Proceedings of the 2019 5th International Conference on Advances in Electrical Engineering (ICAEE)
26-28 September, Dhaka, Bangladesh

Designing and Sizing of standalone solar homes system integrated microgrid*: for rural electrification*

Muhammad Taheruzzaman
Energy Distribution and High Voltage Engineering
Brandenburg Technical University Cottbus,
Cottbus, Germany
Department of Electrical and Electronic Engineering,
Uttara University, Bangladesh
House#6, Road#15, Uttara Sector#6, Dhaka-1230, Bangladesh
taher.tum@gmail.com

***Abstract*—Access to electricity in the remote areas is challenging, and investing the bottom up electrification concept for DC micro grid (DC-MG). In this paper, the surplus electricity from the SHS (Solar Home System) within the DC micro grid in Bangladesh demonstrates the hidden potential to share amongst households within the same DC-MG. A single SHS is the initialization process, next the neighboring households including SHS and household without PV are the continuation of the cluster of bottom-up electrification. The surplus electricity from all SHSs' and sharing among the community is called bottom-up electrification. Hence, the SHS generated surplus electricity shared along within the neighbor households. The tropical regions including South Asia and sub-Saharan countries mainly based on PV system have proven to be appropriate and suitable for rural electrification. Sharing the surplus electricity would be the opportunities that not only gives reliability in system but also utilizing the excessive power improve the life standard of the community. The eminent tool for energy modelling and optimization Homer Pro microgrid simulation tool used to design the optimal size of the micro grid.**

***Index Terms*—Solar Home System (SHS), decentralized power generation, DC-micro grid, sizing and planning of Micro grid.**

I. Introduction

Access to reliable energy is one of the basic requirement for improving the living standards of the community in rural and areas, for enhancing education, healthcare, and socio-economic development. Unfortunately, about 1.0 billion population permanently has no access to electricity [1], and 80% of inhabitants are living in rural and remote areas [2]. Amongst, all the developing countries, Bangladesh is one of the poorest electrification rates with less than 32% of households are electrified. In the densely populated, least-income country of 158.5 million people (in 2014), with the overall electrification rate 59.6% in 2012, about 40% of people in Bangladesh depend on kerosene for lighting purposes [3]. Electricity consumption per capita basis an increase by a little from 96 kWh (in 2002) to 122.43 kWh (in 2003) in Bangladesh [4] [5]. According to world bank report, the life standard influence rural inhabitants towards electricity consumption increase about 200% in last 5 years [4], the consumption of electricity upsurges almost 10 times (from 5.14 TWh in 1990 to 57.47 TWh in 2016) last two decades reported in [6]. Rural Electrification is a fundamental constituent for socio-economic development for poverty-stricken rural communities [5] [7] [8] [9] [10]. The SHS are extensively accepted and popular standalone system in Bangladesh. As mature and effective means of electrification, about 0.5 million SHS already installed remotely isolated location around Bangladesh [11] [12]. Notwithstanding, both government and international community, have effective effort to pace of rural electrification in the developing countries is still very sluggish [13]. But the complexity and some factors including local conditions, energy mix planning requires not only a deeper understanding of the problem but also perceptive idea of mitigation and effective framework toward sustainability development [14].

Rural electrification is more challenging than urban electrification in provisions of energy policy, finance, and institutional barriers. There are some common facts and features that influence rural electrification more complicated; least number of connections per kilometer of the line, low level of consumption, low demand of industrial load, heterogeneous landscape, and decisively lack motivation for private investors. Regardless of these challenges, some countries have been successfully electrifying to their rural community [5] [15]. Bangladesh is one of the pioneers in electrifying rural areas among others, holds a special place to electrifying remote and rural communities by off-grid PV systems such as standalone SHS and mini-grid. Bangladesh has experienced continuous development in the current years, but still facing extending shortages in the requirements of electricity and infrastructure services. The country ranked 134th out of 144 countries based on quality electricity supply in 2012 [16], which means the most problematic obstacles to do business in Bangladesh. According to vision-2021, Government has intended widespread access to electricity by jubilee year of its independence in 2021. The vision for addressing the enhance electricity generation and increase access to electricity by renewable energy conversion, load management, adopting grid and off-grid electrification

