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ECONOMICAL AND PERFORMANCE EVALUATION OF DIVERSE GRID-CONNECTED SOLAR WATER PUMPING SYSTEMS FOR AGRICULTURE IN INDIA

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ABSTRACT

The agriculture sector in a developing country like India still requires proper irrigation facilities and the motivation of the farmers towards cultivation. The government of India has already planned to implement the scheme of 10 lakh grid-connected solar water pumps by 2022; thereby the farmers can generate the revenue through the excess energy supplied to the grid. The novelty of this work has two objectives. First, reduction of the total amount of energy consumption on all the feeders when a grid-connected Solar Water Pumping System (SWPS) used in place of the conventional grid system. The annual energy consumption of 15.65M.U is reduced to 7.64M.U when the SWPS is used in place of conventional grid supply. A total of 19 feeders merely for agriculture purposes are considered in this study at Rajanagaram, Andhra Pradesh, India. Second, the operation of the pumps in different combinations to estimate the performance indices like net Life Cycle Cost (LCC), Levelized Energy Cost (LEC), and pump operating time. In this particular study, 1.2HP, 3HP, and 5HP pumps are considered individually and also with seven different combinations. Out of the total ten combinations, three are selected based on the performance indices. The entire analysis is carried out in this paper concerning the paddy field as it is one of the major crops in the area of the study and as well as across the country. This study helps to understand the need for the implementation of the grid-connected SWPS for the sustainable energy and economical growth of the country.

Keywords: grid-connected SWPS, LCC, LEC, pump operating time.

1. INTRODUCTION

Mainly, the agriculture sector has the constraint which is related to the dependency of farmers on pumps for irrigation. Another constraint from a farmer's point of view is that many of the crops are seasonal and hence they are deprived of regular sources of income. Because of these constraints, the government of India targeted to install 27.5 lakh including off-grid and grid-connected solar water pumping systems to facilitate the farmers with uninterrupted clean and green power by 2022. Out of all these, 17.5 lakh come under the scheme of solarisation of the pumps where the grid connection is not available referred to as off-grid pumps, and the remaining 10 lakh come under the grid-connected scheme. The off-grid connected pumps are merely used for the replacement of existing fossil fuel-based pumps only but not for a new installation purpose. In this scheme, there is no support from the government side to the farmers in terms of buyback power because their pumps have not been grid-connected. It would be done in the future, whenever their location is getting connected with the grid. About this, one lakh grid-connected pumps are considered to be installed in pilot mode by 2019. In this scheme, farmers can meet their irrigation needs and they can sell the excess energy to the DISCOMS. Therefore, farmers can feed surplus power to the grid and save electricity and water. And also, they can get a secondary source of income [1].

For the year 2016-17, the total electricity consumption is 1, 95, 473GWh. This consumption is nearly 18.33% of the total consumption of the country's energy [2]. The agriculture sector in India is a major source of economy and plays a significant role in providing employment to nearly 50% of the workforce of the country. The share of this sector is 17-18% to the Gross Domestic Product (GDP) of the country [3]. In general, farmers need a sufficient amount of water for the crop through the supply of timely input sources in terms of electricity or diesel. Across India [4], electrical pumps of about 20 million and diesel pumps of about 9 million are being used for agriculture or irrigation applications on the basis of 0.5 million pumps every year. Keeping in view of the cash flow, there is a disproportion between electric pumps and solar pumps being used by the farmers [5]. Farmer's choice to go for either solar or electric pump would be affected by the factors like new connection, reliability, and quality of the supply. Therefore, solar pumps might be more promising and attractive in the states where time to get a new connection is such a long time.

