Smart grids and photovoltaic integration-analysis of residential grid connected system in north Cyprus

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Abstract. This is a case study of residential photovoltaic grid connected system in North Cyprus and its integration with the local utility as part of transformation from old grid systems to modern Smart Grids on Island. The Study also provides information regarding the exact solar power energy produced by the residentially installed grid connected systems, the integration of the solar Photo Voltaic systems installed with the local Utility Grid using the net metering along with calculating the system cost for the consumers and the performance ratio of installed system .The present work discusses the design and installation of a residential grid connected solar photovoltaic system in terms of maximum power, size and cost. The simulation of the solar system was done using professional engineering software PVSyst V5.74 and the overall performance of the system was checked. The result shows that the system installed in Lapta, North Cyprus is performing very well as performance ratio is 78% and that the return on investment for a common household installation on island is about 8 years. Also the energy injected to the utility is found to be 0.01MWh per year for one household under full load conditions. The design and simulation of Grid Tied P-V System for medium sized house hold in Lapta, North Cyprus was done in order to determine the performance of the whole system during the year. Also power, sizing and cost was studied and analyzed. The novelty of this article lies in the fact the no study has yet been done regarding the amount of power which is sent back to the utility grid by residential grid connected systems using smart meters and the readiness of utility grids to handle large amount of power supplied from the solar installations to the grid in North Cyprus. This article can help local communities, engineer, researches and the utility grid to find the ways in which they can handle huge electricity inflow in their grid systems by the future instalments of residential solar grid connected systems beside introducing Grid Codes used internationally required for such installations at all levels. The main purpose of study is to see how much energy is sent back to the Grid under full load conditions for a common residential grid tied system and how well is local utility doing regarding integration of the solar PV systems and making the current grids smart enough to handle two way communications.

1 Introduction

The world is using various energy resources for the production of electricity. The electricity is being produced using the fossil fuels, nuclear, hydroelectric generation, gas and coal. As the population is increasing, so is the demand for energy and meanwhile the natural resources are reducing dramatically due to triggered climate change. The world is trying to cater for the huge difference between the future demand and production of electricity. The maximum electricity is being produced using the coal power plants and that is causing a huge damage to the environment and climate. The other options like coal, oil and gas cannot be considered as an unlimited source for production of power as these natural resources are getting scares. The clean option is the Nuclear power but after the meltdown of the Fukushima Daiichi nuclear plant in Japan due to the tsunami caused by severe earthquake on March 2011 the disaster is considered as worst in nuclear power history which caused huge environmental and humanitarian losses. The governments around the world are now very cautious regarding building of new nuclear power plants in fact many civil rights groups are protesting to close the already functioning nuclear plants. The only option for the clean energy production with the unlimited natural resources left is through the renewable energies [1]. As the renewable power installations are increasing at a tremendous scale so there is a need to upgrade the grids so they may integrate new means of distributed power generators. As the solar installations are increasing worldwide and after the COP21 the hike in energy being produced using Solar is widely expected.

2 SMART GRIDS

The transformation of old grids into the advanced grids according to the current needs of world is very important.

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A smart grid concept can be defined as: “A smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved” [3].

The introduction of smart grids can enhance the overall performance and functionality of the power delivery system.Fig.1 shows the model setup of Smart Grid. Increase in PV generation facilities and their Integration in Smart Grids can be a mean of achieving the desired goals as decided by the UNFCC [2].

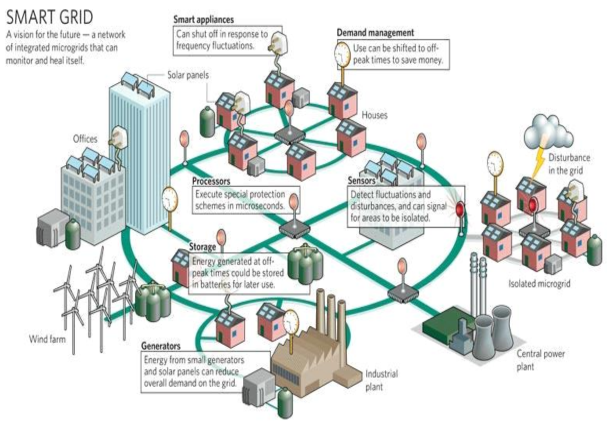


Fig. 1. A Model Set up of Smart Grid.

