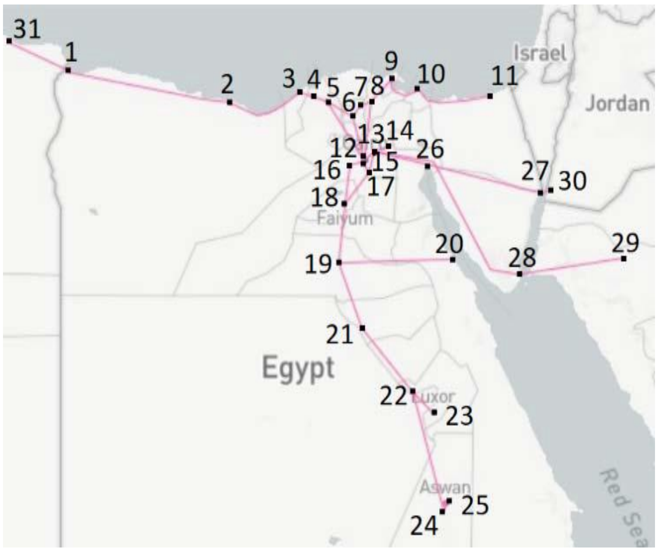

Fig. 1. The Egyptian Electricity Grid [11]**.**

Power flow analysis is used to verify the collected data. If any constraint or reliability limits is violated, then data fine tuning is applied. Transmission lines capacity and load demand are updated until the system converges.

III. SOLAR ENERGY DATA MODELING

The amount of energy produced by any PV panel cannot be predicted as the weather conditions is chaotic as the concept of the butterfly effect. However, the present study is based on forecasting the weather and solar radiation in Egypt which is more professionalin studying the economic feasibility.

The declination angle (d) of the PV panel is calculated daily using (1)as given in[2], where $n$represents each day of the year.

$$\boldsymbol{d = 23.45^\circ \, sin\left(\frac{360}{365}(n + 284)\right)} \quad (1)$$

The declination angle (d)values for each day of the year are calculated using (1) and illustrated in Fig. 2.

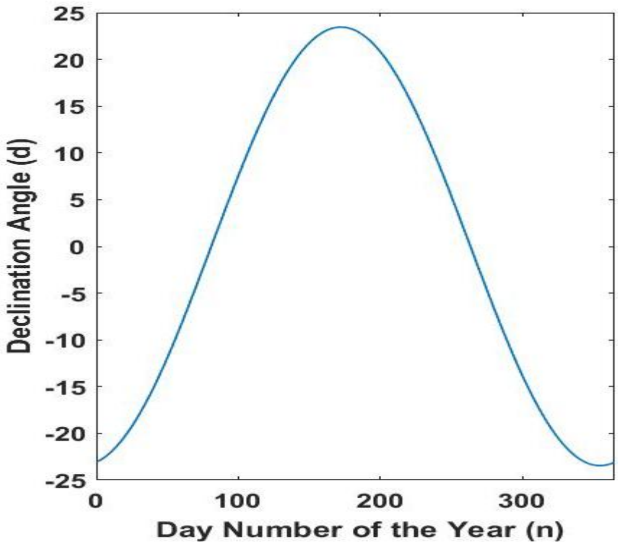

Fig. 2. Declination Angle(d)of each Day(n) of the Year.

The yearlyoptimum collector angle (s)is calculated using (2)as given in [2]according to the location of the PV panel. Latitude L is 26.82 for Egypt.

$$s = L - 1.5d - \left(\frac{|d|L}{180}\right) \quad (2)$$

TheOptimum angle (s) values for each day of the yearare calculated using (2) and provided in Fig. 3.

