DESIGN AND POWER QUALITY ANALYSIS OF HYBRID RENEWABLE ENERGY SYSTEM FOR THO CHU ISLAND, VIETNAM

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Abstract: *Using renewable energy sources for providing electricity in remote area is an economical-technical solution and reduces environmental pollution. Tho Chu island, Phu Quoc district, Kien Giang province, is currently supplied by diesel generators, causing environmental pollution and high-power generation costs. This article presents hybrid renewable energy system (HRES) design including diesel generator, photovoltaic system and energy storage system for Tho Chu Island. In addition to calculating and selecting of equipment, ensuring power supply for the load, the paper also examines the frequency and voltage quality, considers the harmonic distortion of the power supply system. The simulation results obtained from PYsyst and Matlab/Simulink software show the effectiveness of the HRES.*

Keywords: Tho Chu island; Hybrid renewable energy system; PV system; Power quality.

1. INTRODUCTION

For remote areas or islands where the national electricity system is unavailable, the construction of electricity grids is technically impossible, the cost per unit of electricity produced is very high and diesel generators are currently considered the main power source. However, diesel generators have a major drawback of high costs and environmental pollution while the renewable energy potential in these areas is significant, Tho Chu island is a typical example.

Tho Chu is an island located in the southwestern border of Vietnam and is powered mainly by diesel generators in Ngu beach. There are some installed solar panels with small capacity. The construction of national grid connected to the island is not economically and technically feasible, therefore, energy projects need to be implemented in near future. Renewable energy sources such as wind and solar are growing rapidly and becoming an important part of the national electricity system, can be a reasonable solution for powering remote islands, such as Tho Chu. In particular, the solar battery system (PV system) is considered an appropriate option with lower investment costs than wind energy. PV system has the advantage of a clean energy source, abundant reserves, noise free, and the electricity generation cost is declining [1].

With advantages and potential applications, the research on Hybrid Renewable Energy System (HRES) has been reported by many groups [2-5]. These researches mostly focus on analyzing models, designing, and evaluating technical-economic factors of the system. The control algorithms, stability and power supply reliability of the HRES system were also studied in [2-4]. In addition, there are also reports on specific system design to power given isolation area [4, 5].

This paper presents research on the design and evaluation of the HRES system for Tho Chu Island, Vietnam. Because of the huge potential of solar energy on the Island, the authors proposed a power supply system including PV system, diesel generator and energy storage system. The calculations and design of HRES including PV systems, diesel generator, energy storage system for Tho Chu island will be presented in Section 2. Furthermore, the power quality analysis of the HRES was also examined to evaluate its performance in Section 3. Finally, the conclusions and perspectives will be presented in section 4.

2. DESIGN OF THE HYBRID RENEWABLE ENERGY SYSTEM

2.1. The electricity demand of Tho Chu island

Tho Chu is a border island with an area of over 1300ha. By 2020, the island's population will be 2031 people, including 544 households living mainly on fisheries. Based on the Decision No. 633/D-TTg on electricity supply norms, the island's electricity demand in 2020 is estimated about 775 MWh/year, equivalent to the average daily power consumption about 2122.5 kWh/day. Base on the population, the production and business data of the island, we can assume the load parameters and daily load profile as table 1.

Table 1. *The load parameters of Tho Chu island.*

Load types	Unit	Power per unit of load (W)	Used time (h)	Electricity consumption (kWh/day)
Lighting equipment	1000	50	9	450
Communication equipment	300	150	8	360
Fan, air conditioners	630	125	12	945
Kitchen equipment	430	150	5	322.5
Medium motor	3	5000	3	45
Total electricity consumption				2122.5

