COST COMPARISON FOR WATER PUMPING EMPLOYING SOLAR PHOTOVOLTAIC CELLS AND DIESEL FOR IRRIGATION

مقارنة اقتصادية لضخ مياه باستعمال الخلايا الكهروضوئية والديزل فى الرى

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ملخص

يقدم هذا البحث طريقة لإنشاء مزرعة بمساحة خمسة وعشرين فدان باستعمال نظم رى بالتقطير والرش. وقد تم إختيار نظام تغذية قدرة كهربية ذو كفاءة أفضل و تكلفة أقل، مع الأخذ فى الإعتبار الطرق المعتادة لمنابع توليد القدرة الكهربية بأن تكون متيسرة ومستعملة مثل مولدات الديزل.

متوسط حجم مياه الرى المطلوبة للمواسم الأربعة المختلفة هو ١٢٠ متر مكعب/فدان. لضخ هذه الكمية من الماء يلزم مضخة بقدرة ١٥حصان لرفع المياه من قناة الرى بالإضافة إلى مضخة قدرها ٢٠ حصان. فى هذا النظام يغطى أقصى حمل بمضخة قدرها ٢٠ حصان. نظام التوليدالمستخدم هو نظام مشترك من وحدة توليد ديزل مع وحدة توليد كهروضوئية.

فى البحث المقدم تم دراسة أربع نظم توليد مختلفة هى: ١-نظام كهروضوئى مستقل مجزأ لجزئين إحداهما لمضخة الرى والثانى لإستخدامات المزرعة، ٢ -وحدة توليد ديزل منفردة، ٣-وحدتان توليد ديزل، ٤-نظام مشترك من وحدة ديزل لتشغيل مضخة ووحدة نظام كهروضوئى لتغذية الإستخدامات المختلفة للمزرعة.تكلفة الكيلووات ساعة المولد من هذه النظم الأربعة المقترحة هى: ٠,٠٥٧٦٣، ٠,٠٢٦٧٣، ٠,٠١٦٨٣، ٠,٠١٨٢١ جنيها مصريا على الترتيب. النظام الرابع بالرغم من أنه أعلى تكلفة من النظام الثالث إلا إنه يتميز بالتالى: ١- يحتاج إلى صيانة أقل. ٢- لا ينتج عنه تلوث بيئى ٣- لا ينشا عنه ضوضاء. ٤ - أكثر إعتمادية وإستقرار.

1-ABSTRACT

This paper presents a trail to establish a farm of 25 feddans using sprinkler and drip irrigation systems. Along with choosing the most efficient and low cost power supplying the system, keeping in mind the tradional ways of power electricity generating sources.
The area of the farm is 25 faddans, as an average, they will be irrigated by water 50 times per year. The volume of each irrigation water as an average of the different seasons is 120 cubic meter/faddan totaling 3000 cubic meter/irrigation. This amount of water requires 15 horse power pump to draw water from the irrigation canal and/or 20 horse power to lift the underground water. So that, the power unit required to operate the pump will be considered as 20 horse power which will cover the maximum load. The proposed pattern for this farm is a stand alone generating system which can be a diesel generating set, photovoltaic generating unit or combination from them.
This paper studies four different generating systems. These systems are : 1- photovoltaic array consisting of 2-units one for irrigation pump and the other for farm utilities, 2- single diesel generating set, 3- double units of diesel generating set and 4- combined system of diesel unit to operate the irrigation pump and the utilities and the PV-array to feed the utilities during irrigation.

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The results of this study reveals that the cost of a kilowatt hour generated from these four systems are: 0.05763, 0.02673, 0.01683 and 0.01821 LE., respectively. The fourth system, though the total cost is higher by 8.156% than the third one, yet it is more reliable because it is less maintenance, no pollution, no noise, no troubleshooting and more independence and stability.