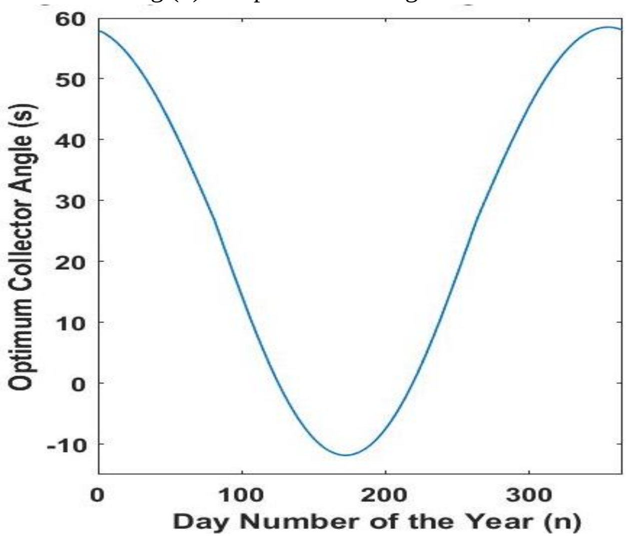

Fig. 3.Optimum Collector Angle (s) of each Day (n) of the Year.

Average solar radiation values(I_s) receivedby the PV module surfacewas calculated using (3)as given in [2].

$$I_s = I * R_B \quad (3)$$

Where I is the solar radiation received if the panel is in the horizontal position [2], it is a function of the time of radiations hitting the collector surface and the climate conditions, and $R_B$is the solar radiation angle factor, which differs according to the location of the PV panel on the hemisphere[2].

The average solar radiation (I_s) values for each day of the year are calculated using (3) and shown in Fig. 4.

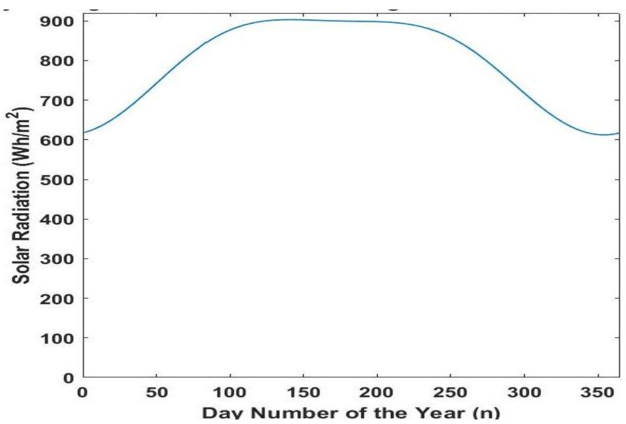

Fig. 4. Average Solar Radiation (I_s) of each Day of the Year (n) Hitting the Surface of a PV Module.

Average power produced by the PV panelis calculated using (4) as given in [2].

$P = \eta * I_s * A(4)$

Where, η and A are taken from the technical details of the PV panel proposed in our study[12]. The data sheet of the 300 W PV panelshows that the area of the panel (A) is 1.42 m^2, and its efficiency (η)is 17.89%.

The average power produced (P) obtained throughout the year are calculated and presented in Fig. 5.

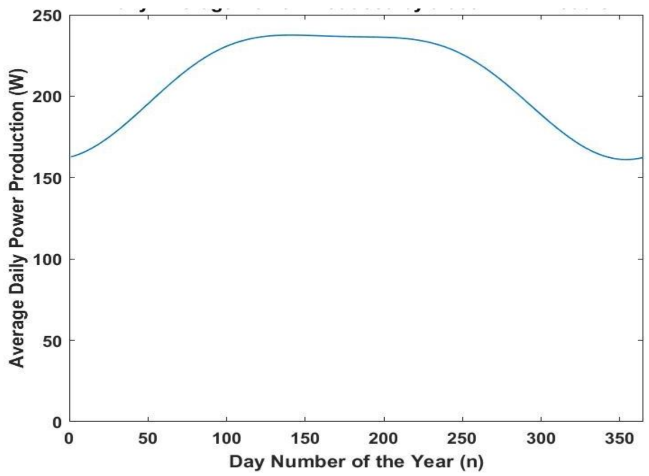

Fig. 5. Daily Average Power Produced by a 300 W PV Module.

