Impact Of Integrating Biogas And Canal Based Small Hydropower Plants In A Hybrid Power System

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Abstract - In evolving countries like India, there is a swift growth in load and energy demand due to heavy industrial development, urbanization and economy rise. Most of this demand is met through power generation from conventional sources which have adverse environmental impact. Renewable energy resources provide a good alternative but lack of continuous generation, high initial cost, complex control, conversion between AC and DC generation, grid integration etc. are some of the drawbacks associated with renewable energy sources. To overcome these disadvantages and to efficiently utilize the available energy resources, a hybrid power system combining the advantages of individual power sources, can be seen as a preferred option to generate and deliver power. In this paper, an attempt has been made to perform techno-economic analysis of a hybrid power system existing in an educational facility with conventional grid power supply, diesel generator and photovoltaic generation and the results are summarized. An augmentation for the existing system has been proposed with biogas and small hydropower generation systems as these resources are available within the accessible limits of the study area.

Keywords – biogas, small hydropower, hybrid power system, renewable energy, grid integration, techno-economics.

1. INTRODUCTION

Electricity is the crucial part for industrialization, development, economic growth and enhancement of excellence of life in society [1]. India is world's 3rd largest producer and the 4th largest consumer of electricity. In order to reduce the use of fossil fuels, the most feasible way out is to increase our reliance on Renewable Energy Sources (RES) [2]. The isolated rural areas can be electrified by RES as in many cases extension of grid to these areas is uneconomical [3]. Apart from electrification of individual house hold by renewable energy, Integrated Renewable Energy System (IRES), distributed generation & Hybrid Power System (HPS) can also be developed to supply power. These require the information of constraints like existing technologies, available government policies, customer requirement and resource limitations [4, 5]. In order to reduce the complexity of operation and increase efficiency, power system has changed from regulated or vertical mode of operation to deregulated mode of operation. There are many causes that fueled the concept of deregulation of the power industry. One major thought that prevailed during the early nineties raised questions about the performance of monopoly services. Due to initiation of deregulated power system many different types of power systems and sub-systems came into existence viz. smart grid, micro grid, distributed generation, IRES, HPS etc [6]. Each system has its own benefits and also complexities in coordinated operation with main grid. In the present study, HPS is opted because it is the integration of the RES along with the conventional sources. The main purpose of the HPS is to combine multiple energy sources and/or storage devices which are complement of each other. Thus, higher efficiency can be achieved by taking the advantage of each individual energy source and/or device while overcoming their limitations [7]. In this paper, an attempt has been made to perform techno-economic analysis of a hybrid power system in an educational facility with conventional grid power supply, diesel generator, photovoltaic generation and proposed biogas and canal based small hydropower plants. The results summarized provide information regarding load assessment, simulation studies and economic evaluation of existing hybrid power system along with the proposed new biogas power generation system. These results are useful in understanding the operational techno economics of the existing system, devise more efficient operation and maintenance strategies, which finally reduce the dependence on conventional sources for energy needs and increase renewable energy utilization.

Study Area

GMR Institute of Technology (GMRIT) is an academic institution catering to the needs of engineering education, situated in Rajam, a small remote town in Andhra Pradesh state of India having the geographical co-ordinates of 18.4665 N, 83.6608 E. GMRIT is established in the year 1997 by the GMR Varalakshmi foundation, the Corporate Social Responsibility (CSR) wing of GMR Group. At inception, the institute has five blocks with a total connected load of nearly 700 kW. At present GMRIT has a total connected load of 1450 kW. The existing power supply system in GMRIT is a HPS. The choice of the site has been taken from the fact that it is the only educational institution having a HPS in Srikakulam district of Andhra Pradesh state with Net Metering method provided by the Eastern Power Distribution Company of Andhra Pradesh Limited (APEPDCL), supplying power through 11kV bus interconnection

