Economic Analysis of a Grid Connected PV Systems: A Case Study in Khulna

Amit K. Podder, Md. Rakibul Hasan, Narruttam K. Roy, and Md. Mostafizur R. Komol

***Abstract*—This paper presents a detailed design of an on-grid PV system that meets the electrical needs of a typical domestic building in the southern corner (i.e. Khulna) of Bangladesh. The system comprising of the photovoltaic array to capture solar energy, a power converter to change over between AC and DC, grid connection and lead acid battery to store energy. The modelling is completed by assessing the required load, choosing and deciding the proper specifications of the components associated with the system. Different factors, for example, the geographic area, atmospheric condition, solar irradiance and load consumption upon which the whole work depends are all considered. The cost optimization of the system is performed as per the system's net present cost, cost of energy, operating expense and initial capital. Additionally, an efficient algorithm to manage the system energy along with power flow is proposed. The techno-economic analysis of the proposed system is performed by using HOMER simulation software. Simulated results indicate that the proposed model meet the load demand and show tasteful execution.**

***Index Terms*—Photovoltaic Array; Grid-Connected PV; Energy Management; System Sizing; Cost Analysis.**

I. Introduction

Due to the fast escalation of prices, depletion of stocks, severe emission of greenhouse gases and climate exchange impact of fossil fuel, there might be a targeted focus on other breeding system with a higher potency of energy usage. In that case, renewable energy resources like solar, wind etc. perform a top-notch role. Bangladesh has an enormous potential for renewable energy which can be used to meet the electricity shortage. The geographical status of Bangladesh could be very favorable for the use of solar energy. The quantity of solar radiation in Bangladesh varies from 1575 to 1850 kWh/m^2, that's 50-100% better than in Europe. Most of the power generating stations are fossil fuel based but they are now not surroundings pleasant and are answerable for an Earth-wide temperature boost. Therefore, for tackling load shedding issue, an inexhaustible on-grid system with a battery backup can be a superior alternative [1]-[2].

Solar photovoltaic is presently, after hydro and wind power, the crucial renewable electricity source in terms of globally hooked up capacity. Photovoltaic (PV) power generating structures change over the sun powered vitality promptly into electricity using state-of-the-art semiconductor materials. PV systems fluctuate in intricacy.

A few are called a "stand-alone or off-grid" system because they are the only supply of energy to a domestic load, water pump or distinctive load. Standalone systems can be intended to keep running with or without a backup battery. Other diverse PV systems are alluded to as "grid-connected" systems. At the point when the extent of power produced by utilizing PV system surpasses the client's load, additional vitality is traded to the grid, turning the customer's electric meter in reverse. On the other hand, the client can draw required power from the utility when vitality from the PV system is deficient to supply the building's load.

Numerous Scientists from distinct parts of the arena had been contemplating on Solar PV system relying on the pleasant of resources in addition to the climatic, financial and regulatory situations at that given place. The capacity of sun powered vitality for seven districts in Jordan was explored in [3] which made an inspiration of utilization of sunlight based PV system. To amplify the output power from distributed energy resources (DERs) through their optimum usage by utilizing HOMER software was studied in paper [4], [5]. For efficient energy management between PV system, Grid and Battery various algorithms are proposed in different articles. Further to that, scientists additionally insight on particular site applications, for example, a university campus [6], hotels [7] and resorts [8] or some other buildings that that may require some sizeable measure of energy.

This paper proposes an efficient energy management algorithm to control the operation of an on-grid PV system for a typical domestic building in Khulna. System improvements, cost analysis and correlation among different cases are examined on the premise of the cost of vitality, pay-back period, and ecological discharge and so on. Optimization of the system identifies the best end result out of various alternatives. The system is reenacted and upgraded utilizing Hybrid Optimization Model for Electric Renewable (HOMER).

