Design and analysis of a PV system to meet all its energy requirements of an apartment in Abu Dhabi

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***Abstract*- This paper presents a detailed load analysis, modeling of a Grid-connected photovoltaic (PV) system and costs analysis for an apartment in Abu Dhabi. For load analysis, an apartment with an area of 550sq.ft. was selected. The main apartment load is air conditioning due to the hot climate. A three year's of load data has been used for simulation and optimization. The designed system has a 16.44kW, PV, an MPPT controller, and an 8.2kW DC/AC 3-phase inverter to supply electric power to the utility grid. The proposed model is optimized in Homer Pro software and the detailed model is simulated in MATLAB/Simulink. Using other software like PVsyst for sizing, a detailed analysis is performed, and simulation studies are presented. The simulation results show the stability of the system and the advantage of using a PV grid-connected system. The cost of the designed system has been compared with the electricity bills considering saving and using Homer optimized results; the feasibility of the proposed system is presented.**

Keywords— Renewable energy, Grid-connected PV, sizing of a PV system, load analysis, energy model for an apartment.

I. INTRODUCTION

Electricity is the most useful form of energy, and the current lifestyle has been dependent on electricity more than ever before. The major part of the energy is being produced from non-renewable energy sources at this point, which raises a big question mark on future economies of countries. Considering this fact, countries including U.A.E are taking initiatives to encourage people to find more sustainable solutions to fight excessive carbon-dioxide emissions and climate change. As a result, Dubai took the initiative in 2015 to start the "Shams Dubai" program which allows net metering [1] on a small scale. Soon after, Abu Dhabi started encouraging with ruling out net metering and improving safety standards of photovoltaic (PV) under net metering [2]. Although net metering has an upper cap of not exceeding 5MW according to recent regulations of Abu Dhabi, it still encourages a lot of residential consumers to adopt to this somewhat emerging trend of UAE.

Soon after UAE's governments started announcing the future of green buildings in 2011, people started making attempts to build and test alternate energy models for an arid climate. One of the most recent attempts in April 2019 has been made to have a detailed analysis of photovoltaic (PV) analysis of dry and hot environment residential buildings where 38% energy consumption of a residential facility can be covered by solar energy [3]. Since there are a lot of variables such as clean water supply from the government of Abu Dhabi and some buildings, use a central heating and cooling system. So, a detailed analysis is required where the idea of Self Consumption (SC) can be effectively implemented. This study will focus on detailed calculation of energy consumption of a residential apartment and how to design a sustainable PV system for a residential apartment in hot and dry climate like Abu Dhabi with consideration of continuous sandstorms and dust particles affecting the efficiency of the PV panel as mentioned in the literature [4],[5].

II. LITERATURE REVIEW

It is highly important to understand the electricity consumption and demand of residential apartments to effectively design building model, plan broader policies, and overall distributed system planning. When an alternate energy consumption of an urban residential facility using a PV system is considered [6], and the idea of storing excess energy produced from the PV system kicks in. There are several recent attempts to calculate the energy consumption of standalone apartment energy consumption [7] and centralized energy distribution systems [8], which shows that it is more cost-effective to have a cartelized battery storage for SS apartment-style building. A detailed analysis is required considering the factors related to the environment and regulations of Abu Dhabi city [9] and most importantly these approaches consider ideal as oppose to the bottom-up approach used in the proposed solution.

A. Approach and methodology:

A typical approach to analyzing the consumption of electricity and analysis of residential units is generally categorized according to the type of data use and desired results. High level aggregated data at a wider network or substation can be used as a top-down approach, while here metered electricity load data at the consumer level is used as bottom-up approach and simulation data from a computer-aided software has been used with specific model design. There are few related examples which use similar bottom-up approach and comparison with the simulation of the computer-aided model [10], to visualize the overall consumption of a unit throughout the year in arid environment [11] and also the strategies of retrofitting efficient energy consumption techniques where the climate get hostile and extremely hot [12] but a detailed analysis is required that shows easy steps of designing a complete model.

