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Integration of Renewable Energy System Solar PV with Diesel

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This paper describe the sizing of solar PV, DG set and battery bank Hybrid Power System (HPS) for different configuration for share of solar &diesel power. Different configurations for integration of solar PV with diesel energy systems are explained in detail. The energy availability and economics of the integrated energy system are highlighted

Key words: *Solar Photovoltaic Energy Systems, Integration of Renewable Energy, Life Cycle Costing, Optimal Hybridization,*

1.0 INTRODUCTION

The design of a Hybrid Power System (HPS) must provide a reliable and cost-effective power supply to the load. The control of HPS is more complicated due to the characteristic of power generation from renewable energy systems vary from one source to other, difficult in prediction of generation because these systems are seasonal and stochastic in nature, scheduling of conventional generators, lack of knowledge on power quality issues, etc.

There are two types of HPS can be adopted based on the level of penetration of renewable energy systems: a) fraction of the total load is supplied by the renewable energy systems i.e., a conventional generator (diesel) will be working continuously. In this system, the reliability and availability of power is good, the control is simple, the fuel savings are modest and a minimum of supervision is needed. b) another option is renewable energy as the main source of energy and conventional generator as a stand-by power. In this case, a complicated controller is essential, reliability and availability factors are modest, fuel savings are good [1].

The conventional PV system has unstable output characteristic dependent on weather conditions in a short period, although PV array output average shows nearly regular characteristics to have a peak output nearly at noon [2]. Therefore, Integration of this solar PV with other renewable energy source or conventional power is an important way of increasing utilization, energetic and exergetic efficiencies of energy conversion systems.

Such integration encounters complexities arising from the diverse nature of the solar energy sources, low energy densities, intermittent availability and stochastic elements. Recent developments in processing, control and management of power are enabling stable operation of solar PV-diesel support integrated systems.

2.0 INTEGRATION OF ENERGY SYSTEMS

The solar power is optimized based on the load requirement and accordingly the size of DG set and battery bank are arrived.

The solar PV and WTG with DG set can be integrated in three different configurations i.e.,

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series, switched and parallel [3], [4], [5]. In series configuration the overall efficiency is low and large capacity of energy storage system is required. The switched and parallel configurations are more suitable for low load, medium load and high load operations [6]. The three modes are [7], [8]:

- Solar PV or WTG with inverter only – low load operation
- DG set and charging battery by DG set power – medium load operation
- Solar PV or WTG with inverter and DG set in parallel – high load operation.

The expert controller is developed using MATLAB SIMULINK tool using the modular concept. The modularity of the controller integrates various types of generators with different priority options, loads, knowledge base system and database. One of the key points of modular concept is to use the high-level abstraction models of HPS. The high-level models shall contain information about their behaviour and interaction that are essential to the expert controller functions such as scheduling of generators, protection of components against overload/underload, ensuring power balance, grid stability, etc.

The controller will control the operation of inverter, battery charger and DG set operation. During start-up the controller chooses inverter only operation, if the notional battery state of charge is above minimum level. When the load increases above the set value, the diesel will be started and introduced in parallel with the inverter. In order to get more efficiency of DG set, it is economical to operate the DG set more than 85 % of its capacity. When the load is less than 85 % of DG set rating the excess power is used to charge the battery bank. Depending on the actual site load, the resulting system operation could involve either load sharing or battery charging. When the load on DG set falls below a chosen value, the system will revert to inverter-only operation [9].

Figure 1 gives the flow diagram of the integrated energy system. The input to the controller are solar (SPV) power or Wind Generator (WTG),

