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Xuan Truong Nguyen, Lang Tung Nguyen, Quang Hung Nguyen, Benoit Delinchant

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Grid-connected PV system design option for nearly Zero Energy Building in reference building in Hanoi

Nguyen Xuan Truong

Energy department
University of Science and Technology of Hanoi
Vietnam Academy of Science and Technology
Hanoi, Vietnam
nguyen-xuan.truong@usth.edu.vn

Nguyen Lang Tung

Energy department
University of Science and Technology of Hanoi
Vietnam Academy of Science and Technology
Hanoi, Vietnam

Abstract— Building is responsible for more than 40 percent of energy consumption and one third of greenhouse gas emissions. Europe has established the path towards nearly zero-energy buildings (nZEB), soon required in every new construction and large renovation in existing buildings by 2020. Achieving nZEB required the use of photovoltaic modules for generating electricity. In Vietnam, photovoltaic systems are in most cases not used in building today. This research, we aim to implement the platform that will be dedicated to prototyping and tools to support research training in the reference building. In order to achieve nZEB, a 15 kWp of PV array will be installed in the rooftop of this building to compensate the energy needed. The objectives are to benefit from PV source, to improve energy efficiency and to reduce cost of electrical consumption in different scenarios. The Photovoltaic simulation tool is important in predicting the energy production from the solar panels. The first study investigates the use of a simulation tool PVSYST as a method of informing the design decision of building installed photovoltaic system. Input to the simulation software such as meteorological data has been evaluated.

Keywords—nearly zero energy building; photovoltaic source; simulation tool; rooftop; energy efficiency.

I. INTRODUCTION

People spend around 90 % of their time in buildings while about 40 % of primary energy needs in USA and Europe, nearly 30 % in China and even up to 80 % in Hong Kong, are due to buildings. Buildings are also one of most significant contributors of GHG emissions [1]. Nearly zero energy building, an initiative concept for sustainable building, has attracted increasing attentions as a solution for saving energy, reducing global GHG emissions and responding to global warming. In order to achieve a high energy performance level in building, it take typically advantage of passive design techniques and active solar technologies such as solar collectors for domestic hot water and space heating, PV-panels for generating electricity [2]. PV array installed in the building contributes to the reduction of the primary, conventional energy supply, as well as the reduction of CO₂ emissions in the built environment. Distributed PV systems can be installed as façade or on rooftop applications in order to maximize the benefits of clean and quiet power generation. Façade

installation can be optimized by observing the orientation and distance to length ratio. Rooftop application can observe the tilted angle and curved installation. In addition, PV sitting optimization should play an important role in making competitive solar electricity [3].

Vietnam has enjoyed a period of rapid economic growth which has significantly pressure on the infrastructure and environment, coupled with urbanization and industrialization. These factors have driven a pressure of increasing demand for building, energy consumption, and waster and pollution management. Construction statistical data showed that each year, the average of housing floor areas constructed are increasing incessantly, and 20 % of the national energy consumption is a direct product of building sector [4, 5]. Country is facing massive challenges implementing reliable, efficient and modern electricity systems, in order to achieve responsibly three high-level goals: energy security, economic development and climate change mitigation. The government is already reacting for sustainable power supply, grid capacities, energy efficiency and demand side management approaches and technologies with participation of governmental organizations, university and scientific institutions [6]. The Prime Minister has ratified the project “Energy Efficiency Improvement in Commercial and High-Rise Residential Buildings in Viet Nam”, which was sponsored by the United Nations Development Program through a non-refundable aid of the Global Environment Facility. Its aim is to reduce CO₂ emission by improving the effectiveness of using energy in commercial and high-rise residential buildings in Hanoi and Ho Chi Minh City. The objective will be achieved through implementation of three components: improvement and enforcement of energy efficiency building code, building market development support initiatives, and building energy efficiency technology applications and replications. Vietnam’s year average solar irradiation of 4.89 kWh/m²/day makes it a good site for promoting the use of PV electricity generation [7, 8]. However, solar energy is still at the research and demonstration stage. There is no buyback scheme or feed-in tariff for PV systems, and the costs of implementing renewable projects remains high. In this initial study, we use the simulation tool PVSYST to determine the slope of an on-

grid PV system, which will be installed on an office building rooftop, taking into account panel orientation, Hanoi meteorological conditions, solar cell technology and inverter connections. The first results will be helpful as a pre-decision of implementation of real system.