978-1-7281-4934-9/19/$31.00 ©2019 IEEE

advancement and efficiency. On the constructive side, off-grid electrification is anticipated to cover about 30 million by 2016 (18% of the population), whereas about 15 million in 2013 [12]. Adaptation of vision 2021 and "Electricity for all" plan that largely relies on conventional fissile fuel, Government of Bangladesh is promoting renewable energy goal of at least 5% power conversion from renewable sources by 2015 and 10% by 2021. Despite vision, "energy for all" has set energy efficiency targets of 10% by 2015, 15% by 20121 and 20% by 2030 [17]. Now Natural gas is the only imperative source of commercial energy generation in Bangladesh, and about 86.26% of electricity was generate by natural gas based in 2007-2008. Owing to turn down in the availability of natural gas in the present time, the government is heartening and encouraging off-grid renewable energy technologies in the rural areas [18]. PV-based energy and Solar Home Systems (SHSs) are the highest-flying technology in Bangladesh and SHS project with Bangladesh is one of the most successful projects in the world [19].

The living standard has drastically changed in the last couple of years, the extensive infiltration of some modern technologies including mobile phones, smartphone, modern equipment required more electricity as some demand increases which is the serious challenge in the demand management side [20]. Solar electricity has become quite affordable, accessible and flexible due to cost trimming PV panel worldwide [21]. Efficiency is the main factor in producing photovoltaic electricity, the cost decreases from US$ 1.09/kWh to US$ 0.20/kWh and lifespan vary from 15-25 years [22]. standalone microgrids are typically designed for providing continuous power support for least demand for isolated or remote areas [23]. Area-wise, Sub-Saharan region, and South Asian countries are the poorest, where only 48.4% and 11.9% have access to electricity. The low rate of access to electricity in these regions, which is disappointing the growth that providing the adequate rural electricity has been partially attributing on cost recovery especially privately financed [24]. Though GOB government of Bangladesh is the main institute to finance in the access to electricity. Privately financed projects are getting subsidies from GOB via IDCOL (infrastructure Development Company limited) which encourages to invest more in rural electrification.

II. Challenges of Rural electrification

Electricity access is one of the jovial terms of energy in the tropical country like Bangladesh, but the lack of electricity is frequently hampering socio-economic development services such as health in hospital, agricultural, and education. Bangladesh is one of the densely populated country, an estimated 161 million people, known as the ninth heavily populated country in the world, and over 75% of total population are living in rural and remote areas. According to [25], in the context of Bangladesh the build-up of redundant infrastructure exacerbating the challenges of high Capex (capital expenditure). Presently in Bangladesh, only about 30% of households have the access to the national grid electricity.

The total poverty reduction in the rural electrification has emphasized the prominence of socio-economic development with productive uses. There are several researchers 'remarks on not only the grounds of costs and institutional capacity but on the grounds of lack of more integrated planning of affordability and flexibility.

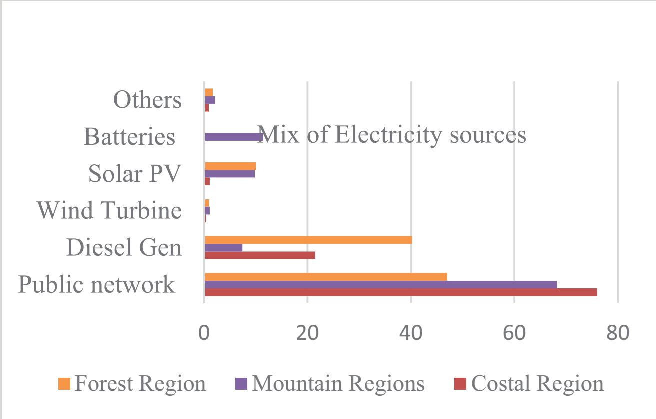

Fig. 1. Mix of electricity sources in remote areas in Bangladesh

An agrarian country like Bangladesh, the socio-economic development is an important constraint for overall infrastructure development by rural electrification [26]. According to REP (rural electrification report), only 20% of households' recipients of electricity from PV system, which are mostly situated in the remote areas, while 78%of individual HH (households) have the PV systems are their only electricity source [27]. Due to demand for cleaner and energy efficient for solar PV, the battery use has been reduced from 25%to 21%.