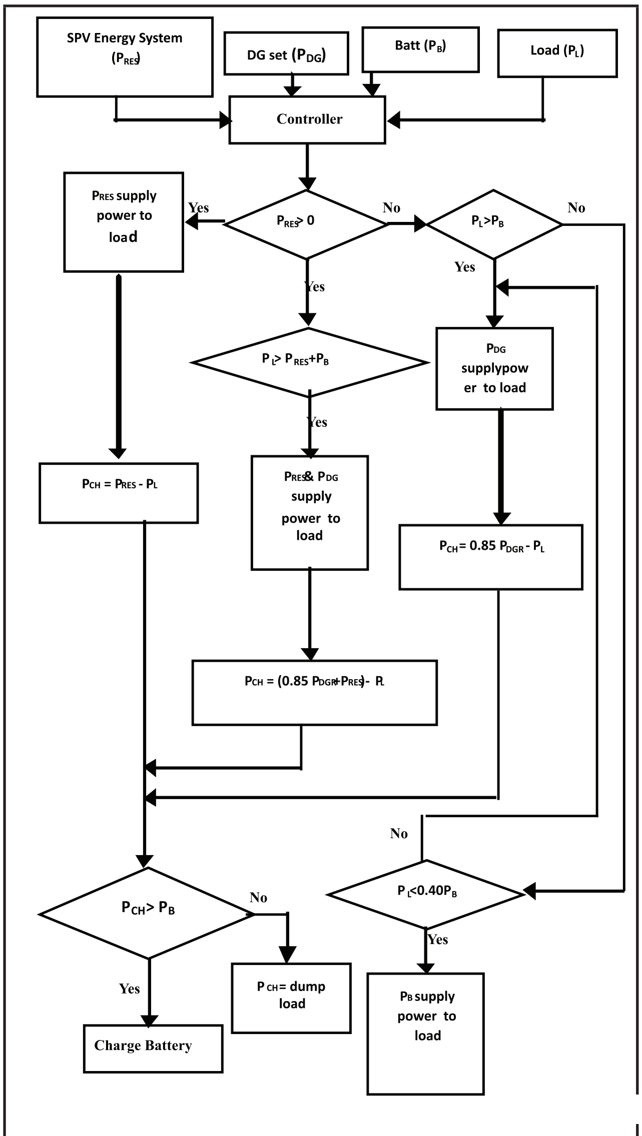

FIG. 1 FLOW DIAGRAM OF INTEGRATION OF ENERGY SYSTEMS

DG set power, Battery power and load. The controller senses the load if solar power or wind power is available, the SPV or WTG supply the power to load. If the SPV or WTG power is not there and load is less than battery charge, the battery provides the power supply to load. If the battery charge is lower than the load, the DG set will start and supply the power to the load. The DG set will always run at 85 % of its rating to get better efficiency. The surplus power of DG set is used to charge the battery. In case, the battery is fully charged, the DG set will operate under partial loading. If the load is more than the sum of SPV or WTG power & Battery charge, the DG set will start and supply the power to load. When the SPV or WTG power is more than load and the battery is fully charged, the power will be drained through dump load, which is a rare case.

3.0 LOAD DETAILS

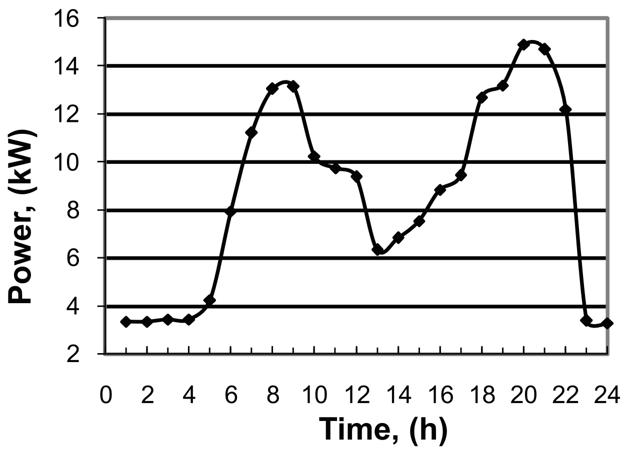

FIG. 2 LOAD PATTERN OF A TYPICAL DAY.

A typical remote hamlet is selected for analysis. The load pattern of a typical day for the selected site is presented in Figure 2 The daily average energy requirement is 206.08 kWh/day and the peak power is 14.9 kW for a typical day. The morning peak is between 0700 to 1000 hours and the evening peak is between 1600 to 2200 hours. The energy ratio between peak to non-peak is 56 %, which is normal. The variation of load throughout the year is computed by using HOMER software [10].

4.0 INTEGRATION CRITERIA

In order to maximize the use of renewable energy system, solar photovoltaic and conventional power (DG set) along with energy storage (Battery bank) three different combinations of Solar PV, DG set and Battery banks are sized to meet the load requirement by using a simulation tool. The optimization is discussed with respect to energy system availability, cost, reliability, operation & maintenance (O&M), pollution and power quality.

4.1 Integration of Solar PV with DG set

Integration of solar PV with DG set is studied for three different configurations:

a) Integration A: Solar PV rating of 8.0 kW, DG set rating of 15.0 kVA and Battery Bank of 4.5 kW & energy of 36 kWh/day

b) Integration B: Solar PV rating of 12.0 kW, DG set rating of 12.5 kVA and Battery Bank of 6.0 kW & energy of 44 kWh/day

c) Integration C: Solar PV rating of 16.0 kW, DG set rating of 10.0 kVA and Battery Bank of 7.0 kW & energy of 51 kWh/day

Table 1 gives the variation of rating and energy supplied by different energy sources for three different combinations.

TABLE 1

VARIATION OF RATING AND ENERGY SUPPLIED BY ENERGY SOURCES.