II. METHODOLOGY

A. Platform for nZEB at University building

In Vietnam, the low voltage power grids (220/380V), which consist of low voltage distribution grid and power supply grids in industrial and building sector, is uneven quality, is non-compliant with technical standards, and has high losses. It is actually not easy to apply common smart-grid standard in operation, but it is necessary to give priority to address scientific research on smart grid technologies at local level, that known as “micro smart grid”, in order to eventually improve the current national power grid and effectively operate the electricity system. We focuses our research on the micro smart grid development at the building level.

The power supply system for platform will be from a Photovoltaic generation, an electrical storage and power grid. The PV system at power scale of 15 kWp including an inverter and solar panels will be installed on the rooftop of reference building. This system extracts the maximum power obtainable from the PV array under different working conditions to provide a portion of the building power demand. The load includes lighting systems, heating ventilation and air-conditioning systems, and elevator. Besides, the monitoring system allows collecting data that can be analyzed providing information for the optimal operation. The energy controller reads all the data measured by the transducers for managing and running the equipment following the different selected modes. The energy manager controls the delivery of energy, the run of charges and discharges batteries (Fig. 1). The main objectives of this project are to benefit from photovoltaic power supply, to improve energy efficiency and to reduce cost of electrical consumption in different scenarios.

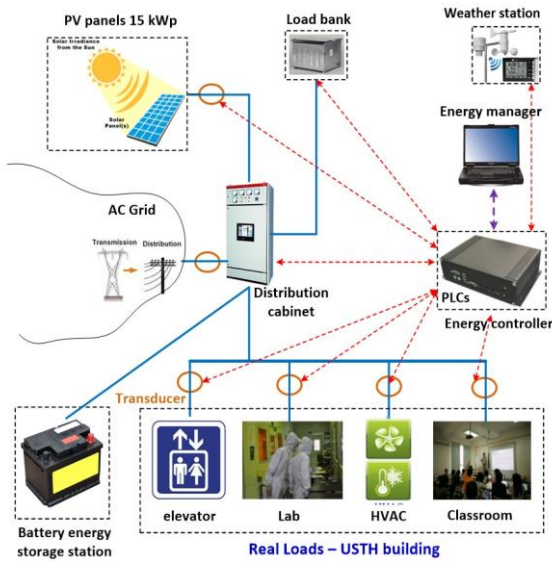


Fig. 1. Building energy management design for University building

B. PV system design option

1) PV array simulation tool

Simulations have been performed by using PVSYST [9] and typical Vietnamese year weather files that include average hourly diffuse, direct normal and global horizontal radiation values. It is a PV analysis software program developed by the Energy group at the University of Geneva in Switzerland, can be used at any location that has meteorological and solar insolation data. This program is designed for the study, sizing, simulation and data analysis of complete PV systems, directed for architects, engineers and researchers, enduring quite beneficial tools for academia. It is suitable for grid-connected, stand-alone, pumping and public transport systems, and offers an extensive meteorological and PV-components database.

2) Solar radiation climate

The solar radiation climate database of an area is extremely important for estimating the performance of solar energy collecting systems. Vietnam is located in South East Asia, extending between latitudes 9°N and 23°N. The geographical location of the building and the local weather conditions influence the optimal tilt of the PV modules and is, therefore, of great importance. The building in this study is located in Hoang Quoc Viet Street, Cau Giay District, Hanoi, in the northern of Vietnam at a latitude of 21°N. Several studies that addressed the solar resource maps show that global horizontal irradiation in annual daily average reaches around 3.4 kWh/m²/day in the north of the country. In the case of direct normal irradiation the annual daily average is around 2.5 kWh/m²/day, with approximately 1,500-1,700 hours of sunshine makes it a good site for promoting the use of PV systems [7, 8].