The paper is organized in six sections. Section II presents the geographical profile and load demand of the selected site. Section III describes the cost analyzing parameters and the simulation software for accessing the economic expenditure of the proposed system. Section IV and V represents the simulation model and its optimization results. Finally, a conclusion is drawn in Section VI.

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II. Geographical Profile & Load Demand

A grid connected PV system has been planned in this paper by using HOMER to assess and ordain the cost of the system. Before the system sizing, available insolation of the solar energy and load profile should be evaluated because they play a significant role for the optimization of the size of power system. Therefore, they are exhibited in the following sections.

A. Study Area and Solar Irradiance Resources

The southern city of Bangladesh, Fulbarigate, Khulna, near the campus of Khulna University of Engineering and Technology is considered as the study area of this work. Fig. 1 shows the geographical location of the study area on the map [9]. The latitudes and longitudes of the selected site is between 22°54.6825′N and 89°30.996′E. The climate region of Khulna in the summers are invariably hot (mean maximum 41°C and mean minimum 25°C) with large variation and low relative humidity averages (25%). The yearly normal solar irradiance is assessed to be 4.75 kWh/m^2/day [9]. The monthly average solar radiation and clearness index is shown in Fig. 2.

Fig.1. The geographical location of the study area on the map

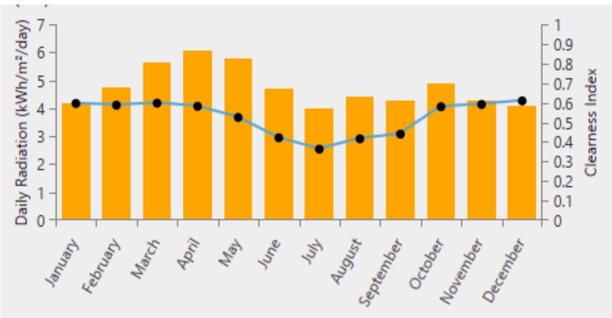

Fig. 2. The monthly average of solar radiation and clearness index

B. Load Profile Assessment

The profile of electrical load is the most important parameter for this type of studies. In this work, an expected residential load demand is presented in Fig. 3. The evaluated information is assembled by taking interview of the people on their normal utilization of electrical appliances. Fig. 3 shows the everyday normal load profile in which the pinnacle demand is found at 18:00 to 23:00 h which decides the size of the system. Here, the maximum load consumption is considered as 2.45 kW. An arbitrary fluctuation of 5% every day and 5% time-step were presented for the optimization of the system. Seasonal profile of load demand throughout the year is shown in Fig.4.

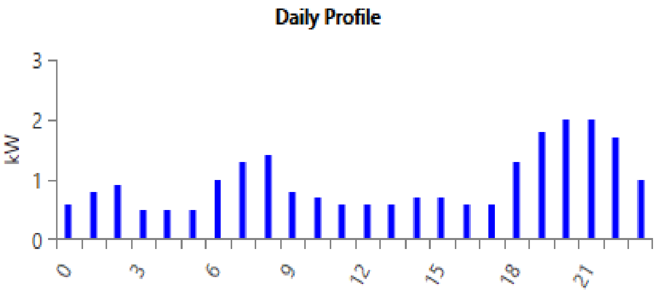

Fig.3. Variation of load demand during 24 hours

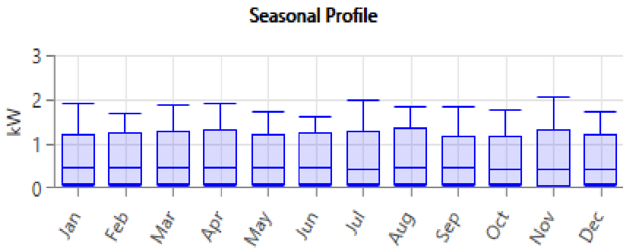

Fig. 4. Seasonal profile of load demand throughout the year.