To summarize the above data, monthly average values is tabulated in Table-I using the recommended average days for monthsproposed in[13]. Average monthly values of the declination angle (d), optimum collector angle (s), average solar radiation (I_s), average power generation (P) and solar radiation duration hitting the surface of PV module t.

Table- I. Monthly average values of Solar Data Modeling.

Month	Day of Month n (Day)	Declination Angle d (degree)	Optimal Collector Angle s (degree)	Solar Radiation I_s(Wh/m^2)	Average Power P (W)	Duration of Solar Radiation t (hours)
Jan	17	-20.92	55.08	644.63	169.53	8.51
Feb	47	-12.95	44.32	732.42	192.61	9.11
Mar	75	-2.42	30.09	822.00	216.17	9.84
Apr	105	9.41	11.30	884.16	232.52	10.64
May	135	18.79	-4.17	902.85	237.43	11.32
Jun	162	23.09	-11.25	901.18	237.00	11.66
Jul	198	22.48	-10.25	898.95	236.41	11.61
Aug	228	13.45	4.63	887.01	233.27	10.93
Sept	258	2.22	23.16	841.53	221.31	10.15
Oct	288	-9.60	39.79	756.37	198.91	9.35
Nov	318	-18.91	52.37	663.89	174.59	8.67
Dec	344	-23.05	57.96	616.72	162.19	8.34

The total solar energy(E)produced is calculated using (5) and found to be equal 774.28 KWh/year.

$E = \sum_{n=1}^{365} P * t(5)$

where, t is the solar radiation duration in hourshitting the surface of PV module[2]which differs from one day to another.

IV. RENEWABLE ENERGY SIZING AND ALLOCATION ON THE ELECTRICITY GRID

A proposed methodology is introduced to minimize the overall electricity cost and the shadow price consists of four main steps:

Step 1 is “Supply Stack Modeling using Merit order curve” which is used for finding the benchmark of the electricity shadow price.

Step 2 is “The Optimal Power Flow Analysis for Multiple Region Electricity Market” which solves the power system showing the overall cost function value, the optimal generation from each power plant and the electricity shadow price for each region in the Egyptian unified power network.

Step 3 is “Solar Power Plants Allocation and Sizing”, which will discuss introducing PV power plants at certain locations with certain capacities to limit the high shadow prices at some regions.

Step 4 includes “Economic Feasibility Study” which will evaluate whether adding thePV power plantsis profitable or not.

A. Step 1: Supply Stack Modeling using Merit Order Curve

Basic supply stack model is applied by plotting the Merit order curve[14] as shown in Fig. 6. The marginal cost is plotted versus the cumulative generation capacityof each power plant, the power plants are arranged in an ascending order of their marginal cost.It is found that the market clearing price is 41.87€$/MWh$ for an average load demand and 50.837 €$/MWh$ for peak load demand. The profit made by each power plant is the difference between the market clearing price and the marginal cost of generation of the power plant.

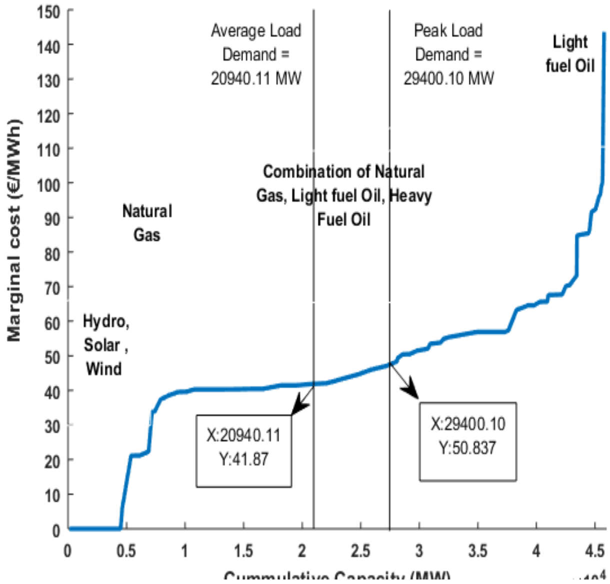

Fig. 6. Merit Order Curve of Various GeneratingPower Plants Technologies.