Sl. No.	Particulars	Integration A	Integration B	Integration C
01	Peak Power Rating of SPV, (kW)	8.0	12.0	16.0
02	Rating of DG set, (kVA)	15.0	12.5	10.0
03	Battery bank capacity (Peak power in kW)/ Energy, (kWh/day)	4.5/36	6.0/44	7.0/51
04	Energy supplied by SPV to load, (kWh/day)	59.58	75.72	84.29
05	Energy supplied by SPV for battery charging, (kWh/day)	2.50	17.55	40.07
06	Total energy supplied by SPV, (kWh/day)	62.08	93.27	124.35
07	Energy supplied by DG set to load, (kWh/day)	110.75	87.11	71.36
08	Energy supplied by DG set for battery charging, (kWh/day)	33.25	25.70	10.36
09	Total energy supplied by DG set, (kWh/day)	144.00	112.81	81.73
10	Energy supplied by Battery bank to load, (kWh/ day)	35.75	43.25	50.43

4.1.1 Integration A

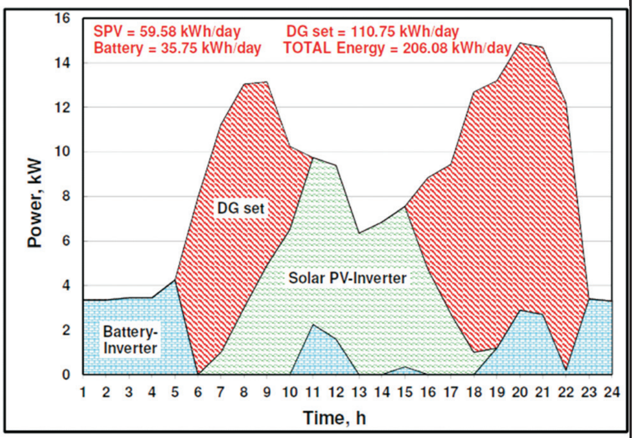

FIG. 3 AVERAGE DAILY ENERGY SUPPLIED BY SPV, DG SET & BATTERY (INT. A)

In this integration minimum solar PV power about 30 % is planned and rest from conventional power. Figure 3 shows the average daily energy supplied by Solar PV, DG set and Battery bank with time for a typical day. The solar energy is supplied during 0700 to 1800 hours. The total energy supplied to load by Solar PV is 28.91 % of total energy requirement and the excess energy is being used for charging the battery bank, which forms 7 % of battery bank capacity. The Battery bank caters the load during 0100 to 0500 hours, 1100 to 1200 hours and 1900 to 2400 hours. The energy supplied to load by Battery bank is 17.35 % of total energy requirement. The DG set is being switched on (when Solar PV power & battery power is less) during 0600 to 1000 hours and 1600 to 2200 hours. The energy supplied by DG set to meet the load forms 53.74 % of total energy requirement and for battery charging is 33.25 kWh/day (93 % of battery bank capacity). Figure 4 shows the variation of battery charging by solar PV and DG set. It can be seen from the Figure that from only 12:00 hours to 15:00 hours (2.50 kWh/day i.e., 7.0 % of battery capacity) when solar radiation is less, the battery will be charged by DG set. During 05:00 to 11:00 hours & 15:00 to 19:00 hours (33.25 kWh/day i.e., 93.0 % of battery capacity), the battery will be charged by solar PV after meeting the load.

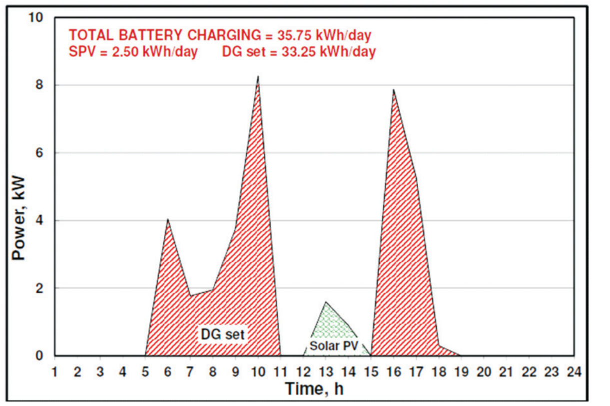

FIG. 4 BATTERY CHARGING BY SPV & DG SET (INT. A)

Figure 5 shows the monthly energy supplied by Solar PV, DG set and Battery bank for typical one year.The total annual energy supplied by SPV is 16.306 MWh/y (21.60 % of total energy) for the load directly and 0.239 MWh/y for battery charging during surplus power. The energy supplied by DG set to load directly is 44.977 MWh/year (59.59 % of total energy) and 16.357 MWh/y for battery charging. The total energy supplied by battery is 13.048 MWh/y(17.29 % of total energy). The unmet load is 1.15 MWh/y (1.52 % of total energy). The round trip efficiency of battery is assumed as 90 % and the battery deep discharge is 40 %.