III. Methodology

A. HOMER

HOMER is a micro scale control programming software that improves the undertaking of assessing outlines of both off-grid and grid-connected power systems for an assortment of uses. This software is created by National Renewable Energy Laboratory (NREL) in USA [9]-[10]. Information data is given to HOMER which incorporates residential load (per year/month of load information), sustainable assets, segment specialized points of interest and costs, imperatives, controls, kind of dispatch procedure, and so forth. Solar irradiance, load demand, segment subtle elements & expenses are considered here as information data to HOMER.

B. Cost Analyzing Parameters of HOMER

1) Cost of energy (COE):

The average cost/kWh of usable energy generated by the system is known as Cost of Energy.

$$COE = TAC/\left(L_{prim,AC} + L_{prim,DC}\right) \quad (1)$$

Where, $L_{prim,AC}$ and $L_{prim,DC}$ are the AC primary load and DC primary load respectively.

2) Net present cost (NPC):

It is the present estimation of the considerable number of expenses of introducing and working that is related to the system lifetime, less the present estimation of the considerable number of incomes that it procures over the system lifetime [10]. It can be computed as

$$NPC = TAC/CRF(i, Rpr_j) \quad (2)$$

Where, *TAC* is the total annual cost ($), i is the interest rate (%), Rpr_j is the system lifetime (year) & *CRF* is the capital recovery factor.

3) Total annual cost (TAC):

It is the yearly value of the total net present cost. It can be presented as below [10].

$$C_{ann,tot} = CRF(i, R_{proj}).C_{NPC,tot} \quad (3)$$

Where, $C_{ann,tot}$ is the total net present cost ($), i is the yearly discount rate (%).

4) Operating Cost: The operating cost is the annualized value of all costs and revenues other than initial capital costs. HOMER uses the following equation to calculate the operating cost:

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \quad (4)$$

5) *Operation and Maintenance Cost:*

The O&M cost of a part is the cost related with working and keeping up that segment. The aggregate O&M cost of the framework is the total of the O&M expenses of every system part.

6) Capital recovery factor (CRF):

This is a ratio factor for evaluating the present value of a series of equal annual cash flows [11].

$$CRF(i, N) = i(1 + i)^N / \{(1 + i)^N - 1\} \quad (5)$$

IV. Simulation Model

An on-grid PV system is developed here using HOMER. The grid connected PV system composed of a solar array, power converter, backup battery, electric load and grid connection as shown in Fig. 5. For verifying the system performance under various conditions, simulation studies have been carried out using real weather data. For evaluating the cost of the system, the following specifications of the system component are considered.

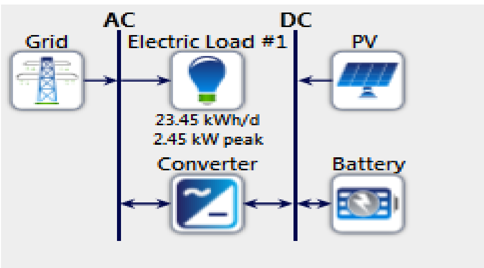

Fig. 5. Complete model of a grid connected PV power system

A. PV Array

The proposed PV modules to be utilized as a part of the system reenactment are 24 V, 235 W (at 1000 W/m^2, and 25℃). The PV module is named as JA JAM6(K) 48-235, manufactured by JA Solar. Evaluated capital and substitution cost of PV is 252 US$/kW [9]. The lifetime was thought to be 25 years with an efficiency of 17.91%. The PV panel is a flat plate type and it has an operating temperature of 45℃ with a temperature co-efficient of -0.410. Capacities of different PV panels (0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5 kW) were considered in the analysis. An MPPT controller is also considered here which capacities are also varied according to the PV panel capacities for the optimization of the system.

B. Power Converter

The simulation model comprises of a 4.6 kW Generic system converter with an efficiency of 95% and lifetime of 15 years with capital and substitution cost of $300 and operating and maintenance (O&M) expenses being zero.

