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Full Length Research Paper

Building integrated photovoltaics (BIPV) module in urban housing in Khartoum: Concept and design considerations

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This paper searches to find out building of integrated photovoltaic (PV) system designs in Khartoum. It discussed technical issues and the design of an integrated PV in domestic use, within an urban approach towards sustainability in energy. PV systems can be used to develop the solar energy in almost all kinds of applications. Exploiting of solar energy for domestic use is one avenue where the energy produced from the sun is converted into electricity to power most if not all the appliances available at our homes and residences. Building a PV system is the process of designing, selecting and calculating the ratings of the equipment employed in the system. This process depends on a range of factors such as geographical location, solar irradiation and load requirements. The procedures utilized in building were introduced and the equipment of a grid-connected PV system was selected based on the watt-hour demand which was 3.8 kW. As a case study, a residence in Khartoum with low energy consumption is selected.

Key words: Photovoltaic, Khartoum, module.

INTRODUCTION

Buildingintegrated photovoltaics (BIPV) is a PV application close to being capable of delivering electricity at less than the cost of grid electricity to end users in certain peak demand niche markets (Blanton et al., 1996). BIPV acceptance varies seriously by and within, country depending upon climate, built environment, electricity industry structure, government policies, local product offerings, market stimulation mechanisms, consumer demand, existing industrial capabilities and the forms of tariff arrangement for grid-connected PV power generation (Bakos et al., 2003; Green, 2003; Nieuwenhout et al., 2001; Watt et al., 1997). Mason et al. (2001) experienced solar home systems in developing countries.

BIPV grid-connected system involves combining solar PV electricity technologies with those of building construction (Schmid, 1992). This subject is of great interest to those in the fields of energy conservation and building design. However, it cannot be underestimated in the context of the more familiar notion of sustainable development (Kaldellis et al., 2004). The concept of sustainability is more relevant than ever and support systems which use; sustainable energy, the mostly used was BIPV (Moharil and Kulkarni, 2009). The essential aspects and sustainability of energy must become the cornerstone of the researchers design philosophy. It processes the design sustainable buildings that rely on renewable resources to provide most, and eventually all, of their own energy need (Beerbaum and Weinrebe, 2000). The most promising renewable energy technology

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is PV power (Chaurey et al., 2004). PV power is a truly elegant means of producing on-site electricity. The important feature which influences design of the sustainable house was climate and solar radiation at the case study location. The climate of Khartoum in the summers are invariably hot (mean maximum 41°C and mean minimum 25°C) with large variation; low relative humidity averages (25%). Winters can be quite cool. Sunshine is very prevalent. Dust storms occur in summer (Alnaser et al., 2007). The climate is a typical desert climate where rain is infrequent and annual variation in temperature is large. Khartoum is located at 15.38 latitude and 32.28 longitudes. Energy planners have long envisioned large utility-scale solar power plants covering large expanses of desert (Alnaser et al., 2007). While this vision has many favorable attributes, the economics require careful investigation. Grid-connected PV systems require the allocation of land (Markvart, 2000) which must be acquired and prepared to accept the PV system (Billinton and Karki, 2003), the cost of land and the site work must be considerable. In Sudan, the lack of available large open tracts of land has effectively precluded the large-scale grid connected of PV system option as afforded to develop renewable energy resources for electricity generation (Omer, 2007). The residential sector consumes upwards of 17% electrical energy in Sudan. More than 80% of this is generated using fossil fuels that contribute immensely to environmental pollution and global warming. The use of energy efficient measures and renewable energy, complimenting fossil fuels can reduce electrical power outages during peak demand, and more importantly, cause a reduction of gaseous pollutants. BIPV can be of the form of (1) roofing materials, (2) wall and fenestration materials (Bendel et al., 2008), and (3) flexible PV modules (Norton et al., 1997) and can be integrated to the roof of new buildings or where major roof replacement is undertaken. Methods of integration include exchangeable PV shingles, prefabricated PV roof panels and insulated PV roof panels (Norton et al., 1997). Fully integrated BIPV roofing systems must perform the function of a standard roof and provide water tightness, drainage and insulation. Most retrofitted roof-mounted systems are though not however, fully integrated into the roof structure (Wieting, 2005).