As per the report [6], in most of the states of India, grid-connected SWPS are not economical due to the subsidized extension of the grid, subsidized solar water pumps, payments on the feed-in tariff, and electricity for free of cost. However, near a hundred percent grid infrastructure of rural areas in India and the government's willingness to buy-back power makes grid-connected solar water pumping systems a strong case for agriculture use. However, there are some concerns in the present schemes offered by the states: (1) The 'one-size-fits-all' approach of pump size is failing to meet the specific needs of the end-user; (2) lack of a scientific approach for quantification of benefits to help the farmer make informed decision in favor of grid-connected solar pump as an alternative to diesel and grid-connected pumps. The authors of [7] reviewed and found that solar photovoltaic system applications in agriculture would be a promising alternative and specifically for the remote area due to its advantage of maintenance and pollution-free.

In [8, 9], it has been presented that the viability of the techno-economic evaluation of SWPS in India. In this study, it has concluded that the economical viability of SWPS could be achievable in India through capital subsidy and financial incentives provided that the consideration of location has a significant role in its technical viability. This could be possible because of the availability of many sunny days and the long duration of the sunlight. Another interesting and important dimension of solar pumps is the accelerated withdrawal of groundwater. Tushaar Shah and Avinash Kishore consider that the promotional strategy for solar pumps is not just an energy solution but a composite energy-and-water solution; and that while solving the energy problem, solar pumps can aggravate the water problem [10]. Grid-connected SWPS are being promoted by many of the states in India to encourage the farmers by means of buy-back power as a business model. For instance, the state of Karnataka provides incentives for framers who save the ground-water and power as a part of solar promotion policy known as Surya Raitha. With these kinds of policies, farmers could be able to raise the yield of the ground-water and energy with the help of revenue generated through buyback power because of net-metered SWPS [11].

According to [12], the rate of increase in demand for the energy for the agriculture sector is 3.5% per anum. The major challenge for Indian utility is managing the electricity for the agriculture sector according to the growing demand for diversity and food. Most of the farmers in many of the states of the country are being supplied with insufficient hours of a low-quality power supply is all about 7-10 in a day and often off-peak hours? The government of India had promoted about 1.3lakh off-grid SWPS as on date for agriculture purposes with the subsidy by keeping in view for addressing the power shortages and changes in climate [13]. Though the government has been supporting farmers with financial subsidies, SWPS are not become popular because of unawareness and high starting cost. Also as many of the states are giving highly subsidized/free power, there is no incentive for farmers to adapt to renewable energy technologies. Besides, off-grid solar pumps may also worsen the problem of withdrawal of more than required water and thus may further worsen groundwater availability. To this context, a study is carried out to address the advantage of the implementation of the grid-connected solar water pumping system as follows:

2. NEED OF THE PROPOSED METHODOLOGY

There is a need for methodology proposed in this paper because of the following potential benefits with the grid-connected solar water pumping system for both farmers and utility companies.

a) Farmers become independent in getting power supply for their agriculture needs.
b) An additional source of income can be generated due to excess energy supplied to the grid.
c) Energy consumption on the feeder level gets reduced when compared with the conventional grid electricity system.
d) The unit cost of energy generated can be reduced with the help of pumps of different capacities used in different combinations.

3. METHODOLOGY

Step-1: Acquisition of Feeder Details in the Area of the Study

Under Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL), a 33/11KV feeder system located at Rajanagaram Mandal has identified for the study of implementing solar water pumping systems. The feeder system in this area is exclusively meant for agriculture purposes. Therefore, this system is considered for the study and consisting of 19 feeders as shown in Figure-1. The pumps located in this area are supplied with feeders for the irrigation of different crops.

Step-2: Percentage of Land Cultivated for the Rice (Paddy) Crop

The major crops cultivated in the area of study have shown in Figure-2. From the figure, it has been observed that rice cultivated is about 33%, which is more than other crops.

Step-3: Representation of the Acreage, Number of Pumps, and Consumption of Energy

From the following Table-1, the total acreage, total number of pumps, and total energy consumed on each feeder have been obtained. The data, shown in the steps from 1 to 3 are obtained from [14].