It is observed that the load demand was supplied with the least priced power plant. The hydro, solar and wind power plants share in supplying the market with its full capacity. And since the generation capacity of these power plants was less than the required load demand, the power plants with higher production cost shared in supplying the rest of the load demand in ascending order until the supply-demand balance is reached. The power plants on the right-hand side of the load demand value shown in Fig. 6 will not share in supplying the demand as these plants have high cost and participating in the market will not be profitable.

B. Step 2: The Optimal Power Flow Analysis for Multiple Region Electricity Market

In this section, Optimal Power Flow (OPF) analysis is applied to the Egyptian electric unified power network using MATPOWER toolbox in MATLAB[15]. MATPOWER is employed to calculate the optimization cost function in an easy way[16]. In this case study, the objective function is to minimize the overall cost of electricity, considering the equality constraint of the supply-demand balance and the inequality constraints are the production capacity of each power plant, the transmission line capacity and the voltage profile limit at all busses.

Optimal power flow analysis is applied to the Egyptian electricity grid considering each bus as a region having its own and different electricity market price according to the variable cost of generation of the power plants supplying each region.

The optimal power flow analysis was studied for two-time steps; average load demand and peak load demand. The solution shows theoptimal power generation by each power plant, the power system losses, the overall cost of electricity and the shadow price.

The objective cost function value, the overall load demand and the overall power generation is presented in Table-II.

Table- II. OPF Results for Average and Peak Load Demand

	Average Load Demand	Peak Load Demand
Overall Cost (€/hr)	672,588.09	1,122,809.45
Load Demand (MW)	20,940.10	29,400.10
Power Generation (MW)	21,287.50	29,645.00
Time to Converge (sec)	1.26	1.31

Table-III shows the shadow price at each region in case of average and peak load demand.

Table- III. Shadow Price for Average and Peak Load Demand.

Bus No.	Shadow Price (€/MWh)		Bus No.	Shadow Price (€/MWh)	
	Average Load Demand	*Peak Load Demand*		*Average Load Demand*	*Peak Load Demand*
1	46.00	57.66	17	44.83	52.18
2	45.00	55.57	18	43.27	54.29
3	43.99	53.70	19	42.05	49.87
4	43.57	53.10	20	41.44	41.44
5	41.53	50.49	21	63.93	85.42
6	44.05	50.82	22	52.72	80.57
7	45.76	52.51	23	92.35	92.35
8	45.08	51.03	24	0.00	0.00
9	46.03	49.55	25	0.00	0.00
10	44.29	48.01	26	43.45	50.48
11	45.33	49.32	27	43.48	50.53
12	44.60	51.95	28	45.12	51.92
13	44.90	51.58	29	45.12	51.92
14	45.61	52.76	30	43.48	50.53
15	44.61	52.02	31	46.00	57.66
16	43.98	51.80			

The shadow price differs from one region/bus to another as each bus is supplied from different power plant according to the input generation data. The average shadow price is 43.92 €/MWh and 51.65 €/MWh for average and peak load demand respectively, while the highest shadow price for both demand levels; average and peak load demand was recorded at bus 23 Luxor city with the value of 92.35 €/MWh, which is the production cost of the Upper Mobilepower plant. As theUpper Mobile power plant has the highest production cost in the power plants contributed in supplying the load demand.

It is observed that the shadow price at some regions is very high compared to the solution obtained from the basic supply stack model conducted using the merit order curve. This happens as the renewable energy power plants, having low production cost didnot contribute with all its capacity to serve the load demand. As the power flow in the branches is forced/limited with the transmission line capacity and the transmission line loss minimization constraints.

That is why higher priced power plants share in supplying the load demand as they are closer to the load, this will minimize the power flow on the transmission lines and at the same time reduce the power losses on the grid.

It is required to reduce the shadow price in all regionsto be equal to the shadow price obtained from the merit order curve for both average and peak load demand for the sake of customers benefit and at the same time reduce the overall cost function.