Within PVSYST, it is possible to define new monthly meteorological values and redefine the location of the project as well as import both monthly and hourly meteorological data from a number of other databases. The meteorological data embedded in PVSYST for Hanoi is a synthetic hourly or monthly meteorological file set from Meteonorm in 2005 (the data collected from 1991 to 2010). It is a database containing climatological data for solar engineering and could also be used to calculate solar radiation on arbitrarily oriented surfaces [10]. Fig. 2a shows the monthly average global irradiation of Hanoi in which the minimum value is in January, about 67.6 kWh/m², in contrast, the maximum value peak at 161.6 kWh/m² in July and August. And the average value is about 1391 kWh/m² per year. Another data source, for instance, irradiance is Climate-SAF PVGIS (online access) which demonstrates the average daily global irradiance (Fig. 2b) with the peak average value of 595 W/m² in July and August and 13 hours of sunshine.

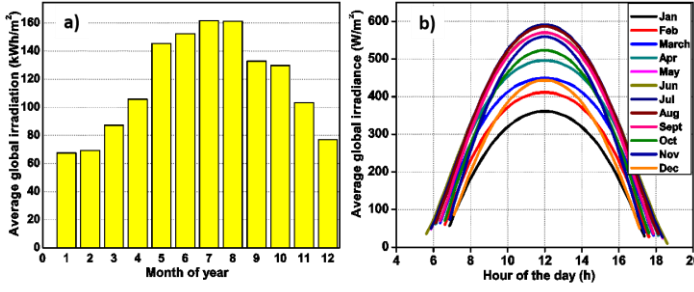


Fig. 2. Value of average global irradiation in kWh/m² from Meteor Norm (a) and in W/m² from Climate-SAF PVGIS (b)

3) PV array installation

The building has one 37.9 meter high block, with a 939 meter square rooftop. The architectural installation of PV modules on the rooftop represent on the Fig. 3.

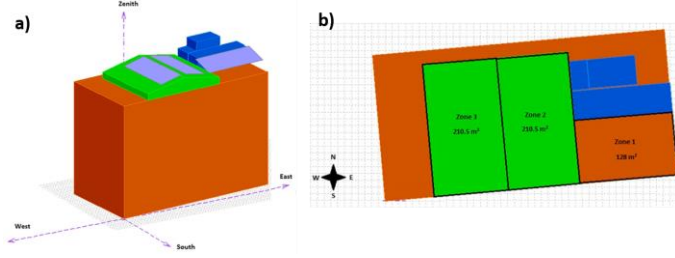


Fig. 3. Architectural installation of PV array in rooftop building with 3 zones available

Collector inclination: The placement of the PV modules is described using the plane azimuth A_m and the tilt angle θ_m . The tilt angle, is the angle between the horizontal plane and the PV module.

Collector orientation or azimuth angle: The azimuth has different definitions, but in this paper the plane azimuth, is defined as the angle between the orientation of the collector plane and south (in the northern hemisphere). For geographical locations in the northern hemisphere like Hanoi, the optimal azimuth for PV panels is $A_m = 0$ i.e. facing south. However, it might not be possible to install the PV panels along the optimal orientation due to the characteristics of the roof of the reference building. There are two options for installation of a PV system:

- Free standing: The PV array is set up on a frame in the flat yard of the rooftop (zone 1 with the surface of 128 m² and azimuth of -5°). The frame is 2.5 m high from the rooftop, then inverters can be installed on the yard below. We can optimize the tilted angle to have the highest harvested energy.
- Rooftop sited: The PV array is set up on two sides of the inclined metal roof of the building (zone 2 with the surface of 210.5 m² and azimuth of -95°), and zone 3 (128 m²) with azimuth of +85°. Because of the constraints of this metal roof, both tilted angle and azimuth of the system are fixed.

The performance of PV modules depends on the cell temperature, solar irradiance and module type. We select crystalline silicon cells (mono-crystalline, poly-crystalline). A PV system 15 kWp was simulated in PVSYS using 48 modules of XL SW 335 rated at 335 Wp whose specifications

are shown in TABLE I, having a combined installed power of 16080 Wc.