DESIGN

The system was designed for maximum output in summer and has an acceptance half-angle of 36° providing a collection time of 7 h. It was characterised experimentally for high-latitude bi-facial cell BIPV applications (Adsten, 2002). Different configurations were made for grid-connected, roof integrated, east/west, spring/fall and wall integration. Adsten (2002) illustrated that the cross-section of roof integrated is designed for Stockholm conditions. The highest optical efficiency reported was 56% for a bi-facial based MaReCo. In contrast, optical efficiency of 91% was predicted for dielectric-filled BIPV covers (Zacharopoulos, 2001) and 85% for an air-filled asymmetric compound parabolic (CPC) BIPV system (Eames et al., 2001; Mallick et al., 2004).

Design will be established by the number of modules, the dimensions of the modules and the total dimensions of the system to be integrated into a roof. This case avoided some modules that have integrated diodes to make a short cut when a row of cells is covered or shaded. Alternating current (AC) modules also must isolate the impact of shading as each module's, that mean shading was avoided, direct current (DC) power output is converted to AC and drawn individually with a converter. In this case, to get the power which was loaded at the sustainable house (Abu-Jasser, 2010) PV technologies, with polycrystalline cells, are less impacted by irregular shading effects, due to different electrical connection characteristics and better performance in low light. Inverter characteristics are also critical, since most have a cut-off point. In general, shading should be avoided as a possible (Zahedi, 1998) fully integrated single house design item (Markvart et Al., 2006). Although the architect may make creative decisions that are needed from the start, in particular (Zahedi, 1998), from structural and building services engineers, and get information and ideas about energy, and comfort systems and structural design, with all technical requirements as shown in Table 1. Designs at AL-Azhari city in Khartoum State converting sunlight into electricity through the use of PV cells as part of integrated building systems is an appropriate way of accessing renewable energy. The PV conversion process is silent. It as no moving parts and is pollution-free. The vast areas are offered by the roofs. The slope angle (β) with the roof is defined as the angle between the plane of the solar collector in question and the horizontal, (β) is positive, the orientation of the surface is toward the equator, and when negative, it is toward the pole (Bari, 2000). The optimum design of a BIPV system although based on a building's electrical load profile, PV output and balance- of-system characteristics must be cognoscenti of building design constraints, building location, offset costs, climate and future load growth (Watt et al., 1997). System economic viability depends on local electrical loads and utility prices (Mallick et al., 2001; Mondol et al., 2006). Approximately 25 to 30% (Sick and Erge, 1996) of energy consumed in buildings in industrialised countries is electricity. PV can be integrated on virtually every conceivable structure from bus shelters to high rise buildings. BIPV modules fabricated directly onto building materials can, in high-volume production lead to lower substrate, distribution and installation costs (Ji et al., 2008).

Sizing and modelling system with processer

This component features the estimation of the size and cost of a PV system. The design sizing system is derived by determining the load and available sunlight. It requires the type of module and efficiency of the module, which for this case is shown in Figure 1 together with the battery bank.

RESULTS AND DISCUSSION

Design of BIPV house in Khartoum of 3.8 kW/day depends mainly on installing polyvinyl chloride (PVC) panels in italics ceilings (Bungalow) and connection of batteries with internal network of solar house, in addition 533 – 637 to that home connection with the National electricity network to allow some part of the house to use public network electricity and other part could use PVC electricity at 23° until it is completely attacked of direct

Table 1. System architecture summary.

Component	Characteristic
PV system power	5 kW
Type of building	Roofing tile PV
Integration	integration and double-Glazed PV Glass integration
Type of cell	Mono-crystalline silicon
Technology	cell (roof) and Poly-crystalline silicon Cells (windows)
Array dimensions	34.2 m²
Weight	120 kg (double-glazed PV glass)
Inverter	Line Back FX (Nihon Den chi Co. Ltd.) 4.5 kVA
Monitoring	Horizontal pyrheliometer, inclined phyheliometer, air temperature

