DESIGN OF AN EFFICIENT MICROGRID SYSTEM FOR A LOCAL AREA

P. D. Singh

Assistant Professor, Department of Electrical Engineering,
North Eastern Regional Institute of Science and Technology, Nirjuli, India

Ajay Upadhaya, Michael Simte, Heisnam Jimbrow Singh

Department of Electrical Engineering, North Eastern Regional Institute of Science and
Technology, Nirjuli, India

ABSTRACT

Microgrid (MG) system has a vital role in fulfilling the ever increasing electricity demand in the continuously expanding power systems. Significant power can be integrated from Renewable energy sources such as solar, wind and small hydro to MG systems. MG may a distribution power network of either low voltage level or medium voltage level consisting of various energy sources from distributed generations (DG's) such as photovoltaic system, fuel cell, biomass, wind, small hydro, energy storage systems, etc. MG can be a single controllable system which can be operated in islanded mode without connecting to main grid or grid-connected mode. This study presents the design of MG system based on a given load data and available resources for minimum cost of energy, maintenance and replacement. The design is carried out using HOMER Software so as to maximize the energy usage from the DG's instead of grid supply to meet most of the load demand in the MG system. The study presents an approach to an efficient MG system design based on available renewable power generation units for the most efficient distributed energy sources and optimum ratings of the components required to meet the load demand of a known local area. It also presents the techno-economic feasibility study of the MG system so designed. The simulation results and discussions are presented.

Keywords: Microgrid System, Battery Energy Storage, Distributed Generation, Grid Connected and Islanded Microgrid System, HOMER, Solar PV

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1. INTRODUCTION

The conventional electricity generation from fossil fuels contributes in degradation of the environment. Moreover, the demand of electricity is increasing day by day necessitating to

inject more of renewable energy which is available in the form of distributed energy. Distributed energy sources such as PV, Wind, Tidal, Micro Hydro, Fuel cells etc. in conjunction with these conventional sources can supplement the increasing demand. These Distributed Energy Resources (DER) can alone form a small grid called Microgrid to supply a particular area while feeding the excess generation to the main grid [9]. MG can therefore operate in island mode or grid connected mode. In island mode, the MG is sufficient to meet the local load demand and it does not supply electricity to the grid nor take it from the grid. In grid connected mode, the MG takes from the grid during shortage of power generation and supply to grid during when the power generation exceeds the required load demand. In a microgrid, the power generation as well as the load are constantly changing. MGs are formed by a number of Distributed Generations which do not provide constant power generation [8]. The DERs need to be properly interfaced with power electronic devices for controlling the flexibility of operation with improved power quality and energy output [10]. HOMER software is a popular computer tool which can perform simulation and optimisation of stand-alone and grid-connected electric power systems having various DERs [1, 6]. HOMER software has been used in many studies for assessments of potential of wind energy [2], wind-diesel system [3], zero-energy homes [4], stand-alone system having hydrogen [5]. HOMER has also presented simulation study of a system having 100% load demand met by renewable energy sources [6]. This paper presents design of MG system consisting of PV array system, a MPPT with boost converter for PV array, a battery with bidirectional charge controller, a three-phase inverter to convert DC to AC power, transformer for AC voltage conversion, load and a grid. A maximum power point tracking (MPPT) controller is required to extract the maximum power in the PV through the boost converter. A storage unit like battery helps to maintain stability during transient and varying load conditions. A charge controller is used for controlling the battery to charge and discharge during excess and shortage of power respectively [7]. The techno-economic feasibility analysis of the MG system is carried out using HOMER. The simulation results and analysis are presented and discussed in the subsequent chapters.

2. MG SYSTEM DESIGN USING HOMER SOFTWARE

In this work, Homer Pro is used as it provides the some readily available data of location such as Sunshine, Wind Speed, Rainfall, Temperature, etc. Moreover, it provides the option to used real time components as well as user defined components. Resources like daily, monthly, yearly data of temperature, Wind Resource, Solar Radiation, etc. are directly obtained from NASA server. Approximate maximum size of components and pattern of resources are suitably defined based on the local load area considered. For the study, the load assessment is carried out for the local area under consideration followed by system designing as follows.

2.1. Electric Load Profile

The energy consumed by the locality under study is found to be 537 kWh/day with peak demand of 55.24 kW and load factor of 0.41. The random variability from day to day and time step are assumed to be 5%. The load profiles for the specified system can be shown by HOMER in Figures 1 (a) and (b). The load is at its peak from 7 pm to 8 pm and minimum between 12 am to 3 am.

Figure 1 (a) Daily Load Profile of the Area (b) Daily Load Profile with 5% Variability

2.2. Design Considerations

Based on the load assessments, the MG design considers a system including a Generic PV, 1kWh Li-Ion Storage Batteries, Converter, Load and Grid as shown in Fig. 2. The complete system descriptions viz. Solar resource, Temperature resource and detail of the various components are discussed in the following sub-headings.