Step-4: Estimation of the Acreage, Number of Pumps, and Consumption of Energy for the Paddy Field

From the following Table-2, total acreage, the total number of pumps, and total energy consumed on each feeder are obtained when the conventional grid electric supply is considered. The data has been obtained based on the percentage share of the paddy i.e. 33% shown in Figure-2.

Step-5: Estimation of Energy Consumption and Economic Analysis Using Grid-Connected SWPS

The authors of [15] have estimated the energy consumption for irrigation of one acre of the paddy field using the grid-connected SWPS with three different capacities. In this study, they have estimated the excess energy and hence the economical benefits are hi-lighted. Pump operating time also estimated for each case separately and are shown in the following Table-3.

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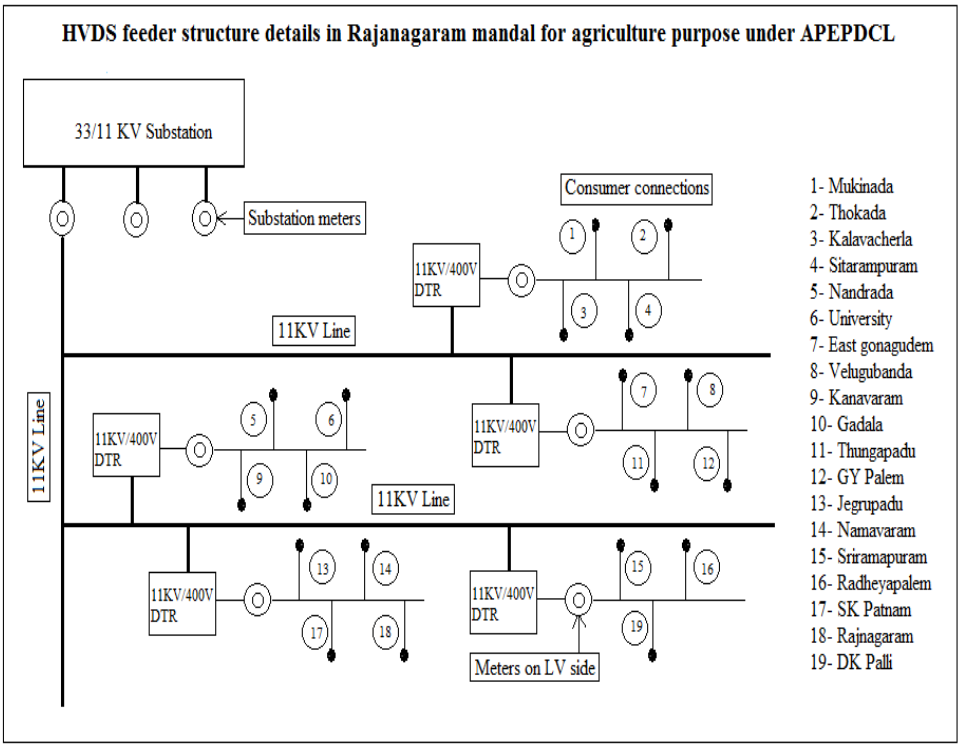

Figure-1.