The load profile of the present study area is characterized by annual electricity consumption of 5248 kWh/d, peak load of 501 kW and a load factor of 43.7%. In this analysis, the day to day & time step to time step random variability of load is taken as zero. The energy requirement varies daily and monthly depending on several factors like work break hour, institute operating time, vacations, events and seasonal changes. a 700 kW PV plant has been installed with a capital (replacement) cost and O&M cost of $812405 and $2660 respectively. A life span of 20 years has been considered for PV panels without tracking devices. The PV arrays are installed with an inclination angle equal to the latitude of the site i.e 18.98^{o} [8]. Two generators of rating 500 kVA and and peak load power respectively, under emergency conditions. The capital (replacement) cost and operation & maintenance cost of generators are $44873 & $29915 and $1.079 & $0.820 for higher and lower rating respectively. A life time of 15000 operating hours has been considered with a minimum and maximum load ratio of 30% and 80 % respectively. 380 kVA have been installed in the premises to generate base. To facilitate the power flow between AC and DC components, a 750kW converter was installed with a capital (replacement) cost of $28046. The converter is operated at 100% capacity relative to inverter and it can also operate simultaneously with an AC generator [9]. Grid interconnection of the existing HPS is facilitated by DISCOM with different tariffs via. normal tariff and time of day (TOD) tariff. Normal tariff will be charged by the DISCOM between 00:00 to 18:00 & 22:00 to 00:00 daily at a rate of 0.112 $/kWh and TOD tariff will be charged daily from 18:00 to 22:00 at a rate of 0.130 $/kWh. The fixed demand charge per kVA will be charged at a rate of 5.55 $/kVA.

Proposed New Generation Sources

Biogas

Nowadays, biogas is one of the most popular renewable energy which can produce combustible gas through biological degradation of organic compounds known as anaerobic digestion in educational institutions. The composition of biogas is mainly methane (50- 75%), carbon dioxide (25-50%), nitrogen (0-10%), hydrogen (0-1%) and hydrogen sulphide (0-3%). It is a colorless, odorless gas and burns in similar way as natural gas. Raw materials for biogas are cow dung, poultry manure, agricultural residues, municipal waste, fish waste, water hyacinth etc. which are high in organic content. The whole anaerobic digestion process can be divided into three steps: hydrolysis, acidification, and methane formation. Mainly three types of bacteria are involved in the whole process. There are two types of anaerobic digestion; Mesophilic digestion (35-40°C) and Thermophilic digestion (55-60°C). Mesophilic digestion tends to be more robust and tolerant than the thermophilic process but gas production is less. A successful pH range for anaerobic digestion is 6.0 - 8.0 and carbon-nitrogen ratio (C/N) close to 30:1 for achieving an optimum rate of digestion. Biogas potential can be assessed by the food waste from the faculty quarters, canteen and hostels of the institute. It has found that a 100 Kg of food waste is daily getting from the faculty quarters, canteen and hotels. The monthly biomass resource of the food waste is shown in Figure 1. In order to assess the biogas potential, the assessment of biogas is done on the basis of food waste. Here collection efficiency is assumed to be 70%, gas yield per kg of wet dung 0.56m3/kg, calorific value of biogas is 4700kcal/m3, conversion factor is 860, generator efficiency as 28%, generator efficiency 95% and the diesel engine efficiency as 28%. Methane content of few waste substrates is shown in Table 1 [9].

From these values the total gas yield and energy yield can be calculated as:
Total Gas Yield (m^3) = (Gas yield per kg of wet food waste) * (Total food waste availability) = (0.56) * (100) = 56 m^3

Energy yield (kWh/d) = (Total gas yield (m^3))* (calorific value of biogas)* (Diesel generator efficiency)*(Generator efficiency) = (56*4700*0.28*0.95)/(860) = 81.40 kWh/d
Power (kW) = Energy/time = 81.40/24 = 3.39 kW.

By considering the further extension of the institute, it has been proposed that a 5kW biogas power plant has been proposed. The capital cost, replacement cost and operation and maintenance cost of the biogas power plant was considered as $ 8333, $7083 and 0.15$/hr respectively.