Figure 2 Schematic Diagram of Microgrid System Design

2.3. System Description

2.3.1. Solar Resources

The solar data for the location was loaded from the Hybrid Optimization Model for Electric Renewables (HOMER) database by specifying the locations coordinates of 27.1°N 93.62°E. It has a relatively strong solar resource with a daily radiation annual average of 3.95 Kwh/m²/day. A graph of the global horizontal radiation is shown in Fig. 3. The months from April to June have the highest values of solar radiation.

Figure 3 Monthly Average Radiation

2.3.2. Temperature Resource

The daily temperature of the selected location throughout the year is shown Fig. 4. The annual average temperature was found to be 23.89 °C. The temperature is highest during May and June followed by April, July and August.

Figure 4 Monthly Average Temperature

2.3.3. PV Module

Solar PV modules are arranged in series-parallel connection. PV Array is the main source of generation. In this hybrid design, a Generic 1kW flat is considered. The capital cost and replacement cost are taken as \$600 and \$550 respectively. The maintenance cost is assumed to be \$ 5/yr. De-rating factor of 90% is considered. The sizing for simulation is taken by Homer Optimizer.

2.3.4. Battery

A battery bank not only provides the backup power but also helps in maintaining constant voltage across the load. Its capacity should be sufficient enough to store energy for operating the load during cloudy days and night times. The capital and replacement costs are taken to be \$300/kW. Some specifications of the battery are given in Table 1 and detail specifications is given in the Appendix.

Table 1 Specifications of Battery

Nominal Voltage	24 V
Nominal Capacity	167 Ah/1 kWh
Roundtrip Efficiency	90%

2.3.5. Converter

The converter used is bidirectional that converts electrical power from AC to DC or from DC to AC. In our simulation we have considered a generic system converter given in HOMER library. For a 1 kW system the installation, capital and replacement costs are taken as \$200 and \$150 respectively.

Table 2 Converter Efficiency and Life Expectancy

Inverter Input	Rectifier Input
Lifetime : 25 Years	Relative Capacity : 100 %
Efficiency : 95%	Efficiency : 95%

2.3.6. Controller

For the required design, the simulation is carried out with controller Load Following dispatch (LF). In load following dispatch, the grid is used only when the DG is unable to produce sufficient power for load.

2.3.7. Grid

The Microgrid is provided with an alternative to connect to the grid. When power generated is less than load demand, power may be taken from grid or else it injects power to the grid. The sale capacity to the grid is set to 34 kW and purchase capacity from the grid is 100 kW/month. Interconnection charges of \$3000 and standby charges of \$500/yr are considered. The cost of grid extension is assumed to be \$300/km.

3. SIMULATION AND RESULTS OF MG DESIGN BY HOMER SOFTWARE

The complete model consisting of defined PV System, Battery, Converter, Load and Grid is simulated using Homer Optimizer. Sizing of components is done by Homer Optimizer. 861 solutions were simulated. 612 were feasible, 86 were omitted. HOMER provides different configurations of all the systems which are feasible under the defined search constraints. Then, they are arranged according to the minimum cost MG based on the total net present cost (NPC). By analysing the optimization result in categorized way, it can be said that among all the system configuration, the configuration of PV and Grid is found to be the most optimum one. Since the desired system is to minimize dependency on grid, the second configuration with battery is taken. The system NPC and COE of this configuration is lesser than that of the other configuration. The optimization result of the system is shown in Fig. 5.

Architecture				Cost				\$			
PV (kW)	1 kWh (L)	Converter (kW)	Dispatch	NPC (\$)	COE (\$)	Operating cost (\$/yr)	Initial capital (\$)	Ren. Frac. (%)	Total Fuel (L/yr)	Capital Cost (\$)	Production (kWh/yr)
101		61.4	LF	\$212,094	\$0.0681	\$10,520	\$76,102	51.3	0	60,525	143,039
103	24	61.8	LF	\$218,875	\$0.0700	\$10,380	\$84,684	52.0	0	61,822	146,104
			LF	\$253,968	\$0.100	\$19,622	\$300.00	0	0		
24	0.0648		LF	\$270,933	\$0.107	\$20,145	\$10,513	0.00883	0		

Figure 5 Optimization Result

For comparison of the optimized result two cases are considered.

Case 1: In this case, the second configuration with the most optimized result including grid, PV, converter and battery is considered.

Case 2: In this case the third configuration from the optimization result is considered. In this configuration only the grid is considered.

In these two cases, it can be seen that the NPC and Levelized cost of energy (LCOE) of the Case 1 is lower than that of Case 2. The CO₂ emission of Case 1 is also lower than that of the Case 2. Hence, the second configuration i.e. Case 1 is found to be the most optimum solution for feeding the load demand of the location. Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for Case 1 are also found lesser than that of Case 2 as shown in the table below.

Table 3 Comparison between Case 1 and Case 2

Parameters	Case 1	Case 2
Net Present Cost	\$219,061	\$253,968
CAPEX	\$83,590	\$3000
OPEX	\$10,479	\$19,622
LCOE (per kWh)	\$0.0704	\$0.100
CO ₂ Emitted (kg/year)	73,631	123,816
Fuel Consumption (L/year)	0	0

The simulation results can be summarised as follows.