The net metering is a key to bridge gap between the supply and demand in electric systems while helping in reduction of greenhouse gases and CO2. The concept of smart grid can be considered just like the introduction of internet as in long term smart grids will not only be considered as 2-way power, 2-way communication, 2-way service delivery and IT support but will be a bread and breakfast for all of people around the world from 20 years from now just as the internet was in 90s.

The following are the main requirements necessary to make basic changes in the present distribution networks for smart grids [4]:

1) Self-healing from power disturbance events can be achieved by network with high reliability and high security levels. Also the use of sensors and measuring equipment along with the decentralized control is required.
2) The optimum use of assets and applying the concepts of demand response and demand side management can make the grids economical.
3) The integration of multiple energy resources, electric vehicles and effective management of pollution and CO2 emissions resulting in low carbon networks.
4) The use of smart devices which can communicate both ways and use of information technology that allows two-way communication between the consumers and utility.

The main applications and benefits of smart grid include the empowerment of customer choice and control along with the provision of security and safety management. Smart grids can provide the customers with critical peak pricing/Time of Use (ToU) rates, green power choices, prepaid metering, voluntary or automatic control of home energy demand along with high power qualities. From utility point of view the smart grids can help in detection of energy theft, tamper detection, monitoring of usage patterns along with managing the electric feed in from the customers using renewable energy and storage of electricity [5].

The smart grids can also facilitate new programs for load management, demand response, distribution generation, Automatic meter reading, new communications with customers, remote service switch, and cold load pickup and system cyber security.
The research and advancement in Smart Grid technologies is being done by various companies for the following sectors [6]:
-Advanced Metering Structuring
-Grid Optimization
-Home Area Networks (HAN)/Building Area Networks (BAN)
-Demand Response
-Software / Apps

Table 1. The main up gradation and changes in old grids in order to be Smart.

Current power distribution systems	**Future smart grid power distribution systems**
Electromechanical	Digital
No response/feedback networks	Optimization in Real time
Centralized generation	Decentralized generation including power generation from renewable sources of energy
limited elements and sensors measurement	complete elements and sensor measurement
Single way or no communication	dynamic communication or two way communication
limitation on network control	No limitation on network control
physical test and evaluation network everything is handled manually	distant test and evaluation network for remote handling
Not much services provided to subscriptions and customers	Several services provided to subscriptions and customers
Hierarchical structure	Network structure

Manual commission	Automatic retrieval

3 SYNCHRONIZATION OF THE GRID TIED SYSTEM WITH THE UTILITY

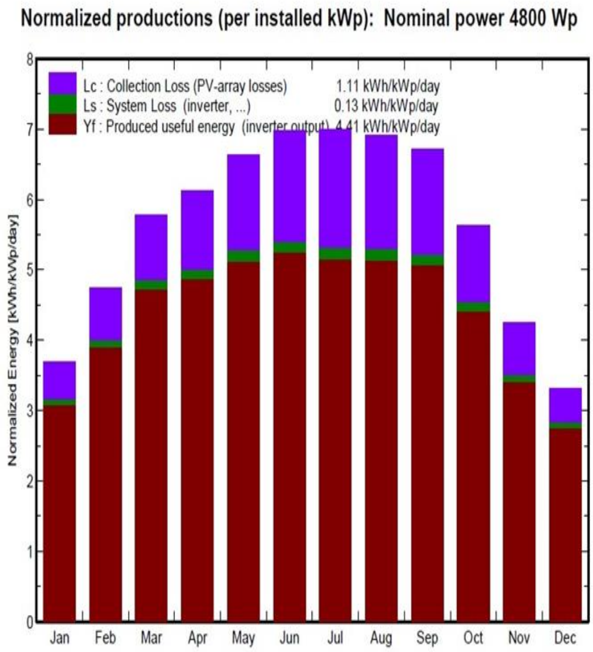
The integration of the Grid with the installed photovoltaic system is done using the grid-tied inverters keeping in view the topologies and the codes for Grid Integration. The standard of power provided by the photovoltaic system for the on-site AC loads and for the power delivered to the utility is judged and governed by practices and quality standards on voltage, flicker, frequency, harmonics and power factor as per recommended by ANSI/IEEE Std 519-1981. etc. [7].