B. Other adaptable approaches to improve efficiency:

A lot of detailed analysis has been done since the announcement of green energy initiative from UAE government, and most of the studies focus on residential buildings and comparison of small houses, and literature shows that Abu Dhabi and Sharjah are one of the best places to use PV technologies [13]. Even the government of Abu Dhabi is ruling out a lot of new policies and regulations of net-metering to encourage green technologies and to compensate gaps between the costs of PV production and the revenue from utilizing or selling the PV electricity. Self-consumption can be defined as the share of the total PV production directly consumed by the PV system owner [14]. There are two major technologies that increase PV self-consumption and improve the usability of the PV system, first using the batteries which have discussed previously, and the second most important one is load shifting. Manual load shifting can also be done on small scale residential building to increase self-consumption, where most items at nighttime are utilized on a minimum level because of the unavailability of solar energy. Finally, third and most important type is a grid connect system which is most convenient to use in UAE considering huge saving cost on batteries and system supplies excess energy to the grid during day when city needs energy for industry and at night when there is no solar energy and also less industry load on city grid, energy is used from the grid which has been supplied earlier.

III. SITE SELECTION AND LOAD ANALYSIS:

For the case study to implement an alternate energy solution on a domestic level, an average apartment in Abu Dhabi (Al-Markaziya) has been selected in the heart of the bustling city. Figure 1 shows a huge solar energy potential on the selected site, where it is mostly clear with a few overcast days [14]. Moreover, figure 2 shows somewhat less favorable conditions for wind turbines considering low wind speed and high humidity and heat which increases equipment and maintenance cost. However solar power generation is the most favorable form of energy production as compared to other alternative methods. PV solution is in fact also encouraged by the Abu Dhabi government by passing net-metering regulations [15], according to which all domestic customers producing energy from solar rooftop systems are given energy credits for their excess energy. These points can be redeemed in the form of energy consumption later as well.

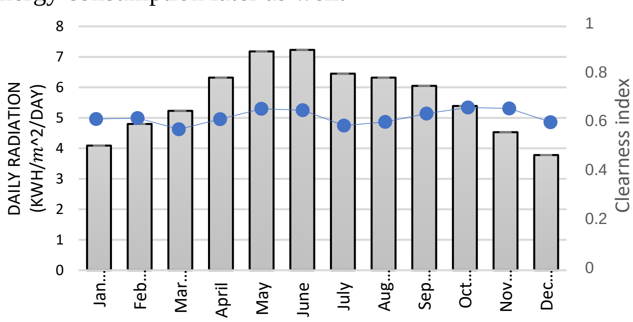

Figure 1 Solar energy potential for Abu Dhabi city (NASA)

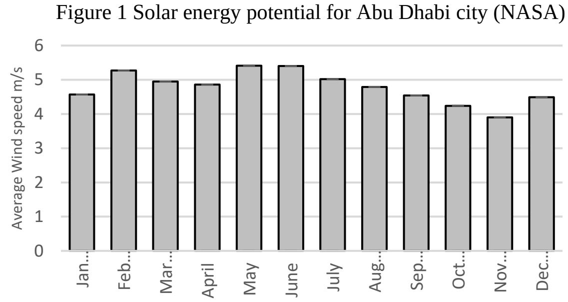

Figure 2 Wind speed data for selected location at the height of 40m (NASA)

Now, if we take a look at the last four years' energy consumption data of the apartment, it shows a similar trend. Figure 3 shows an average energy consumption of the last four years of 1-BHK, which has two splits AC, four big LED lights, three light bulbs and other miscellaneous households like a refrigerator, etc. This apartment shows an average consumption peak during the evenings as this belongs to a working-class family. Figure 4 shows