2.2. Structure diagram and system design

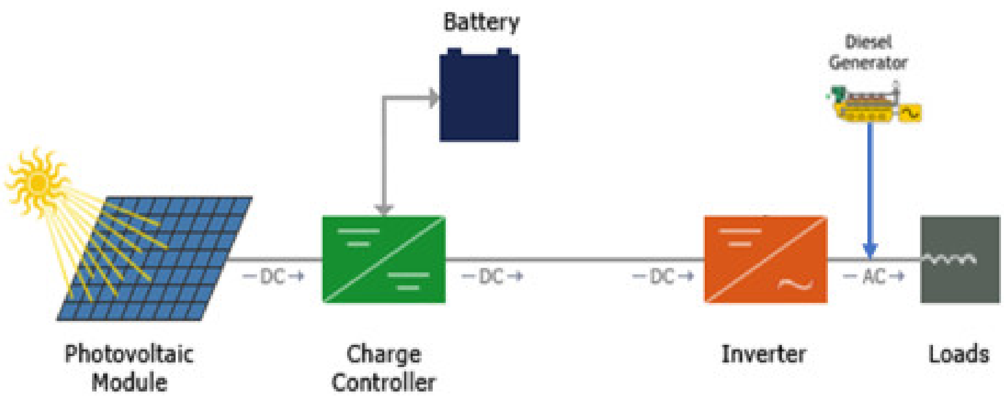

Figure 1. *The structure diagram of the HRES.*

With good potential for solar energy in Tho chu island (the average solar radiation of 5.3 kW/m2), the author builds a HRES including PV system and diesel generator which uses an extra energy storage system to enhance operation and improve reliability of power supply. The structure diagram of the HRES is shown in figure 1.

The equipment parameters suitable to the load and the geographical characteristics of the island will be calculated, analyzed and determined as follows.

2.2.1. Selecting and installing PV system

PV system capacity: With the installation location selected, ignoring the effect of the solar panel title angle and the temperature effect and considering the overall performance of the systems η=100%, the peak power of PV systems is determined with [6, 7]:

$$\mathrm{E_{Wp}} = \frac{\mathrm{I_0.E_d}}{\mathrm{I_T.\eta}} \approx 400\ (kW) \tag{1}$$

where I_0 = 1000W/m^2 is solar radiation at standard conditions; E_d is the calculated load capacity of Tho Chu island; I_T = 5.3 kW/m^2 is the average solar radiation of the island.

From the above data, the PV system has capacity of 400 kWp and be able to provide maximum power for the daily load.

Solar panels: The selected solar panels must ensure compatibility between electrical specifications with other components of the system and compliance with applicable technical standards. Solar panels suggested for the proposed system is polycrystalline photovoltaic cells with rated power of 315 Wp, a minimum life cycle of 25 years, a reduction average yield of 0.7%/year and designed to comply with the existing IEC standards. In order to connect the panels in a chain, the wire of the panel with a cross-section of 4mm^2 have used. The selected conductors must satisfy the heating condition and permissible voltage loss (less than 1.5%) [8].

Calculating the tilt angle of solar panels: PV system on Tho Chu Island is located at 93^0 North latitude and 103.05^0 East longitude. Through calculation by PVsyst software, the optimal tilt angle to receive the maximum radiation amount is 12^0-13^0 and the azimuth direction is 0^0, the total irradiation in this inclined range is 1864 kWh/m^2. Conversion factor compared to global horizontal irradiance GHI is 1.02 (increase of 2%). The solar panels are so installed with 12^0 of tilt angle and 0^0 of azimuth.

Calculating the distance between solar panels: The distance is determined by the tilt angle, shading limit angle and optimal area used. The shading limit angle chosen such that the system will have no internal shade from 9am to 3pm of the Winter Solstice (21/12) and the its internal shade loss must less than 1%. From the calculation result, the distance between the two rows of string panels is at least 0.8m. However, in order to reserve for construction solutions, maintenance and cleaning panels, the distance between the rows of string panel is chosen as 2.5m which satisfies the condition of no internal shading and the internal shading loss is 0.5%.