The average monthly energy generation by SPV and DG set along with share of SPV is presented in Figure 6 The share of SPV is varying between 17.75 % to 27.2 % of total energy supplied to load.

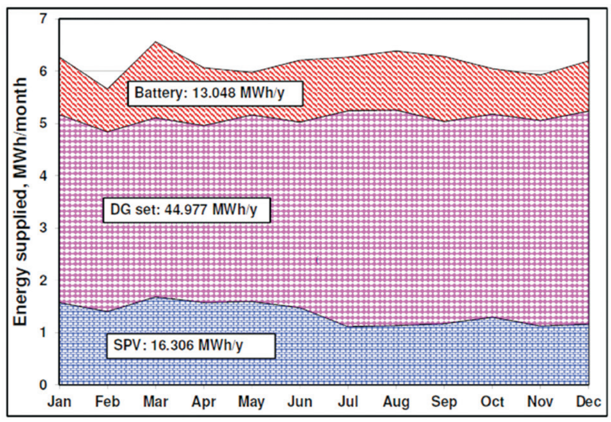

FIG 5 MONTHLY ENERGY SUPPLIED TO LOAD BY SPV, DG SET & BATTERY (INT. A)

TABLE 2						
LIFE CYCLE COST ANALYSIS FOR INTEGRATION A.						
Component	**Initial cost, (Rs in lakhs)**	**Annual-ized capital cost, (Rs in lakhs./y)**	**Annualized replacement cost, (Rs. in lakhs /y)**	**Annual O&M cost, (Rs. in lakhs /y)**	**Annual fuel cost, (Rs. in lakhs /y)**	**Total Annu-alized cost (Rs. in lakhs /y)**
Solar PV	14.4000	1.9279	0.0000	0.0050	0.0000	1.9329
DG set	4.5000	0.6025	0.1184	0.0000	11.3986	12.1195
Battery	1.0000	0.1339	0.0018	0.0033	0.0000	0.1390
Inverter	0.8750	0.1171	0.0019	0.0063	0.0000	0.1253
Total	20.7750	2.7814	0.1221	0.0146	11.3986	14.3167
Levelized cost of energy : Rs. 19.26 per kWh						

Table 2 gives the life cycle cost analysis of the system for integration A. The total initial investment is Rs. 20.78 lakhs, the total annualized cost is Rs. 2.78 lakhs per year. The levelized cost of energy generation is Rs. 19.26 per kWh with average SPV share of 22.43 %.

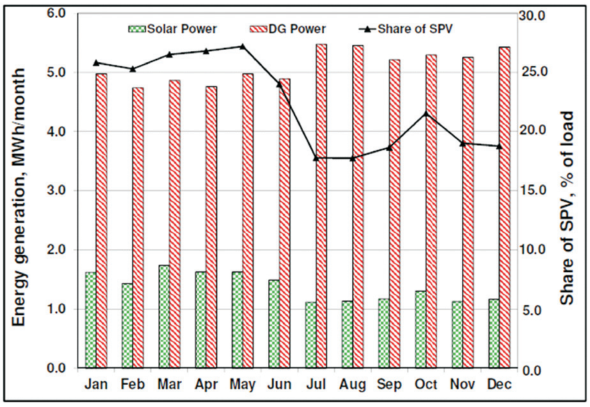

FIG. 6 AVERAGE MONTHLY ENERGY SUPPLIED & SHARE OF SPV, DG SET & BATTERY ENERGY (INT. A).

4.1.2 Integration B

In this integration, the size of SPV is increased to 12.0 kW, so the power requirement by conventional energy source (DG set) is reduced to 12.5 kVA and the battery bank size has been increased.

Figure 7 shows the energy supplied by Solar PV, DG set and Battery bank with time for a typical day. The solar energy is supplied during 0700 to 1800 hours. The total energy supplied to load by Solar PV increased to 36.74 % of total energy requirement and the excess energy is being used for charging the battery bank, which is also increased to 40.58 %. The Battery bank caters the load during 0100 to 0500 hours and 1800 to 2400 hours. The energy supplied to load by Battery bank is increased to 20.99 % of total energy requirement. The DG set is being switched on during 0600 to 1000 hours and 1600 to 2200 hours. The energy supplied by DG set to meet the load is reduced to 42.27 % of total energy requirement and for battery charging is also reduced to 59.42 %. Figure 8 shows the variation of battery charging by solar PV and DG set. It can be seen from the Figure that from 07:00 hours to 10:00 hours and 15:00 to 18:00 hours (17.55 kWh/day i.e., 40.6 % of battery capacity) when solar radiation is less, the battery will be charged by DG set. During 10:00 to 16:00 hours (25.70 kWh/day i.e., 59.4 % of battery capacity), the battery will be charged by solar PV after meeting the load.

