Chapter 6 : Energy management system for microgrid

This chapter discusses integration and optimal use of various available energy resources in a stand-alone microgrid. To meet the energy demand, Integrated Renewable Energy System (IRES) approach has been proposed and analyzed using Hybrid Optimization Model for Electric Renewable (HOMER) software, developed by National Renewable Energy Laboratory, Department of Energy, USA. Different energy generation units, such as photovoltaic (PV), wind, diesel, and biogas were investigated along with energy storage units, such as batteries and fuel cell. This chapter begins with the estimation of load profile, followed by the modeling of each component of microgrid which includes various available energy sources at local scales, storage system and back-up generators. Then, seven scenarios (realistic as well as futuristic) with different combinations of energy sources and storage systems have been designed and investigated using HOMER software on the basis of their Levelized Cost of Energy (LCOE) supply and Net Present Cost (NPC). Thereafter, comparisons of all the scenarios are presented and optimal IRES for a study location is proposed. Subsequently, policy barriers are studied and possible interventions are suggested.

6.1 Load profile

The energy management system is developed at local scale for a village, Thumkunta (a village in Ranga Reddy district) with latitude 17.56° and longitude 78.55°. Thumkunta village is chosen as study location, falls in one of the regions with higher solar as well as wind potential. At the same time Raga Reddy district has highest built-up land and therefore highest area available for roof-top PV system installation. Thumkunta village is one of the prosperous villages and has semi-urban population with decent energy demand. The village is located at the outskirts of the district and has large land for cultivation including some barren land. It has an approximate area of 5.2 km^2. The population of Thumkunta village was 4199 in 2001 (Census 2001). As per Census 2011 data, Thumkunta village has a population of 4220 and 999 households. This data shows that the population of the village has increased by 0.5% in last 10 years and population in 2017 could be estimated as 4233. The electrical energy demand for the study location was obtained from the Telangana State Southern Power Distribution Company Limited (TSSPDCL), as shown in Appendix-VII. Annual domestic demand for 2017 was observed to be 3,157 MWh units. Therefore, the per capita energy demand comes out to be 745 kW/year. Monthly profile has been generated by collecting the data from January 2017 to December 2017. The monthly average electrical energy demand of Thumkunta village is presented in Figure 6.1. Also, Figure 6.2 shows the hourly load profile for June, which has maximum energy demand in the year. To develop and analyze IRES at the study location, electrical energy demand of 100 households along with the energy demand at a medical centre and a school is considered, which have an approximate yearly energy demand of 317 MWh.

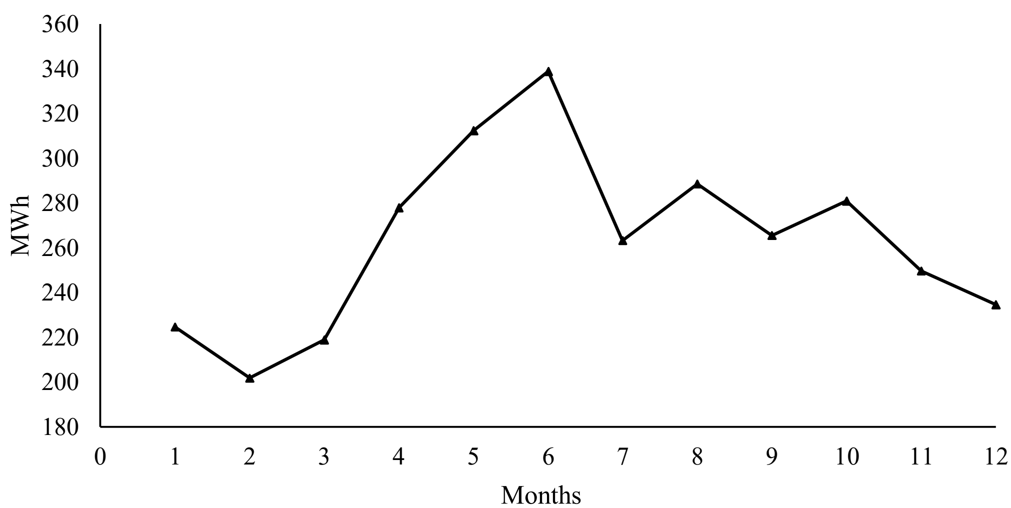

Figure 6.1. Annual load profile for Thumkunta village (2017).

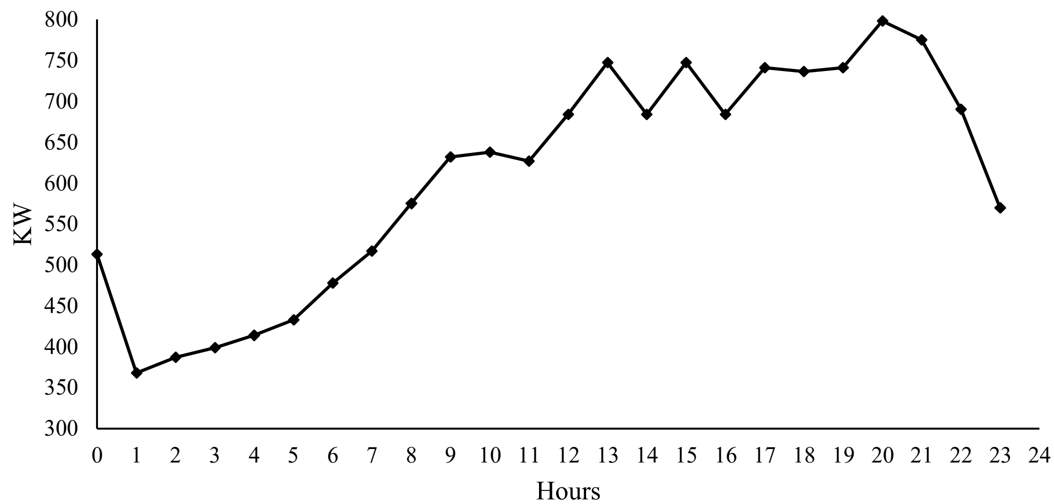

Figure 6.2. Hourly load profile for Thumkunta village in the peak month (June).