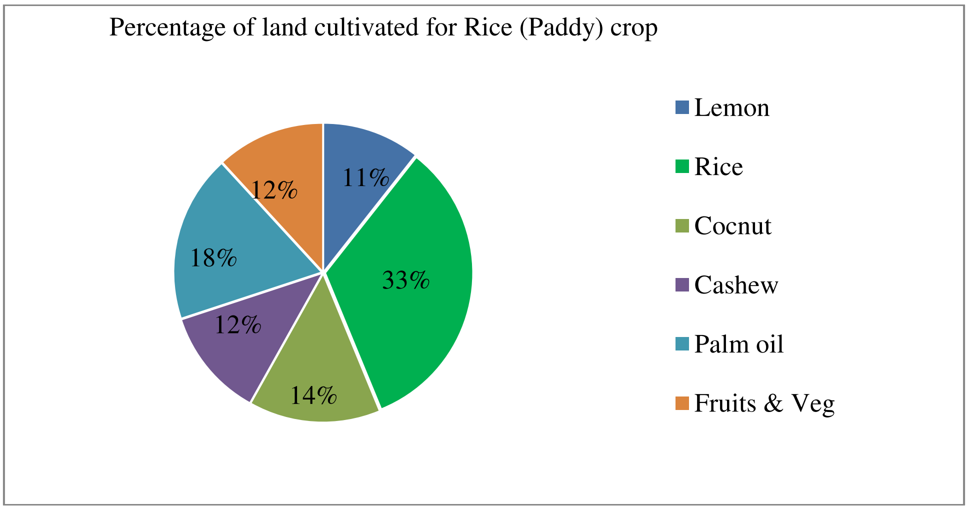

Figure-2.

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Table-1. Representation of the acreage, number of pumps, and consumption of energy.

S. No	Name of the Feeder	Total Acreage	Total number of pumps used	Energy consumed (M.U/annum)
1	Mukinada + Mallampudi	1910	213	6.16
2	Thokada	2415	188	3.42
3	Kalavcherla	1411	172	1.28
4	Sitarampuram	22	10	0.61
5	Nandarada	1302	183	1.51
6	University	233	29	2.15
7	East Gonagudem	323	59	0.78
8	Velugubanda (Rajnagaram)	376	61	4.49
9	Kanavaram (Rajnagaram)	1331	160	2.72
10	Gadala (Palacharla)	151	29	2.93
11	Thungapadu	2035	186	1.94
12	G Y Palem	1917	229	3.56
13	Kondagunturu + Jegurupadu	1081	160	0.29
14	Namavaram	2800	341	1.51
15	Srirampuram	769	56	1.59
16	Radheyapalam	793	83	3.07
17	S K Patnam	1410	128	2.11
18	Rajanagaram MHQ	41	15	7.91
19	D K Palli (part of Nandarada)	1243	194	1.39
Total		21563	2496	49.48

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Table-2. Estimation of the acreage, number of pumps, and consumption of energy for the paddy field.

S. No	Name of the Feeder	Paddy (Acreage)	Number of pumps used	Energy consumed (M.U/annum)
1	Mukinada + Mallampudi	586	72	2.07
2	Thokada	213	63	1.15
3	Kalavcherla	537	58	0.43
4	Sitarampuram	0	0	0
5	Nandarada	204	62	0.50
6	University	0	0	0
7	East Gonagudem	302	20	0.26
8	Velugubanda (Rajnagaram)	163	21	1.51
9	Kanavaram (Rajnagaram)	81	54	0.91
10	Gadala (Palacharla)	75	10	0.98
11	Thungapadu	833	63	0.65
12	G Y Palem	962	77	1.19
13	Kondagunturu + Jegurupadu	967	54	0.09
14	Namavaram	1409	115	0.51
15	Srirampuram	6	19	0.53
16	Radheyapalam	76	30	1.03
17	S K Patnam	10	43	0.71
18	Rajanagaram MHQ	39	5	2.66
19	D K Palli (part of Nandarada)	800	65	0.47
Total		7263	831	15.65

Table-3. Estimation of load energy, excess energy and pump operating time.

Parameter Considered	SWPS-1.2HP	SWPS-3HP	SWPS-5HP
Load energy (kWh/day)	3.51	3.51	3.51
Excess energy (kWh/day)	5.56	8.70	16.51
Pump operating time (hrs)	5.37	2.80	1.75

The economic analysis [16] of the grid-connected SWPS can be understood by using the following terms.

Life Cycle Cost (LCC)

The LCC of an SWPS is the sum of the initial capital investment cost, the present value of operation and maintenance cost, and the net present value of all replacement costs of other components like inverter & motor-pump over the life period.

Life Cycle Saving (LCS)

If the revenue generated by employing excess solar energy supplied to the grid then the financial benefit over a life cycle period of the system is known as LCS.