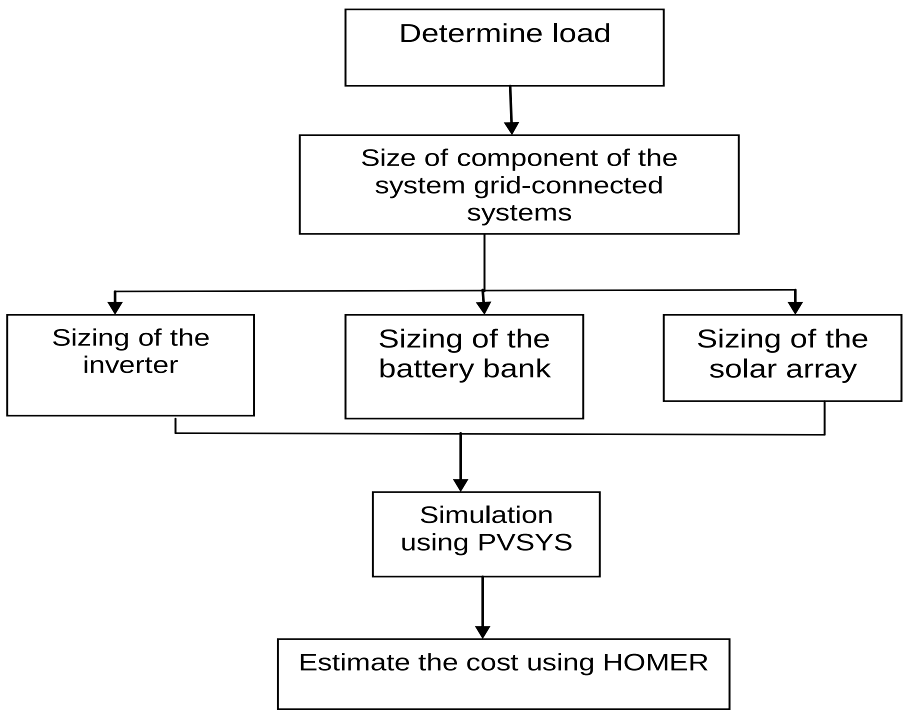

Figure 1. Sizing system processer.

sun angle during the day. Figure 2 shows the position of the sun at solar noon; a PV panel oriented to the north and titled at the slope of roof (Deutsche Gesellschaft für, 2008; Hankins, 1995). The direction of north and south with 23° is restricted fully ventilated in the state of Khartoum. Of the location, this deals with Abu-Jasser (2010) that it can be obtained from the roof-top mounting system as on-roof mounting, leaving the existing roofing material in place, and in-roof mounting, where the modules take over the function of the roof tiles that obtain the position of system; the tilt of roof was influenced on the successful capture of the solar radiation and functional architeure design as Abu-Jasser (2010) resulted.

Installation of orientation of modules and the roof

The roofs were directed towards the east inclined to the north direction depending on the west inclined to the south direction (Alnaser et al., 2004). Markvart et al. (2006) and Stackhouse and Whitlock (2009) dealt with the result obtained from the optimum time to get maximum power 12 to 1:30, as optimum time to capture most of solar radiation depending on the result of solar radiation as shown in Figure 2. According to geographical mandate studies of Khartoum state, the roof was directed towards east and west with an inclined direction. Abu-Jasser (2010) found that the geographical location of the Gaza Strip makes it one of the relatively sun-rich regions

Figure 2. Installation photovoltaic module.

in the globe. It is located in the northern hemisphere area of the earth at 31.3° latitude and 34.3° longitude with an annual incident solar irradiance of about 2000 kWh.m^{-2} (Markvart, 2000). This implies that the solar panel must be mounted facing the south to capture a maximum amount of solar energy, and the number of days of autonomy where the system will operate without receiving an input charge from the sun is approximated to 4 days according to the record (Borowy and Salameh, 2002; Moharil and Kulkarni, 2009). Conversely, the minimum and maximum power generated values are obtained from historical data and their effect on demand is also studied. The loss of load hours is calculated considering the power generation and load requirement of different months with different locations.That means, the optimum angle of slope of roof was β 23°.5 at Khartoum location to get the maximum power, the status of each of those considerations must be included in the design models for BIPV (Omer, 2007). The single house contains the different activities of normal housing as the bedroom, living room, a reception and a small kitchen serves medium and large family depending on the model, that ranging from that of two rooms and a reception for men, another for women and various bath rooms, and the largest model in three sleeping rooms and reception for men, another for women and various bath rooms. Those activities load was 3.8 KW/day as results found shown in Figure 3 for different appliances for single home user load. It has been found that for this system each home user consume energy around 224 W/day of Wh/day with a peak demand of nearly as shown in Table 1. The system also gives the opportunity for expanding its capacity in order to manage with the increasing demand in the future (Masters and Wiley, 2004). This was done by increasing either the rated power of diesel generator, renewable generator or both of them (Nayar et al., 1993). Abu-Jasser (2010) found that the maximum load was 4.8 in Gaza and Sasitharanuwat et al. (2007 found that this mode of operation is particularly suitable for systems with relatively small renewable energy penetrations that obtained the size of the system in small sizing of renewable energy using BIPV which depends on the load and suitability of whole system component. PV system was positioned upon the roof, and distant from the first PV modules were thought to be appropriate over the life of the building when other PV sub-arrays will be positioned much closer to it (Sims et al., 2003). It was also thought that if more space for PV equipment became necessary because the area was approximately 40 m² required for standard equipment in the system design, in this case, an approximately 10 m² of additional space is required for PV related equipment. Thus, the PV plant floor area is about 4 to 5% of the total array area. Sims et al. (2003) and Wieting, 2005 found the result that were issued in optimizing the use of isolated small PV power generation in remote areas and revealed the procedure to evaluate different PV methods considering the stochastic nature of the insulation and the load requirement, that acquiring the installation of the grid-connected system has a most important command factor of evaluating the success which is the construction way and the functional design.