The national grid of Bangladesh, PGCB (Power Grid Company of Bangladesh) is the ultimate source of electricity for the inhabitants of rural shown in fig.1, afterward the diesel fuel generated electricity but the cost of electricity is about US $ 0.54. Due to geographical facts long line transmission cost higher. The power generation is not yet met our demand, as self-healing SHS is becoming popular.

There are some challenges about rural electrifications:

- Non-availability of power due to the shortage of generation and supply
- The high cost of grid extension
- High operation and maintenance
- A better regulatory framework needs to design using the local government and central government
- High capital cost; lack of financing and subsidies
- Lack of access of credit for the consumers.

Typically, rural areas are situating far away from the national grid; therefore, the high cost respired for grid expansion. World

Bank cited that, the grid extension costs vary from \$6,340/Km in the densely populated country such as Bangladesh. However, the solar home system (SHS) or standalone PV system integrated mini/micro grid would be the best possible solution in Bangladesh. For instance, the Pico PV system cost about US\$ 50, and SHS subsidized 50 W cost the US \$ 450 [28].

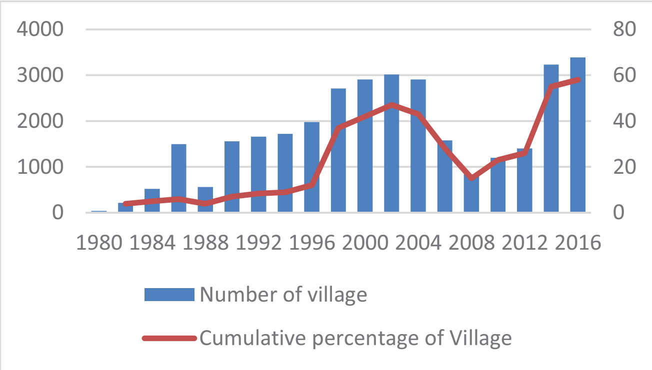

Fig.2Electrification progress in Bangladesh from 1980-2016

Last couple of years, especially year 2012standalone PV system and SHS is started its boom. In the year 2016 and 2017 the rate of escalation touches its remarkable point. The significance of PV and consequence of enhancement, the energy access through decentralized PV panel-based system involvement in bringing economic and social reimbursement in the rural area [29] [30] [31].At the present research correspond to electrification by PV system is challenging for both rural and urban confine the development in Bangladesh, India, Pakistan, Sri Lanka, and Nepal. Although, Bangladesh most widespread PV applications deploy around the remote region including standalone SHS (solar home system) and Solar Lanterns (SL); and centralized application such as solar mini-grid (SMG).

III. Microgrid System Design

In the recent past, the most prominent and useful renewable source of energy is predominantly solar, and standalone PV system and SHS has enormous potential in Bangladesh. As PV generated power and the loads are DC, among all neighboring SHS integrated into a low voltage DC network, and the community-based DC micro grid is more efficient [32] - [33]. The higher efficiency, protection and power quality encourages DC micro grid for rural electrification in South Asia and Sub-Saharan. The advantages of the DC grid over the AC system for rural electrification as follows;

- The community based microgrid consumers do not have to buy emergency generator
- PV system and SHS easily interconnected within the microgrid system
- Each household system not required battery storage, the central storage system enhance consistency and steady operation.
- Decentralized control in each SHS, ensures reliability and easily monitor the remotely installed SHS.

A. Solar Home System (SHS) Design

In order to access to electricity in the rural areas, especially the regions where the enormous solar potential is available but the utility grid not frequently accessible solar home system and standalone PV system recommended. Most of the SHS in the developing countries are uses for lightings, as rural households could save up to the capacity range of SHS is depending on a couple of factors such as-

- Load and consumption profile characteristics
- Solar panel peak power (Watt peak)
- Capacity of energy storage or battery capacity (Ah)

The critical components of a typical SHS consisting of 12 V DC battery [34], solar power generator (PV panel), and the battery control unit (BCU), Charge controller, and DC loads. The most critical component battery capacity considered as 60 Ah to 100 Ah. As the battery is very expensive component due to their sensitivity to maltreatment by the end user, while deep cycle batteries recommended. For rural electrification in the developing and underdeveloped countries including in South Asia and sub-Saharan region, the ratio of battery capacity and PV panel capacity (Ah/W_P) considered at range from 0.9 to 1.5. The PV panel capacity considered as 45 W_P to 65 W_P. The sizing of the system depending on the adequate voltage and current of every single component that envoy the performance to meet the electric demand. The sizing of PV panel for SHS system depending on a couple of factors including the daily energy required from PV panel (E_d), peak power (P), total current I_{DC}.