Net Life Cycle Cost (Net LCC)

It is the difference between LCC and LCS.

Levelized Energy Cost (LEC)

The LEC is the cost per unit production of energy. LCC, LCS, Net LCC, and LEC are obtained [15] for the grid-connected solar water pumping system to irrigate the one acre of paddy field. Three different pumps have been considered with the capacities of 1.2HP, 3HP, and 5HP. For all these pumps, the data is obtained as follows and shown in Table-4. In Tables 3-4, all the values are specified per acre. These values are taken into consideration and applied for the above-said area of the study. Therefore, the values of energy consumption, LCC, LCS, and net LCC have been calculated on each feeder and for all three pumping systems i.e. for 1.2HP, 3HP, and 5HP. These values are shown in the following Tables 5-7.

4. RESULTS AND DISCUSSIONS

Using the data obtained as shosn above, the following results are made. In Figure-3, it has shown that the comparative result of energy consumption between the conventional grid supply system and the grid-connected solar water pumping system. Through the conventional grid supply system, the energy consumption is 15.65M.U/annum whereas it is 7.64M.U/annum only through a solar water pumping system. Therefore, 8.01M.U of energy per annum can be saved by the utility companies if the pumps are supplied with solar energy through the grid connection system.

Table-4. Estimation of LCC, LCS, Net LCC and LEC.

Parameter Considered	SWPS-1.2HP	SWPS-3HP	SWPS-5HP
LCC (INR in Lakhs)	1.61	3.67	5.94
LCS (INR in Lakhs)	1.06	1.66	3.14
Net LCC (INR in Lakhs)	0.55	2.01	2.80
LEC (INR)	1.01	2.74	2.31

Table-5. Feeder wise estimation of economical indices for 1.2HP SWPS.

Feeder No	Name of the Feeder	SWPS - 1.2HP					
		Number of pumps	Acreage	Energy consumed (M.U)	LCC	LCS	Net LCC
1	Mukinada + Mallampudi	586	586	0.61	94.34	62.11	32.23
2	Thokada	213	213	0.22	34.29	22.57	11.72
3	Kalavcherla	537	537	0.56	86.45	56.92	29.53
4	Sitarampuram	0	0	0	0	0	0
5	Nandarada	204	204	0.21	32.84	21.62	11.22
6	University	0	0	0	0	0	0
7	East Gonagudem	302	302	0.32	48.62	32.01	16.61
8	Velugubanda (Rajnagaram)	163	163	0.17	26.24	17.27	8.97
9	Kanavaram (Rajnagaram)	81	81	0.08	13.04	8.58	4.46
10	Gadala (Palacharla)	75	75	0.07	12.07	7.95	4.12
11	Thungapadu	833	833	0.87	134.11	88.29	45.82
12	G Y Palem	962	962	1.01	154.88	101.97	52.91
13	Kondagunturu + Jegurupadu	967	967	1.02	155.68	102.50	53.18
14	Namavaram	1409	1409	1.48	226.84	149.35	77.49
15	Srirampuram	6	6	0.006	0.96	0.63	0.33
16	Radheyapalam	76	76	0.08	12.23	8.05	4.18
17	S K Patnam	10	10	0.01	1.61	1.06	0.55
18	Rajanagaram MHQ	39	39	0.04	6.27	4.13	2.14
19	D K Palli (part of Nandarada)	800	800	0.84	128.80	84.80	44.00

Note: LCC, LCS & Net LCC are to be mentioned in INR millions

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Table-6. Feeder wise estimation of economical indices for 3HP SWPS.