C. Step 3: PV Power PlantsAllocation and Sizing

Sizing and allocation of the PV power plants is only applied to regions that are having conventional power plants having generation cost higher than 42.05 €/MWh in supplying average load demand and 51.47 €/MWh for peak load demand, which is the market clearing price obtained from the basic supply stack model conducted in step 1 using the merit order curve.

Renewable energy power plants are added to the regions with high shadow price, with the capacity that allows it to replace the highly priced conventional power plants. Thus, the demand will be supplied by the least priced power plants leading to cut down the shadow price to the required values.

Planning of the PV power plants that we need to introduce to the electricity grid is based on the lowest average power generated from the PV panel over the 365 days of the year. According to the analysis done in this study, the lowest average power produced from a 300 W PV panel in Egypt is almost 53.68% of its maximum power.

The number of PV panels to be added at a certain bus is calculated by dividing the average power required by the lowest average power generation of the PV module obtained through the whole year which is 161.05 W in the current study. The size and location of the PV power plants is shown in Table-IV.

Table- IV. PV Power Plants Sizing and Allocation

Bus No.	Active Power Generation (MW)	Rated Power of each Power Plant (MW)	No. of Panels (300W PV Panel)	Approximate no. of Panels
3	1390	2589.42	8630790.31	8630791
6	900	1676.6	5588281.5	5588282
8	420	782.41	2607864.7	2607865
9	1164	2168.41	7227510.74	7227511
11	28	52.16	173857.65	173858
12	2563	4774.59	15914183.87	15914184
13	1260	2347.24	7823594.1	7823595
19	1254	2336.07	7786338.89	7786339
21	895	1667.29	5557235.49	5557236
23	282	525.34	1750994.87	1750995
26	381	709.76	2365705.83	2365706

After adding the PV power plants at the above buses. The following results are achieved, in case of average load demand, the objective function value 245255.16 €/hr. The average load demand is 20940.10 MW and the total power generated is 21268.27 MW. In case of peak load demand, the objective function value 559923.83 €/hr. The peak load demand is 29400.10 MW and the total power generated is 29749.91 MW. That makes a yearly cost saving in the objective function equal to 427332.93 €/yearand 562885.62€/year for average and peak load demand, respectively.

Also, the shadow price in all regions are highly affected in a positive way for both average and peak load demand as shown in Table-V.

Table- V. Market Clearing Price after adding PV Power Plants.

Bus No.	Market Clearing Price (€/MWh) Average Load Demand	Market Clearing Price (€/MWh) Peak Load Demand	Bus No.	Market Clearing Price (€/MWh) Average Load Demand	Market Clearing Price (€/MWh) Peak Load Demand
1	41.60	45.77	17	40.17	42.38
2	41.30	44.13	18	36.30	40.96
3	40.40	42.66	19	33.11	37.01
4	40.95	42.49	20	33.11	41.44
5	40.44	40.86	21	33.11	37.01
6	41.60	41.84	22	33.11	37.01
7	41.60	43.22	23	33.11	37.01
8	37.83	42.06	24	33.11	37.01
9	37.39	41.22	25	33.11	37.01
10	38.23	40.27	26	38.66	41.07
11	38.86	41.31	27	38.69	41.11
12	40.28	42.26	28	39.71	42.22
13	39.53	41.95	29	39.71	42.22
14	40.14	42.90	30	38.69	41.11
15	40.32	42.30	31	41.60	45.77
16	39.11	41.88			

At some regions, the shadow price is very low and sometimes reach zero, as the load is only supplied with renewable energy power plants and no conventional power plants is sharing in supplying the load demand at these regions. This was found at bus 19,20,21,22,23 and 24.

To assure profit to the renewable energy power plants investors sharing in the electricity market and to maintain the market clearing price in all regions at reasonable price without huge variation between different regions, the market clearing price at regionshaving low shadow price value isset as the average shadow price value, which is 33.11€/MWh in case of average load demand and 37.01€/MWh at peak load demand.