6.2 Modeling of microgrid system

Stand-alone microgrid with different combinations of distributed generators (DGs) and storage systems are developed and analyzed using HOMER software. HOMER software allows investigation of several permutations of the overall system with varying capacity of each component. These permutations were tested to check whether they could meet the load requirements or not. HOMER software was used to obtain a list of feasible permutations, which can meet the demand and were sorted according to the economic indicators, such as LCOE and NPC.

6.2.1 Components of microgrid

All components of microgrid considered in this study are discussed below:

6.2.1.1 Photovoltaic panels

The predicted solar radiation at Thumkunta village, based on the methodology described in Chapter 4 is used for developing IRES in HOMER software. The annual average solar radiation at Thumkunta village is observed to be 5.44 kWh/m^2/day and has 300 sunny days in a year. A standard derating factor of 80% and ground reflectance of 20% was assumed. The life of a PV panels (Polycrystalline, Energy Alternatives India) was considered 25 years with a capital cost of Rs. 70,000/kW. The monthly solar radiation for a study location has been shown in Figure 6.3. In the present investigations, operating and maintenance costs of PV panels have not been considered, as it is very negligible.

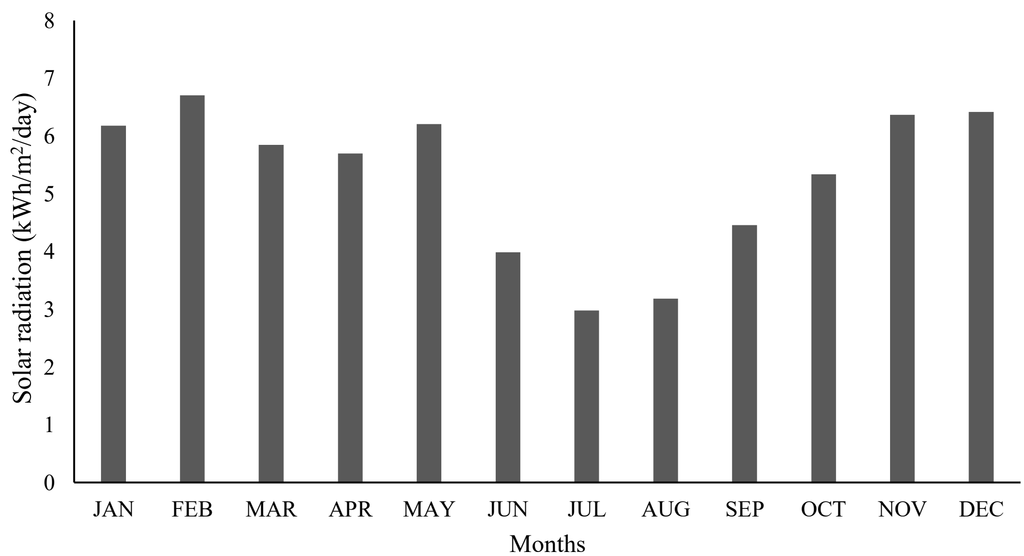

Figure 6.3. Annual distribution of solar radiation at Thumkunta village.

6.2.1.2 Wind turbines

A wind turbine generates electricity by converting kinetic energy of wind into electrical energy. Wind farms have become reliable source of renewable energy and can replace fossil fuels, which in turn can reduce carbon emissions. The wind turbines (3 kW, Diamond Engineering Enterprises, India) used in the analysis are of 3 kW capacity, which have a capital cost of Rs. 50,000/-. The operating cost considered Rs 180/yr. The lifetime is taken as 20 years and a hub height of 17 meters is used in this study (Castellanos *et al.*, 2015). The cut-in, cut-out and rated speed of the turbine are 4, 24 and 14 m/s, respectively. The predicted monthly mean wind speed based on the methodology described in Chapter 3 at Thumkunta village is presented in Figure 6.4. Power generation profile of a chosen wind turbine is shown in Figure 6.5.

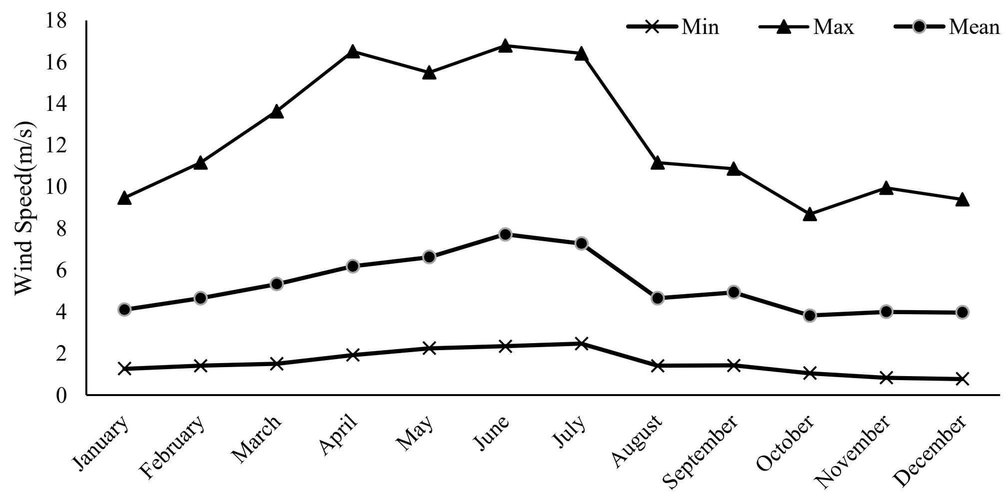

Figure 6.4. Annual distribution of wind speed at Thumkunta village.