Feeder No	Name of the Feeder	SWPS – 3HP					
		Number of pumps	Acreage	Energy consumed (M.U)	LCC	LCS	Net LCC
1	Mukinada + Mallampudi	586	586	0.61	215.06	97.27	117.86
2	Thokada	213	213	0.22	78.17	35.35	42.81
3	Kalavcherla	537	537	0.56	197.07	89.14	107.93
4	Sitarampuram	0	0	0	0	0	0
5	Nandarada	204	204	0.21	74.86	33.86	41.00
6	University	0	0	0	0	0	0
7	East Gonagudem	302	302	0.32	110.83	50.13	60.70
8	Velugubanda (Rajnagaram)	163	163	0.17	59.82	270.58	32.76
9	Kanavaram (Rajnagaram)	81	81	0.08	29.72	13.44	16.28
10	Gadala (Palacharla)	75	75	0.07	27.52	12.45	15.07
11	Thungapadu	833	833	0.87	305.71	138.27	167.43
12	G Y Palem	962	962	1.01	353.05	159.69	193.36
13	Kondagunturu + Jegurupadu	967	967	1.02	354.89	160.52	194.36
14	Namavaram	1409	1409	1.48	517.10	233.89	283.21
15	Srirampuram	6	6	0.006	2.2	0.99	1.21
16	Radheyapalam	76	76	0.08	27.89	12.61	15.27
17	S K Patnam	10	10	0.01	3.67	1.66	2.01
18	Rajanagaram MHQ	39	39	0.04	14.31	6.47	7.84
19	D K Palli (part of Nandarada)	800	800	0.84	293.6	132.80	160.80

Note: LCC, LCS & Net LCC are to be mentioned in INR millions

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Table-7. Feeder wise estimation of economical indices for 5HP SWPS.

Feeder No	Name of the Feeder	SWPS – 5HP					
		Number of pumps	Acreage	Energy consumed (M.U)	LCC	LCS	Net LCC
1	Mukinada + Mallampudi	586	586	0.61	348.08	184.00	164.08
2	Thokada	213	213	0.22	126.52	66.88	59.64
3	Kalavcherla	537	537	0.56	318.97	168.61	150.36
4	Sitarampuram	0	0	0	0	0	0
5	Nandarada	204	204	0.21	121.17	64.05	57.12
6	University	0	0	0	0	0	0
7	East Gonagudem	302	302	0.32	179.38	94.82	84.56
8	Velugubanda (Rajnagaram)	163	163	0.17	96.82	51.18	45.64
9	Kanavaram (Rajnagaram)	81	81	0.08	48.11	25.43	22.68
10	Gadala (Palacharla)	75	75	0.07	44.55	23.55	21.00
11	Thungapadu	833	833	0.87	494.80	261.56	233.24
12	G Y Palem	962	962	1.01	571.42	302.06	269.36
13	Kondagunturu + Jegurupadu	967	967	1.02	574.39	303.64	270.76
14	Namavaram	1409	1409	1.48	836.94	442.42	394.52
15	Srirampuram	6	6	0.006	3.56	1.88	1.68
16	Radheyapalam	76	76	0.08	45.14	23.86	21.28
17	S K Patnam	10	10	0.01	5.94	3.14	2.8
18	Rajanagaram MHQ	39	39	0.04	23.16	12.24	10.92
19	D K Palli (part of Nandarada)	800	800	0.84	47.52	251.20	224.00

Note: LCC, LCS & Net LCC are to be mentioned in INR millions

It is observed from this study that the number of pumps required is 7, 263 because each pump is specified to feed the water to the paddy field of one acre and the total acreage of the area is 7, 263. For example, the implementation of a grid-connected solar water pumping system with 1.2HP capacity requires 7, 263 pumps. The details of energy consumption, excess energy that can be supplied to the grid, and pump operating time or time taken to feed the field with water for one acre have shown in Table-3. Similarly, the data has also provided for 3HP and 5HP pumps.