B. Load Profile of SHS and Micro Grid

In the DC MG which is configured along with 80 SHS (each SHS load profile are same and 10% day to day variation), as each SHS are produces surplus electricity and those can be shared with other households 40 households without PV panel in the DC MG system, and also utilizes for community productive use. An estimated load profile of the MG had a peak power exceeding 11 kW and 26.8 kW from 7:00 to 22:00 winter and summer respectively, during summer DC ceiling fan lighting loads consumes mostly whereas winter only lighting consumes electricity mostly. All the households including SHS loads are assumed it and load profile present in table I.

TABLE-I: Load profile of each SHS

Load profile of typical SHS

Nr. of Appliances & capacity	Total energy		Energy consumption	
	Summer	Winter	Summer	winter
CFL (4 x 6W)	30	30	120	120
Fan (3x60W)	420	0	1440	0
M. Charger (2x3W)	9	9	18	18

TV (1x100W)	100	120	100	100
Total energy consummation (kWh/day)			1.1678	0.358

Conventionally the rural residents require less amount electric power compared to the urban, and the DC appliances including LED lights, DC fan, DC television, and mobile charger requires 75% less energy and overall cost decreased by 50% [35]. The table data is considered the appliances those are used in the study location at 22.947552°N, 89.843413°E in Bangladesh.

C. Sizing of PV Module of Micro Grid

The daily energy required from the PV panel:

$$E_d = \frac{\text{average enery consumption per day}}{\text{each component efficiencies}}$$

To produce the peak power by the PV panel, the number of hours solar irradiate at maximum solar insolation (kW/m^2).

$$P_P = \frac{\text{daily enery required for SHS}}{\text{minimum Sun peak hours}}$$

The operating current of course generated by PV panel, which is depending on the solar insolation, while the DC current can be calculated at peak power dividing by the DC voltage of PV panel.

$$I_{DC} = \frac{\text{Peak Power}}{\text{DC voltage of the SHS system}}$$

The total number of modules required for the SHS depending on the module current (I_{PV}), rated PV module current (I_r), system voltage (DC), and rated PV module voltage. Assuming the parallel module N_P and Series module N_S the system.

$$N_P = \frac{\text{Module Current}}{\text{Module Rated Current}}$$

$$N_S = \frac{\text{SHS system DC voltage}}{\text{PV module rated voltage}}$$

Total number of modules need in the SHS

$$M_T = N_P \times N_P$$

D. The Sizing of Battery of Micro Grid

In the solar home system and PV standalone system, the battery used in the PV system which sized by ampere-hours (Ah) under standard test condition 25˜ , that specifies the maximum depth of discharge (DOD) of the battery. The capacity of the battery (CB) measured by the amount of energy that can be delivered by a battery when it was fully charged. Capacity determined by the active material (amount of electrolyte) that measured voltage. The capacity of a lead-acid battery is determined by measuring the average load current during a discharging that lasts a specific time and brings the battery voltage down to an end present value at which the battery is considered to be discharged completely. Such as a 12 V lead-acid battery when reached at 10.4 V, it is delineated battery is fully discharged. The capacity rating of the battery is express in ampere-hours (Ah). For instance, a 200Ah lead-acid battery rated for 200 Ah that will deliver 10 A of load current for 20 hours under standard temperature conditions or 50 A current for 4 hours. The depth of discharge (DOD) defined by the degree of how much battery potential or energy that consumed by the loads from the battery. The autonomy of battery for SHS recommended is 4-5 days. Several researches have recommended maximum DOD of 80%, which means 25% of charged left in the battery. The capacity of battery-expressed bellow:

$$C_B = \frac{E_L \times N_A}{V_{syst} \times \eta_{overall} \times DoD_{max}}$$

Where,

E_L	= Electric load consumption (kWh)
N_A	= Number of battery autonomy (days)
V_{SYST}	=Voltage of SHS system (V)
$\eta_{overall}$	= Overall efficiency of system (%)
DOD_{MAX}	= maximum depth of discharge

As each the individual SHS system have the capacity 65W$_P$, and load of SHS mainly are for lighting, consequently 100 Ah lead acid battery used in the system.