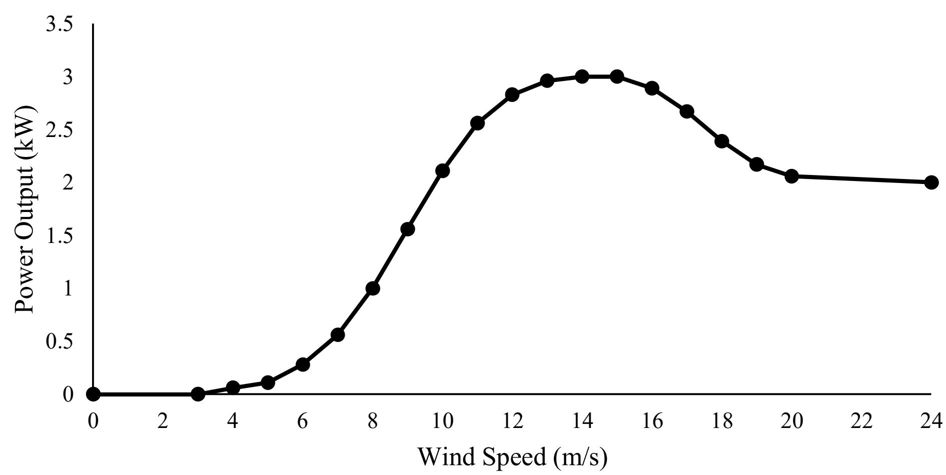

Figure 6.5. Power output Vs wind speed.

6.2.1.3 Li-ion battery

Li-ion battery (6V, Dongguan Liliang Electronics Ltd. China) was used as a storage technology as it is cheaper and easily available. This battery has a nominal voltage of 6 V, nominal capacity of 1 kWh, roundtrip efficiency of 90%, maximum charge current of 167 A and maximum discharge current of 500 A. The capital cost of this battery is Rs. 22,400/-, lifetime is 15 years and throughput is taken as 3000 kWh. The initial charge of the battery is assumed to be 100% and the minimum charge level is maintained at 20%. The maintenance cost is assumed to be Rs. 100/year.

6.2.1.4 Diesel generator

The energy available from PV as well as wind systems is intermittent in nature. To achieve higher reliability of energy supply throughout the day a backup system, such as diesel generator or battery storage system is required in a stand-alone microgrids. A diesel generator (100 kW, Rajat Power Corporation, India) used in the present study has rated capacity of 100 kW. This generator has a fuel curve intercept of 2.80 lit/hr and a fuel curve slope of 0.253 lit/hr/kW. Capital cost of this diesel generator is Rs.2,50,000/- and minimum load ratio is 25% with a lifetime of 15,000 hours. Per liter cost of diesel during the investigations is assumed as Rs. 63.5/-.

6.2.1.5 Biogas generator

The agro-domestic waste is used for producing biogas, which is then used as a fuel in the generator. As per the Telangana Government assessment report, 2018 the average daily available biomass has been reported as 5.97 tonnes/day at Thumkunta village. The capital cost of biogas based generator (Hi-tech Energy Savings Equipments, India) is taken as Rs. 1,00,000/kW with a lifetime of 15,000 hours. The minimum load ratio is taken as 25% and the slope for the fuel curve has been taken as 1.9.

6.2.1.6 Fuel cell (hydrogen storage system)

The hydrogen storage system is a relatively new technology for producing electricity. It converts chemical energy into electrical energy. Fuel cells are unlike batteries, as they require a continuous source of fuel and oxygen (air) to carry out the chemical reaction. This system consists of three components: fuel cell, hydrogen tank, and electrolyzer. The fuel cell's (The

California Energy Commission) lifetime is taken as 50,000 hours. The capital cost of fuel cell is taken as Rs. 2,95,000/kW. The electrolyzer (Elade, China) with an efficiency of 85% and a lifetime of 15 years is used. The capital cost for electrolyzer has been taken as Rs 3,50,000/kW. The hydrogen tank (Wilson Cryo Gases, India) with a lifetime of 25 years and capital cost of Rs. 17,500/kg is used.

6.2.2 Financial aspect of the different component

The capital cost and operation and maintenance cost of each component considered for microgrid development in IRES is summarized in Table 6.1.

Table 6.1. Financial aspects of different components considered for microgrid.

Equipment	**Capital cost (Rs.)**	**Operation and maintenance cost (Rs/year)**	**Source**
PV panels	70,000/kW	-	Energy Alternatives India (India)
Wind turbines (3 kW)	50,000	180	Diamond Engineering Enterprises (India)
Biogas generator	1,00,000/kW	200	Hi-tech Energy Savings Equipments (India)
Diesel generator (100 kW)	2,50,000	15000	Rajat Power Corporation (India)
Converter	44,520	-	Sun Electronics (Florida)
Li-Ion battery	22,400	100	Dongguan Liliang Electronics Ltd. (China)
Fuel cell	2,95,000/kW	50	The California Energy Commission
Electrolyzer	3,50,500/kW	-	Elade (China)
Hydrogen tank	17,500/kg	-	Wilson Cryo Gases (India)

6.2.3 Economic variables

To evaluate the feasibility of each scenario, an economic analysis is performed, which includes economic variables, such as LCOE and NPC. The LCOE is calculated using equation (6.1) in Rs/kWh.

$$LCOE = \frac{C_{ann,tot} - C_{\text{boiler}} H_{\text{served}}}{E_{\text{served}}} \tag{6.1}$$

where,

$C_{ann,tot}$ = the system's total annualized cost (Rs/yr).

C_{boiler} = boiler marginal cost (Rs/kWh).

H_{served} = total thermal load served (kWh/yr).