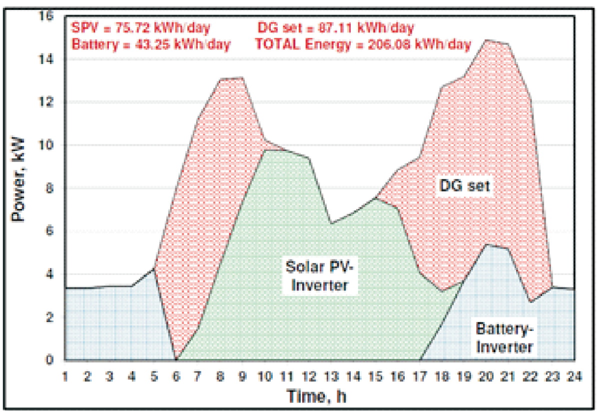

FIG. 7 AVERAGE DAILY ENERGY SUPPLIED BY SPV, DG SET & BATTERY (INT. B)

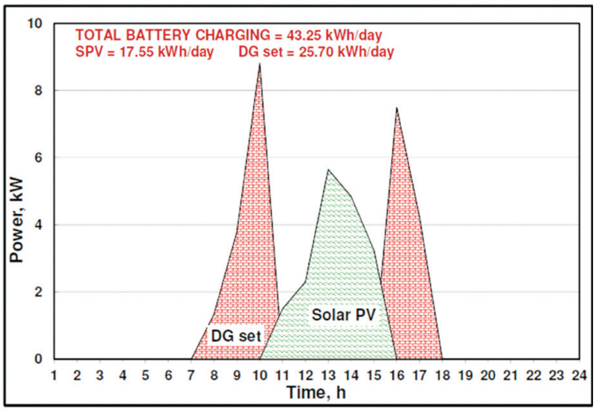

FIG. 8 BATTERY CHARGING BY SPV & DG SET (INT. B)

Figure 9 shows the monthly energy supplied by Solar PV, DG set and Battery bank for typical one year.The total energy supplied by SPV is 22.155 MWh/y (29.35 % of total energy) for the load directly and 2.754 MWh/y for battery charging during surplus power. The energy supplied by DG set to load directly is 38.004 MWh/year (50.35 % of total energy) and 14.722 MWh/y for battery charging. The total energy supplied by battery is13.693 MWh/y (18.14 % of total energy). The unmet load is 1.63 MWh/y (2.16 % of total energy).

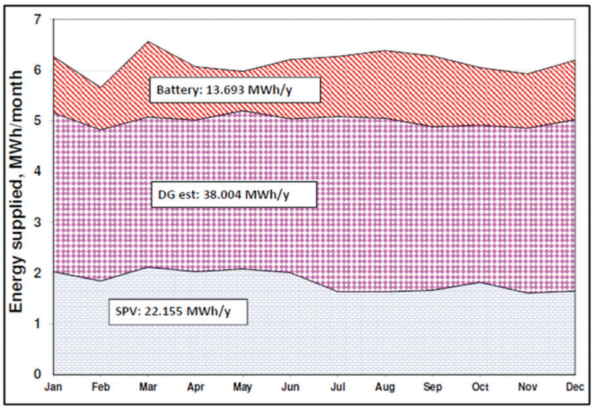

FIG. 9 MONTHLY ENERGY SUPPLIED TO LOAD BY SPV, DG SET & BATTERY (INT. B)

The average monthly energy generation by SPV and DG set along with share of SPV is presented in Figure 10. The share of SPV is varying between 26.64 % to 40.80 % of total energy supplied to load.

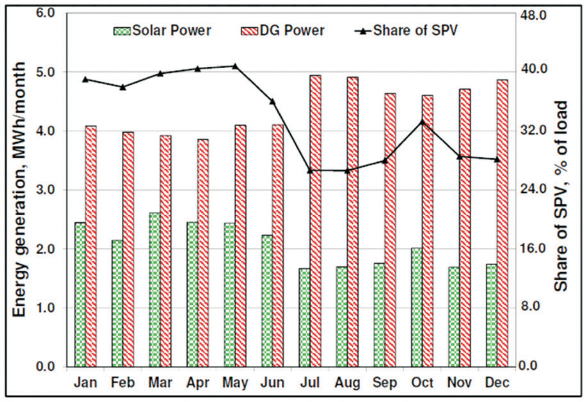

FIG.10 AVERAGE MONTHLY ENERGY SUPPLIED & SHARE OF SPV, DG SET & BATTERY ENERGY (INT. B).