E. SHS's integrated Microgrid

The proposed MG consisting of 120 neighboring households which including 70 SHS (prosumer) and other 40 households without PV panel act as consumers, a water pump for irrigation (working from 7:00 am to 11:00 am), a fish market for electric loads (freezer and lighting), and battery. The community-based battery bank which stands for storage surplus electricity that delivered by the 84 SHSs. The MG voltage level considered 12 V, and battery bank voltage 48 V. For better optimization sizing of MG, using real electricity consumption and solar insolation data that simulate overall demand profile that replaced by the SHS instead house without PV panel inspired bottom up swarm concept. Two different cases considered for sizing the MG and optimize the number of SHS needed for stable in operation.

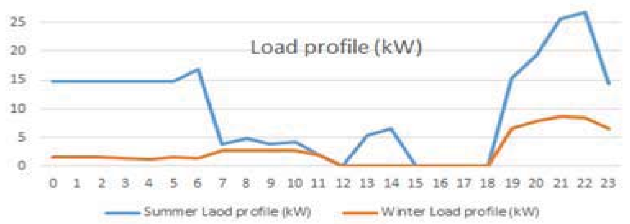

Fig. 3 Load profile of proposed SHS integrated Micro Grid

Some propositions recommend cost reduction possible by 20% with improved energy conversion efficiencies that possible through a fully DC microgrid [36].The distributed storage in DC micro grid system which minimizing the conversion steps on community storage [37] [38].The increases the number of DC appliances at the end-user, the losses at point of load (POL) AC-DC conversion have been appraised to around 15% [39] .

IV. Result and Discussion

A. *SHS produced electricity and surplus electricity*

The SHS with 65 WP, that generates about 102 kW each year but the individual SHS consumes about 73 kW. However, each SHS produces 28.3 % of the surplus of electricity shown in fig.1. Each of SHS tied along with a lead acid battery with the capacity of 100Ah and the SOC (in %) of battery standards remains for the simulation 30% to 100%.

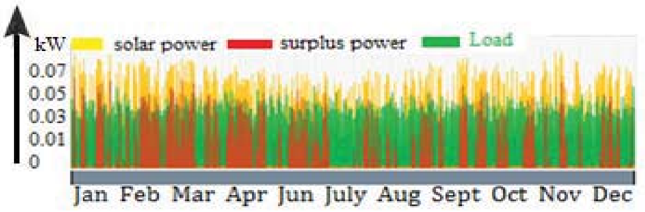

Fig.4 SHS Power generation vs self-consumption and surplus electricity

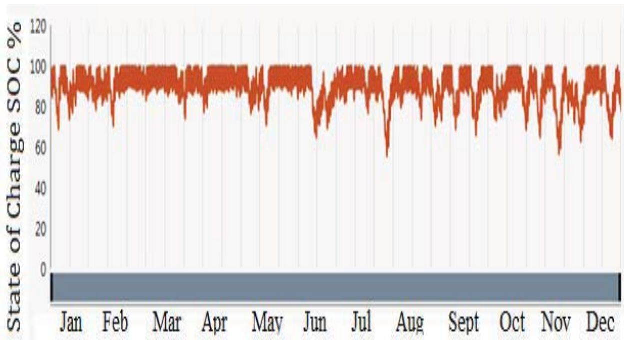

Fig. 5 Each SHS battery SOC percentage over the year

The load household load profile same as present in table 1, then for different watt-peak, a solar home system (SHS) produced the different range of surplus electricity present in table-II

TABLE II
Surplus Electricity of different SHS (Watt-Peak)

SHS capacity (W_P)	Surplus electricity (%)
65	28.3
85	33.2
100	42.12

B. *Case-1: 100 Houses including 84 SHSs'*

Case-1 considered along with 84 SHS integrated MG, which generated about 10,195 kW throughout the year and about 8,382 kW electricity consumption by 100 households (include 84 SHSs). Rest energy consumed by the water pump and fish market. During June to November the local fishing time, as the fish market excessive demand influence on the community-based storage system shown in fig. 4. In that month, the SOC frequently drifted down to 50%. Nevertheless, the excessive demand for daytime, when PV generated electricity directly supplies to the fish market for freezing fish.