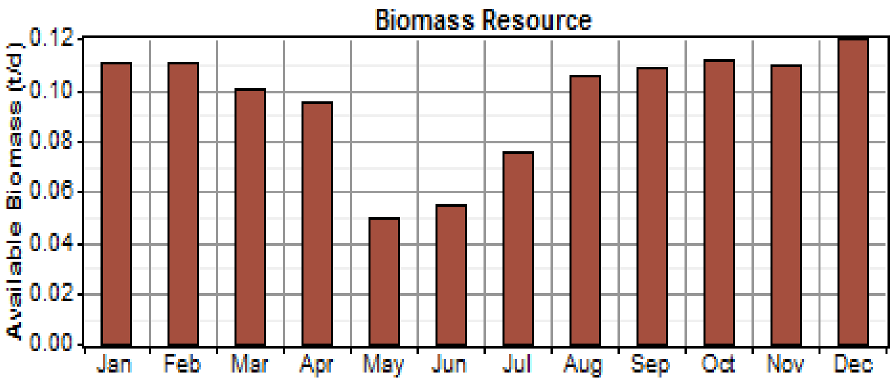

Figure 1. Monthly biomass resource from food waste

Table 1. Methane content of few waste substrates

Substrate	**Biogas yield (m3/kg)**
Pig Manure	0.25 - 0.50
Cow Manure	0.2 - 0.3
Human Excreta	0.3 cu.m/Person
Chicken food waste	0.35 - 0.6
Food waste	0.5 – 0.6
Fruit and vegetable waste	0.25 – 0.5
Garden waste	0.2 - 0.5
Leaves	0.1 - 0.3

1.2 Canal based small hydropower

Small Hydropower (SHP) is the highest density energy resource and more efficient compared to other renewable sources of energy. Hydraulic turbines convert the pressure of water into mechanical power of shaft, which is further used to drive an alternator, or other machinery. The power obtainable is proportional to the product of pressure, head and volume flow rate. The universal formula for any hydro system's generated power output is given by Eq. (1).

$P = \eta \rho g Q H$ ----- (1)

Where, P is the mechanical power produced at the turbine shaft (kW), η is the hydraulic efficiency of the turbine, ρ is the density of water (kg/m3), g is the acceleration due to gravity (m/s2), Q is the volume flow rate passing through the turbine (m3/s), and H is the effective pressure head of water across the turbine (m). Hydraulic efficiencies in the range of 80 to over 90% (higher than most other prime movers) are available with the present day turbine manufacturing technologies [10].

A potential canal based SHP site is available 5km away from the study area. If an interconnection can be made in cooperation with government, DISCOM and the institute to reap the benefits of this SHP, it would be environmental friendly initiative towards sustainability by the institute as well as reduce the dependence of the institute on grid (fossil fuel based power generation) for its energy needs. The design flow rate is estimated to be 736 l/s and gross head available is 5m. The capital cost including interconnection costs is estimated to be 65000$. Operation & maintenance cost of 1% of capital cost, replacement cost of 50% of capital cost and an operational life of 40 years has been considered.

Simulation

In this study, two different types of HPS configurations have been considered for analysis purposes. The models employ a combination of generating sources in each case and the results obtained are analyzed based on technical, economic and environmental parameters such as Cost of Energy (COE), Net Present Cost (NPC), Renewable Fraction (RF) and carbon emissions.

Diesel Generation/PV/Grid

Figure 2 illustrates the diesel generator/ PV/grid configuration. Three combinations of DG capacities have been considered i.e., 380 kW, 500 kW and 880 kW. PV capacities of 0 kW and 700 kW has been considered. According to Andhra Pradesh State Electricity Regulatory Commission (APSERC), the sell back price/kWh of a system is $0.106818.