Table 3 gives the life cycle cost analysis of the system for configuration B. The total initial investment is Rs. 27.73 lakhs, the total annualized cost is Rs. 3.71 lakhs per year. The levelized cost of energy generation is Rs. 18.07 per kWh with average SPV share of 33.04 %.

4.1.3 Integration C

In this integration, the size of SPV is increased to 16.0 kW, so the power requirement by conventional energy source (DG set) is reduced to 10 kVA and the battery bank size has been increased.

Figure 11 shows the energy supplied by Solar PV, DG set and Battery bank with time for a typical day. The solar energy is supplied during 0700 to 1800 hours. The total energy supplied to load by Solar PV increased to 40.9 % of total energy requirement and the excess energy is being used for charging the battery bank, which is also increased to 79.46 %. The Battery bank caters the load during 0100 to 0700 ho urs and 1800 to 2400 hours. The energy supplied to load by Battery bank is increased to 24.47 % of total energy requirement. The DG set is being switched on during 0600 to 0900 hours and 1700 to 2200 hours. The energy supplied by DG set to meet the load is reduced to 34.63 % of total energy requirement and for battery charging is also reduced to 20.54 %. Figure 12 shows the variation of battery charging by solar PV and DG set. It can be seen from the Figure that from 07:00

TABLE 3						
LIFE CYCLE COST ANALYSIS FOR INTEGRATION B.						
Component	**Initial cost, (Rs in lakhs)**	**Annual-ized capital cost, (Rs in lakhs./y)**	**Annualized replacement cost, (Rs. in lakhs /y)**	**Annual O&M cost, (Rs. in lakhs /y)**	**Annual fuel cost, (Rs. in lakhs /y)**	**Total Annu-alized cost (Rs. in lakhs /y)**
Solar PV	21.6000	2.8918	0.0000	0.0050	0.0000	2.8968
DG set	3.7500	0.5021	0.0915	0.0000	9.5238	10.1173
Battery	1.5000	0.2008	0.0029	0.0033	0.0000	0.2070
Inverter	0.8750	0.1171	0.0019	0.0042	0.0000	0.1232
Total	**27.7250**	**3.7118**	**0.0962**	**0.0125**	**9.5238**	**13.3443**
Levelized cost of energy : Rs. 18.07 per kWh						

hours to 10:00 hours and 16:00 to 18:00 hours (10.36 kWh/day i.e., 20.5 % of battery capacity) when solar radiation is less, the battery will be charged by DG set. During 09:00 to 16:00 hours (40.07 kWh/day i.e., 79.5 % of battery capacity), the battery will be charged by solar PV after meeting the load.

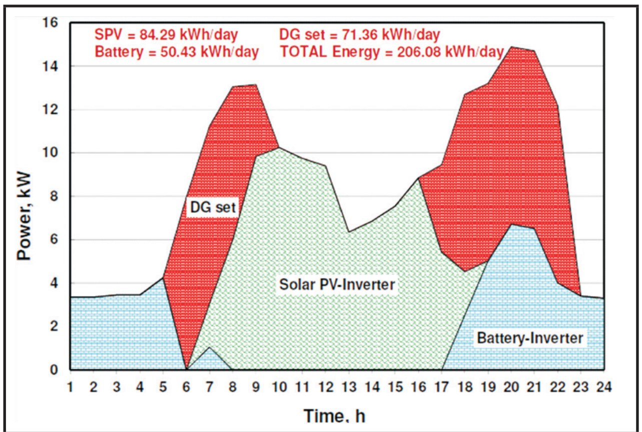

FIG.11 AVERAGE DAILY ENERGY SUPPLIED BY SPV, DG SET & BATTERY (INT. C)

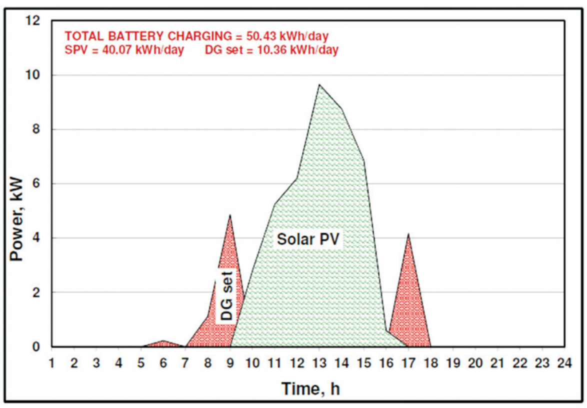

FIG.12 BATTERY CHARGING BY SPV & DG SET (INT. C)

Figure 13 shows the monthly energy supplied by Solar PV, DG set and Battery bank for typical one year.The total energy supplied by SPV is 25.433 MWh/y (33.69 % of total energy) for the load directly and 7.74 MWh/y for battery charging during surplus power. The energy supplied by DG set to load directly is 32.843 MWh/year (43.51 % of total energy) and 11.07 MWh/y for battery charging. The total energy supplied by battery is14.751 MWh/y (19.54 % of total energy). The unmet load is 2.46 MWh/y (3.25 % of total energy).