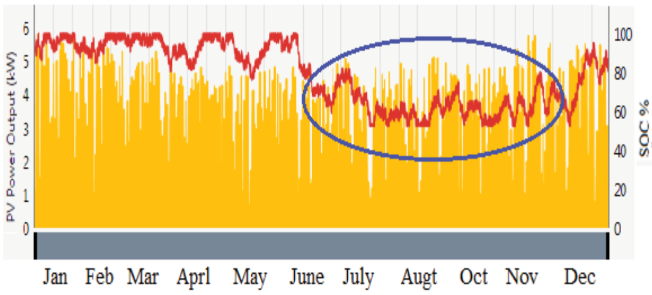

Fig.6 84 SHS generated electricity vs SOC percentage of community-based battery bank

C. *Case-2: only 84 SHSs'*

Considering the future demand and encouraged by the bottom up swarm electrification, altogether 100 SHS integrated MG system produces over 12,000 kW.

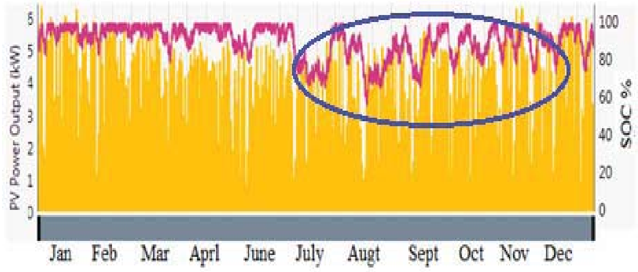

Fig. 7 100 SHSs electricity generation vs SOC percentage of battery bank

When the number of SHS increases the SOC level always in between 90% to 60% as shown in fig. 5. Now if the households' consumption demand increases 10 % to 20% in the future to comply modern life standards can be optimized by the 100 SHSs can also support other 20-30 houses without PV panel and the surplus electricity can also have delivered to the community productive uses, while the distribution approaches gradually constructed bottom up.

D. *Sizing of total battery in number*

The battery bank dedicates to supply electricity to the households without PV panel, irrigation pump, and fish market (freezing load lighting) loads. The loads, which are, consumes from the battery bank, the loads present in table II. The autonomy considered 4 days, overall efficiency 85%, MG system voltage 48 V DC, and DOD considered 70%, and put these values in the equation (7).

From the calculation of the 3*4 = 12 batteries is incorporate within the MG system.

TABLE III

LOAD AND ENERGY CONSUMPTIONS OF DIFFERENT LOADS

Items	Load (W)	Energy consumption
houses	1,168	23.36 kWh
Water pump	640	2.56 kWh
Fish market	3,456	17.28 kWh
Total energy consumption		43.2 kWh

Capacity of Requires, $C_B = \frac{43.2 \times 10^3 \times 4}{48 \times 0.85 \times 0.70}$

The battery bank requires storage capacity 6050 Ah. The Rolls series 40518 deep cycle batteries for 503 Ah selected for 100 hr.

$$N_B = \frac{C_B}{\text{selected } battery \text{ capapcity}}$$

The number of batteries requires for MG 12 batteries

Number of series batteries = $\frac{\text{MG system voltage}}{\text{Battery volatge}}$ = 4

Number of parallel batteries = $\frac{\text{Total numbe of batteries}}{\text{Batteries in series}}$ = 3

V. CONCLUSION

In the modern age, electricity has exceptionally high prominence for the rural inhabitants that complying the millennium development goal (MDG) evidence categories of socio-economic development along with the potential positive health effects through a reduction in kerosene consumption, flexibility in living standards. Bangladesh is one of the pioneers with 60 % electrification in rural and remote areas by using the stand-alone system, especially SHS. Along with REB (Rural Electrification Board), should not only focuses on the ground of costs for infrastructure and institutional capacity but also integrated planning. In addition, it is time to target affordable and flexible electrification where inhabitant's actual needs of electricity.