2-INTRODUCTION

Water and energy are the most important factors required for any human activities. In Egypt the river Nile is the only source of water for agriculture, drinking and industry. Egypt share is about 55 billion cubic meter/year according to international agreement between Egypt and Sudan. The irrigation system followed in Egypt is the traditional surface irrigation system. Water use efficiency of such a system does not exceed 50%. To meet the growth of population and food consumption rate and to reach high level of sufficiency of food production, farming system has to be changed. More land has to be cultivated and use of modern techniques for agriculture have to be followed. To realize all these, modern irrigation systems have to be used in order to maximize the water use efficiency. Water use efficiency is defined as the volume of water required to produce a unit weight of crop(e.g. a kilo gram of wheat grains). Modern types of irrigation systems like drip irrigation and sprinkler irrigation support the economical use of power electricity supply[1].

This paper is a trail to an example a farm of 25 faddans using sprinkler and drip irrigation systems. Along with choosing the most efficient and low cost power supply system, keeping in mind that the conventional ways of power electricity generating sources are available.

It has been used already in real life such as diesel engine coupled on the same shaft with a generating set covering all kinds of loads. Solar cells technology which were introduce by petroleum companies for the navigation systems and then for small applications in desert area. So, using both of the two systems available in the market in this paper is more reliable, efficient and economical for the commercial use to be available for all users[2].

3-TYPES OF IRRIGATION SYSTEMS

One disadvantage of modern irrigation systems is fear of salinization of the land. Such fear may not exit in the case of sandy soil. These systems are costly in installation and maintenance. But high water use efficiency is achieved as will as there is no need to level the land. In addition a lot of literature agreed that more yields are obtained when these systems are compared with the traditional irrigation system[5,6].

3.1 Sprinkler Irrigation System

The main components of the sprinkler irrigation system are:

I- Pumps
II- Main lines
III- Lateral lines
IV- Sprinkler heats
V- Depris screens
VI- Desalting basins
VII- Booster pump
VIII- Take off valves
IX- Flow control valves
X- Fertilizer applicator

Table 1 shows the life time of various components of the sprinkler system[3,4].

Table 1 Life-time of sprinkler irrigation

No.	Equipment	Life-time
I	Well	25 years
II	Moving parts of centrifugal pump 1) Gears 2) Belts 3) Small pipes	 12 years or 25000 hours one year or 2000 hours 2 years or 4000 hours
III	Electric motors	15 years or 30000 hours
IV	Diesel engines	10 years or 20000 hours
V	Pipe Lines: 1) ALUMINIUM 2) PVC	 10 years 6 years
VI	Sprinkler heads	7 years
VII	Valves & connections 1) ALUMIINIUM 2) PVC	 10 years 6 years

3.2 Drip Irrigation System

This system is distributed as drops of water to wet the root zone of plants. The drip irrigation system is used mostly with horticultural crops which are grown on distances like vegetables and fruit crops. Water is distributed through pipes in lines along the rows of the plants and through nozzles or dripers to meet the root zone of the individual plants.
Lot of advantages are released with this system. It has the highest water use efficiency among the different modern systems. Also growth of plants are of high rate. Fertilizer application can be done in more homogeneous way and one more splits which increase the recovery percentages from such fertilizers. It needs more maintenance and frequent closure of the dripers is observed[5].
The main components of the drip irrigation system are:

I- The pump and motor.
II- The main line and the lines under main.
III- The sub lines.
IV- The dripers.

4-SELECTION OF POWER SUPPLY PATTERN

The area of the investigated farm is 25 faddans. It will be irrigated 50 times per year. The volume of water for each irrigation is 120 cubic meter/faddan. Pumping this amount requires 15 horse power pump to draw water from the irrigation canal and/or 20 horse power to lift the under ground water[7].
This farm is supplied from a stand alone generating system, which can be: 1) a diesel generating set, 2) a photovoltaic generating unit or 3) combination from both.
The clearness index(KH) is tabulated in table(2). Monthly average insulation,I, ratio of standard deviation,R and standard deviation of El-Mansoura city are listed in table 2.
These data are used for culculating the size of photovoltaic cells and the quantity of storage capacity. In this system a storage capacity of 287 KWh is required to meet the rquired load of the farm[8].
In this investigation the cost of the solar photovoltaic power system components are:

PV ARRAY COST	20 L.E/WP
BATTERY COST	220LE./KWh
COST OF POWER CONDITIONING SYSTEM	2.0LE./W

Table 2: The clearness index,KH, average monthly insulation,I, ratio of standard deviation,R and standard deviation of EL-Mansoura city (insolation data)

MONTH	KH	MEAN=1 KWh/M² DAY	SIGAM=R	S = S.D.
JAN.	0.580	4.66356	0.40481	1.88785
FEB.	0.623	5.562566	0.3235568	1.8
MAR.	0.672	6.502123	0.23821	1.54887
APR.	0.670	6.62	0.2217	1.46765
MAY	0.656	6.4123	0.223273	1.4317
JUN	0.671	6.451	0.19806	1.277685
JUL.	0.667	6.43	0.20557465	1.323
AUG.	0.664	6.482	0.2213816	1.435
SEP.	0.659	6.38874	0.2453	1.567158
OCT.	0.626	5.7455	0.310	1.7811
NOV.	0.570	4.6935	0.41042	1.9263
DEC.	0.565	4.331	0.432736	1.87418

5-DAILY LOAD CURVE OF THE INVESTIGATED FARM

Different farm activities for various components are calculated and tabulated in table3. The daily load curves of the winter and summer loading are tabulated in tables 4 & 5 and plotted in fig.1 and 2. It is calculated from table.4, that the total net energy per day is 180990 watts[13].

Table 3: Load factor of various farm activities[2]

Type of load	Load position	Net load	Max. load	Load factor
Industrial	Main pump	11.2 KW	11.2KW	1.0
Street lighting	Road lighting	0.5 KW	0.5 KW	1.0
Residential	Lighting + oven	1.25 KW	2.5 KW	0.5
Commercial	Store	0.21 KW	0.3 KW	0.7
Industrial	Sub.pump	15.0 KW	15 KW	1.0
Agriculture	Animals house	0.28 KW	0.4 KW	0.7

Table 4: The daily load curve (winter)

Operation hours	Load type	Load based on individual net load	Nominal load (watts)	Net load (watts)
1	2+6+4*	0.5+0.21+0.28	1200W	990
2	2+6+4	0.5+0.21+0.28	1200W	990
3	2+6+4	0.5+0.21+0.28	1200W	990
4	2+6+4	0.5+0.21+0.28	1200W	990
5	2+6+4	0.5+0.21+0.28	1200W	990
6	3+6+4	1.25+0.21+0.28	3200W	1740
7	3+6+4	1.25+0.21+0.28	3200W	1740
8	3+6+1	1.25+0.21+0.28	17800W	16460
9	3+6+1	1.25+0.21+0.28	17800W	16460
10	3+1	1.25+15.0	17500W	16250
11	3+6+1	1.25+15.0	17500W	16250
12	3+6+1	1.25+15.0	17500W	16250
13	3+6+1	1.25+15.0	17500W	16250
14	1	15.0	15000W	15000
15	1	15.0	15000W	15000
16	1	15.0	15000W	15000
17	4+1	0.21+15.0	15300	15210
18	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
19	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
20	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
21	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
22	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
23	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
24	2+4+6	0.5+0.21+0.28	1200	990

TOTAL	180990W

Table 5: The daily load curve (summer)

Operation hours	Load type	Load based on individual net load	Nominal load (watts)	Net load (watts)
1	2+6+4	0.5+0.21+0.28	1200W	990
2	2+6+4	0.5+0.21+0.28	1200W	990
3	2+6+4	0.5+0.21+0.28	1200W	990
4	2+6+4	0.5+0.21+0.28	1200W	990
5	2+6+4	0.5+0.21+0.28	1200W	990
6	3+4	1.25+0.21	2800W	1460
7	3+4	1.25+0.21	2800W	1460
8	3+4	1.25+0.21	2800W	1460
9	3+4	1.25+0.21	2800W	1460
10	3	1.25	2800W	1250
11	3	1.25	2500W	1250
12	3	1.25	2500W	1250
13	3	1.25	2500W	1250
14	3	1.25	2500W	1250
15	3	1.25	2500W	1250
16	3	1.25	2500W	1250
17	4	1.25+0.21	2500W	1250
18	3	1.25	2500W	1250
19	3	1.25	2500W	1250
20	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
21	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
22	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
23	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
24	2+3+4+6	0.5+1.25+0.21+0.28	3700W	2240
TOTAL				34490w