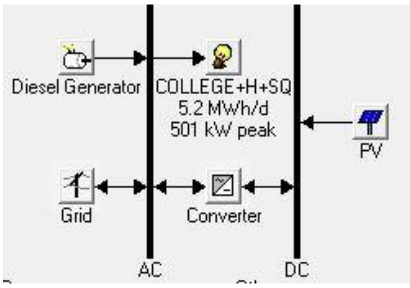

Figure 2. DG/PV/Grid

Diesel Generator/PV/Grid/Biogas/SHP

From figure 3 it can be understood that the diesel generator, PV system, grid details are same as mentioned earlier but it has been propose to design and install a 5 kW biogas and 30.7kW SHP plant for the institute.

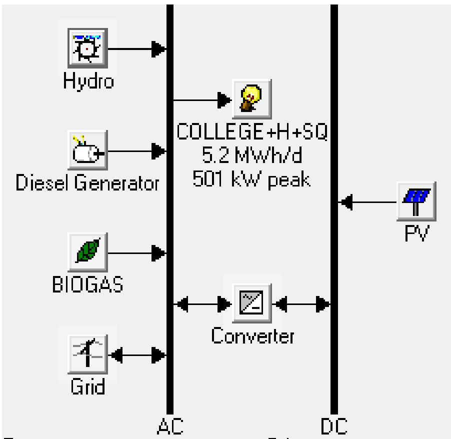

Figure 3. Grid/diesel generator/PV/Biogas/SHP

2. RESULTS

In this section techno economic analysis has been done for the two configurations mentioned in Section 4. Techno economic evolution incorporates optimization studies taking into consideration various combinations of available energy generating resources and gives various parameters as output. In this study, COE has been considered to identify the best optimized operating schedule. The results of techno economic evaluation have been presented in Tables 2 and 3 below.

Table 2: Optimized results of DG/PV/Grid

PV (kW)	**DG (kW)**	**Converter (kW)**	**Grid (kW)**	**Initial capital ($)**	**Operating cost ($/yr)**	**Total NPC ($)**	**COE ($/kWh)**	**RF**	**Diesel (L)**	**Label (hrs)**
700	--	500	700	834,453	1,57,577	2,516,551	0.125	0.51	--	--
700	--	750	700	843,802	1,56,830	2,517,922	0.125	0.51	--	--
--	--	--	700	0	2,59,654	2,771,748	0.138	0	--	--
--	--	250	700	825,105	1,85,329	2,803,455	0.139	0.48	--	--
700	380	500	700	864,368	2,03,613	3,037,888	0.151	0.51	66,321	1,126
700	380	750	700	873,717	2,02,865	3,039,260	0.151	0.51	66,321	1,126
700	500	500	700	879,326	2,18,473	3,211,476	0.159	0.5	87,265	1,126
700	***500***	***750***	***700***	***888,675***	***2,17,726***	***3,212,848***	***0.16***	***0.5***	***87,265***	***1,126***
700	380	250	700	855,020	2,31,365	3,324,792	0.165	0.47	66,321	1,126
--	500	--	700	48,224	3,20,887	3,473,617	0.172	0	87,265	1,126
700	500	250	700	869,978	2,46,226	3,498,380	0.174	0.47	87,265	1,126
700	880	500	700	926,693	2,65,528	3,761,147	0.187	0.48	1,53,586	1,126
700	880	750	700	936,042	2,64,781	3,762,519	0.187	0.48	1,53,586	1,126
--	880	--	700	95,591	3,67,942	4,023,288	0.2	0	1,53,586	1,126
700	880	250	700	917,345	2,93,281	4,048,051	0.201	0.45	1,53,586	1,126

Table 3: Optimized results of DG/PV/Grid/Biogas/SHP

S.No.	**PV (kW)**	**Hydro (kW)**	**DG (kW)**	**BGAS (kW)**	**Con (kW)**	**Grid (kW)**	**Initial capital $**	**Operating cost ($/yr)**	**Total NPC**	**COE ($/kWh)**	**RenF**	**diesel (L)**	**Bmas(t)**	**DG (hrs)**	**BGAS (hrs)**
1	700	30.7		5	750	700	917,135	1,45,022	2,533,688	0.12	0.56		22		2,903
2	700	30.7			750	700	908,802	1,45,804	2,534,072	0.12	0.55				