TABLE I. PARAMETERS OF SUNMODULE XL SW-335

Quantity	Value
Area of module	1.96 m ² (72 cells/module)
Nominal power	335 Wp
Avg. panel efficiency	17.05 %
Rated voltage	37.8 V
Rated current	8.93 A
Open-circuit voltage	47.4 V
Short-circuit current	9.62 A
Nominal operating cell temperature	46°
Power temps coefficient	-0.304 %/K

III. SIMULATION

A. Estimation of optimal orientation and power output of PV array in building

1) Tilted angle optimization of PV array installation

PVSYS offers two options for the dimensioning of the PV system; to either size by planned power, or available area. Since area is abundant at the rooftop of building, the system is dimensioned based on the electricity demand, and existing policies regarding grid-connected PV system. Due to uncertainties in the daily power load, the system is designed to be well below the daily load during sunlit hours, at 15 kWp. Also, the simulations give specific production rates and can easily be expanded to a system of a different dimension. In this phase of pre-sizing, we do not mention the economic factors and forecast the energy demand of load. The simulations only consider about choosing which type of PV module and inverters. PVSYS has a built in system that matches the number of inverters with the number of strings. It also proposes a number of modules in each series, and the number of strings based on the sizing parameter. This is to assure that all requirements regarding current, voltage and power levels are met. When an inverter have multiple MPPT inputs, PVSYS divide the operating power between the inputs. Two inputs take half the nominal power at each input. It is not possible to share the power unequally between each MPPT input. The main reason for choosing two different modules of Sunmodule XL SW 335 (mono-crystalline and poly-crystalline) and two kind of inverters (central inverter and string inverter) was to compare the performance of different types of well known (TABLE II). These technique conditions are used together with the numbers proposed by PVSYS to set design the configurations in (TABLE III). The inclination and orientation of the modules within each string must be identical.

TABLE II. PARAMETERS OF INVERTERS

Type of inverter	Number	Nominal power	Operation voltage	DC input peak
Ingecon Sun 15 TL M	1	15 kW	300-820 V	50A (2 inputs 20/30 A)
Conext 5000E	3	5 kW	100-540 V	36A

TABLE III. SIMULATED ARRAY/INVERTER COMBINATIONS

Inverter	Num.	Mod. in series	String	MPPT input/String input
Ingecon Sun 15 TL M	1 (three phase)	12	4	2/2
Conext RL 5000E	3 (mono-phase)	8	6	1/2

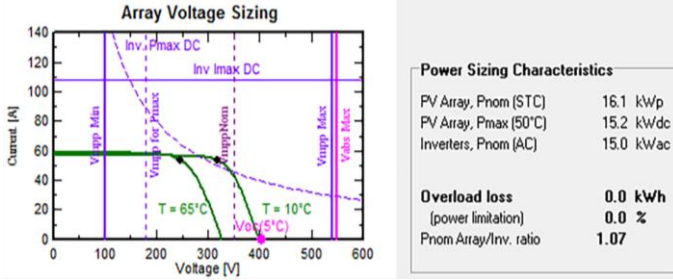
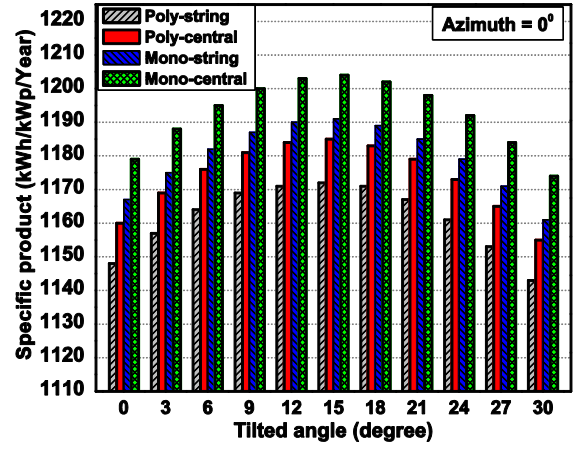
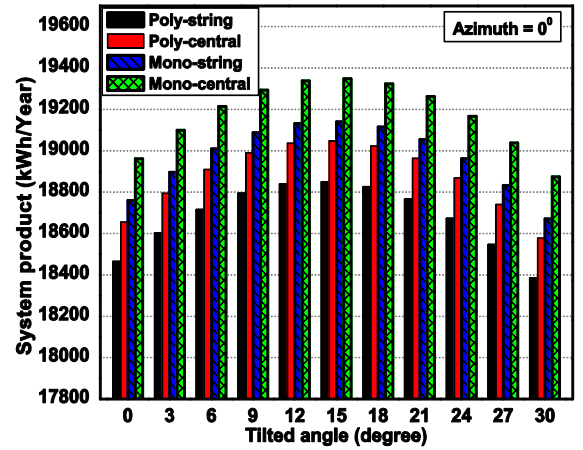