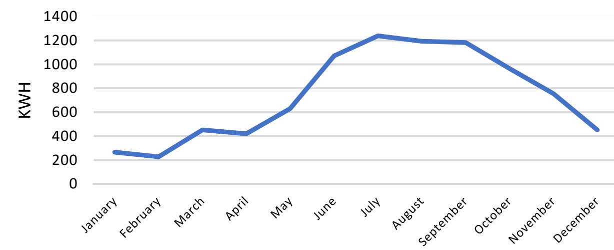

Figure 3 Average monthly power consumption of selected site

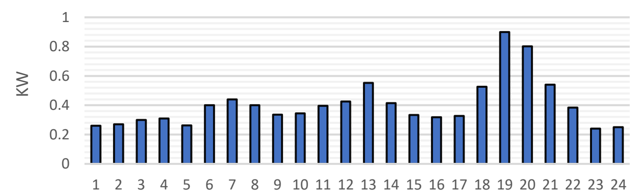

Figure 4 Average hourly profile of load in a day

hourly profile throughout the week, which can be scaled later. Although the trend has been a bit different on the weekend overall energy consumption in a day was in the range of ±10% which is to be noted at 22.7KWh/day. Further hourly seasonal load data was approximated using reports generated by smart meter and, figure 5 shows that during the peak hours in July, load reach to maximum rated consumption of 5KWh.

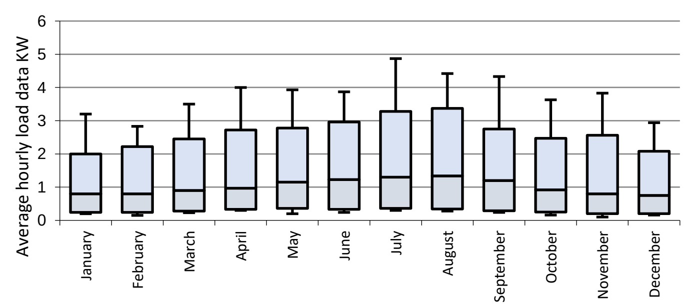

Figure 5 Approximated seasonal load data for the apartment

Now, considering data given in figure 1 shows the average solar potential of 5.6KWh/m^2/day. Whereas, the apartment selected for analysis has an area of 550sqft. So,

say η_pv=15%

$$Available\ energy = \frac{5.6\ KWh}{m^2 day}\ X\ 0.15\ X\ 50.1m^2 = 42.084\ \frac{KWh}{day} \quad (1)$$

Which shows the apartment can produce double the amount of electricity required to sustain. But this building has five floors and six apartments on each floor, which means there will not be enough space for everyone to install solar panels on the roof. For that purpose, solar park has to be created away from the site or walls of the building should be utilized to install a solar panel.

An entirely different study needs to be done on how a maximum area of a building and the characteristics of PV installation. Finally, after simulation of the system in PVsyst, results are verified, and the area required for installation of the PV system was calculated to be 30m^2, and the sizing results are further verified using the Homer Pro tool.

IV. System Specification and Optimization:

For steady-state system analysis and optimized solution, Homer pro software has been used. It allows the user to do sensitivity analysis with all the possible scenarios and gives the user the flexibility to quickly see the impact of on final results with a modified system to get desired optimized results. Now, considering a Grid-connected system structure as shown in figure 7, integrated blocks selected in the Homer Pro software for simulation and optimization, where sensitivity analysis has been performed generates over a 1000 different combination has been analyzed. Finally, the best possible solution considering capital cost, operating cost, power rating, deterring factor and other variables.

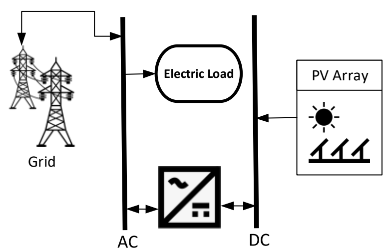

Figure7 System dynamics considered for Homer pro optimization

For simulation purposes, solar system SUN Power (SER-220P) has been selected where an estimated one plate costs C$350 including installation cost. The detailed specification has been shown in table 1. Several software like Homer pro, Hybird2, and RET screen provide resource estimation based on historical data. Considering the urban setup, evolving load profile, calculation of shades of nearby buildings or trees and tilt properties of PV panel other software like PVSyst, Solar Pro and Ecotect helps in optimization to calculate the closest estimate to practical values.