3		30.7		5		700	76,684	2,47,566	2,836,284	0.135	0.06		23		2,920
4		30.7				700	68,351	2,48,416	2,837,428	0.135	0.05				
5	700	30.7	380	5	750	700	947,050	1,83,695	2,994,687	0.142	0.56	64,554	22	1,096	2,903
6	700	30.7	380		750	700	938,717	1,84,477	2,995,070	0.142	0.55	64,554		1,096	
7	**700**	**30.7**	**500**	**5**	**750**	**700**	**962,008**	**1,96,111**	**3,148,044**	**0.15**	**0.55**	**84,940**	**22**	**1,096**	**2,903**
8	700	30.7	500		750	700	953,675	1,96,893	3,148,427	0.15	0.55	84,940		1,096	
9		30.7	380	5		700	106,599	2,86,238	3,297,283	0.157	0.06	64,554	23	1,096	2,920
10		30.7	380			700	98,266	2,87,089	3,298,427	0.157	0.05	64,554		1,096	
11		30.7	500	5		700	121,557	2,98,654	3,450,640	0.164	0.05	84,940	23	1,096	2,920
12		30.7	500			700	113,224	2,99,504	3,451,784	0.164	0.05	84,940		1,096	
13	700	30.7	880	5	750	700	1,009,375	2,35,434	3,633,745	0.173	0.53	1,49,494	20	1,096	2,600
14	700	30.7	880		750	700	1,001,042	2,36,208	3,634,035	0.173	0.52	1,49,494		1,096	
15		30.7	880	5		700	168,924	3,37,977	3,936,331	0.187	0.05	1,49,494	20	1,096	2,617
16		30.7	880			700	160,591	3,38,819	3,937,391	0.187	0.04	1,49,494		1,096	

3. CONCLUSIONS

In this paper, the techno economic analysis of a HPS has been carried out by considering two configurations. From Table 2 it can be observed that, among all the optimized results, the result with 700 kW PV, 500 kW Diesel Generator, 700 kW grid and converter with 750 kW is chosen as the optimized one. Considering the worst case scenario of grid failure, the 500 kW DG is sufficient to supply the required load demand. If further, load is increased DG cannot meet the demand and load shedding has to be done for insignificant loads. Although 880 kW DG is available which can accommodate the load increase, it is not considered as optimal due the capital cost which is two times when compared to 500 kW DG capital cost. During day time PV system is sufficient to meet the load. During night time the load is approximately 300 kW. Therefore, DG of 500 kW is sufficient to meet the load. Further, by utilizing the available resources, a new biogas and small hydropower energy systems has been designed and proposed. From Table 3 it can be observed that, the result with 700 kW PV, 500 kW DG, 5 kW biogas, 30.7 kW SHP, 750 kW converter and 700 kW Grid chosen as the optimized one. A cost of electricity of COE of $0.16 and $0.15 has been obtained for configurations 1 & 2 respectively. **C**onsidering the worst case scenarios such as grid failure during night hours, unavailability of PV generation during nights and also to ensure reliable and continuous supply, configuration 2 i.e. DG/PV/Grid/Biogas/SHP is considered as optimum in this case. Also, the NPC and CoE are lower for configuration 2 as compared to configuration 1. In comparison to configuration 1 i.e DG/PV/Grid which is existing now in the facility, the addition of biogas and SHP plant i.e configuration24 makes a significant impact in reducing the dependence on fossil fuels. It can be clearly observed from Tables 2 and 3 that, even though the reduced cost difference in Total NPC and CoE is very less, the increase in RF from 0.5 to 0.55 and reduction in diesel usage from 87,265 litres to 84,940 litres proves configuration 2 to be economic as well as more environmentally friendly alternative justifying biogas installation in the facility.

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