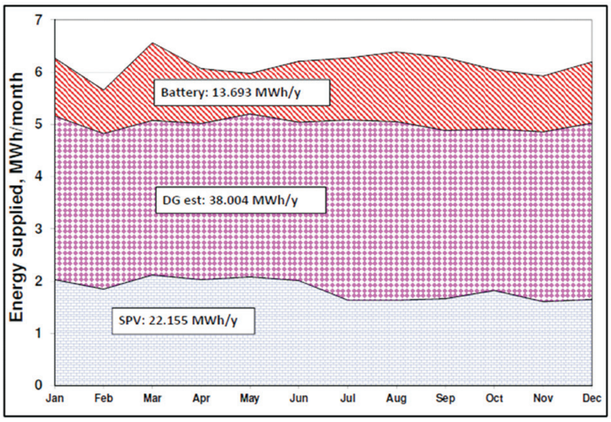

FIG. 13 MONTHLY ENERGY SUPPLIED TO LOAD BY SPV, DG SET & BATTERY (INT. B)

The average monthly energy generation by SPV and DG set along with share of SPV is presented in Figure 14. The share of SPV is varying between 35.51 % to 54.40 % of total energy supplied to load.

TABLE 4

LIFE CYCLE COST ANALYSIS FOR INTEGRATION C.

Component	Initial cost, (Rs in lakhs)	Annualized capital cost, (Rs in lakhs./y)	Annualized replacement cost, (Rs. in lakhs /y)	Annual O&M cost, (Rs. in lakhs /y)	Annual fuel cost, (Rs. in lakhs /y)	Total Annualized cost (Rs. in lakhs /y)
Solar PV	28.8000	3.8557	0.0000	0.0500	0.0000	3.9057
DG set	3.0000	0.4016	0.0663	0.0000	7.6402	8.1081
Battery	2.0000	0.2678	0.0063	0.0033	0.0000	0.2774
Inverter	1.3125	0.1757	0.0028	0.0047	0.0000	0.1832
Total	**35.1125**	**4.7008**	**0.0754**	**0.0580**	**7.6402**	**12.4745**
Levelized cost of energy : Rs. 16.81 per kWh						

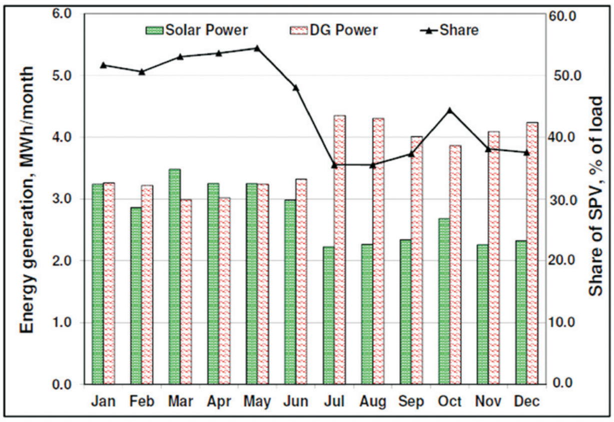

FIG. 14 AVERAGE MONTHLY ENERGY SUPPLIED & SHARE OF SPV, DG SET & BATTERY ENERGY (INT. C).

Table 4 gives the life cycle cost analysis of the system for integration C. The total initial investment is Rs. 35.11 lakhs, the total annualized cost is Rs. 4.70 lakhs per year. The levelized cost of energy generation is Rs. 16.81 per kWh with average SPV share of 44.02 %.

Figure 15 gives the variation of share of SPV with higher penetration of solar energy in integration. It can be seen from the figure that as the sizing of SPV increases the share of energy supplied by SPV increases.

Figure 16 shows the variation of initial capital investment and annualized cost for different configuration. Both initial capital investment and annualized cost increase with the increase of share of SPV.