TABLE I

Table 1 SUNPower (SER-220P)

Parameters	Index	Values
Maximal power	Pmax	219 W
Open circuit voltage	Voc	36.3 V
Short circuit current	Isc	8.3A
Voltage at MPP	Vmp	29.02A
Current at MPP	Imp	7.58A
Temperature	Isc	0.061745
Shunt resistance	Rsh	95.1262
Series resistance	Rs	0.37152

V. Detailed System Design:

After a detailed analysis of the system, analyzing similar system dynamics [16] [17][18], a controller has designed as been designed which follows a similar parent [19], also shown in figure 8. Previously, it has been concluded that the most optimized solution, as shown in figure 9, is to have a Grid-Tie system with MPPT and battery controller. This system has a payback period of around 13 years with more reliable and economical solution. As can be seen in figure 8, required power should be 14.5KW from the PV system. The system is connected to the grid, and the most challenging part is to have controller designed to match the frequency of the grid, THD should be less than 0.1%, so, for this purpose, a generalized study helps implement ways to reduce error [20] and to reduce harmonics[21].

A. System presentation:

The presented system model of PV solution, composed by:

- SER-220P PV module with the parameters is shown in table1 and total power of 16.4KW as optimized in PVsyst and Hommer.
- Boost converter and the transformerless system have been presented to step-up the voltage of the PV system to 500VDC which makes the system scalable for future usage with multiple sub-systems and loads.
- Feedback and Phase-locked loop system with self-filter output
- A three-phase coupling transformer of 380/25kV.
- Controller blocks have been used to track maximum power point and to control the magnitude, frequency, and total harmonics disturbance with VLL = 380V and the grid frequency to be 50Hz.

Figure 8 represents the flow chart and figure 9 represents the actual modeling of the control circuitry of the system using MATLAB/ Simulink software. A detailed analysis shows the stability of the system with grid-connected configuration.