E_{served} = total electrical load (kWh/yr).

Total NPC represents life-cycle cost of the energy system. This includes all costs and revenues that occur within the project lifetime. With the NPC, costs are positive and revenues are negative; therefore, least NPC is desired.

6.2.4 Alternate scenarios

Seven different scenarios have been investigated, as shown in Table 6.2. These scenarios are referred to realistic and futuristic. Realistic scenarios are those which considers commercially available technologies and futuristic scenarios are those which considers new/research stage technologies. Scenario 'A' has used wind and diesel as the primary energy generators and Li-ion battery as the storage technology. Scenario 'B' has used PV and diesel as the primary energy generators and Li-ion battery as the storage technology. Scenario 'C' has used PV and wind as primary energy generators and Li-ion battery as the storage technology. Scenario 'D' has used PV as the primary energy generation unit and fuel cell as energy storage technology. Scenarios 'E' has used wind as the energy generation unit and fuel cell as energy storage technology. In scenario ‘F’, biogas generator has been used. Scenario ‘G’ is an attempt at using IRES method and make a combination of energy generation and storage units, which can lead to an optimal result.

Table 6.2. Technologies involved in seven different scenarios.

Scenario	Technologies involved	Realistic/ Futuristic
A	Wind +Diesel+ Li-ion battery + DC-AC	Realistic
B	PV + Diesel +Li-ion battery + DC-AC	Realistic
C	PV + Wind + Li-ion battery+ DC-AC	Realistic
D	Wind + Fuel cell + Electrolyzer + Hydrogen tank + DC-AC	Futuristic
E	PV + Fuel Cell + Electrolyzer + Hydrogen tank + DC-AC	Futuristic
F	Biogas generator	Realistic
G	PV + Wind + Li-ion battery + Biogas + DC-AC	Realistic

6.3 Scenario analysis

Each scenario is simulated separately using HOMER software. Different permutations obtained from simulation are studied and compared for its economic viability. Result from the previous scenario is taken as input to modify the next scenario. Each scenario result is discussed with regard to its advantages and limitations. The analysis is carried out for COE, NPC, Operating Cost (OC), Initial Capital Cost (ICC) and Renewable-energy Fraction (RF).

6.3.1 Scenario A: wind + diesel + li-ion battery + AC-DC

The architecture of scenario ‘A’ is shown in Figure 6.6. The simulation results are presented in two possible options, which are with and without battery. The option having no battery has LCOE (75.97 Rs/kWh), that is, almost double the option with battery (41.78 Rs/kWh), as shown in Table 6.3. The NPC and operating cost are also almost doubled. Even though the ICC is less, the LCOE is high, hence it is not feasible to implement.

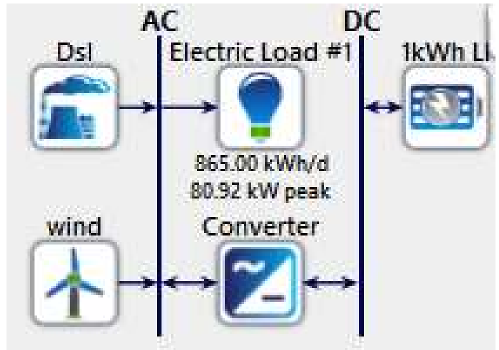

Figure 6.6. Architecture of scenario A: Wind + Diesel + Li-ion battery + AC-DC.

Table 6.3. Analysis of scenario A: Wind + Diesel + Li-ion battery + AC-DC.

S. No.	Wind 3kW (quantity)	Diesel (kW)	1kWh LI (quantity)	Converter (kW)	COE (Rs /kWh)	NPC (crores Rs)	OC (crores Rs/yr)	ICC (crores Rs)	RF (%)
1	542	100	434	72.48	41.78	17.10	1.10	4.02	27.39
2	430	100	0	0.00	75.97	31.00	2.23	2.18	15.98

It can also be observed that renewable energy fraction in the first option is 27.4% of the total energy generated, which means rest of the energy is generated by diesel generator. In the second option, only 15.9% of the total energy is generated by wind and rest by diesel generator. This happens because, when batteries are used, the excess energy generated by the wind is stored in the batteries. It can also be seen that there is a huge reduction in cost even with more number of wind turbines. When no battery is used, the energy generated by wind turbines is directly used to meet the energy demand, as there is no storage system involved in. In the absence of wind resources, diesel generator needs to be used, and this increases the associated costs.

6.3.2 Scenario B: PV + diesel + li-ion battery + AC-DC

The architecture of scenario 'B' is shown in Figure 6.7. The simulation results are presented in three possible options as shown in Table 6.4. In the second option, when no diesel generator is used, there are a few advantages; the operating cost is very low as operations and maintenance costs are very less for PV and batteries. The renewable energy fraction is 100%, which means, all the energy is being generated through PV. But the disadvantage is increase in number of PV panels and correspondingly more number of batteries have to be used, which leads to a greater initial capital cost. Furthermore, LCOE and NPC are increased. In the third option, when no battery is used, the ICC comes down and is 5% of the ICC of the 2nd option. Apart from lower ICC, all such associated costs as LCOE and NPC increase. It can also be observed that due to lesser renewable energy fraction (11.33%), PV panel cannot be used to meet the night energy requirements and excess energy produced during day time cannot be stored due to the absence of a battery system.

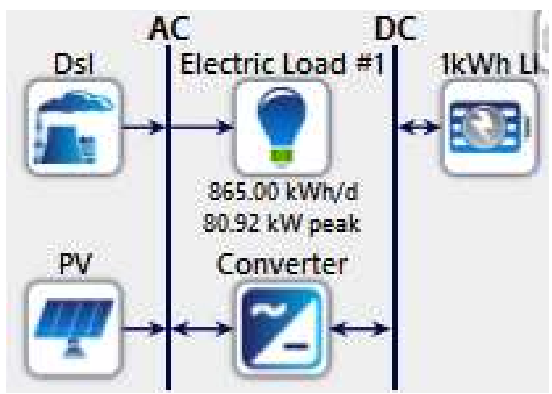

Figure 6.7. Architecture of scenario B: PV + Diesel + Li-ion Battery + AC-DC.