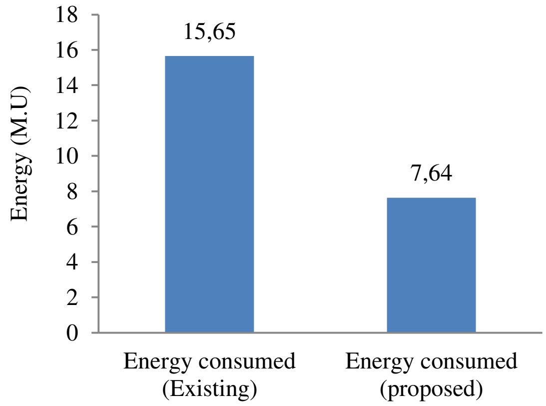

Figure-3.

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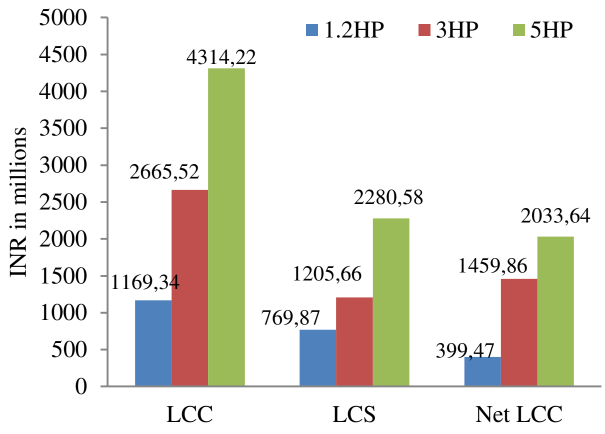

Figure-4.

With the help of the above data, the values of economical indices like LCC, LCS, and net LCC are specified in Figure-4 when the same kind of pump i.e. either 1.2HP or 3HP or 5HP pump is used for irrigation purposes all over the field covered under all 19 feeders. Form these results, it can be said that 1.2HP exhibiting the lowest value with regard to net LCC but, the pumping time is very much high when compared with the other two pumping systems. In contrast to this, the 5HP pump is exhibiting vice-versa. So as to balance this situation the following strategy has been implemented wherein pumps are considered with different combinations from A to G as shown in the following Table-8.

The % share of pumps is considered as shown in Table-8. For example, combination-A is consisting of an equal share of all three pumps i.e. 33% of each. The remaining combinations are also represented in different proportions. Accordingly, pumps are divided into a particular number and mixed together to operate. In Figure-5, LCC, LCS, and Net LCC values of each combination are shown and observed that combination G has the lowest value for Net LCC.

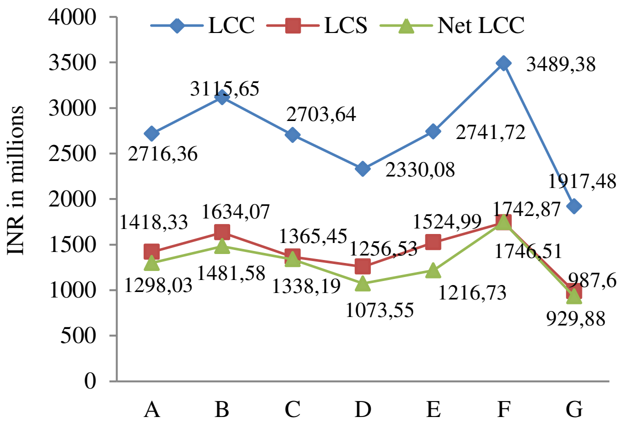

Figure-5.

The cost of unit energy generated i.e. LEC values are calculated for all the combinations and are presented in Figure-6. The LEC value should be as low as possible for the system to be more economical. The combination-E is consisting of the lowest value for LEC. And also, from Figure-7 it is observed that the operating time of the pump is low for the combination-F. From above all these results, consolidated Table-9 is presented. From this table, it can understand that combination-E has better performance than other combinations concerning LEC. Combination-F has better performance than other combinations concerning pump operating time, and combination-G has better performance than other combinations concerning net LCC. Therefore, the other four combinations from A to D are excluded and E, F, and G are considered.