C. Battery

A battery is utilized in the system with a specific end goal to destroy the contradictory condition like overcast days, blustery days or inadequate solar radiation. The name of the battery bank is Surrette S-260, produced by Rolls Battery, with a nominal capacity of 3.12 kWh, throughput 1704.90 kWh [9]. Its effectiveness is around 80%. In this study, it is just utilized amid any fault on the network to keep up the coherence of supply.

D. Grid

In an on-grid system, grid is considered as a reinforcement control source or overabundance control safeguard. The cost of electrical vitality is considered as $ 0.1/kWh for buy and $ 0.05/kWh available to be purchased back to the grid [10].

V. Optimization Results

The proposed system turned into design in HOMER via placing the perfect input resource parameters. The optimization of the system is done based on the cost analysis and the energy management of the system. These two optimizations are narrated below:

A. Energy Management

The proposed flowchart as in Fig. 6 is used for the energy management of the simulated grid-connected PV system. In the beginning, the model updates generated solar power (P_{solar}), required load (P_{load}) and also the SOC of the battery (SOC_{bat}). If any change occurs, then the extent or lack of solar power is determined. After serving the required load, if there are extent of energy then it is stored in the battery. But for better management of battery, its SOC is not permitted to exceed 80%. If battery is fully charged, then the extra energy if exists is sold to the grid. On the contrary, when the solar radiation is low, the generated power from PV is not enough to supply the required load. So other energy source is required to meet the load. If grid is available the required energy ($P_{required} = P_{load} - P_{solar}$) is purchased from the grid. In case of failure of grid, the required energy can be fed to the load from storage battery. For proper management of battery, it is carefully operated so that its SOC cannot be lower than 20%. If the SOC goes lower than 20% then there's no option exist except shedding of non-critical loads.

B. Cost Analysis

Fig. 7, 8 and Table I, II, III display the optimization outcomes for the proposed on- grid PV system. The total system is characterized into three cases. The three cases are revealed below:

1) *Case I Grid only system:*

The total NPC and COE of grid only system is found as $11,065 and $0.100 as shown in Table I. The yearly electricity cost, production and consumption is given in Table I.