* The different numbers of load type in tables 4 and 5 mean:

1	2	3	4	5	6
Main pump (15HP)	Road lighting	Lighting	Store	Back up submersible pump(20HP)	Animals house

6- WATER PUMPING SYSTEMS

6.1 Double Photovoltaic Systems

Here two photovoltaic systems utilised. The first to feed the water pump of 20HP and the second will be used in feeding the other utilities. The total energy required is split into two groups. The first group to the storage of 151KWh/day demonstrated table 5 required in the month of December as maximum for the water pump.

The second group 31KWh/day, in table 7 for the small appliances utilities. The two figures 238KWh and 50KWh as stored energy for lighting so that the capacity of storage batteries have to considered[9,10].

This system was proposed in order to seek the posibilities of reducing the cost of the single system. The costs of the two groups are 1,521,704LE and 316,012LE. For the PV array of the water pump and that of the other utilities totaling 1,837,716LE as shown in tables 6,8. Life time of the PV power system is taken as 20 years.

Table 6: Storage capacity for lighting and area of a stand alone PV power system for irrigating pump(load factor,M=0.8)

MONTH	AREA,m^2	C,DAYS #	C,KWh
JAN.	476	1.40244	211
FEB.	364	0.9146	138
NOV.	476	1.4634	220
DEC.	530	1.5853	238

This capacity is sufficient to meet C (day).

Table 7: Size and costs of different PV elements

PV ARRAY SIZE	NORMAL SIZE /DEGRADATION FACTOR=53/0.9	58.88888 KWP
BATTERY SIZE	NORMAL SIZE/DEPTH OF DISCHARGE=238/0.95	250.53KWh
PV ARRAY COST	58888.8*20	1177776LE.
BATTERY COST (Appendix A)	250.53*220	55116.6LE.
POWER CONDITIONING SYSTEM	58888.8*2	117777.6LE.
TOTAL		1350920.7LE.
ENGINEERING+INSTALLATION+COM MISSNING+PROJECT MANAGEMENT	1.09*TOTAL	1472503.4LE.
MAINTENANCE	1.01*PREVIOUS	1487228.4LE.
REPLACEMENT OF THE BATTERY	BATTERY COST* 0.695*0.9= 55116.6*0.695*0.9	34475.5LE.
FINALLY TOTAL COST	THE SUM.OF THE LAST TWO PREVIOUS RESULTS	1,521,703.9LE.

Table 8: Solar cells array sizes and battery storage capacities for the winter months(load factor,M=0.8)

MONTH	AREA	C,DAYS	C,KWh
JAN.	99	1.40244	44
FEB.	76	0.9146	29
NOV.	99	1.4634	46
DEC.	110	1.5853	50

6.2 Single Diesel Generating Set

A unit of a capacity of 50KVh will be installed in order to feed the water pump as well as the other utilities. It will operate 8760 hours/year. The total cost as depicted in table 9 is 852,410LE. This unit and its capacity are chosen on the bases of Helwan company of diesels engines[7].

Table 9: System design and cost of a PV system required for a daily load of 151KWh[13]

PV ARRAY SIZE	NORMAL SIZE /DEGRADATION FACTOR=11/0.9	12.22222 KWP
BATTERY SIZE	NORMAL SIZE/DEPTH OF DISCHARGE=50/0.95	52.64KWh
PV ARRAY COST	12222.2*20	244444LE.
BATTERY COST	52.64*220	11580.8LE.
POWER CONDITIONING SYSTEM	12222.2*2	24444.4LE.
TOTAL		280469.2LE.
ENGINEERING+INSTALLATION+COM MISSNING+PROJECT MANAGEMENT	1.09*TOTAL	305711.5LE.
MAINTENANCE	1.01*PREVIOUS	308768.6LE.
REPLACEMENT OF THE BATTERY	BATTERY COST* 0.695*0.9= 11580.8*0.695*0.9	7243.8LE.
FINALLY TOTAL COST	THE SUM.OF THE LAST TWO PREVIOUS RESULTS	316,012.4LE.