2.2.2. Selecting inverter

For 150kW - 500kW of PV systems, 3-phase inverters with more than two connected cabinets are used [9]. The fact that PV system capacity is decreased due to factors such as solar radiation, temperature, pressure, aging of solar panels and dirt sticks to the glass surface of panels. Therefore, the AC/DC conversion ratio is usually in the range: $0.8 \le \frac{P_{inverter}}{P_{array}} \le 1$

The decision to install the PV system will need to comply the power range and specifications of the selected inverter. There are usually the following limits [10]:

- P_{array} < 10kW requires using 1 phase inverter and P_{array} > 100 kW requires using 3-phase inverter.
- 10 kW < P_{array} < 100 kW, it is possible to use a 3-phase inverter or multiple single-phase inverters split evenly across phases.

The input and output parameters of selected inverter are suitable for the parameters of the solar panels and the grid connected. From the above analysis, the author uses the 3-phase inverter 400kW.

2.2.3. Selecting diesel generator and an energy storage system

Because of the PV system capacity is fluctuated and not very large, choosing the hybrid ratio between PV system and diesel generators is so extremely important, which directly affects the power quality of the system. Besides, there is only one diesel generator with the task of balancing the power, so the paper proposes the rated power of diesel generator should be 400kW. In the case of losing the solar source, the diesel generator will burden the entire system.

The energy storage system is only charged from PV source. The most important task of the energy storage system is to ensure the operation of the system during diesel generator's failure. The energy storage system on the island is designed to provide an average load of 24 hours and the system can work well during 12 hours of maintenance of the diesel generator twice a year.

After calculating all the system parameters, we have a HRES design including: PV system with the configuration of installing panels consisting of 10 panels connected in series to raise the $V_{mpp}(20/60^0C)$ = 550/463V and 127 series in parallel will have $I_{mpp}(STC)$ = 748 A; Seil_Soleil 400 inverter is connected directly to a 400kW diesel generator and battery storage system with a capacity of 14400Ah.

2.3. Analysis of the power supply capacity and evaluation of economic efficiency of the HRES

2.3.1. Analysis of the power supply capacity

From configuration parameters of the systems, the operability of HRES is simulated via PVsyst. Meteonorm data is used for meteorological data.

With the configurations established for HRES, the simulation results as generating power, power generating times, annual electricity consumption will be evaluated. The simulation systems parameters are illustrated in figure 2. The obtained results are presented in table 2 and figure 3.

Table 2. *The simulation results.*

Parameters	Values
PV system power	400 kWp
Inverter power	360 kWac
Electrical energy	562 MWh/year
Conversion factor	0.724
Average annual power output	1404 kWh/kWp/year
Average daily power output	3.68kWh/kWp/day
PV system loss	0.92kWh/kWp/day

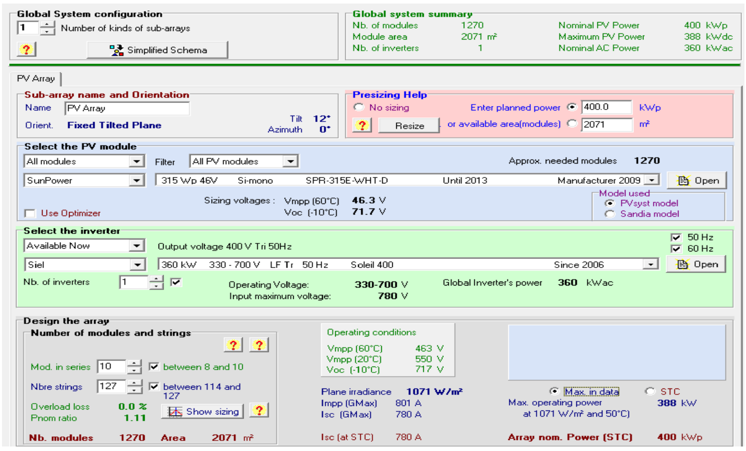

Figure 2. *The simulation systems parameters.*

Thus, the PV system has produced 562 MWh/year to meet 66% of electricity consumption on the island. The main operating time of the diesel generator is from 18h to 21h, at this time the energy stored in the battery storage is exhausted, the generator operates only under load or no load in other times of the day.