D. Step 4: Economic Feasibility study

In this study,the aim is to install the PV power plants based on a more professional qualified data. Economic analysisis carried outto check if the alternative of adding PV power plants is accepted or not from the economical point of view.

1) Solar Power Plant Cost

The construction of PVpower plant requires a comprehensiveinvestigation of the share of different parameters of the installation process andcomponents used in PVpower plants. Table-VI shows the share of each item as a percentage of the overall cost of the power plant[2].

Table- VI. PV Power Plant Components and Installation Processes[2].

Item No.	Item Name	Percentage (%)
1	PV Module including the MPPT	52 %
2	Inverter	9 %
7	Construction (Area excavation, Construction Mounting, Wire Fence)	9 %
3	Boosting Transformer (Transformer Kiosk and Transformer)	2 %
4	AC and DC Cables	3 %
5	DC Power Distributing Center (Including Distribution Cabinet, Cables and Protective Materials and External Lightning Protection Earth)	7 %
6	Monitoring and Control System (SCADA, Communication Cables, Camera and Digital Video Recorder)	7 %
8	Mounting System (Earthing, Board Packages and Panel Mounting)	5 %
9	Study Project Design and Financing Cost	4 %
10	Unexpected Expenses and others	2 %
Total Cost		100 %

According to Table-VI, the cost ofPV panelsrepresents about 52% of the total cost of the PV power plant[2].All economic data was discussed for the same reference year 2020.The cost of each PV panel [12]and the maximum power point tracker MPPT[17]is 85 €.

Table-VII shows the total first cost required for constructing each PV power plant installed in the current case study taking into consideration the items mentioned earlier.According to the Egyptian renewable energy tax incentives (Presidential Decree No 17/2015), an addition amount of 2% will be added to the actual cost to include taxes[18].

Table- VII. Cost Analysis of PV Power Plant.

Bus No.	PV Panels Cost(€)	Total Cost of PV Power Plant Installation (€)	
		Without Taxes	With Taxes (2%)
3	435,793,530	838,064,481	854,825,771
6	282,168,476	542,631,684	553,484,318
8	131,678,625	253,228,126	258,292,688
9	364,937,876	701,803,607	715,839,679
11	8,778,592	16,881,907	17,219,546
12	803,553,049	1,545,294,326	1,576,200,212
13	395,035,876	759,684,377	774,878,065
19	393,154,713	756,066,756	771,188,091
21	280,600,874	539,617,065	550,409,406
23	88,412,788	170,024,592	173,425,084
26	119,451,319	229,714,075	234,308,357
Total First Cost of all PV Power Plants Construction and Installation Process (€)			6,480,071,216

2) Operating and Maintenance Costs

Operating and maintenance costs of PV power plants are less than conventional power plants running by other technologies. The operating and maintenance cost includes the following; cleaning costs of PV panels, employees' wages, and energy consumed by the power plants[2].

a) Cleaning Costs

The cleaning costs of PV panels has a big share in thePVpower plant maintenance. Cleaning a PV panel costs 0.5 € [2].The weather conditions, the amount of energy generated, and the management of the plant are the main factors that affects the cleaning strategy. In this study, five times cleaning process is assumed to be carried out in a year[2].The total cleaning cost for the system calculated in this study is 163,565,905 €/year, for the whole plants.

b) Employees' Wages

The three employees found in any PV power plant are an engineer, a technician and a security officer[2]. The minimum wagesof low skilled labor and high skilled labor in Egypt are67, 72 and 96 €/month for the security officer, technician and engineer[19], respectively. To the investor the real value of the wages is higherthan the minimum wages[2].

Table-VIII shows a detailed description of the actual employees' wages for any PV power plant.

Table- VIII. Wages of Employees in PVPower Plant[19].

Engineer's Salary (€/month)	204
Technician's Salary (€/month)	123
Security's Salary (€/month)	113
Total Employees' Wages (€/year)	5,280

c) Energy Consumption by PV Power Plants

It is found that a one MW PV power plant have system components that consumes 1.6 kW per hour[2]. The cost of energy consumed by the system components is considered as operating and maintenance costs. The annual energy consumption of each PV power plant and its cost is calculated in Table-IX. The total annual cost of energy usage by all PV power plants in our case study was found to be equal 3,086,174 €/year.