Table 2. Details of Total House Hold Load

Equipment	Quantity	Power(W)	hr/day	hr/month	kWh/year
Split AC (2kW)	1	2000	10	300	7200
Split AC (1.5Kw)	4	6000	10	300	21600
TV	1	700	8	240	2016
Bulbs	20	200	2	60	144
Swimming Pool Motor	1	750	1	30	270
Microwave	1	800	0.30	9	86
Iron	1	1000	0.50	15	180
Misc. Appliances	-	1000	0.75	23	270
				Total KWh/yr.	**31,766**

4 SOLAR POWER SYSTEM DESIGN

For grid integration we are using grid tied inverters and smart meters for net metering purposes. The solar power system will be controlled based on available sun irradiance and demand. The designing of the solar power system is based on the expected loads in a household, the characteristics of the selected PV module and the metrological data available for the region [8]. In this study, P-V system feeding a medium sized house hold is designed. The system is designed according to the load demand in such a way that it balances the requirement with the generation keeping the cost minimum. The residential solar system under study is located in Lapta, North Cyprus. The first step in design process is to accurately determine the loads. The total energy depends on the usage of the appliances per hour during the whole day and that is solely dependent upon the user. Typical home appliances and estimated operating time per day is shown in table-2 below. As the total estimated energy required for the home is 31,766 kWh per year so dividing it by the number of hours in a year (8760) we get approx.: 3.6 kW as an average load. The proposed system designed, keeping in view the needs of the end user is a grid tied system which is sized to operate autonomously with the potential to provide support to the grid. In this system 16 PV polycrystalline panels of 300W each (model: HT72-156p-300) manufactured by Shangai Aerospace Automobile Electromechanical Co. Ltd. (SAAE) are used. The solar power system is divided into 2 arrays, each having 8 PV panels each. In our system we are using centralized topology for inverters and only one grid tied inverter GW4600-DS manufactured by Jiangsu GOODWE Power Supply Technology Co., Ltd. is used which can have Max. DC input power of 5400W.



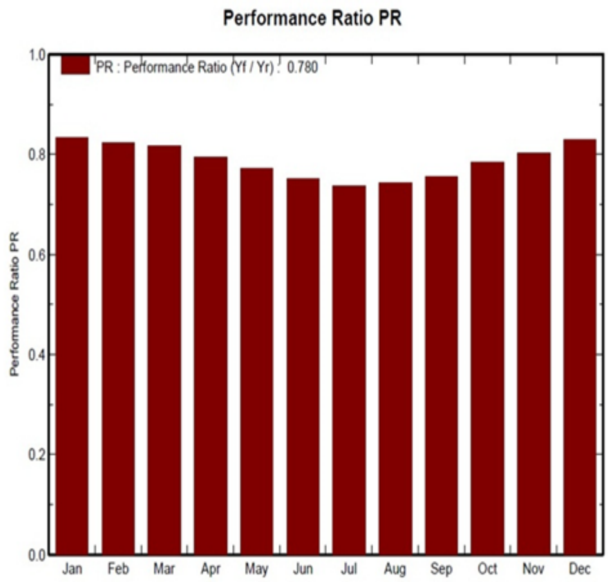


Fig. 3. Normalized Productions and Performance Ratio of System from PVSyst

5 GRID TIED SYSTEM DESIGN SIMULATION AND RESULTS

The simulation is done using the data sheets of the selected equipment in PVSyst simulation software. The results of the complete simulation for the residential grid tied connection provide very detailed information. After the simulation the details regarding the "Energy use and User's needs" can analyzed. It can be seen that available energy supplied to the house from the solar power system is about 7730.4 kWh/ year and is mentioned in column "E-Avail". Also the user's required load as calculated earlier in Table1 is depicted in column "E Load" as 31766 kWh / year. The column "E User" shows the Energy supplied to the user and "E Grid" is the energy supplied to the grid. Our Grid connected system is using Kamstrup smart meters for the net metering purpose and these columns are only available if load is defined in Grid Tied system.