In the first option, operating cost of the system is greater than that of second option which does not use diesel generator and the initial capital cost is ten times the ICC of first option with no batteries. However, LCOE and NPC are the least for this case and it is a feasible solution, as the costs associated are less. The renewable energy fraction of 87.32% indicates that a high percentage of energy is generated by PV and the excess energy generated by PV is stored in the batteries and used at night and during cloudy days. Overall, it is a very effective option.

Table 6.4. Analysis of scenario B: PV + Diesel + Li-ion Battery + AC-DC.

S. No.	PV (kW)	Diesel (kW)	1kWh LI (Quantity)	Converter (kW)	COE (Rs/kWh)	NPC (crores Rs)	OC (crores Rs/yr)	ICC (crores Rs)	RF (%)
1	240.60	100	697	77.22	16.62	5.56	0.151	3.61	87.32
2	574.99	0	1082	95.25	19.42	7.87	0.077	6.87	100
3	46.05	100	0	0.00	20.52	8.38	0.621	0.34	11.33

6.3.3 Scenario C: PV + wind + li-ion battery + AC-DC

The scenario 'C' is developed to investigate whether only PV and wind combined with a battery will be able to meet the electrical demand without diesel generator or not. The architecture of scenario 'C' is shown in Figure 6.8.

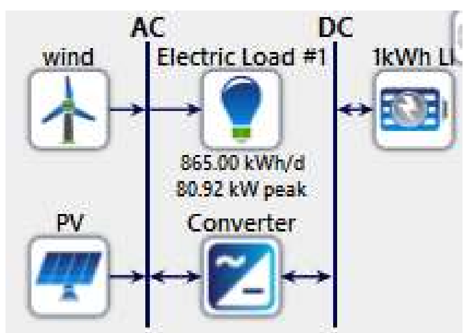

Figure 6.8. Architecture of scenario C: PV + Wind + Li-ion Battery + AC-DC.

In this scenario, wind and PV are used; so the renewable energy fraction is 100%. The LCOE for this scenario is Rs. 20.75, which is comparable, but has an NPC of Rs. 8.41 crores and ICC of Rs. 6.81 crores, which is not cost competitive. PV produces 481 kW of electricity whereas 87 wind turbines produce 261 kW of electrical energy demand, which is almost half of that generated by PV. The number of batteries used are 1131 to store the excess energy generated and provide electricity at times when there is no sunlight and wind speed is also very less. Overall, the scenario proves to be very expensive and to install PV panels and wind turbines, a huge area is required which makes this option non feasible.

6.3.4 Scenario D: wind + fuel cell + electrolyzer + hydrogen tank + DC-AC

In this scenario, hydrogen fuel cell is considered with wind turbines to meet the electrical energy demand (Figure 6.9). Fuel cells can be used for many purposes, such as industrial, commercial and domestic power generation. Fuel cells can be very useful when it comes to power generation in remote areas such as spacecraft, weather stations, certain military applications, and rural locations. The problem with fuel cell technology is its being in the development stage, and very high capital costs. It can be seen that 30 wind turbines have been used due to which the renewable energy fraction comes out to be 23.46%. The LCOE is observed to be Rs 63.64 and NPC be Rs. 25.89 crores. The operating cost and initial capital cost are 1.11 and 11.43 crores respectively. The LCOE and NPC observed in this scenario are quite high. Thus the fuel cell technology cannot be implemented with wind turbines in the present times, as the costs associated with this are quite high and termed it as a futuristic scenario.

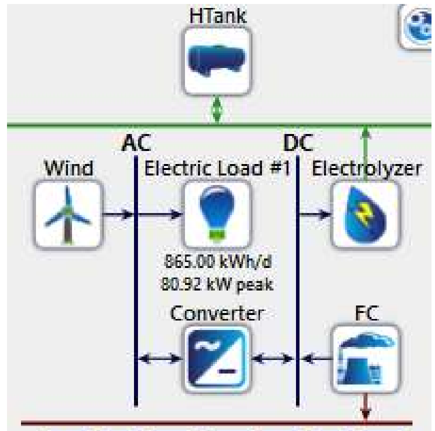

Figure 6.9. Architecture of scenario D: Wind + Fuel cell + Electrolyzer + Hydrogen tank + DC-AC.

6.3.5 Scenario E: PV + fuel cell + electrolyzer + hydrogen Tank + DC-AC

In this scenario, as shown in Figure 6.10, hydrogen fuel cell technology has been explored (which is a relatively new technology and hence capital costs are very high) along with PV. The analysis gives two possible options as shown in Table 6.5. The LCOE of both options is substantially high. The first option has lower LCOE and NPC and uses approx. 500 PV panels.

In the second option, the LCOE and NPC are higher, which shows how expensive the fuel cells combined with electrolyzer and hydrogen tank are. Though the initial capital cost in the second option is lesser as compared to first, the operating cost in the second option is much higher. The first option has 39.8% of renewable energy fraction whereas, in the second option it is 0%.

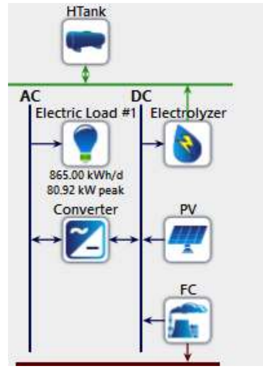

Figure 6.10. Architecture of scenario E: PV + Fuel cell + Electrolyzer + Hydrogen Tank + DC-AC.

