Design & Analysis of an Optimized Grid-tied PV System: Perspective Bangladesh

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Abstract— **In Bangladesh, the role of Distributed Generation (DG) is increasingly being recognized as a supplement and an alternative to large conventional central power supply. The government and many non-governmental organizations have tried to comprehend and strived to address the problem of energy through promoting Solar Home Systems (SHSs) in off-grid areas. Though centralized economic system that solely depends on cities is hampered due to energy deficiency, the use of solar energy in cities is never been tried widely due to technical inconvenience and high installment cost. To mitigate these problems, this paper proposes an optimized design of grid-tied PV system without storage which is suitable for Bangladesh as it requires less installment cost and supplies residential loads when the grid power is unavailable. This paper also analyzes the implementation outcome of integrating this grid-tied PV system in grid connected areas, especially in the capital of Bangladesh.**

Index Terms— **PV system without storage, Grid-tie inverter, Critical AC load, Transfer switch, Control scheme, Anti-Islanding, Net metering.**

I. Introduction

Due to rising cost and depleting storage of fossil fuels along with the increasing concerns for global climate change, utilization of Renewable Energy (RE) in national scale has become indispensable for any country in the world. In case of Bangladesh where dwindling resources and acute power crisis hinder the economic prospect and industrial growth adamantly, it is even more pressing to maximize the utilization of RE.

At present, Bangladesh relies heavily on fossil fuels especially Natural Gas (NG) resources for its power generation and its present proven NG reserve would be ceased by 2015. [1] According to the National Energy Policy, the projected demand in 2005 of 5,720 MW with deficiency of around 700 MW will increase gradually to 11,794 MW by 2020 for low economic growth of 6% and for a higher growth rate of around 8% it should be 17580 MW.

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With conventional resources which already started to shrink, it is not possible to even get closer to attain the target. It is evident why Bangladesh Government recognizes the indispensability of RE and adopted Renewable Energy Policy on 18 December 2008 where target has been set to generate 5% of the total electricity from renewable sources by 2015 and 10% by 2020. [2]

Even for low economic growth of 6% where prediction indicates demand on 2020 is 11,794 MW that means Bangladesh needs to generate 1,794 MW from renewable resources to meet the target set by Government. This target is improbable, not impossible; mainly due to the geographical location of Bangladesh. Here, RE resources like Solar, Wind and Biomass are proven many times to be abundant. But most importantly, sunlight is available here throughout the year all over the country and the diffuse component of solar radiation is around 50% so that non-concentrating PV or thermal collectors should be most suitable for use. [3]

In this scenario, already, the village community of Bangladesh adopted the simplest but yet most effective one, the off-grid home PV systems. On the contrary, city dwellers are not sufficiently interested to utilize Solar Home Systems (SHSs) largely due to technical inconvenience, high installment cost and absence of policy enforcement. This paper demonstrates a technically optimized low cost grid-tied PV system in perspective of Bangladesh and how it can be a boon for the city dwellers to curtail the monthly cost and also contribute to the grid.

II. Off-grid Vs Grid-tied PV System

Currently in Bangladesh, most of the PV systems are installed in rural areas which have very little chance of getting connected to the national grid within 5-10 years. That's why off-grid SHSs are the most popular standalone renewable energy application enjoying maximum growth rate for several years in Bangladesh. 8,00,000 SHSs are so far installed contributing 40.5 MW out of 47 MW coming from renewable sources. [3][4]

Typical configuration of a rural off-grid PV system in Bangladesh is depicted bellow in Fig 1.