6.3 Double Diesel Generating Sets

This system is inefficient because the 50 KWh unit is needed during the operation of the water pump only. The other unit of 6 KWh is required for the utilities only. The farm will be irrigated 50 times per year and each irrigation requires 30 hours/year, so the irrigation pump operates 1500hours/year. The concept of this system is to have two generators, the first of 50KVA to operate the irrigation pump of 1500 hours/year. The total cost of such a unit as shown in table11 is 227,350LE. The second of capacity 6KVA to work 7260hours/year and the total cost of this unit as shown in table 11 amounts to 309,370LE. The total cost of this system is 536,720LE. The reduction in the cost due to use of double diesel generating sets instead of a single set is 37.66%.

Table 10: Cost of a 50KVA diesel generator set operates 8760 hours/year

Capital cost	Running cost	Maintenance& spare parts	Kind of the set &the capacity	Total cost
55000+ 7500 = 62500 LE.+10%sa le taxes	In 30 hours changing oil+fuel=50LE. In case of calculating that 0.5 load factor	Overall maintenance every 1000 hours=2500LE.	DUETZ-50 KVA	68750 LE.
	In 20 years=292200 LE.	In 20 years=438000 LE.		730500 LE.
	Oil, diesel filter every 100Hr=30LE.	Running maintenance every month=40LE.		
	In 20 years= 52596LE.	In 20 years=9600LE.		53160 LE.
Total cost				852410 LE.

Table 11: Cost of a 6KVA diesel generator set operates 7260 h/year

Capital cost	Running cost	Maintenance& spare parts	Kind of the set &the capacity	Total cost
11300+ 6000 = 17300 LE.+10%sa les taxes	In 30 hours changing oil+fuel=30LE.	Over hall maintenance every 1000 hours=750LE.	DUETZ-6 KVA	19030 LE.
	In 20 years=292200 LE.	In 20 years=438300 LE.		254,100LE.
	Oil, diesel filter every 100Hr=20LE.	Running maintenance every month=30LE.		
	In 20 years= 29064LE.	In 20 years=7200LE.		36240 LE.
Total cost				309,370LE.

Table 12: Cost of a diesel generator set of a 50KVA operates 1500hours/year

Capital cost	Running cost	Maintenance& spare parts	Kind of the set &the capacity	Total cost
55000+ 7500 = 62500 LE.+10%sa les taxes	In 30 hours changing oil+fuel=65LE.	Over hall maintenance every 1000 hours=2500LE.	DUETZ-50 KVA	68,750LE.
	In 20 years=65000 LE.	In 20 years=75000 LE.		140,000LE.
	Oil, diesel filter every 100Hr=30LE.	Running maintenance every month=40LE.		
	In 20 years= 9000LE.	In 20 years=9600LE.		18,600LE.
Total cost				227,350LE.

6.4 Combined PV Array and Diesel Generating Set

As seen from the previous discussion, most of the energy needed for the irrigation pump represents 82.6% of the total energy. The PV array will be devoted to feed all power required for utilities and the diesel unit will operate the irrigation pump[11,12]. Table 13 shows the solar cells array size and battery storage capacity of the PV system combined with the diesel generator. The cost of the PV/diesel combined system and the comparison between the four investigated systems are shown in tables 14&15.