3.1. Cost Summary

The cost summary is shown in the table below. The project is designed for 25 years and the lifetime of all the components are assumed to be 25 years. Therefore, the replacement cost and salvage are found to be nil. The cost of the resource is also found to be nil since no fuel is used in the system as shown in Table 4.

Table 4 Net Present Costs

Name	Capital (in \$)	Operating (in \$)	Total (in \$)
Generic 1kWh Li-Ion	7,200	310.26	7,510
Generic Flat Plate PV	60,603	6,529	67,132
Grid	3,300	128,632	131,932
System Converter	12,487	0.00	12,487
System	83,590	135,471	219,061

3.2. Electrical Summary

The simulation results below give the electrical energy exchange and capacity detail of all the components. Table 5 and 6 show the electricity produced, stored and supplied from the grid. Also, it is seen that there is no unit of energy demand left unmet.

Table 5 Energy Profile

Quantity	Value	Units
Electricity in Excess	11854	kWh/yr
Demand left Unmet	0	kWh/yr
Capacity Shortage	40.3	kWh/yr

Table 6 Production Scenario

Component	Production	% Units
Generic Flat Plate PV	143224	55.1
Grid Purchases	116505	44.9
Total	259729	100

The statistics of PV module for the location considered are obtained as shown in Table 7. The simulation results give a rated capacity of 103 kW for supplementing the local load with a capacity factor of 16.2%. The total energy production for this system is found to be 143,224 kWh/yr. The specifications of the battery system is given in Table 8. The overall energy exchange detail of the battery system, system converter and grid are depicted in Tables 9, 10 and 11 respectively.

Table 7 PV System Statistics

Quantity	Value	Units
Rated Plant Capacity	103	kW
Average Output	16.3	kW
Average Output/day	392	kWh/day
Plant Factor	16.2	%
Total Energy Production	143,224	kWh/yr

Table 8 Generic 1kWh Li-on Battery Specifications

Quantity	Value	Units
Batteries	24	Quantity in Number
String Size	4	Number of Batteries
Parallel Strings	6	Strings
Bus Voltage	24	Volt

Table 9 Generic 1 kW Li-Ion Battery Result Data

Quantity	Value	Units
Average Cost of Energy	0	\$/ kWh
Energy Inflow	7,239	kWh/yr
Energy Outflow	6,533	kWh/yr
Battery Storage Depletion	19.2	kWh/yr
Energy Losses	725	kWh/yr
Annual Throughout	6,887	kWh/yr

Table 10 System Converter Statistics

Quantity	Value	Units
Operational Hours	5,451	hrs/yr
Energy Outflow	124,131	kWh/yr
Energy Inflow	130,664	kWh/yr
Energy Losses	6,533	kWh/yr

Table 11 Grid Exchange Rate

Time Period	Energy Received (kWh)	Energy Injected (kWh)	Net Energy Received (kWh)	Maximum Demand (kW)	Energy Bill	Demand Bill
Annual	116,505	44,631	71,874	55.2	\$9,419	\$31.25

4. CONCLUSION

Microgrid consisting of Solar PV, Battery System with Grid connection is employed to meet the load demand of a proposed residential area. HOMER Pro Software was employed for getting the optimized design of the Microgrid. The optimization result with integration of renewable energy resources are taken into consideration. Accordingly, the comparison between two configurations was presented and it was found that the system design consisting of 103 kW Solar PV, 24 kWh capacity battery and 61.8 kW converter with grid connected system is found to be more feasible. The Net Present Cost (NPC) and Cost of Energy (COE)

of the optimum design were found to be minimum compared to that of the other cases. The CO₂ emission on the optimum design was found to be 73.631 kg/yr which is lesser than that of the other cases. The Solar PV generation is 143224 kWh/yr which is 55.1% of the total power required and the remaining 49.9% i.e. 116505 kWh/yr is purchased from the grid. Hence, the system is dependent on main grid to some extent which could be improved by implementing other renewable resources in future. Thus, in all, this paper has presented an approach to design an efficient Microgrid system to meet the load demand of a proposed residential load and its analysis has shown that the system is feasible and optimum. Future studies may incorporate some more renewable energy resources like small hydro power plants, wind energy, biomass, fuel cells, etc. to further reduce the load shared by the main grid.

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APPENDIX

1. PV System:

Model: SunPower SPR-305E-WHT-D

PV type: Parallel String – 66, Series connected module per string – 5

- ☐ Maximum Power - 305.226W
- ☐ Cells Per Module – 96 N-Cell

Module data	V	I
V_{oc} , I_{sc}	64.2V	5.96A
Max. power point	54.7V	5.58A
Temperature Coefficient	-0.27269 %/ deg.C	0.061745 %/deg.C

2. Battery System:

- ☐ Type – Lead Acid, Nominal Voltage – 24V, Rated Capacity – 167Ah
- ☐ Initial state-of-charge – 30%, Battery response time – 20sec
- ☐ Maximum capacity – 104.1667Ah, Cut-off voltage – 165V
- ☐ Fully charge voltage – 500V, Nominal discharge current – 20A
- ☐ Internal resistance – 0.022Ohms, Capacity at nominal voltage – 31.0278Ah