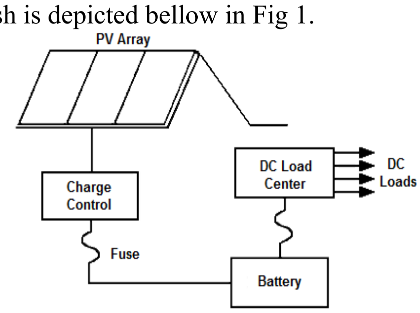

Fig. 1. Schematic of a off-grid PV system with DC loads

But to reach the goal of having 10% energy from renewable sources, we need to grab every opportunity of scaling up. If we closely follow the technology trend of developed countries in this regard, we find 90% of the European PV systems are Grid-connected [5]. Following to the world trend of grid-tied PV market, cities like Dhaka, Chittagong, Khulna etc. have high potentials to utilize the solar energy through grid-tied PV systems.

Configuration of a typical grid-tied PV system is depicted bellow in Fig 2.

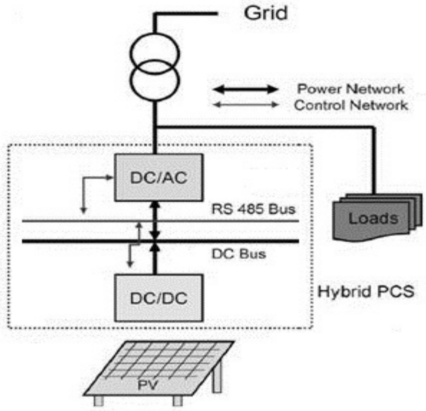

Fig. 2. Schematic of grid-tied PV system

III. Proposed Grid-tied PV System

We propose a grid-tied PV system without storage to power up on-site electrical loads; serve energy to the grid when the system output is greater than the on-site demand and backup the on-site critical load as well when the grid power is unavailable.

A. Configuration:

As Fig 3 illustrates, the proposed system will consist of PV arrays, a step-up dc–dc converter, a grid-tie inverter (GTI) and an automatic AC transfer switch. PV arrays convert solar energy into electric energy. Step-up dc–dc converter boosts the array voltage to a higher level; the GTI inverts the DC power produced by the PV array into AC power aligned with the voltage and power quality requirements of the utility grid and the transfer switch changes supply source and also selects serving loads according to availability.

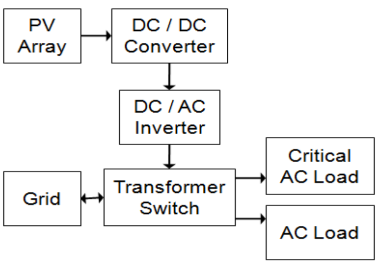

Fig. 3. Configuration of proposed grid-tied system

In normal condition, the system power up on-site electrical loads and serve energy to the grid if the system output is greater than the on-site demand. Net metering would allow the homeowner to sell energy back to government. But when the utility grid power is not available or when the utility voltage level or frequency goes beyond accepted limits, the system automatically disconnects the grid through an anti-islanding scheme. In this condition, existing battery less grid-tied PV systems do not serve the residential loads also. But in our proposed design it will supply residential loads during the grid failure or blackout for load shedding by an automatic AC transfer switch. This feature is indispensible considering the grid load shedding condition in Bangladesh.

B. Grid-tie Inverter

The major component of Grid-tied PV system is the GTI which along with regulating the voltage and current received from solar panels ensures that the power supply is in phase with the grid power. On AC side, it keeps the sinusoidal output synchronized to the grid frequency (nominally 50Hz). The voltage of the inverter output needs to be variable and a touch higher than the grid voltage to enable current to supply the loads in the house or even supplies excess power to the utility.

Through the Fig 4, a simplified schematic, depicted below, the operation principle of a grid-tied inverter with three power stages is illustrated.

At the first stage, the DC input voltage is stepped up by the boost converter by a combination of inductor L1, MOSFET Q1, diode D1 and capacitor C2. The inverter has to provide a galvanic isolation between input and the output. With a step-up transformer T1, the first stage (boost converter) may be omitted.