Table 6.5. Analysis of scenario E: PV + Fuel cell + Electrolyzer + Hydrogen Tank + DC-AC.

S. NO.	PV (kW)	FC (kW)	Elect. (kW)	HT (kg)	Conv. (kW)	COE (Rs/kWh)	NPC (crores Rs)	OC (crores Rs/yr)	ICC (crores Rs)	RF (%)
1	496	250	100	15	74.27	62.10	25.26	0.80	14.8	39.8
2	0	250	100	15	72.95	63.49	25.80	1.11	11.3	0

FC = Fuel cell; Elect. = Electrolyzer; HT = Hydrogen Tank; Conv. = Converter

6.3.6 Scenario F: Biogas generator

Scenario ‘F’ is simple compared to other scenarios as shown in Figure 6.11. The biogas potential (around 6 tonnes/day) has been taken as a resource for this scenario. The data has been obtained from Biomass Knowledge Portal, Telangana Government. Total biomass potential of Telangana has been reported as 20572.2 kt/yr with a total area as 4908.1 kha. Potential for Thumkunta village has been calculated by using a simple unitary method, taking the area of Thumkunta village as 5.2 km^2.

The results show that biogas generator can be used with other renewable energy technologies and can be a very good replacement for diesel generator as fuel. Biogas generator alone cannot be used as the operating costs place a considerable burden, and can lead to financial constraints. The main reason for this is the cost of cleaning and feedstock collection. The total fuel consumed works out to 1,902 kg in a year. The LCOE comes out to be Rs. 20.04 and NPC as Rs. 8.18 crores. Operating cost and initial capital cost are Rs. 55,55,203 and Rs. 1 crore respectively.

Figure 6.11. Architecture of scenario F: Biogas Generator.

6.3.7 Scenario G: PV + wind + li-ion battery + diesel+ biogas + DC-AC

In this scenario, all the available renewable energy resources are considered (except fuel cell) to investigate the IRES approach (Figure 6.12). The simulation results give five possible options as represented in Table 6.6. All five options have been analyzed based on the economic variables like COE, NPC, operating cost initial capital cost and renewable energy fraction.

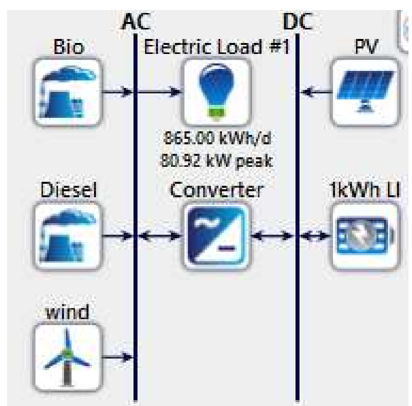

Figure 6.12. Architecture of scenario G: PV + Wind + Li-ion Battery + Diesel+ Biogas + DC-AC.

Table 6.6. Analysis of scenario G: PV + Wind + Li-ion Battery + Diesel+ Biogas + DC-AC.

S. No.	PV (kW)	Wind (3kW)	Bio (kW)	Diesel (kW)	LI (1kWh)	Converter (kW)	COE (Rs/kWh)	NPC (crores Rs)	OC (crores Rs/yr)	ICC (crores Rs)	RF (%)
1	217.85	32	100	0	717	63.75	14.49	5.91	0.104	4.57	100
2	225.51	0	100	0	709	67.18	14.62	5.96	0.116	4.46	100
3	218.93	56	100	100	702	65.01	14.62	5.96	0.098	4.69	99.86
4	226.74	0	100	100	720	62.44	14.87	6.07	0.121	4.50	99.66
5	0.00	80	100	0	94	40.6	18.03	7.35	0.430	1.79	100

In 5th option, it is found that initial capital cost is the least among all combinations. However, the LCOE and NPC are considerably high compared to other options; besides, operating cost which is maximum (Rs 43,02,287). Main reason for this is the operating cost associated with PV, which is very low compared to that of biogas generator. Since there is no PV used in this scenario the power generation from biogas and wind turbines increases which in turn increases the operating cost of biogas generator, as it has to be cleaned regularly.

In 4th option, no wind is used but PV and diesel are introduced, which bring the operating cost down to Rs. 12,13,638, that is almost one-fourth of the 5th option's operating cost. The LCOE and NPC cost also decreased as the excess energy being generated by PV is stored in the batteries. ICC has increased due to use of 226 PV panels in this scenario.

In 3rd option, only wind turbines are added to 4th option, which results in lower operating cost, as the number of PV panels and batteries decreases. Moreover, addition of wind turbines results in lesser load on biogas generator.

In 2nd option, wind and diesel have been removed and the results are almost the same as in the 3rd option. The key differences are that the operating cost increased by a small amount and the number of PV panels and batteries increases as well. Though LCOE and NPC remain the same, it can be seen that renewable energy fraction becomes 100%, as no diesel generator has been used.

In the 1st option, which is the most optimized option has 100% RF and gives the best result in terms of LCOE and NPC. There is no diesel used which makes it completely green system, using 217 kW of solar energy, 32 wind turbines of 3kW output, a 100kW biogas generator and 717 units of 1kWh Li-ion batteries. It has an operating cost of Rs 10,36,975, which is the second lowest of all scenarios. The LCOE and NPC, which are the main parameters for this study are the least in this case.

6.4 Comparison of scenarios and IRES analysis

Figure 6.13 shows the comparison of best option in each scenario for NPC and ICC. Figure 6.14 shows the LCOE comparison of all scenarios (best combination) that have been considered.