The DC microgrid designed by 84 SHS and each of SHS sizing with different PV capacity such as 65 $P_o$ssibly produced 28.9%of surplus electricity. The sizing of the system also considered as 84 SHSs generated electricity is not only meet these 84 households loads but also supply excessive electricity to others neighboring households. As the electricity, consumptions in the proposed location are limited during evening hours. The micro grid system design with 100, SHS (capacity of 65W_P) followed by bottom-up swarm electrification concept. Therefore, the electricity needs to store in the community-based battery storage system (CBS); the surplus electricity from the SHS is storage in the CBS. When needed the electricity for 100 houses (including 84 SHSs), the CBS delivered the electricity, especially in the evening and nighttime. If all 84 SHSs PV capacity considered 65 W_P, and the surplus electricity can meet more 16 households without PV panel. In the case-2, when 84 SHSs is connected with CBSs the discharge rate is observed 75% to 90% of SOC especially in the month from June to November. On the other hand (case-1), 100 houses including 84 SHSs the discharge of battery shown 55% to82%. If we considered 100 SHSs, the surplus electricity generated from the 100 SHSs can be met the demand of 30 excess houses of same load profile explained in this paper. However, the system designed with 100 SHSs (with capacity 85 WP), the future demand 10 % to 20% can be met to complying modern living standards, and the surplus electricity can also have delivered to the community productive uses. The micro grid system requires storage capacity 6050 Ah, the system design with Rolls series 40518 deep cycle batteries for 503 Ah selected for 100 hr. The size of the storage system of micro grid can be design with 12 batteries with the capacity of each battery is 100 Ah and 4 days of autonomy (4 batteries in series and 3 batteries in parallel). The DC micro grid model can also design and the optimal size allows; determine the dependence between the random number of SHSs and storage.

VI. REFERENCES

[1] WEO-2018, "International Energy Agency," Energy access database, October 2018. [Online]. Available: http://www.worldenergyoutlook.org . [Accessed 20 December 2018].

[2] IEA, "Access to Electricity Today," Access to Electricity Today: WEO-2011 New Electricity Access Database, 2011. [Online]. Available: http://www.worldenergyoutlook.org/resources/. [Accessed 19 August 2017].

[3] BBS, "Socio-economic and Demographic Report, Bangladesh Population and Housing Census 2011," Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, 2012. [Online]. Available: http://www.bbs.gov.bd/WebTestApplication/userfiles/Image/BBS/Socio_Economic.. [Accessed July 2015].

[4] Electric power consumption (kWh per capita), "All Countries and Economics: Bangladesh," OECD & IEA, The World Bank, Washington DC , 2017.

[5] D. F. Barnes, "The challenge of rural electrification: strategies for developing countries, first. ed. Resources for the Future," Washington DC, USA, 2007.

[6] IEA statistics for BangladeshK, "Global Engagement: key stats for Bangladesh: 1990-2016," International Energy Agency , 2018 .

[7] D. Barnes, S. Khandker and H. A. Samad, "Energy poverty in rural Bangladesh," *Energy Policy,* vol. 39, pp. 894-904, 2011.

[8] ESMAP, "Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies," ESMAP Technical Papaer, Washington DC, USA, 2007.

[9] D. Palit and A. Chaurey, "Off-grid rural electrification experiences from South Asia: Status and Practice," *Energy for Sustainable Development,* vol. 15, pp. 266-276, 2011.

[10] W. Bank, "Financing for Rural Electrification and Renewable Energy Development Project: Bangladesh," World Bank, Washington DC, USA, 2010a.

[11] IDCOL, "Renewable Energy Projects: IDCOL Solar Eenergy Program," IDCOL and Ministry of Power and Mineral Resources Bangladesh , Dhaka, 2010.

[12] REEIN, "Solar PV Electrification Program in Bangladesh," Renewable Energy and Environment Information Network, Dhaka, Bangladesh , 2010.

[13] C. Paul, "Infrastructure, rural electrification and development," *Energy for Sustainable Development,* vol. 15, pp. 304-313, 2011.

[14] S. Theodorou, G. Florides, and S. Tassou, "The use of Multiple Criteria Decision Making Methodologies for the Promotion of RES through Funding Schemes in Cyprus," *Energy Policy: A Review ,* vol. 38, p. 7783–7792, 2010.

[15] M. Mohan, "The economics of rural electrification projects," *Energy Economics,* vol. 10, pp. 3-17, 1988.

[16] T. W. Bank, "Project performance Assessment Report: Rural Electrification and Renewable Energy Development Project," World Bank, Dhaka, 2014.

