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Optimal Utilization of Hybrid Renewable Energy System with Incentive Based Demand Response Program

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Abstract - Demand response plays a vital role in electricity market to maintain energy balance between supply and load. In this paper Optimal Utilization of Hybrid Energy System with Incentive Based Demand Response Program (DRP) is proposed. Incentive based demand response program is implemented using Hybrid optimization model of electric renewables (HOMER) while optimizing the bidding with minimum cost of energy (COE) , net present cost (NPC) and maximizing the returns. Two incentive sensitivities are analyzed for various configuration of hybrid system. This DRP encourage the consumers to participate and to reduce their peak load. Finally, HOMER based simulations are carried out which shows efficacy of our proposed Incentive Based Demand Response Program.

Keywords: Cost of energy, Demand Response, Energy, Hybrid, Incentive, Net present.

I. Introduction

Due to high prices and diminishing nature of conventional energy sources, renewable energy can be used as an alternate to supply energy demand. In many countries utilities are serving the minimum load with non conventional energy sources. Renewable energy source with storage system has been widely used these years due to their high potential in coping with intermittent generation. Several analysis regarding optimization and modelling of hybrid energy sources have been analyzed from design, control and operation in [1-4]. With high potential for sensitive analysis, simulation and optimization Hybrid optimization model of electric renewables (HOMER) is used in [5] for the integrated renewable energy sources to get least value of energy. Grid connected energy system is optimized using artificial bee colony algorithm and HOMER in [6].

Conventionally power sector is structured as a vertical integrated system utility. But in state like Punjab after restructuring in 2010 jurisdiction of generation and distribution of power comes with Punjab state power corporation limited (PSPCL) and transmission jurisdiction goes with Punjab state transmission corporation limited (PSTCL) [7]. Due to restructuring of power sector, open access becomes feasible for independent power system operators, which leads to competition in electricity market [8].

Smart grids equipped with advance metering infrastructure (AMI) leads to utilization of DRPs in electricity market to maintain energy balance between supply and load. With integration of smart grid with renewable energy system nothing much can be done from supply side, as mainly demand side management is required to match the availability of supply. Issues like privacy in

Incentive based DRPs are presented by [9], ensuring the protection to customers privacy by splitting the meter data and real identity. Incentive based utility cost algorithm is proposed in [10] to address the privacy issue in DRP. Aggregating customers demand framework is proposed in [11] where load reduction requests are effectively handled and participants of DRP are rewarded in incentive based scheme. Incentive mechanism reward to reduce is demonstrated in [12] to reward the tenants through collocation operators, optimum DRP price is obtained using an effective algorithm. Two stage model for optimal bidding with incentive based DRP is presented in [13] while maximizing social welfare. An incentive based

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balanced equilibrium is the proposed in [14] between grid and demand side to minimize procurement cost. Additional incentives are provided to mitigate overloading of system [15] where a framework is proposed to maximize profit of aggregator with consumer welfare. Integrated industrial energy system is proposed in [16] where a three level interaction is presented between supply and demand and provides incentives for curtailing the load. DRP with a flexible approach including Photo Voltaic (PV) system with battery storage is proposed in [17].

This work proposes various aspects of hybrid system along with incentive based DRP and its prospective impression. The aim of proposed study can be framed as below:

- Optimization and utilization of hybrid energy based system with incentive based Demand response program.
- Finding minimum cost of energy (COE) with least Net Present Value (NPV) while minimizing Annualized cost of the system.
- Deciding the suitable configuration of system by sizing of PV, batteries, utility and converter with different demand response incentives.
- Compare economics of the system with the utility bill savings while performing demand response incentives.

II. Problem Formulation

Main purpose of DRPs is to incentivize consumers and encourage them for participation in DR events to reduce their load demands during DR event by shifting their load demand from peak load hours to off peak hours. This paper proposes incentive based Demand Response Program (DRP), which is further classified into two system programs, Normal Demand Response (NDR) and Commercial Demand Response (CDR). NDR, needed 2 hours of advance notification for calling an event, Rs.125 per kW will be paid by utility to consumer for his load reduction. Events can be called between 7:00 AM to 19:00 PM on any day between 01 May to 30 September. (This particular time period is considered due to paddy season in Punjab, India. As energy demand is at peak during paddy season). In CDR, 21 hours prior notification is required for calling an event, consumer will get Rs.100 per kW for reducing his load. Events can be called between 00:00 AM to 19:00 PM on any day between 01 May to 30 September. Simulation sensitivities are carried out by HOMER software [18]. Net Present Cost (NPC) is economically main feature of HOMER output, which is associated with present value of investments costs. The total annualized cost is computed using the annualized value of the total net present cost given in (1)

$$C_{ann,tot} = CRF(i, R_{proj})C_{NPC,tot} \quad (1)$$

where:

$C_{NPC,tot}$ the total net present cost of system[Rs.]
i discount rate annualy [%]
R_{proj} Lifespan of project [yr]
CRF Capital recovery factor.