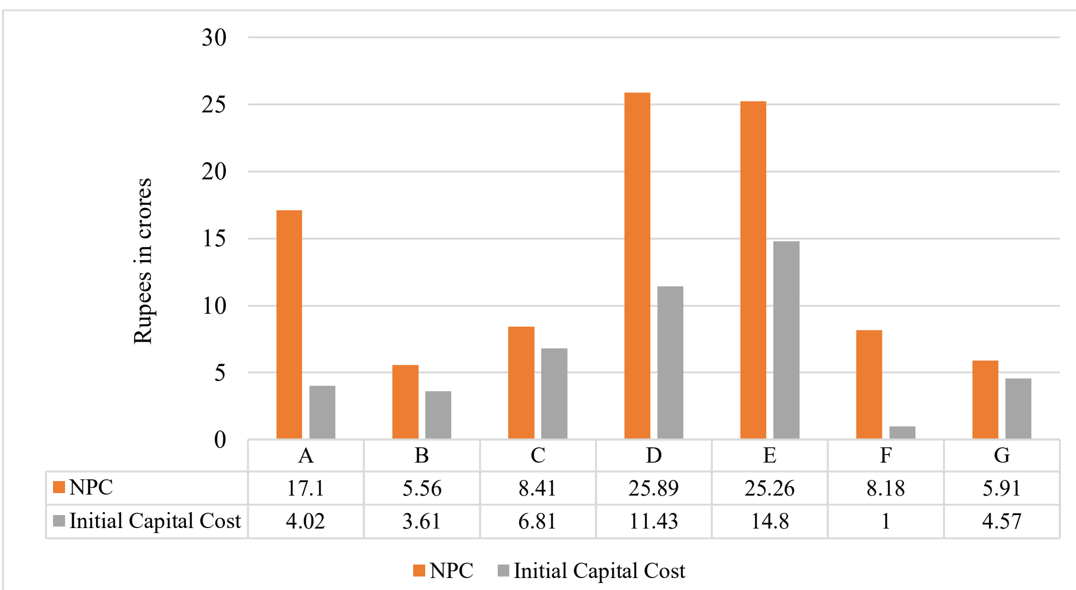

Figure 6.13. Comparison of all scenarios based on NPC and ICC.

In scenario A, wind turbines are used and the LCOE and NPC are increased since turbines requires favorable conditions to operate and cannot be used during low wind speeds. In scenario B, the LCOE and NPC are less because PV panels are more reliable and there is less variation in solar radiation as compared to wind speed in Thumkunta village. In scenario C, the LCOE and NPC increase slightly as wind turbines and PV panels are used together. In the scenarios D and E, fuel cell is used along with wind and PV. The LCOE and NPC are very high in both the scenarios as compared to others, as fuel cell is a new technology and it needs time to develop as an alternative solution. So, these scenarios (D and E) are considered futuristic. In scenario F, biogas generator is used which proves to be a good resource for energy generation. ICC of this scenario is the least among all the scenarios. However, due to limited resource biogas generator is not able to meet the total energy demand. Scenario G (IRES), which integrates all possible renewable energy resources into a microgrid, has the lowest LCOE and NPC. Figure 6.15 shows the contribution of various renewable energy sources while meeting the energy demand. It can be observed that 85% of total energy demand is met using PV panels followed by 11% and 4% from biogas generators and wind turbines, respectively. This scenario indicates that PV system is most economical and a feasible option for power generation in Thumkunta village.

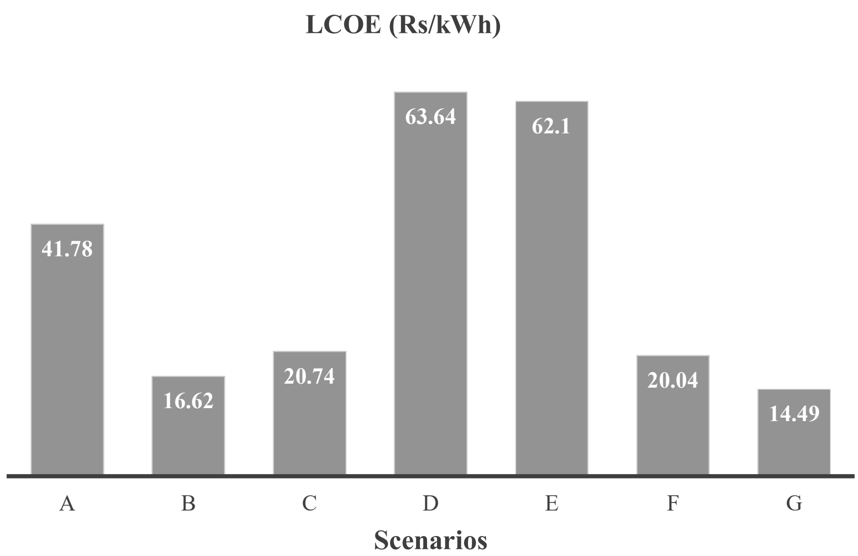

Figure 6.14. Comparison of LCOE in all scenarios.

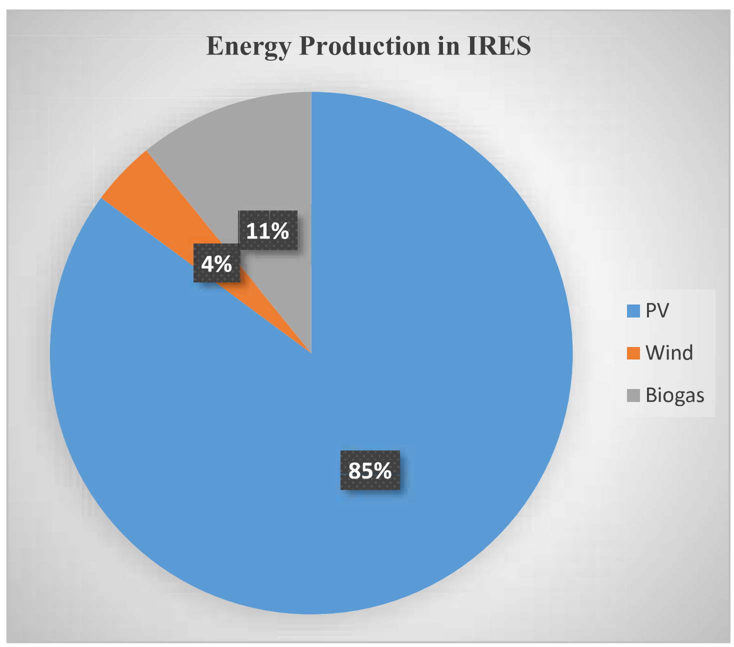

Figure 6.15. Energy generated by different renewable resources in IRES.