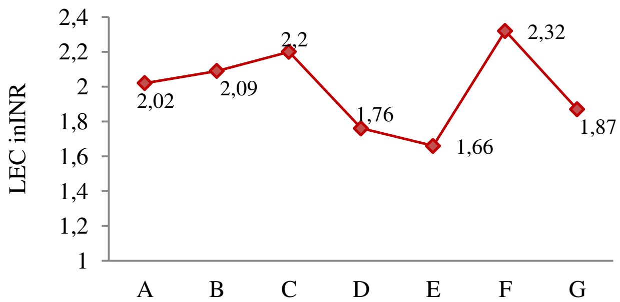

Figure-6.

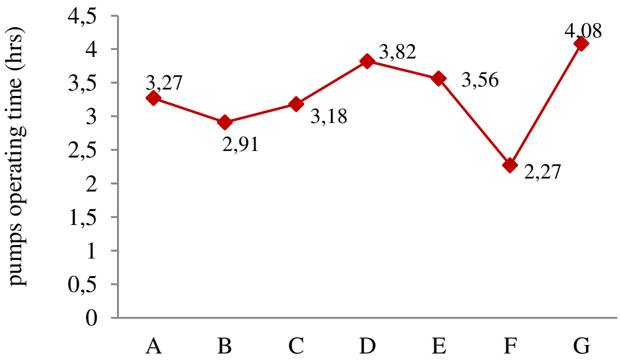

Figure-7.

Table-8. Usage of pumps in different combinations.

	A	B	C	D	E	F	G
Combination of Pumps used	1.2HP +3HP +5HP	1.2HP +3HP +5HP	1.2HP +3HP +5HP	1.2HP +3HP +5HP	1.2HP +5HP	3HP +5HP	1.2HP +3HP
% of pumps	33 +33 +33	25 +25 +50	25 +50 +25	50 +25 +25	50 +50	50 +50	50 +50
Number of pumps	2421 +2421 +2421	1816 +1816 +3631	1816 +3631 +1816	3631 +1816 +1816	3631 +3631	3631 +3631	3631 +3631

Table-9. Verification for the better possible combination of the pumps.

Combination of the Pumps	Net LCC	LEC	Operating time
A	×	×	×
B	×	×	×
C	×	×	×
D	×	×	×
E	×	√	×
F	×	×	√
G	√	×	×

Table-10. Estimation of Net LCC, LEC and operating time for the better possible combination.

Combination of the Pumps	Net LCC (INR in millions)	LEC (INR)	Operating time (hours)
1.2HP only	399.47	1.01	5.37
3HP only	1459.86	2.74	2.80
5HP only	2033.64	2.31	1.75
E	1216.73	1.66	3.56
F	1746.51	2.32	2.27
G	929.88	1.87	4.08

Along with the first three cases which are nothing but exclusive use of individual pumps without any combination, the other three cases E, F, and G are also shown in Table-10. From this table, 1.2HP SWPS is considered with regard to net LCC when pump operating time is not a constraint. 5HP SWPS is considered with regard to the pump operating time when net LCC is not a constraint. And finally, E-SWPS is considered because the above two constraints can be satisfied when the average net LCC, LEC, and operating time values of 1.2HP and 5HP pumping systems are nearly equal to the E-SWPS.

5. CONCLUSIONS

The proposed method in this paper helps to fix the direction for researchers and the system designers to implement the grid-connected SWPS in the areas where the infrastructure of the grid is available especially in India. Results obtained from this study are in the lines of meeting the objectives of the study. The study about grid-connected SWPS in this paper tells about how the burden on the utility companies in terms of energy can be reduced. In this study, it is observed that the reduction of the burden is almost equal to 8.01M.U per annum on all the feeders in the area of the study. Farmers also can gain the economical benefits through the excess energy that can be supplied to the grid by employing the SWPS. Despite using a single type of pump for irrigation application, a combination of 1.2HP and 5HP has given a good result. Combine the use of pumping systems can limit the constraints when they are solely used.

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