Tilt roof of building integrating photovoltaic

Sloped roof constructions are very common for residential buildings and are most suited for a PV installation if orientated approximately towards the equator. The roof systems are particularly useful for sites situated towards the quarter where overhead sunlight is predominant. Form and color of modules and system cells are typically dark blue in color. Different colors of the type of module also have an impact on color (Emmanuel,

Figure 3. Planning of residence in Khartoum.

2005). Frameless modules give a very harmonious impression as the roof is not disturbed by frame patterns of different color or material to that of the cells as shown in Figure 3. Benemann et al. (2001) and Celik (2002) had smaller frames in the same color as the cells are almost invisible at the surface.

Planning concern of installation

The calculation of the residential sector is composed around a service center, the group of neighborhood housing and a service center provided that contains the basic services needed as shown in Figure 3. Dalton et al. (2009) planning used that kind of technology in supplying energy as indicated by the figures of design and planning it implemented in this paper as the rules of planning. The amount of irradiation in the residence depends on the latitude of the building and the local climate as (Dalton et al., 2009) found to get a perfect design. The maximum irradiation depends on the orientation, and the angle of the collection surfaces also put in to consider for latitudes 32° north; good results (over 90%) can be achieved between southeast and southwest with system tilt angles 23° as shown in Figure 2. Orientations between east and southeast and between southwest and west are acceptable for tilt angle 23°. These agree with Kaldellis et al. (2004) who got that to determine the optimum dimensions of an appropriate stand-alone PV system, able to guarantee the coverage of remote consumers energy demand located area A. Detailed energy balance analysis of selected PV system was done on an hourly basis. Abu-Jasser (2010) and Kaldellis et al. (2004) showed that the equipment used to construct the stand-alone PV system for the suggested remote residence described earlier are summarized with some details and specifications in Table 1 which define his load in Gaza that obtain the electrical appliances available at the residence are itemized with their power ratings and time of operation during the day to obtain the average energy demand in watt-hour per day.

Design the array

The researcher designed the array based on architecture design of the house and upon the roof as two parts of array. Twenty (20) modules of one part has contact with the other part with same number of this module. After running our software, we found that the plane irradiance was 1000 w/m^2 (Crassard and Rode, 2007).

For the section of this array (with 20 module), the output power was 3.8 kwh. It means that the output of power was appropriate with the design of electricity requirement that validated that the selection of the type of module and array was sufficient to generate the power which was needed for the design, with all requirement, slope of angles and orientation, and the system component design.

Sizing of the solar array and system design at Alazhari city

To avoid the risk of under sizing, we begin by dividing the total average energy demand per day by the efficiencies of the system components to obtain the daily energy requirement from the solar array:

$$E_{array} = \frac{\text{daily average energy consuption}}{\text{product of component efficiencies}} = \frac{3500}{0.9\times 0.8\times 0.8} = 3.8$$ kWh.day^{-1}

Then the peak power is:

$$P_p = \frac{\text{daily energy requirement}}{\text{minimum peak sun-hours per day}} = \frac{5173}{3.84} = 1508 \text{ W}$$

The total current needed for a DC-voltage of 24 is, I =1608/24=67 A, and according to the selected panel KC50T. The number of series panels, Ns=24/24=1 and the number of parallel panels, Np=67/7.45=40 are approximated to 40 which means that the number of panels needed is 2×20. Also, Abu-Jasser (2010) designed the array and the number of module depends on their load requirement. That means, the sizing of module depend on the factors that affect system sizing. It is to be noted that an average efficiency of 12% was assigned to the PV modules used in the present installation while doing the above calculation.