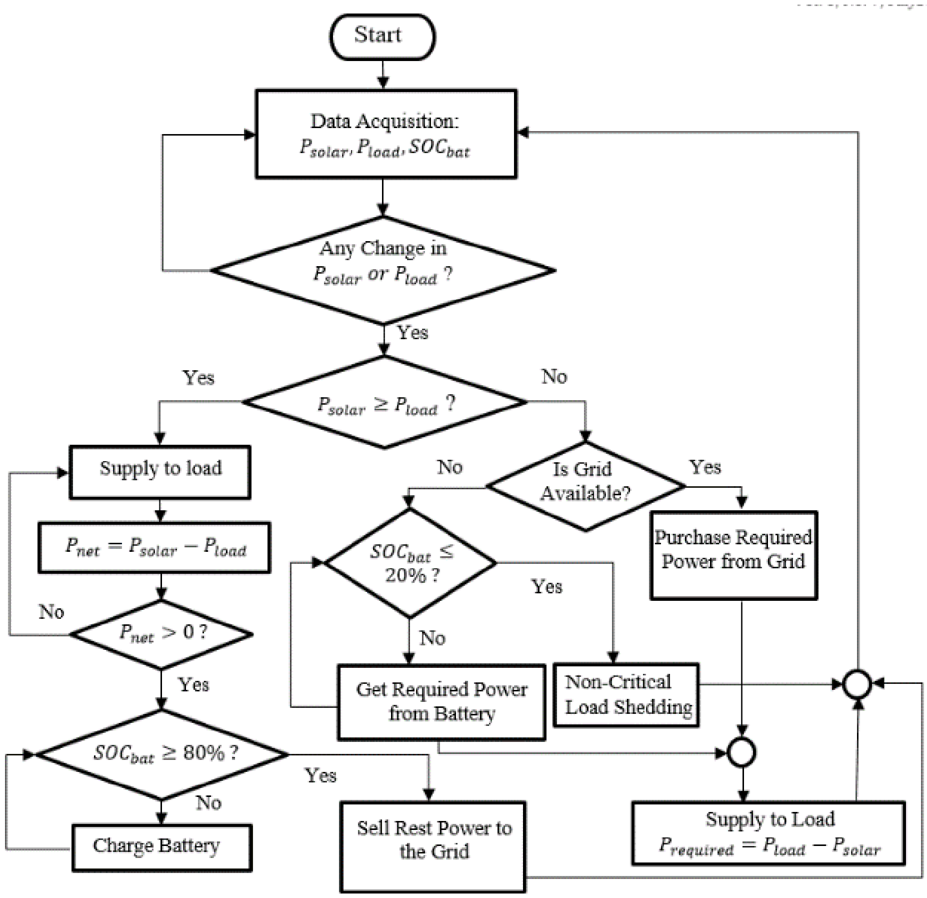

Fig. 6. Flowchart of the proposed algorithm for the grid connected PV system

Architecture					Cost				System	PV		Battery	
PV (kW)	Battery	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Capital Cost ($)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)
5.00		999,999	4.60	CC	$0.0284	$4,792	$166.50	$2,640	55.7	1,260	7,644		
5.00	2	999,999	4.60	CC	$0.0368	$6,212	$204.98	$3,562	55.6	1,260	7,644	5.11	0
		999,999		CC	$0.100	$11,065	$855.93	$0.00	0				
	2	999,999	4.60	CC	$0.130	$14,338	$931.04	$2,302	0			5.11	0

Fig. 7. Screenshot of finding optimization results of on –grid PV system without MPPT controller

Architecture						Cost				System	PV		Battery	
PV (kW)	PV -MPPT (kW)	Battery	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Capital Cost ($)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)
5.00	4.00		999,999	4.60	CC	$0.0343	$5,630	$211.21	$2,900	54.2	1,520	7,246		
5.00	4.00	2	999,999	4.60	CC	$0.0429	$7,050	$249.70	$3,822	54.2	1,520	7,246	5.11	0
			999,999		CC	$0.100	$11,065	$855.93	$0.00	0				
		2	999,999	4.60	CC	$0.130	$14,338	$931.04	$2,302	0			5.11	0

Fig. 8. Screenshot of finding optimization results of on –grid PV system with MPPT controller

2) Case II Grid connected PV system without MPPT controller: The total NPC and COE of grid connected PV system without MPPT controller is found as $6,211.94 and $0.03683 as shown in Fig. 7. The cost of the system proves that this system is cost effective than grid only system. Here the converter is operated in both rectification and inversion mode i.e. both PV system and Grid will charge the battery. The converter and battery loss in this case are 382 kWh/yr and 0.147 kWh/yr. The annual electricity production by PV array & grid and consumption by AC load is presented in Table I. Here, the PV array contribution is 56.9% and the excess energy available from the system is about 4,488 kWh/year which is offered to the grid. According to the considered price, the energy purchased from the grid is cost about $578.7 and the energy sold from the grid is about $224.4.

TABLE I: COST, PRODUCTION AND CONSUMPTION SCENARIOUS OF GRID ONLY SYSTEM

Cost ($) of Grid only System		
Total Net Present cost(NPC)	11,065	
Levelized Cost of Energy (COE)	0.100	
Operting Cost	855.93	
Production of Electricity (kWh/yr & %)		
Grid Purchases	8,559	100%
Consumption of Electricity(kWh/yr & %)		
AC Primary Load	8559	100%
DC Load	0	0%
Emissions (Kg/yr)		
Carbon Dioxide	5409	
Carbon Monoxide	0	
Unburned Hydrocarbons	0	
Particulate Matter	0	
Sulfur Dioxide	23.5	
Nitrogen Oxides	11.5	