Fig. 4. PV Array sizing in PVSYS [9], 12 XL SW 335 poly-crystalline modules in series and 4 strings, using Ingecon Sun 15 TL M inverter

In the inverters specification it is common to include maximum PV array rated power and maximum DC input power. Fig. 4 show the inverter maximum DC input power of 15 kWp, which is the maximum amount of DC power that the inverter can convert to AC. This number is usually lower than the maximum PV array power due to the losses in the system before it reaches the inverter. Finding how many modules that can be connected to an inverter the maximum PV array rated power or maximum DC input power is divided by the peak effect of the module in question. It is assumed that the division is done with respect to the maximum DC input power on account of Fig. 4.

To optimize the tilted angle for PV array on the rooftop of the building, an ideal case was built with azimuth equal to 0° (south faced PV array). The tilted angle of the free standing system was adjusted from 0° to 30°. The result of simulation is shows in Fig. 5 and 6. From the specific energy product and system energy product, it can be observed that the best tilted angle is 15°. However, the result shows no significant difference between 9, 12, 15, 18, and 21 degree tilted angle. That means the tilted angle of South faced PV system for this building can be flexible between 9 and 21 degree. Mono crystalline cell is better choice than poly crystalline cell. Central inverter is better choice than string inverter. With the mono-crystalline and central inverter, simulation shows an annual system production of PV 15 kWp system of 19348 kWh/year, and the specific yearly production is 1205 kWh/kWp/year. The overall performance ratio (PR) is 0.849 and the normalized production is 3.3 kWh/kWp/day. The PR is a measure for the overall losses of a PV system and is defined as the ratio of final energy yield of the PV system in kWh/kWp to a reference yield, which takes only solar irradiation into account.

Fig. 5. Specific product of PV system for $A_m = 0^\circ$ by tilted anglesFig. 6. System product of PV system for $A_m = 0^\circ$ by tilted angles

2) Power output of optimally orientated PV array

Using an optimally orientated PV array with $A_m = 0^\circ$ and $\theta_m = 15^\circ$, PV mono-crystalline modules and central inverter are mentioned, when the yearly data is averaged over 24 h period for each month by estimated in PVSYS, we get the average power production of PV array profile for different months as shown in Fig. 7. Two main observations are:

- The average monthly peak power ranges between 9 kW in July and August and 5.5 kW in January. This indicates that the PV array on an average only produces of 60 % of its rated power even in the sunniest month of the year. The rated power of the PV array using 48 modules of XL SW 335 is estimated under standard test conditions, i.e. 1000 W/m² and 25°C. However, according to Fig. 2, the average global irradiance in July and August is 595 W/m² and the ambient temperature is about 37.5°C.

- PV array generates energy with 13 hours in the summer months while it is only 11 hours in winter.

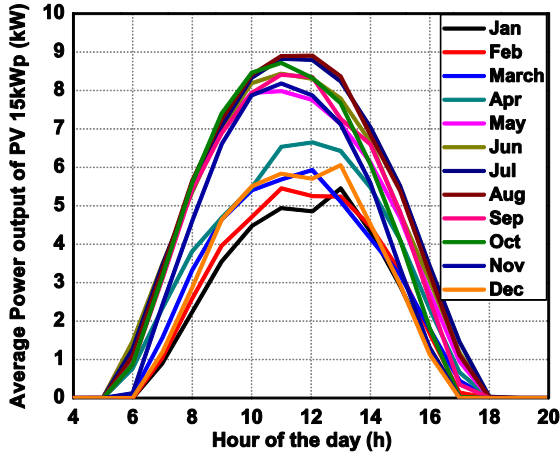


Fig. 7. Average power output of 15 kWp PV array as a function of time of the day for different months.