In this example, a high frequency transformer is used to provide isolation in the second conversion stage. The stage is basically a pulse-width modulator DC-DC converter. The voltage must be higher than the peak of the utility AC voltage. For example, 220 VAC service, the DC link should be > $220*\sqrt{2}= 312$ V.

On the third conversion stage, DC is converted into AC by a full bridge converter consisting of IGBT Q6-Q9 and LC-filter L3, C4. Output LC-filter reduces high frequency harmonics to produce a sine-wave voltage.

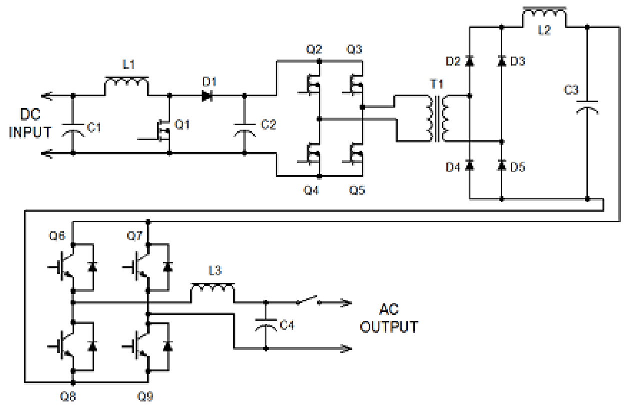

Fig. 4. Schematic of a grid-tied inverter [6]

As GTIs need to comply with utility electrical standards, the output power has to be clean, undistorted and in phase with the AC grid. Typical modern GTIs have a fixed unity power factor which means its output voltage and current are perfectly lined up and its phase angle is within 1 degree of the AC power grid. The GTI has an on board computer which will sense the current AC grid waveform and output a voltage to correspond with the grid. Besides, when the grid is down, the GTI will provide AC output synchronized with own pre-defined references.

C. *Control Scheme:*

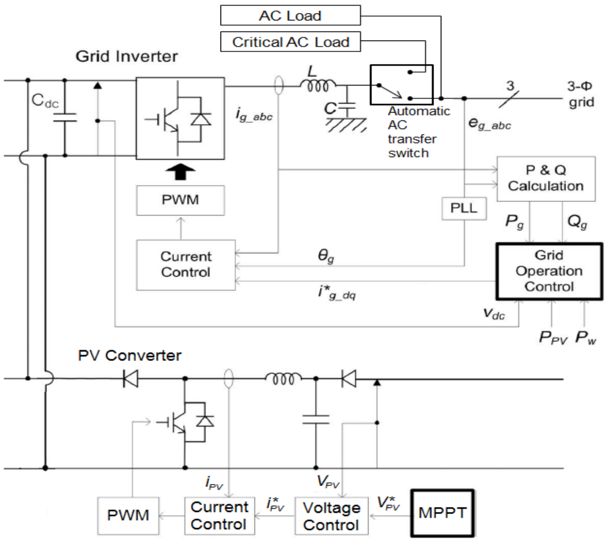

Fig. 5. Schematic control for grid-tied PV system

Here, Fig. 5 demonstrates the control scheme for proposed system. We can describe it in three parts:

PV converter control:

Power output of a PV array depends on the voltage level where it operates under a given condition of irradiance and cell-surface temperature. For efficient operation, a PV array should operate near at the peak point of the $V-P$ curve. Various Maximum Power Point Tracking (MPPT) techniques have been proposed in [7] and [8]. The MPPT block in Fig. 5 senses the PV array current *iPV* and array voltage *VPV* and returns the array voltage command. The PV converter regulates the array voltage *VPV* at the reference voltage *V*PV* commanded by the MPPT controller and boosts it to the level of required dc voltage. Error between the ordered and real voltage is processed through the voltage controller into the ordered current *i*PV,* which is compared with the array current *iPV.*

1. GTI control:

Basic concept of GTI control is to obtain the maximum power from varying insolation and minimize the rating of the inverter by regulating reactive power generation at zero. Below rated insolation, real power from the PV system is regulated to capture the maximum energy from varying insolation to supply either on-site electrical loads, or to supply power to the grid when the PV system output is greater than the on-site load demand in a way that the inverter's power supply is synchronized with the grid power.