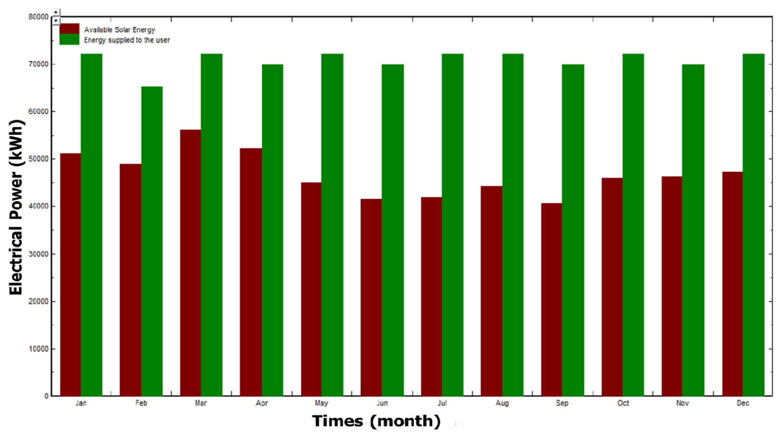

Figure 3. *The total electrical power generated by PV system and the required power of the load.*

The economic values will be calculated specifically about the benefits that the HRES brings to evaluate its effectiveness in next section.

2.3.2. Evaluation of economic efficiency

The financial evaluation for the islanded-hybrid system is analyzed based on the annual power output simulation and the following assumptions:

- 400kWp PV system has an annual electricity output of 562MWh / year. The life cycle of PV system is 20 years. The aging of the panels reduces the output power of the panels 1% / year.
- Total money needed for the whole project: 100% bank loan for 20 years with an annual interest rate of 7% / year.
- Installation costs are calculated as 41% of the total project cost.
- The system's operating time is 20 years with the inflation index being 7%/year. Operation and maintenance cost for the entire system is $19 / year.
- All costs of research and system analysis such as technical assistance, environmental research, economic analysis, operating licenses, land rental fees, land taxes, site clearance fees and others related cost are considered as free. Insurance expenses do not belong to the project cost. Incentives such as reductions in greenhouse gas emissions, subsides encourage clean energy development and another fund are unavailable.

From the evaluated results for the HRES project on Tho Chu Island, the cost per unit of electricity produced by the solar and battery system is $0.18/kWh. Much lower than the cost of electricity powered by diesel generator, but still high, this is caused using battery storage systems. In addition, the HRES also reduces CO_2 emissions. With the conversion rate in Vietnam is 407g CO_2/kWh, the HRES will reduce 4162 tons of CO_2 in 20 years.

3. ANALYSIS AND EVALUTION OF THE POWER QUALITY OF THE DESIGN SYSTEM

After calculating the design of the HREA for a remote area, in order to ensuring the power supply for the load, it is necessary to examine the frequency, voltage quality and the total harmonic distortion voltage (THDv) of the power supply system. So firstly, it’s needed to model, simulate equipment in the HRES and detailed evaluation based on the specified standards. The parameters are evaluated according to IEC standards, national standards TCVN 7447-7-712: 2015 (IEC60364-7-712: 2002), Circular No. 39/2015/TT-BCT [6, 9, 10].

3.1. Modeling HRES

The system model is built with Matlab/Simulink consisting of a 3-phase 380V power grid, 50Hz frequency, a 400kWp Photovoltaic system connected to a 400kW Diesel generator via an inverter, a battery storage systems (240V, 14400Ah), which provide for variable loads with peak power of 275kW. The whole HRES model is presented as in the figure 4.

Photovoltaic array: 400kWp photovoltaic system consists of 1270 Sunpower

315Wp panels divided equally into 4 parallel arrays, each array is controlled by a DC/DC converter. Each array consists of a row of 5 panels in series and 64 rows in parallel.