This shows the effective flow of current from the solar power system to the user's load and to the grid. The last column "SolFrac" represents solar fraction which is a ratio of "E User" and "E Load."

Table 3. Generated table from PVSyst.

New simulation variant

Energy use and User's needs

	E Avail kWh	E Load kWh	E User kWh	E_Grid kWh	SolFrac
January	458.5	2698	457.9	0.589	0.170
February	524.9	2437	523.0	1.879	0.215
March	702.6	2698	701.3	1.302	0.260
April	701.7	2611	701.3	0.361	0.269
May	763.1	2698	762.4	0.736	0.283
June	755.4	2611	755.4	0.000	0.289
July	767.3	2698	767.3	0.001	0.284
August	764.4	2698	764.4	0.031	0.283
September	731.7	2611	731.5	0.273	0.280
October	658.2	2698	655.8	2.417	0.243
November	492.7	2611	492.4	0.258	0.189
December	409.9	2698	409.3	0.573	0.152
Year	7730.4	31766	7722.0	8.420	0.243

Modifier (IAM) and final yearly value is considered as 2002 kWh/m2. The reference incident energy in coll. plane is Yr= 5.65 kWh/m2.day. The maximum amount of radiation received by our panels is in month of July, 6.99 kWh/m2 and the lowest amount are in month of December which is 3.32 kWh/m2. Our PV system produces maximum electricity of 767.3 kWh in July and 409.9 kWh in the month of December.

2- The maximum output at the inverter is EOutinv = 767.3 kWh

3-The total available energy at the output of the inverter annually is 7730.4 kWh

4-The specific production of electricity from our installed system is 1611 kWh/kWp/year.

5-The following losses occur during the photovoltaic conversion in modules:

PV loss due to irradiance level= -3.2%

PV loss due to temperature= -11.5%

Module quality losses= 4.422 kWh per year (-0.1%)

Loss due to mismatching of modules= 176.71 kWh (-2.1%)

Ohmic losses occur during conductance = 90.42 kWh (-1.1%)

6-The normalized productions (per installed kWp): Nominal power = 4800 Wp

Lc: Collection loss (PV array losses) = 1.11 kWh/kWp/day

Ls: System losses (inverter etc) = 0.13 kWh/kWp/day

Yf: Produced useful energy (inverter output) = 4.41 kWh/kWp/day

7-The ratio of normalized system production Yf to the reference incident energy Yr in coll. plane is known as Performance Ratio (PR) and is found as 0.780.

The cost of the system has been reduced by using a single inverter which can have two MPPT inputs and thus gives the best performance of the whole system under all operating conditions. Also the upfront initial cost of the Grid Tied without battery system is lower than with batteries. The net metering of the residential system is being done with the help of Smart Meter provided by the local utility company. It is seen from simulation result that the available energy for the user is 7.72MWh and as per load requirement 24.04 MWh comes from the grid, whereas only 0.01MWh is injected in to the utility grid. The amount injected to the grid seems to be very minimal but if user is using most of the equipment in evening he can still benefit from the local utility company (Kib-Tek) units' compensation scheme for the electric units injected into the grid during the day to be used in evening. Furthermore because of the net metering the rate of return on investment has been calculated as 7.8 years meaning that in this time period the system cost would be recovered back and after that the customer is able to use the produced electricity from system without paying any extra money. As far as the rebates and the feed in tariff for the residential solar home systems is concerned, local utility company KibTek is giving back electric credits for the electricity fed back to their grid to be used by the customer instead of instant cash. It is expected that as the PV installations will rise on island in future customers will be able to get back cash for every electric unit produced but not used and sent back to the grid by the prosumers.