In addition, when the grid fails or goes through blackout for load shedding, the inverter stops output initially, then the transfer switch shifts to inverter only position and finally the inverter starts to give output synchronized to serve the critical on-site loads with own pre-defined references until the grid is back.

2. Anti-islanding control:

The condition where a GTI continues to electrify the grid during an outage is called islanding. According to the technical requirements in IEEE 1547, to prevent this situation, inverter will monitor the voltage and frequency of the grid. If either of voltage and frequency falls outside set parameters, the inverter will shut down. In addition to this passive scheme a more sophisticated active detection scheme is necessary to decrease the non-detection zone. So the inverter will employ a variety of methods to effectively push and pull slightly on the grid voltage and frequency. When the grid is present, this little push-and-pull has no effect. However, if the inverter is the only source supporting an islanding grid, it will quickly push the voltage and frequency outside the inverter's acceptable window of operation, triggering the inverter to shut down.

But the problem is that in Bangladesh power crisis is so drastic that the grid shuts down its feeders many a time in a day and existing battery less inverters will remain off until the grid is back up and running again. In our design we employed an automatic transfer switch so that immediately after turning off its output transistors, the inverter will also use a transfer switch to disconnect from the grid. Once disconnected, however, the inverter will reactivate the output transistors to continue supplying electricity to loads wired into the critical load subpanel which is isolated from the grid. This way, when the grid goes down and the inverter is sending power only to the critical load subpanel, PV power is prevented from energizing the utility lines.

Fig. 6 bellow presents the complete flow chart of our proposed control scheme.

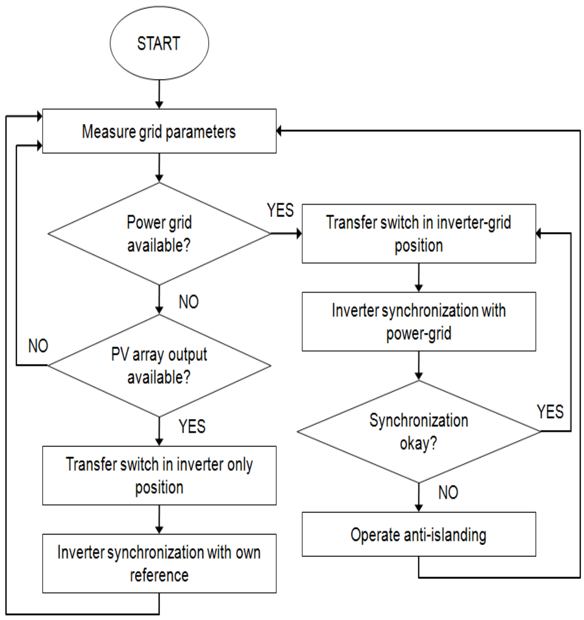

Fig. 6. Flow chart of control scheme

D. *Net Metering:*

In our scheme a customer can also enjoy the opportunity of net metering by selling the surplus energy to the grid when the generation is more than required for on-site demand.

Fig. 7 illustrates the scheme for net metering.

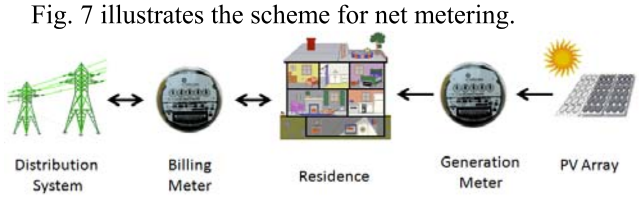

Fig. 7. Net metering scheme for proposed scheme

There will be two separate meter – one is the generation meter and another is the billing meter. The customer will be charged from the data of the billing meter and the total kWh consumption of the site will be the sum of the generation meter and the billing meter.