DC/DC converter using Boost booster including P&O algorithm to track MPP points.

Inverter 3-phase SVC voltage source: PV inverter operated with P/Q control scheme, the active and reactive power outputs of PV are fixed to set-point values P_{ref} and Q_{ref} [11].

Harmonic filters consisting of L and C, which filter out higher order harmonic components.

Diesel generator using synchronous generator model with its parameters referred from 400V-670VA-50Hz-1500RPM generator parameter in library of MATLAB's synchronized generator.

Battery storage system using the Buck-Boost Converter (Bidirectional DC/DC Converter bloc). The supply voltage for the Buck-Boost Converter has a range of 560V to 655V and the battery voltage ranges from 180V to 261.3V.

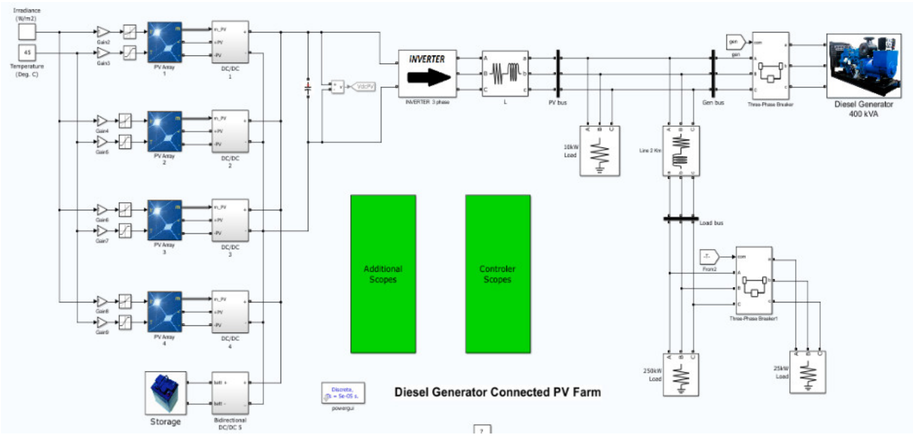

Figure 4. *HRES simulated by Matlab/Simulink.*

3.2. Preliminary analysis and evaluation of the power quality of HRES on Tho Chu island

We consider two scenarios to preliminary power quality assessment of the hybrid power system: the solar radiation changed and the load changed.

3.2.1. Scenario 1: the solar radiation changed

Before time t=2s, the system operates stably, solar radiation Irr = 600 W/m^2; panel surface temperature T=45^{o}C. Power of 3-phase symmetrical load P=275kW. At t=2s, the solar radiation is reduced from 600 W/m^2 to 200 W/m^2 on a battery platform. At t=6s, this solar radiation increases from 200 W/m^2 to 600 W/m^2.

When the solar radiation changes, figure 5 shows that the frequency during the fluctuation exceeds the range of +0.5 Hz, but still within the frequency range of the inverter. The voltage at the power plant connection point ranges from 216V to 225V and is within the allowable length (0.95-1.1pu). The total harmonic distortion at the connection point is 4.25% and is within the permissible range (less than 6.5%).