HOMER calculates discount rate from "Nominal discount rate" and inflation expected rate as shown by (2).

$$i = \frac{D-f}{1+f} \quad (2)$$

where:

D nominal discount rate
f inflation expected rate

To compute value of annuity,capital recovery factor is used as presented by (3) :

$$CRF(i,T) = \frac{i(1+i)^T}{(1+i)^N-1} \quad (3)$$

where:

T number of years.

Expression for cost of energy is given by (4).

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (4)$$

where:

$C_{ann,tot}$ total annualized cost of the system[Rs./yr]
E_{served} electric load served[kwh/yr]

Return on investment (ROI) is given by equation (5)

$$ROI = \sum_{i=0}^{R_{proj}} \frac{C_{i,ref}-C_i}{R_{Proj}\,(C_{cap}-C_{cap,ref})} \quad (5)$$

where:

$C_{i,ref}$ nominal cash flow for base system.
C_i nominal cash flow for current system.
R_{Proj} project lifespan
C_{cap} capital cost of current system.
$C_{cap,ref}$ capital cost of base system.

III. System Design

A. Load estimation

This plan is proposed for an industry having average load of 101.1 kW with average daily consumption of energy 2426.45 kWh/day and peak load is 422.30 kW, at Sirhind having longitude coordinate 30^0 37 N and latitude coordinate 76^0 23 E in Punjab. Proposed plan is connected with grid utility and having a hybrid energy system with PV, converter and energy storage battery as shown in fig.1

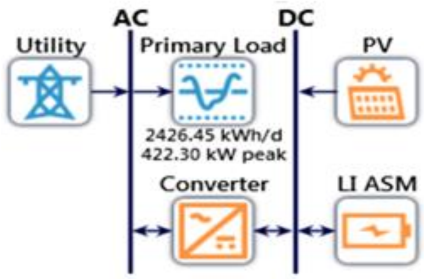

Fig.1 System Portfolio

B. Solar Resource

NASA surface metrology [19] is used for solar resource Global Horizontal Irradiance profile for proposed plan as shown in fig.2 and table 1. Annual average radiation for longitude coordinate 30^0 37 N and latitude coordinate 76^0 23 E is 5.14 kWh/m^2/day. Sufficient amount of irradiance is available in region to generate enough energy through PV system.

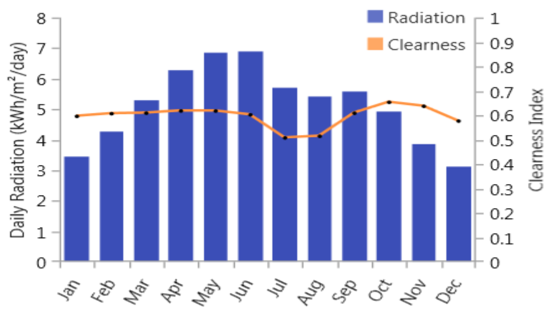

Fig. 2 Global Horizontal Irradiance Profile

Maximum solar radiation availability 6.882 kWh/m^2/day is seen in month of June and minimum solar availability 3.123 kWh/m^2/day is seen in month of December. Table I presents average clearness index and daily radiation profile for each month for the proposed plan.

Table-I: Average clearness index and daily radiation

Month	Clearness index	Daily Radiation (kWh/m^2/day)
January	0.596	3.464
February	0.606	4.281
March	0.609	5.294
April	0.618	6.296
May	0.617	6.859
June	0.602	6.882
July	0.507	5.704
August	0.514	5.395
September	0.609	5.588
October	0.653	4.916
November	0.637	3.873
December	0.576	3.123

C. *Components Details*

For the proposed hybrid energy system various components like PV, converter and energy storage batteries are used. Details of various costs and lifespan of components are given in table-II.

Table-II: Cost Details

Component	Capital cost / kw, Rs.	Replacement cost / kw , Rs.	O &M cost /kw, Rs./Yr	Life Year
PV [5]	70000	63000	0	25
Converter [5]	10500	10500	135	15
Battery Storage [20]	10000	10000	135	10

IV. RESULTS AND DISCUSSIONS

Sensitive analysis having different incentive values with NDR and CDR are presented in all the results. All configurations are compared in same order of NDR and CDR incentive values from table III-VI. Four different configurations having various components and utility along with their sizes are presented in Table III.