E. Key Advantages of Proposed System

a. Properly configured, this grid-tied system enables a home owner to use an alternative generation from solar energy. If the alternative power being produced is inadequate, the deficit will be sourced from the electricity grid.

b. Net-metering allows homeowners to get credit for any electricity the system sends to the grid.

c. If the grid power is not available, still the system will continue to supply critical on-site loads.

d. A typical solar system would require a large bank of batteries to store the energy. This represented a huge investment for the home owner before they could build a functional alternative energy system. By removing the need for an expensive battery pack and replacing the large, expensive grid-tied inverters with smaller, cheaper units that don't need batteries, it brings the implementation of a solar grid-tied home system within the financial grasp of many more people.

e. More power efficient than using a conventional system which uses a battery power bank for electricity storage. It ensures full utilization of solar energy whereas battery discharge rate is 60% in conventional off-grid solar systems in Bangladesh.

f. As batteries degrade with time and need replacement, proper disposal requires extra care. The use of battery system thus is not normally considered as a viable option since the disposal of batteries may also cause other environmental problems.

g. Grid-tied inverters are scalable which allows them to add more solar panels or wind turbines to home. An additional grid-tie inverter in parallel permits scaling up power handling capability.

IV. Prospect Analysis for Dhaka City

Here we analyze the opportunity and implementation outcomes of our proposed system in perspective of Dhaka, the capital of Bangladesh and center of all financial activities. Generally in Dhaka the available rooftops of multistoried buildings are of around 3000 square feet. In this area easily 15kW solar modules can be placed at tilted position. Such buildings are roughly 20000 in number. Hence if these roofs are covered with solar modules 300MW power can be generated confidently. [3] Whereas the daily demand for Dhaka is 1850 MW and load shed is 258 MW. [9]

An ordinary house in Dhaka, may consume around 12-15 kWh/d with a peak demand of nearly 1.1403kW. A 2.5 kW Solar Grid-tied system without battery, through a capital investment of around $6000-8000, could meet 68% of house demand. As system life time is assumed to have 20 years, part of the initial capital cost is highly possible to recover. [10]

And if we increase DC rating of our PV system, the result gap between the on-site demand and on-site generation can get even closer. Dhaka is situated in 23.77 degrees north latitude and 90.38 degrees east longitude. From the solar radiation pattern surveyed in Dhaka and with the help of solar energy calculator *'PV Watts version1'* in [11], we have estimated the energy that will be produced per month in 2011 for a 4 kW Battery less PV system. Besides we have collected the data of energy consumption in recent years for some typical household. Then we have averaged those data, correlated them with typical weather conditions and finally estimated a nominal house energy demand for each month in Dhaka city. At last, in Fig 8 we have depicted the comparison graph between monthly energy demand and estimated generation from a 4 kW PV system for a typical household in Dhaka for 2011.

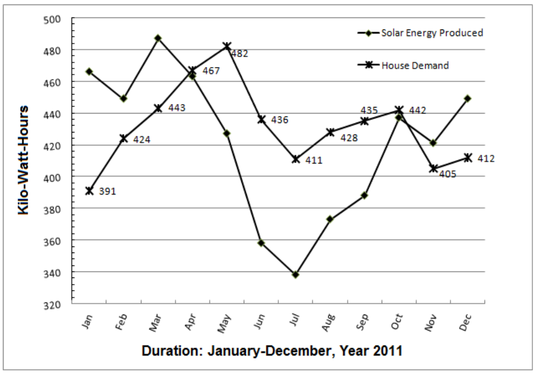

Fig. 8. Monthly estimated generation vs. house demand in a typical house of Dhaka

From the figure, it is evident that a household can save major part of their electricity bill by installing a high-rated grid-tied PV system without battery backup. In general if we can encourage and implement this installation throughout the major cities of Bangladesh, it can also contribute in great extent to the national power generation profile.