TABLE II: COST, PRODUCTION AND CONSUMPTION SCENARIOUS OF GRID CONNECTED PV SYSTEM WITHOUT MPPT CONTROLLER

Cost ($) of Grid Connected PV System without MPPT Controller		
Total Net Present cost(NPC)	6,211.94	
Levelized Cost of Energy (COE)	0.03683	
Operting Cost	204.98	
Production of Electricity (kWh/yr & %)		
PV array	7,644	56.9%
Grid Purchases	5,787	43.1%
Consumption of Electricity(kWh/yr & %)		
AC Primary Load	8559	65.6%
DC Load	0	0%
Grid Sales	4,488	34.4%
Emissions (Kg/yr)		
Carbon Dioxide	821	
Carbon Monoxide	0	
Unburned Hydrocarbons	0	
Particulate Matter	0	
Sulfur Dioxide	3.56	
Nitrogen Oxides	1.74	

3) *Case III Grid connected PV system with MPPT controller:*

The total NPC and COE of grid connected PV system with MPPT controller is found as $7,050 and $0.04293 as shown in Fig. 8. The cost of the system proves that this system is cost effective than grid only system but little costly than case II system because of the MPPT controller. The converter and battery loss are 362 kWh/yr and 0.147 kWh/yr. The annual electricity production by PV array & grid and consumption by AC load is presented in Table I. Here, the PV array contribution is 55.5% and the excess energy available from the system is about 4,143 kWh/year which is offered to the grid. Here, the energy purchased from the grid is cost about $582 and the energy sold from the grid is about $207.15.

4) *Comparison among three cases*

The amount of annual energy generation, consumption and finally COE have been obtained at different conditions to get the optimum system. The optimization analysis reveals that the COE is $0.03683/kwh in case of the grid connected system without MPPT controller (Case II) which is lower as compared to other system. Again, the converter loss of grid connected PV system with and without MPPT controller is 362kWh/yr and 382kWh/yr respectively which shows that the system with a MPPT controller provides a better performance. In case of environmental issue, the data at different cases reveals that the case II emits lower green-house gases than others. Various projects on on-grid & off-grid PV system has been implemented in different location of Bangladesh by Infrastructure Development Company Limited (IDCOL) and Grameen Shakti (GS) [11]-[12]. The cost associated with that projects shows that the cost optimization of this proposed system is relevant to the actual implemented system.

TABLE III: COST, PRODUCTION AND CONSUMPTION SCENARIOUS OF GRID CONNECTED PV SYSTEM WITH MPPT CONTROLLER

Cost ($) of Grid Connected PV System with MPPT Controller		
Total Net Present cost(NPC)	7,050	
Levelized Cost of Energy (COE)	0.04293	
Operting Cost	249.70	
Production of Electricity (kWh/yr & %)		
PV array	7,246	55.5%
Grid Purchases	5,820	44.5%
Consumption of Electricity(kWh/yr & %)		
AC Primary Load	8559	67.4%
DC Load	0	0%
Grid Sales	4,143	32.6
Emissions (Kg/yr)		
Carbon Dioxide	1,060	
Carbon Monoxide	0	
Unburned Hydrocarbons	0	
Particulate Matter	0	
Sulfur Dioxide	4.59	
Nitrogen Oxides	2.25	

VI. CONCLUSION

This paper presents an efficient energy management and cost analysis of a grid connected PV system in the southern region i.e. Khulna in Bangladesh. The proposed PV system has been outlined and improved utilizing HOMER software. All the enhancement is positioned by NPC and all other financial outputs are ascertained and finding the best cost of vitality. The simulation result demonstrates that the on-grid PV is more productive and temperate contrasted. An algorithm is designed to manage the power flow efficiently depending on various conditions of the essential elements of the system. An on-grid PV does not need an additional storage battery for ordinary working situation but used for the continuous operation of the system. Subsequently, one might say that the proposed grid connected PV system with the proposed efficient energy management scheme can be the most appropriate system for the considered study area.

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