[17] M. Hossain, "Progress and Future Plans of Energy Access in Bangladesh," 4 June 2014 .

[18] REPB, "Renewable Energy Policy in Bangladesh," Ministry of Power, Energy and Mineral Resoruces , Dhaka, Bangladesh , 2008.

[19] E. Martinot and A. Cabrall, "World Bank Solar Home System Projects: Experiences and Lessons Learned: Proceedings of the world renewable energy congress VI, Brighton, UK," Elsevier Science, Oxford , 2000.

[20] Energy Strategy Approach Paper," The World Bank Group, October 2009., "Sustainable Development Network," The World Bank Group, October 2009. [Online]. Available: http://siteresources.worldbank.org. [Accessed September 2018].

[21] P. Maher, N.P.A. Smith, A.A. Williams, "Assessment of pico hydro as an option for off-grid electrification in Kenya," *Renewable Energy,* vol. 28, no. 9, pp. 1357-1369, July, 2003.

[22] N. S. Lewis , "Toward Cost-Effective Solar Energy Use," *Science Mag ,* vol. 315, no. 5813, pp. 798-801, 2007.

[23] K. Bullis, "How Solar-Based Microgrids Could Bring Power to Millions of the World's Poorest," Sustainable Energy , 2012.

[24] P. Cook & S. Bhattacharyya, "Rural Electrification and Rural Development," in *Rural Electrification Through Decentralised Off-grid Systems in Developing Countries* , Manchester , Energy for Sustainable Development, 2013, p. 304–313.

[25] S. Groh, "The role of Access to Electricity in the Development Processs: Approaching Energy Process Through Innovation," *Energy for Sustainable Development,* vol. 18, pp. 83-99, 2014.

[26] P. Cook and S. Bhattacharyya, "Rural Electrification and Rural Development," *Springer ,* pp. 13-37, 2014.

[27] Independent Evaluation Group, World Bank , "Project Performance Assesment Report," IEG, World Bank , Washington DC, 2017.

[28] Alliance for Rural Electrification, "Rural Electrification with Renewable Energy: Technologies, Quality Standards, and Business Model," Alliance for Rural Electrification , Brussels, Belgium , 2011.

[29] S. Chakrabarti, "Rural electrification programme with solar energy in remote region — a case study in an island," *Energy Policy ,* vol. 30, pp. 33-42, 2002.

[30] "Solar photovoltaics in Sri Lanka: a short histor," Prog Photovoltaics Res Appl, Colombo, 1994.

[31] D. Laufer and M. Schäfer, "The implementation of Solar Home Systems as a poverty reduction," *Energy Sustainable Development ,* vol. 15, no. 3, pp. 330-6, 2011.

[32] Y. Ito, Z. Yang, and H. Akagi, "DC microgrid based Distribution power Generation System," *International Power Electronics and Motion Control Conference ,* pp. 1740-1745, 14-16 Auguest 2004.

[33] A. Agustoni, E. Borioli, P. Ferrari, et. al., "LV-DC Networks for Distributed Energy Resources," *Cigré Symposium on Power System with Dispersed Generation,* 2005.

[34] ENWET, "Financing of Solar Homes System in Developing Countries," vol. 1, 2011.

[35] Global Leap, "The State of The Off-Grid Appliance Market," U.S. Energy Department , Washington DC , 2016 .

[36] D. Soto & V. Modi, "Simulations of E"ciency Improvements Using Measured Microgrid Data," in *Global Humanitarian Technology Conference (IGHTC)*, IEEE, pages 369–374, 2012 .

[37] W. Stevens & G. P. Corey, "A Study of Lead-Acid Battery Efficiency near Top-of-Charge and the Impact on PV System Design," in *Photovoltaic Specialists Conference, Photovoltaic Specialists Conference*, pages 1485–1488, 1996.

[38] A. C. Brent & D. E. Rogers, "Renewable Rural Electrification: Sustainability Assessment of mini-hybrid o!-grid technological systems in the African context," *Renewable Energy,* vol. 35, no. 1, p. 257–265, January 2010.

[39] Power Supplies, "A hidden opportunity for energy savings," A NRDC report prepared for Natural Resources Defense Council, San Francisco, CA , 2002.