V. Limitation and Scope of Work

Proposed grid-tied system without storage can't supply electricity if utility grid is disconnected during night or on rainy day when sunlight is not sufficient. Installation of a small battery could solve the problem but the installation cost would be higher and efficiency has to be compromised. Power output from certain renewable energy sources, like wind and solar, can be intermittent. Fluctuations in output can negatively affect power grid frequencies, voltages and component performance, causing instability in the power generation system and interrupted service to customers. Concerns about power system reliability limit the amount of new and renewable energy that power utilities and transmission system operators allow to be connected to the grid.

In future we'll go for simulation and hardware implementation of our system and tune it to provide grid quality AC supply restraining harmonics, DC injection etc. Moreover, our utilities should step forward to upgrade the existing girds in Bangladesh in order to get full benefit of grid-tied systems which involves high cost. Net metering and incentive tariff could promote and encourage PV grid-tied electricity generation.

VI. Conclusion

The global solar industry grew at a rate of 30 to 40 percent annually from 1999 to 2005, but has since slowed to 19 percent due to an international silicon shortage. [12][13]

There is a fair chance, in near future; price of the most used raw material silicon for PV array will hike. And as Bangladesh's solar industry which is almost solely dependent on export will face a major crisis.

Immediate measurement needs to be taken before that happens. Although Bangladesh in its existing grid system doesn't quite support effective tie with distributed generation for the time being, integration of grid-tie system with existing system need not total altercation of the system. Proactive initiative to utilize the solar energy through newer technologies, in perspective of Bangladesh, like Grid-tied solar system to complement existing energy system needs to be taken. Although Bangladesh is still in initial stage to address all these issues related to distributed generation, an incentive tariff has been proposed for electricity generated from renewable sources which may be 10% higher the highest purchase price of electricity. So definitely there will be occurring lots of activity regarding grid-tied PV system for Bangladesh in near future and we hope our work will help to decide an optimized way.

So, in this paper we have proposed an optimized scheme which is suitable for Bangladesh to demonstrate how the grid-tied PV systems can be deployed with the idiosyncrasies of this country. We proposed the control structure of converter, inverter and anti-islanding scheme. At last we analyzed the future prospects of this system with respect to a typical household of Dhaka city.

References

[1] "Bangladesh Energy Crisis: Soul Searching", Energy Bangladesh, June, 2009.

[2] Islam Sharif "Renewable energy development in Bangladesh", Executive Exchange on the use and integration of Renewable Energy in the Power Sector, Madrid, Spain, October 19-23, 2003

[3] Bangladesh Renewable Energy Report, APCTT-UNESCAP

[4] Islam Sharif "Renewable energy development in Bangladesh", Executive Exchange on the use and integration of Renewable Energy in the Power Sector, Madrid, Spain, October 19-23, 2009

[5] EPIA – European Photovoltaic Industry Association

[6] http://solar.smps.us/

[7] T. Noguchi *et al.*, "Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic-and-converter module system," *IEEE Trans. Ind. Electron.*, vol. 49, no. 1, pp. 217–223, Feb. 2002.

[8] K. H. Hussein, "Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions," *Proc. Inst. Electr. Eng.—Generation, Transmission, Distrib.*, vol. 142, no. 1, pp. 59–64, Jan. 1995.

[9] Daily Electricity Generation Report, Bangladesh Power Development Board, April 10, 2011.

[10] Developments in Renewable Energy Technology (ICDRET), 2009 Print ISBN: 978-1-4244-6012-0.

[11] http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

[12] Business Week, "What's Raining on Solar's Parade?" (February 6, 2006), www.businessweek.com/magazine/content/06_06/b3970108.htm.

[13] Solarbuzz, "2007 World PV Industry Report Highlights," www.solarbuzz.com/Marketbuzz2007-intro.htm (accessed January 2008).

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