Fig. 8 and 9 show the average daily yield of PV system for different months. The different of PV yield of two time can be observed between January and August. In August, PV yield always reaches a high level with almost no fluctuation around the average value approximately 65.257 kWh/day. There are also cloudy days with low daily yield about of 30 kWh which is showed in these months from May to November. By contrast, in January, PV yield fluctuates dramatically among days in month. There are cloudy days with low daily yield of < 5 kWh and sunny days with yield > 70 kWh. This trend also occurs in the winter: in December, January, February and March.

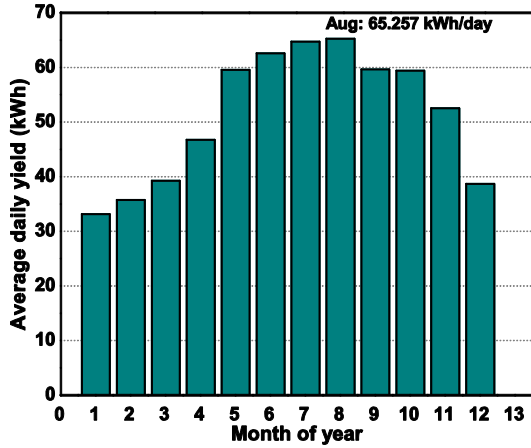


Fig. 8. Average daily yield of 15 kWp PV array for different months.

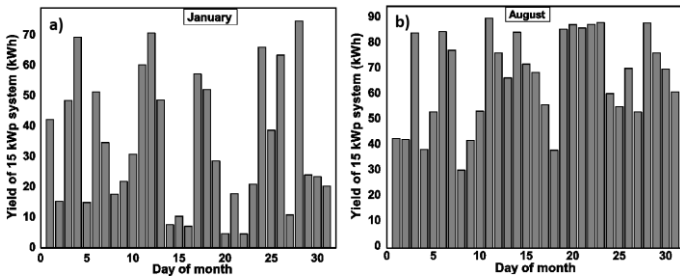


Fig. 9. Average daily yield of 15 kWp PV array for January and August.

B. Analysis of energy production of PV array in building

1) Zone 1

Similar simulation result is showed with zone 1 in the Fig.10 and 11. It can be observed that the best tilted angle is 15° . The best choice is the mono-crystalline and central inverter. Simulation show an annual system production of PV 15 kWp system of 19340 kWh/year, and the specific annual production is 1203 kWh/kWp/year. The overall performance ratio (PR) is also 0.849 and the normalized production is 3.3 kWh/kWp/day. That result shows the insignificant difference compared with the case of the angle $A_m = 0^\circ$.

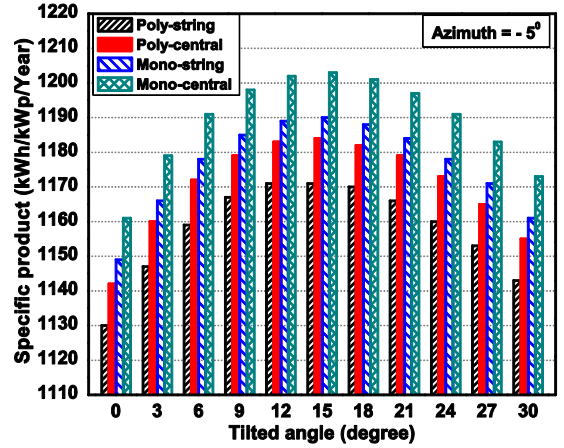


Fig. 10. Specific product of PV system in zone 1, $A_m = -5^\circ$ by tilted angles

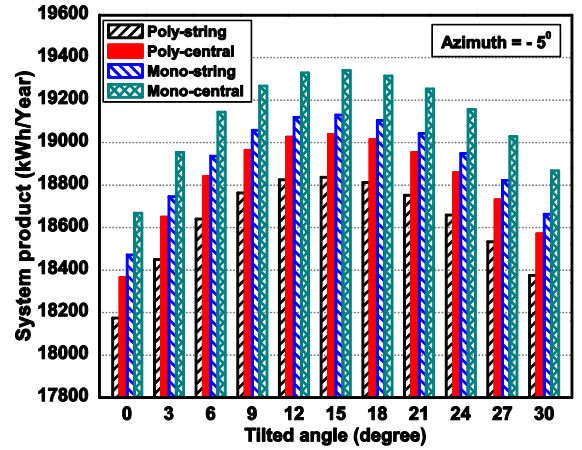


Fig. 11. System product of PV system in zone 1, $A_m = -5^\circ$ by tilted angles