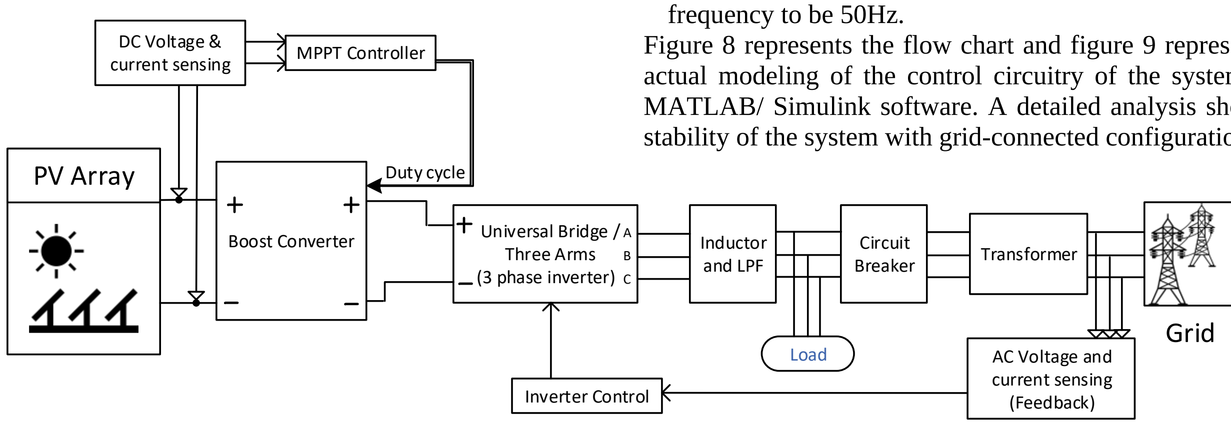

Figure 8 Proposed system flowgraph

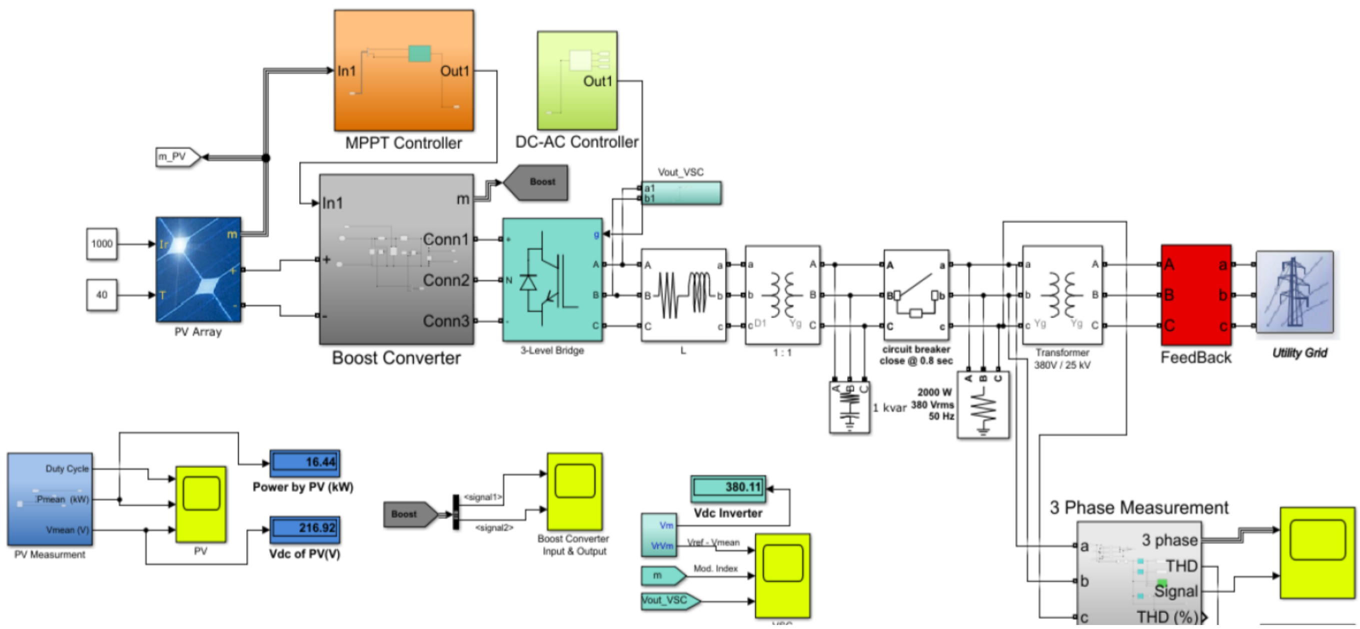

Figure 9 Complete Simulink model in MATLAB showing how proposed system has been designed

B. The PV system Maximum Power utilization:

PV array has been represented in figure 9, and the MPPT controller has been represented in the orange box. There have been eight strings in series of SER-220P and ten parallel strings to sum-up the total energy to be 17.5KWH, and adding standard working conditions 16.44KWH power by the PV system is being supplied to the system as can be seen by the blue measurement boxes. Furthermore, at any instant, it is important to extract maximum power generated by the solar cells. For that purpose, the circuit is required to control duty cycle given to boost converter for continuous controlling PV voltage or current regardless of the system attached to load or connected to Grid. For maximum power point tracking, incremental conductance method has been implemented which has high response time [18], following is the quick explanation where the maximum power point is achieved when:

$$\frac{dV}{dP} = 0 \qquad (2)$$

$$\frac{d(V*I)}{dV} = I + \frac{d(V)}{dV} = 0 \qquad (3)$$

$$\frac{dI}{dV} = \frac{-I}{V} \qquad (4)$$

where P = V*I

dI, dV = components of I and V ripples measured with respect to time

I , V = mean values of V and I measured with a sliding time to supply the adjusted duty cycle to track maximum PowerPoint.