Table- III: System Configuration

NDR Rs.	CDR Rs.	PV/ kW	Battery /No.	Utility /kW	Converter /kW
0	0	30	0	1	23.8
0	100	30	15	1	24.8
125	0	30	37	1	39.6
125	100	30	62	1	52.8

Table III shows that the system configuration without incentive value of DRP in both NDR and CDR doesn't need any battery storage bank. But sytem configuration with incentive DRPs needs battery storage bank. Significant increase in no.of batteries and converter system can be seen in results having both DRP incentive values in NDR and CDR.

Table IV presents cost comparison of all configurations.Different combination of incentive values are used in all scenarios. DRP show least value of energy cost, net present cost and minimum operating cost,when both NDR and CDR incentive values are cosidered collectively in fourth configuration.

Table- IV : Cost Comparison

NDR Rs.	CDR Rs.	NPC Rs.	COE Rs.	Operating Cost Rs./ Yr
0	0	86.8M	7.58	6.53M
0	100	86.7M	7.57	6.51M
125	0	86.6M	7.56	6.48M
125	100	86.5M	7.55	6.44M

Table- V presents system metrics which shows that Internal rate of return, return on investment are maximum with incentive value of Rs. 125 in NDR and Rs.100 in CDR when cosidered simultaneously, year payback time is also reduced in the system as compared to other configurations.

Table -V: System Metrics

NDR Rs.	CDR Rs.	IRR %	ROI %	Payback Yrs
0	0	0	0	0
0	100	6.0	3.8	9.5
125	0	7.2	4.6	8.9
125	100	7.9	5.1	8.5

Table- VI System savings are maximum in utility bill, total bill and demand charge when DRP incentive value of Rs. 125 in NDR and Rs.100 in CDR cosidered collectively. There is no savings without any DRP incentive value

Table-VI : System Savings

NDR Rs.	CDR Rs.	Utility Bill Savings Rs./Yr	Total Bill Savings Rs.	Demand Charge Savings Rs./Yr
0	0	0	0	0
0	100	19,000	2,45,626	18,232
125	0	67,748	8,75,809	66,753
125	100	1,21,359	1.57M	1,21,650

Renewable Load Utility Bid Limit

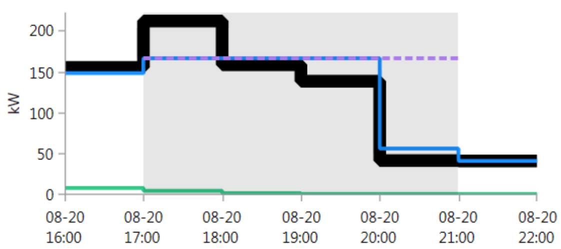

Fig.3 Load Curve Event 20-08-19

Fig.3 shows that the event occurs on 20 August at 17:00 and lasted for four hours. Peak load during event is 212 kW, Actual demand peak is 166 kW. Optimized demand reduction bid is 45.9 kW.

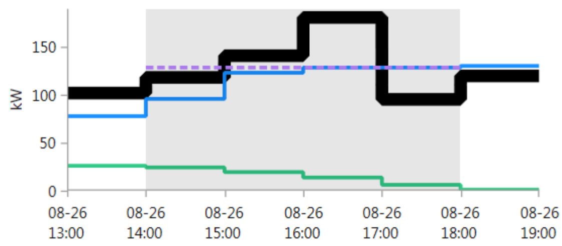

Fig.4 Load Curve Event 26-08-19

Fig.4 presents event of 26 August which occur from 14:00 PM to 18:00 PM. Actual demand peak is 128 kW and peak load during event is 258 kW therefore optimized demand reduction bid is 130 kW.

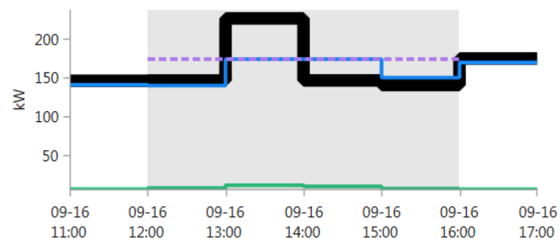

Fig.5 Load Curve Event 16-09-19

Fig.5 shows that the NDR event occur on 16 September from 12:00 PM to 16:00 PM. Actual demand peak is 174 kW and peak load during event is 324 kW therefore optimized demand reduction bid is 150 kW in this case.

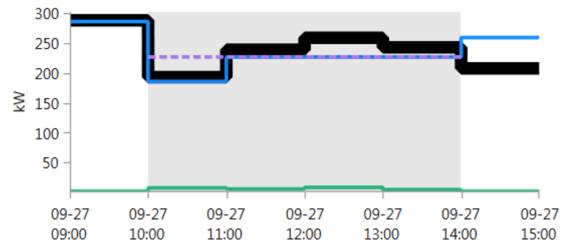

Fig.6 Load Curve Event 27-09-19

Fig.6 shows that the NDR event occurs on 27 September from 10:00 PM to 14:00 PM. Actual demand peak is 226 kW and peak load during event is 259 kW therefore optimized demand reduction bid is 32.7 kW in this case.