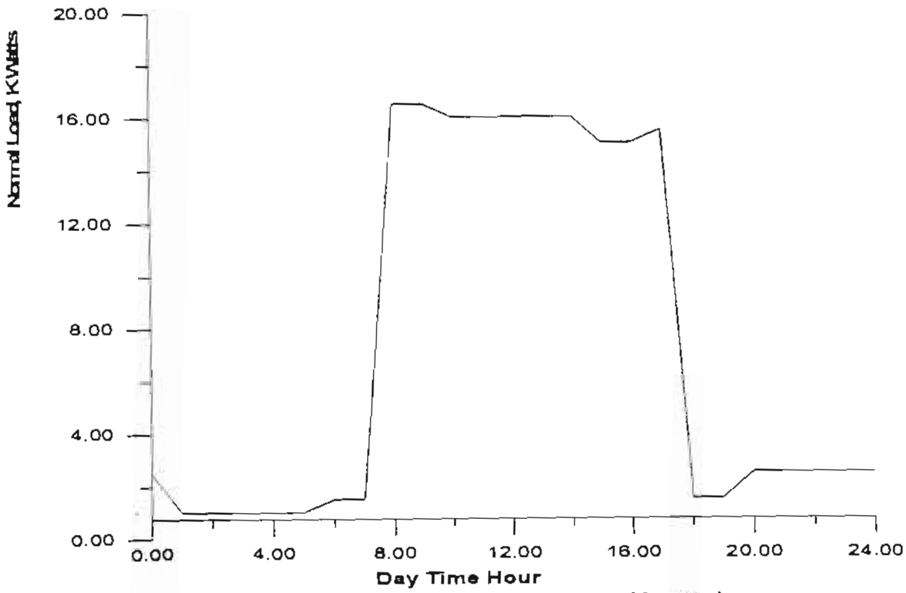

Fig. (1) Load curve (watts / hours)
(Winter)

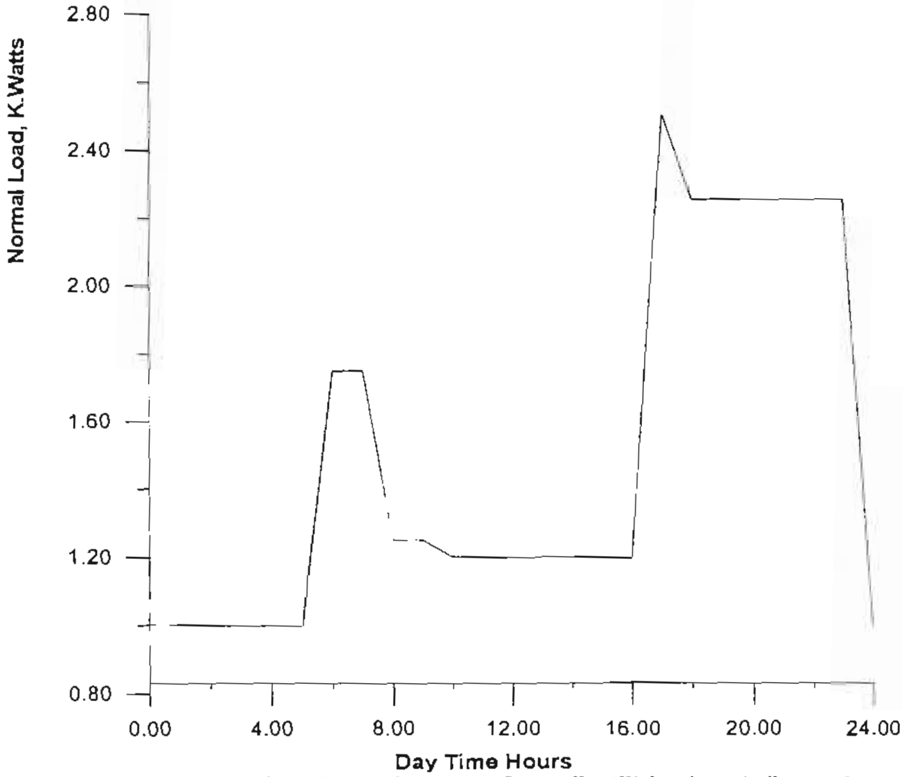

Fig.(2) Load curve of small utilities(watts/hours)
(Summer)