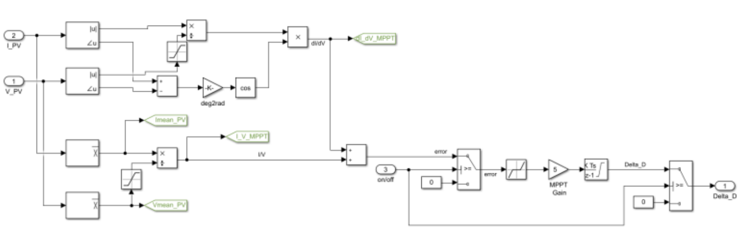

Figure 10 MPPT configuration in Simulink

C. Boost converter:

In this proposed system, IGBT and diode have been used to step up the voltage. In the boost converter, the average output current is less than the average inductor current. [22]. When the switch is ON, the inductor starts to store energy with increasing current through the inductor. On the other hand, when the IGBT switch is closed, the stored energy in the inductor is dispatched. Consequently, the average voltage across the load is greater than the input voltage supplied. Figure 11 shows the diagram of boost converter implemented.

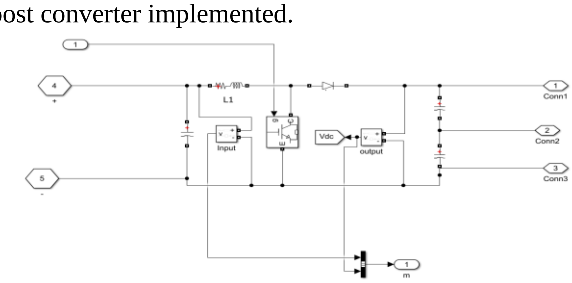

Figure 11 Boost converter

D. DC-AC controller:

To feed current to the grid, DC current supplied by PV system is to be converted into AC that must have exact symmetrical components as the grid. VSC converts 500 VDC into 380AC pure sine wave. It consists of two feed-back control loops:

- An external control loop that regulates DC link voltage to +/- 380 V.
- An internal control loop that regulates grid currents
- The control system uses a sample time of 100 microseconds for voltage and current controllers.

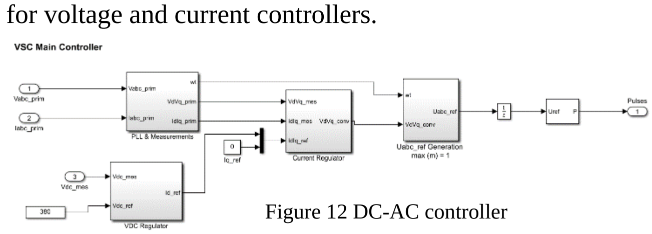

Figure 12 DC-AC controller

Boost converter and VSC converters use pulse width modulation and fast sample time to achieve appropriate resolution of PWM waveforms [24]. Figure 12 shows some details of controller.

E. Simulation results and discussion

The system has been tested at 1000 irradiance and 40 degree of temperature, as can be seen in figure 9, complete system design has be shown in where all components have been tested with full load and Grid connectivity to get stable system and figure 10 represents the detailed arrangements of the components and flowing figure 13 and figure 14 shows stable output of 380V peak value of line-to-line voltage. It is very important to discuss DC to AC controller which has been implemented by getting feedback from phase a and phase b. PLL method gets line-to-line current from the output and then compared it with zero references current value. By using this technique, the whole model shows stable output while connected to grid.

Figure 13

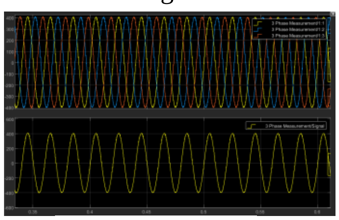

Figure 14

VI. Conclusion

For an average apartment in Abu Dhabi, the proposed system has a huge benefit since it does not require huge amount of investment. Considering the Net-metering rule for Abu Dhabi this system has benefit but at the same time, it is totally dependent on the Gird for getting power back during the usage at nighttime. As it has been discussed that, considering average mostly electricity bill as saving, this system pays off its cost within 15years and starts giving savings. The payback period could be even less if new policies of government is considered where the government is starting to implement taxation policies and the same time encouraging people to use green energy systems, especially rooftop PV systems by constantly improving regulation and policies.

VII. Future work:

This system has been designed as a Grid-connected system, but a standalone system has also been studied during the process. To implement a standalone PV system, an entire study is required, where system is to be tested with battery bank and as cost of batteries affect the overall feasibility of the system so the cost and stability of the system can be analyzed.

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