Sizing of the battery bank

The amount of energy storage required is, = 4500×4 = 18 kWh, where the number 4 represents the number of days. For safety, estimate the previous value by permissible level of discharge, MDOD (75%)

$$E_{safe} = \frac{\text{required energy storage}}{\text{maximum depth of discharge (MDOD)}} = \frac{18000}{0.75} = 24 \text{ kWh}$$

The capacity of the battery bank in ampere-hours is required assuming that we have selected a battery voltage of 12 V: C =24000/12=2000 Ah, and according to the selected battery (UB-8D AGM -250 AH, 12V-DC), the number of batteries needed is, N batteries =2000/250=8 batteries. With DC-voltage of 24 V, four parallel branches are recognized according to the equation Np=8/2=4. Each branch contains 2 series batteries.

Sizing of the voltage regulator

The total current required, I = 9×8.03×1.25=90.34 A, where the current I_{sc} for each of the selected modules equals 8.03 A and a safety factor of 1.25 is used. The number of regulators required is, N =90.34/60=1.5 approximated to 2. According to the selected regulator, Xantrex C-60, 24-V, 60-A, as chosen by Abu-Jasser (2010).

Sizing of the Inverter

The power of appliances that may run at the same time is given by the following P= (10×11+125+200+1000) =1435 W, and the appliances with large surge currents that include motors are 245×3=735 W. To allow the system growth, we add 25% of the previous two values to get total power:

p_{total} = (power of appliances running simultaneously + power of large surge current appliances).

p_{total} =(1435 +735) 1.25 =2712 W=27.12 KW.

The inverter needed must be able to handle about 2712-W 220-Vac. Electronics inverter, LS-3024, 3000-W, 24-Vdc, 220-Vac, proper sine-wave, with a half-hour rating of 3700 W and surge power of 9000 W for 5 s is a good choice (Abu-Jasser 2010). Sizing of the system selection and proper cabling type of cable is the performance and reliability of a PV system. The figure 1 shows a sizing of pv module. The DC-wires between the PV modules and batteries through the voltage regulator must withstand the maximum current produced by these modules.

This current is given by Im=9×8.03×1.25=90.34 A. The optimum wire type for this current is copper wires (AWG), while the AC-wire from the inverter to the electric panel of the residence must withstand the maximum current produced by the inverter output. This current is given by the following formula for a rated AC-voltage of 220 V: Im=3000/ (220×pf) =17.04 A at a power factor of 0.8. An optimum wire type for this current would be 10 copper wires (AWG) in both AC- and DC-wiring the voltage drop is taken not to exceed the 4% value.

The researcher designed the system in accordance with the load requirement of the house at Alazhari city and simulated of these design of system and the battery was conducted using PVSYS.50. The selection of inverter which was appropriate for the architecture design of the sort inverter by powering the number of inverter for one house individually was 1 and the operation voltage which accepted this inverter as details of company manufacturing are given by software between 125.44 to 550 V. The capacity of inventor power was 3.0 kWh; the real voltage was between 125 to 440 V.

The constraint and economics

The life time has been considered to be 25 years and the annual real interest rate taken as 4%. As the system has been designed for single and also for multiple home users like 10 to 50, but the load consumed by the user is low; so operation and maintenance cost has been taken to be 500 SP / year. There is no capacity shortage for the system and operating reserve is 10% of hourly load. Analysis shows that the cost of energy (KWH) is low for the system which is the combination of 50 homes (Roaf and Fuentes, 1999); the load demand for each combination of homes with system architecture and financial summary (Moharil and Kulkarni, 2009). The system simulations showed that with a daily load of 207 kWh/day, the combination of a 12 kWp PV system with a battery backup capacity of 108 kWh would be optimum, given the most suitable strategy for the use of two differently sized solar renewable energy generators now present. Moharil and Kulkarni (2009) yearly system performance of autonomous photovoltaic energy systems with battery storage and simulated used the pre-determined combinations. That means it was shown that the yearly system performance predicted from the 3 and 4 days synthetic data closely agreed with that obtained from the measured data, varying only slightly for different combinations that obtained the reported development of computer approach for evaluating general performance of grid-connect PV system.

CONCLUSION

Design small-scale of housing developments is apparent, with whole requirement of urban planning and technical solution of BIPV grid-connected system. Design was developed and the structure which implement the housing construction process were presented with numerous opportunities for PV roof integration in single-family houses, 10, 20, 50 and for roof integration in single house. Integration of a many numbers of PV systems during construction in residential homes to generate the maximum power from the system with definite load 3.8 kw/day for single house in Khartoum–Alazhari city were carried out. The designer investigated layouts that maximized solar potential, considering day lighting; passive solar gain and the use of PV module.

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