2) Zone 2 and 3

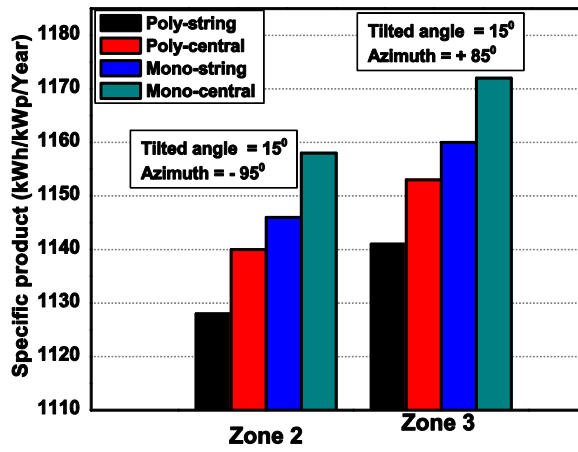


Fig. 12. Specific product of PV system in zone 2 and 3 with $\theta_m = 15^\circ$

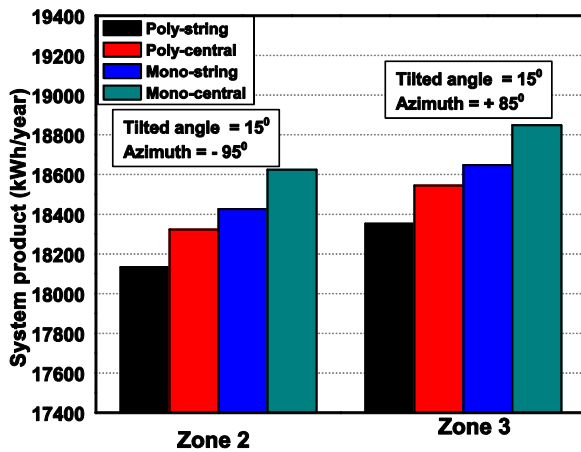


Fig. 13. System product of PV system in zone 2 and 3 with $\theta_m = 15^\circ$

In zone 2 and 3, because of the tilted angle of the metal inclined roof was fixed at 12 degree, we have simulated the cases of 12 degree and 15 degree tilt angle. The azimuth of PV array in zone 2 is -95 degree, in zone 3 is 85 degree. In each zone, 4 cases were simulated by making 4 installing combinations of poly-crystalline and mono-crystalline cells with central and string inverters. As can be seen on Fig. 12 and Fig. 13, installing PV array in zone 3 provides higher energy yield compared to zone 2. With the same tilted angle in three zones (15 degree), the output of zone 1 is higher than zone 2: 3.8 % and zone 3: 2.6 %.

IV. CONCLUSION

A platform “nZEB” with solar energy source and building energy management tool for training and testing is necessary to give priority to research into micro smart-grids in order to eventually improve the current power grid and promote high performance, energy efficiency buildings in Vietnam. PV array provides a direct utilization of the PV power during the daytimes and exploits the solar potential rooftops of buildings,

especially in urban area. In this paper, a PV simulation tool for “smart building system demo”, during the early-stage design is investigated. The first results will be helpful as a pre-decision of installation of real system. In the next step, an on-grid PV system with battery will be considered. The sizing of grid-connected PV system should be mentioned all component and also counted the economic analysis.

Using meteorological data of Hanoi in the period of 1991 – 2010 from Meteonorm, it was seen be that the optimal tilt for PV modules installed on rooftop of the building in Cau Giay-Hanoi to get maximum yield is 15° . The annual yield of a 15 kW PV system using mono-crystalline Sunmodule XL SW-335 connected to central inverter Ingecon Sun 15 TL M was 19348 kWh. The average monthly peak power ranges 9 kW (in July and August) and 5.5 kW (in January). This indicates the PV array on an average only produces of 60 % of its rated power even in the sunniest month of the year.

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