6.5 Feasibility of realistic and futuristic scenarios

In this study, five realistic and two futuristic scenarios are developed considering different combinations of DGs and storage systems. All these scenarios are investigated and compared to propose the feasible scenario for IRES implementation. Initially, no existing subsidy or any reduction in taxes is considered for realistic scenarios. Therefore, even for the best scenario, the cost of energy is higher than the convention cost of energy supply. Moreover, there are some limitations associated with various renewable resources that also have to be considered. Wind farm needs to be placed away from the residential areas, as they produce noise and requires a continuous and unhindered flow of wind requiring a large area to produce a substantial amount of electricity. Similarly, the solar panels require large open area without any adjacent high rise structures. However, placement of rooftop PV system is one of the possible option. The biogas power generation is easy and cheap, which does not need large space as compared to wind or solar power generation. However, there is a limited agro-residue waste produced, which can be used as feedstock for biogas energy system.

Therefore, to make the proposed IRES for microgrid operation more competitive with conventional power supply, various approaches can be considered. The LCOE can be reduced by policy interventions. The existing subsidy on solar rooftop power plant is 30% based on current Ministry of New and Renewable Energy (MNRE) benchmark. Hence, policy interventions are proposed and analyzed: first with no taxes and second with no taxes and subsidy on renewable technologies. PV panels and wind turbines falls into 18% tax bracket, which can be reduced further, a subsidy of 30% on PV and 20% on wind can be introduced. These subsidies will increase domestic manufacturing of solar panels and wind turbines under Make in India program of Government of India. Both the options have been investigated and results are presented in Table 6.7.

Table 6.7. IRES with policy interventions.

Policy	PV (kW)	Wind (3kW)	Bio (kW)	Diesel (kW)	1kWh LI	Converter (kW)	COE (Rs./kWh)	NPC (crores Rs.)	OC (crores Rs./yr)	ICC (crores Rs.)	RF (%)
A	217.15	43	100	0	687	63.42	13.43	5.48	0.096	4.23	100
B	226.75	48	100	0	662	62.38	12.54	5.12	0.095	3.89	100

A = No taxes; B = No taxes + subsidiary

The option with zero taxes reduces LCOE to Rs. 13.43/kWh and there is a considerable reduction in NPC, operating costs and initial capital cost as well. In the second option, the IRES without taxes and with a subsidiary of 30% on PV panels and 20% on wind turbines, further reduces the LCOE to Rs. 12.54/kWh. Similarly, NPC, operating cost and ICC are further decreased. In addition, on top of 30% subsidy given by MNRE, State Governments also give additional subsidy on solar power generation. This subsidy varies in different states. In AP and TS, it is 20%. With State Government subsidy, the LCOE becomes Rs. 11.8/kWh, and still LCOE is higher than cost of conventional power supply. Therefore, further policy intervention based on carbon abetment cost is required to make IRES feasible in present times. The weighted average grid emission factor for coal-based power plant was reported to be 0.98 tCO_2/MWh for the year 2016-17 in Central electricity authority report 2018 of Ministry of Power. From the carbon abetment cost analysis, the social cost of carbon value estimated is approximately \$46/tCO_2 in 2017 (Gillingham and Stock, 2018). This is a conservative value of carbon abetment cost which is reported in academic research, while in other estimation reports, this value is much higher. Therefore, the carbon emission cost per kWh is Rs. 3.15 (1 USD = 70 INR). After considering this carbon abetment cost as a possible policy intervention, LCOE of the proposed IRES is Rs. 8.6/kWh which is close to the cost of energy supply to HT consumers in AP and TS. Moreover, cost of each component of microgrid considered in the present analysis is for one unit from a retail vendor. Hence, if the development of microgrid is carried out at a larger scale, various components of microgrid can be taken directly from the manufacturer at a lower price taking advantage of bulk purchase, which will further reduce the investment in initial capital cost as well as COE.

On the other hand, there are two futuristic scenarios where wind with fuel cell and PV with fuel cell are investigated. In both these scenarios, LCOE is quite high as compared to realistic IRES. Therefore, these are termed as futuristic scenarios. These are not feasible in the present time, as the technology is new/research stage and is yet to be fully commercialized. However, the technologies, such as fuel cell are being researched to increase their performance and to make them cost competitive in the near future.

6.6 Summary

The IRES for microgrid operations has been developed to meet the electrical energy demand of Thumkunta village. The electrical energy demand was considered for 100 houses for the analysis of IRES. Seven different energy scenarios were investigated for the feasibility of microgrid operation. These scenarios were designed to meet the electrical energy demand with daily variation and the different permutations were analyzed based on the economic parameters, such as LCOE and NPC. The IRES approach, which includes PV, wind, li-ion battery, biogas, and DC-AC converters, gives the least LCOE among all scenarios considered. Based on the results of the seven scenarios, policy intervention has been proposed, which includes reduction in taxes and giving subsidies on PV panels and wind turbines along with the carbon abatement cost. This led to a reduction in LCOE and other costs. One of the main findings of this study includes the use of biogas in the IRES approach.

Next chapter presents summary of results and conclusions of the study. The chapter also presents specific contributions and further scope of work.