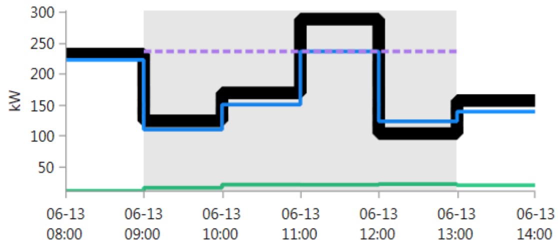

Fig.7 Load Curve Event 13-06-19

Fig.7 shows that the CDR event occurs on 13 June from 09:00 PM to 13:00 PM. Actual demand peak is 235 kW and peak load during event is 288 kW therefore optimized demand reduction bid is 52.8 kW in this case.

Table–VII : NDR events for optimized bidding

NDR Event Date	Peak Load	Actual Load	Optimize demand reduction bid
20-08-19	212 kW	166 kW	45.9 kW
26-08-19	258 kW	128 kW	130 kW
16-09-19	324 kW	174 kW	150 kW
27-09-19	259 kW	226 kW	32.7 kW

Table–VIII : CDR events for optimized bidding

CDR Event Date	Peak Load	Actual Load	Optimize demand reduction bid
13-06-19	288 kW	235 kW	52.8 kW
06-08-19	210 kW	198 kW	11.7 kW
09-09-19	122 kW	42.7 kW	79.1 kW
12-08-19	294 kW	168 kW	126 kW

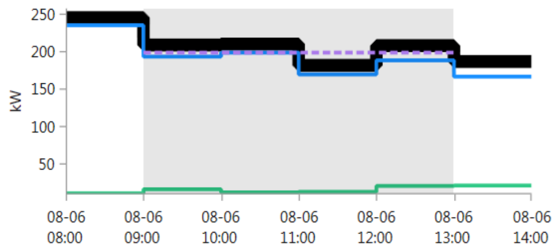

Fig.8 Load Curve Event 06-08-19

Fig.8 shows that the CDR event occur on 06 August from 09:00 PM to 13:00 PM. Actual demand peak is 198 kW and peak load during event is 210 kW therefore optimized demand reduction bid is 11.7 kW in this case.

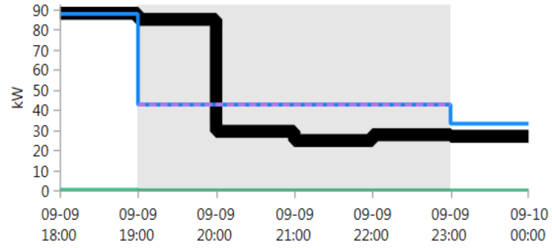

Fig.9 Load Curve Event 09-09-19

Fig.9 shows that the CDR event occurs on 09 September from 19:00 PM to 23:00 PM. Actual demand peak is 42.7 kW and peak load during event is 122 kW therefore optimized demand reduction bid is 79.1 kW in this case.

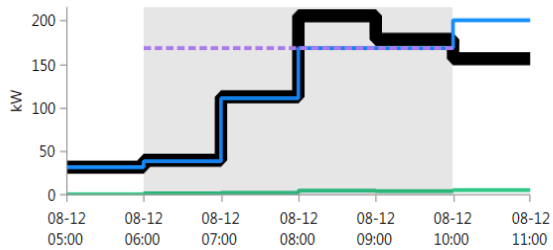

Fig.10 Load Curve Event 12-08-19

Fig.10 shows that the CDR event on 12 August occurs from 06:00 PM to 10:00 PM. Actual demand peak is 168 kW and peak load during event is 294 kW therefore optimized demand reduction bid is 126 kW in this case.

Table VII and VIII summarizes the events in fig.3-10 with their peak load, actual load, and optimize demand reduction bid shown occur during calling an event on various days with DRP incentive value of Rs. 125 in NDR and Rs.100 in CDR, considered collectively.

V. CONCLUSION

This paper presents optimal utilization of hybrid renewable energy system with incentive based demand response programs. Different combinations of demand response incentive programs are applied on various sizing of hybrid configurations and comparison of configurations are carried out. For demand response NDR and CDR are considered while PV and battery storage system is considered in hybrid system. HOMER software is used for sensitive analysis and optimization.

Results show that system sensitivity having incentives values with both incentive programs NDR and CDR considered collectively, is effectively optimizing the bidding with least cost of energy and minimum net present cost. This system is able to reduce payback time and maximize return on investment. Significant savings in utility bill and demand charge shows efficacy of the proposed plan.

In future, proposed hybrid system can be extended with other renewable components like hydel, wind and biogas energy systems and can be compared with other DRP techniques which may improve utility savings.

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