Figure 17 presents the variation of levelized cost of energy with share of SPV. The cost of

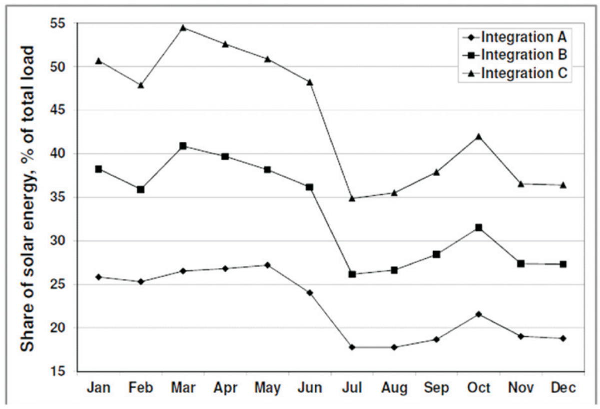

FIG. 15 SHARE OF SPV WITH SIZE OF SOLAR PV SYSTEM.

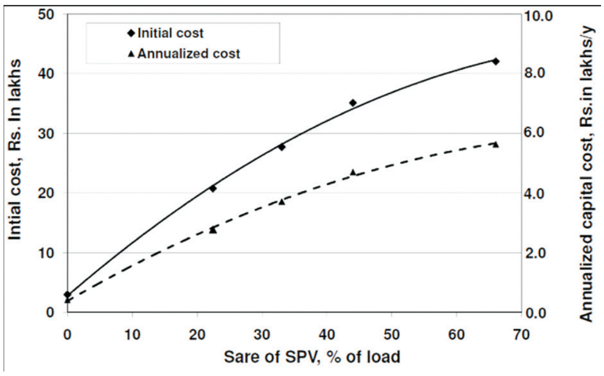

FIG. 16 CAPITAL INVESTMENT & ANNUALIZED CAPITAL INVESTMENT FOR SPV

energy per unit decreases as the share of SPV increases to upto 44 % and then increases may be due to higher initial investment but again it depends on the cost of diesel price (present diesel cost is taken as Rs. 45.0 per litre). If the diesel cost increases the LCOE decreases with increase in share of SPV. Figure 18 gives share of SPV, DG set, Battery & unmet load. As the share of SPV increases the unmet load increases because uncertainty factor increases.

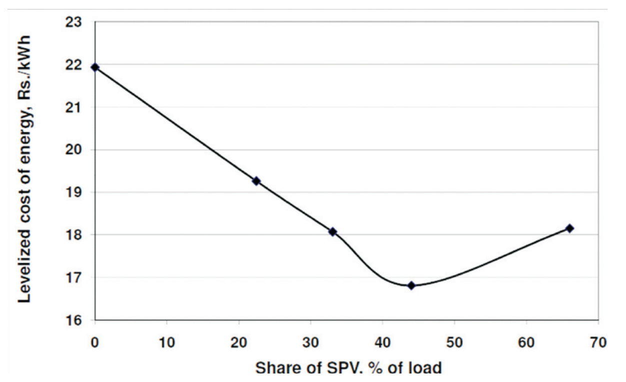

FIG. 17 LEVELIZED COST OF ENERGY OF SPV

5.0 CONCLUSIONS

The integration of Solar PV with conventional power i.e., DG set along with storage battery works out to be lower compared to only DG set operation because of higher diesel cost. At present the cost of generation for DG set is Rs. 21.93 per kWh including O&M and other cost. As the share of SPV increases upto 44 % the LCOE decreases and then increases due to higher initial cost. As the sizing of SPV increases, the share of SPV increases, the share of DG set decreases, the energy supplied by battery increases and the unmet load also increases. For integration, again as the diesel cost increases, the LCOE also increases. Since the cost of diesel is increasing drastically, the solar PV – diesel integration may become economical at later dates.

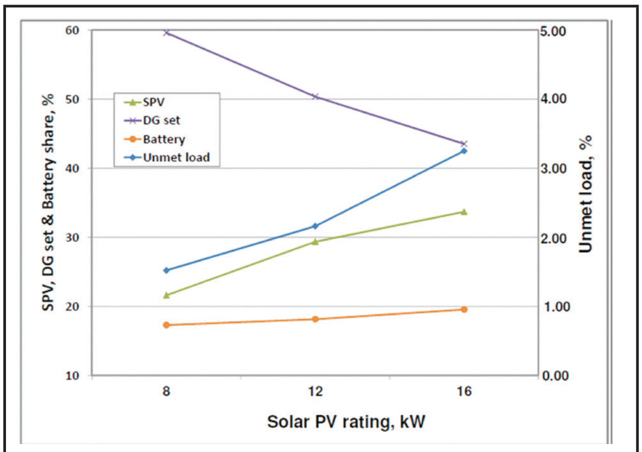

FIG. 18 SHARE OF SPV, DG SET, BATTERY & UNMET LOAD

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