The approach of the local utility company KibTek towards the "Smart Grids" was also observed to be positive and the company has already provided 165,000 smart meters for this purpose which can integrate PV system in local grid and provide two way communications among the utility and the prosumers. The utility company in North Cyprus has also introduced the Automated Meter Management system which is considered as a step towards a transformation from traditional grid to the Smart Grid by the use of information computer technologies (ICT).The installations of PV systems on residential as well as commercial building can help North Cyprus reduce the greenhouse gases and contribute in making global environment clean besides utilizing the excess produced energy fed in to the utility for industrial and economic growth of the country. The European Union has plans to import clean energy produced from solar power plants in MENA (Middle East northern Africa) region [10]. North Cyprus can go for some big solar power plants and besides exporting energy to Europe can also connect Europe super grids with the grids in Middle East and North Africa. This research paper can help the community and the utility to find the exact economic and environmental impacts of residential solar power systems on society.

6 ECONOMICAL ANALYSIS AND EVALUATION OF THE SYSTEM

It is very important to see if our system under study is economically feasible and a good option for producing energy through solar and then sending it to the utility grid. The net metering phenomenon discussed earlier plays a vital role in calculating the rate of return on the investment made by the prosumer. In our case net metering has been achieved by using Kamstrup smart meters. The total cost of the system is based on the market values of the equipment used including the additional miscellaneous costs occurred during the installation of the solar system at the site. The solar system under study in Lapta has been installed by a local solar company based in North Cyprus. The total cost of the installed system provided to us by the local installer for our system is $8460/- only including all the taxes.

Our user's need is "Fixed Constant Load" of 31766kWh/year or 3.63kW. So the excess energy being produced by the solar power system and injected back to the grid is 8kWh/year as per our simulation result. The total usable energy supplied to the prosumer is 7722 kWh/year and under full load conditions the installed system can supply continuous power to the load during the day time without the support of the grid but during the night the grid tied system shuts down and the energy is solely supplied from the grid. As long as the user is not using grid the utility electric bill drops as the meter is not moving and in case excess energy is produced that is fed back to the grid and meter moves in reverse direction. According to the prosumer load demand the local utility company (Kib-Tek) Tariff code applicable is "02 konut tarifesi (0-250 kWs)" with price of 0.40 TL (0.139$).Therefore, in order to calculate the ROI we do calculations using the price of per kWh ($0.1399kWh) provided by local utility company. Hence the energy generation cost per year is $1080.3078 per year and therefore we get the payback period on investment as approximately 7.8 years. The investment appears to be of great deal as the panels are guaranteed for more than 10 years with life expectancy of about 25 years and inverter is guaranteed for 5 years. Once the initial investment is returned the rest of energy being produced is free of charge. This not only helps Utility Company to use the excess energy for the regions where there is short of electricity but also helps the end user to save money and make environment clean. Furthermore, the local utility company is compensating the users for each unit which is injected to their grid by giving away extra electric units to be used at night instead of cash as legislation regarding the feed in tariffs is still under way in North Cyprus. Using the Grid Connected systems the prosumer can reduce their daily, monthly and annual electric bills very effectively.

7 CONCLUSION

In this study, extensive details regarding the designing of the grid tied solar photovoltaic system for a medium sized house in North Cyprus has been provided. The simulation results of the system are analyzed in terms of maximum power, size and cost. The equipment used in the design was commercially available and selected taking into account the PV panel measurements according to the metrological data available used to calculate the total energy available from sun during the year. The end user's power requirements were calculated in order to provide the system which can produce the required electricity during the day. As the Grid Connected system installed is without batteries so it is operational during the day only and at night when the sun goes down or in case of bad weather conditions only, the power is provided by the utility grid. As the weather in North Cyprus is ideal and very sunny throughout the year so the end user is able to get the maximum benefit of the grid connected system throughout the year during the day time. The quality of the installed system is determined by the Performance Ratio which ranges from 60-80%. It is concluded that the performance ratio is 78% which is above the 70% mark and the PV system with performance ratio values above 70% is considered as of good quality [9]. Hence the quality of the system is very good. The 22% of the solar energy is not converted into the usable energy after falling on the PV system due to the losses involved.

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