Table- IX. Cost of Energy Consumed by PV Power Plants

Bus No.	Average Energy Generation (*GWh*/year)	Average Amount of Energy Consumed (*MWh*/year)	Market Clearing Price (€/MWh)	Cost of Energy Consumed (€/year)
3	6663.48	10661.58	40.40	430,776
6	4314.48	6903.18	41.60	287,186
8	2013.42	3221.49	37.83	121,853

9	5580.07	8928.12	37.39	333,811
11	134.22	214.77	38.86	8,346
12	12286.70	19658.73	40.28	791,832
13	6040.28	9664.46	39.53	382,012
19	6011.52	9618.43	33.11	318,466
21	4290.51	6864.83	33.11	227,295
23	1351.87	2163.00	33.11	71,617
26	1826.46	2922.35	38.66	112,981
Annual Cost of Energy Consumed by PVPower Plants (€/year)				3,086,174

3) Annual Profit

The annual profit gained from installing the PV power plants are divided into two parts; selling the amount of energy generated by thepower plants and the savings achieved from installing the PV power plants on theobjective cost function.

a) Selling Cost of Energy Generation

Whilediscussing the economic analysis, the selling cost of the solar energy generated is calculated and shown in Table-X based on the market clearing price in case of average load demand

Table- X. Cost of Energy Sold by PV Power Plants

Bus No.	Average Energy Generation (*KWh*/year)	Market Clearing Price (€/MWh)	Selling Cost of Energy Generated (€/year)
3	6663488499	40.40	269,234,787
6	4314489001	41.60	179,491,261
8	2013428252	37.83	76,158,080
9	5580072143	37.39	208,631,624
11	134228807.5	38.86	5,216,262
12	12286704899	40.28	494,894,912
13	6040284756	39.53	238,757,372
19	6011520888	33.11	199,041,457
21	4290519626	33.11	142,059,105
23	1351873200	33.11	44,760,522
26	1826466974	38.66	70,613,359
Total Selling Cost of the generated Energy (€/year)			1,928,858,739

b) Annual Saving in the Cost Objective Function

Installing the solar energy system made an obvious saving in the overall objective cost function. The value of the cost function before and after installing the PV power plants was 672,588.09€/year and 245,255.16€/year respectively. That makes the yearly saving in the costfunction 427,332.93 €/year.

4) Engineering Economics Analysis

Solar power plants planning is evaluated from the engineering economics point of view[20], while taking into consideration its present worth value, its salvage value, the interest rate of return and the lifetime of thePV power plants.Our analysis plays a vital role in capital investment decision. The decision whether to implement the system or not depends on value addition to the capital amount of money in future[20].

The cash flow diagram is an important tool in any engineering economy analysis[20] as it shows the direction, size and time of the cash flows. The cash flow signs and amounts for the solar power system is shown in Table-XI.By the end of the study period, the salvage value is set as 10 % of the project first cost[2].

Table- XI. Cost Analysis ofPV Power Plants.

Present Value (€)	First Cost of PV Power Plants	Cash out (-)	10,908,587,664	10,908,587,664
Annual Values (€/year)	Total Employees' Wages	Cash out (-)	63,360	1,666,127,696
	Cost of Energy usage in PV Power Plants	Cash out (-)	3,086,174	
	Cleaning Cost of the PV Power Panels	Cash out (-)	163,565,905	
	Total Selling Cost of energy- after paying taxes	Cash in (+)	1,832,415,802	
	Yearly Saving of the total cost objective function	Cash in (+)	427,332.93	
Salvage Value (€)	Salvage Value	Cash in (+)	1,090,858,766	1,090,858,766

The equivalent cash flow diagram [20] of our case study is shown in Fig. 7. The interest rate considered in the study is 12%[21], whilethe study period is 25 years which is the lifetime of the PV panel[12].

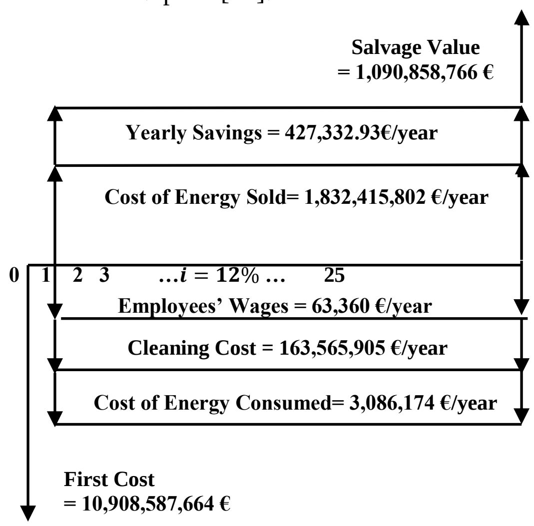

Fig. 7. Net Cash Flow Diagram.

In our case study, the first cost of all power plants is 10,908,587,664 €, the salvage value is 1,090,858,766 €. The interest rate is 12% [21] and the study period is 25 years which is the lifetime of the PV panels. Yearly maintenance and operation costs including employees' wages, cleaning costs of the PV panels and cost of energy consumed by the power plants are 63,360 €/year, 163,565,905 € and 3,086,174 €, respectively.

Yearly cash-in flow including cost of energy sold, and savings in the objective function/overall cost function are 1,832,415,802 € and 427,332.93 €, respectively. The following cash flow shown in Fig. 8 is a simplified cash flow diagram for the previously shown diagram in Fig. 7.

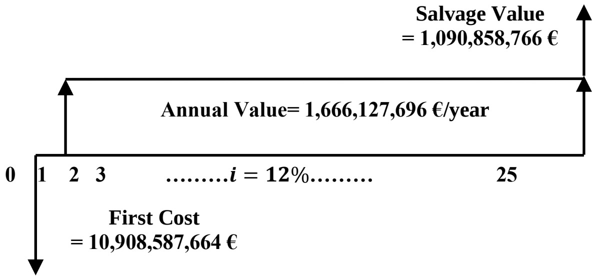

Fig. 8. Simplified Net Cash Flow Diagram.

To evaluate this system, we must find the economic equivalence value of the whole project to decide whether its profitable or not. The net present worth PW value and the annual worth AW value was calculated using the table of factors of the 12% interest rate [20].

Results of the present worth technique and annual worth technique is obtained[20], it shows that the system is profitable.The net present worth PW value and annual worth AW value is2,223,160,966.68 €, and 283,464,209.9341 €/year, respectively.Since the average amount of energy sold yearly is 50,513,077.05MWh/year, that makes the profit of one MWh equals to 5.61 €/MWh.

Another important indicator for the investor is the payback analysis[20], it is an important indicator. The payback period $n_p$is the time required to recover the first cost of the project. It is expressed in years. If the payback period is bigger than the project lifetime then this project is not accepted from the economical point of view. In our case study, the payback period n_p is found to be 13.604 years, which is a good indication since it's less than 25 years the project lifetime.

V. CONCLUSION

In this paper, planning of PV power plants implementation at specific locations and with certain capacity in the Egyptian unified power network grid is studied. Powerful results are achieved technically and economically. From the technical point of view, adding PV power plants reduced the tension on the transmission lines and reduced the power system losses as these power plants are located near the load demand.From the economic point of view, PV power plantsminimized the overall cost function of energy generation and limited the shadow prices in the Egyptian electricity grid to the value set by the design.

Impressiveimpact on the electricity marketisrealizedafter applying theeconomic analysis.It is found that introducing the renewable energy sources in the power system will attract the private sector to invest in the electricity market as it is profitable. Where, investors will share in the electricity market at certain location previously planned to make sure it affects the power system in a positive way.

The payback periodof the proposed project of PV power plants implementation in the current case study is calculated and found to be 13.604 years. The profit of each MWh energy generation is 5.61 €/MWh.

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