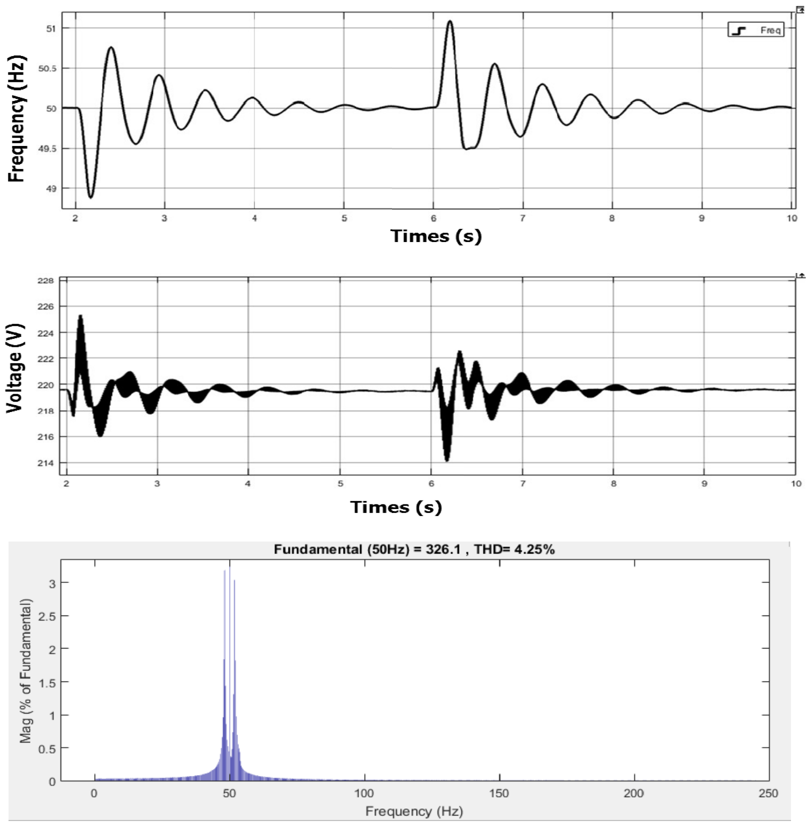

Figure 5. *Frequency, voltage and THDv at PV connection point (scenarios 1).*

3.2.2. Scenario 2: the load changed

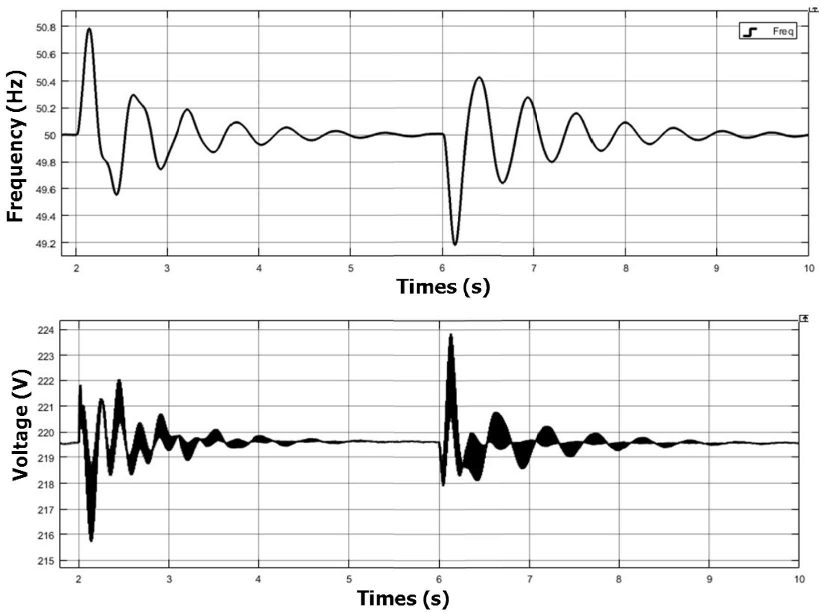

Figure 6. *Frequency and voltage of HRES (scenarios 2).*

Considering the symmetric 3-phase load. Before time t=2s, the system operates stably, solar radiation I_{rr}=600W/m^2; panel surface temperature T=45^{0}C and

P_{load}=275kW. At t=2s, load is reduced from 275kW to 250kW. At t=6s load is increased from 250kW to 275kW.

As the load changes, based on the simulation results (as shown in figure 6), is can be seen that the frequency during the fluctuation exceeds the range of +0.5 Hz, but still within the frequency range of the inverter. The voltage at the power plant connection point is within the allowable length (0.95-1.1pu). The total harmonic distortion within the permitted range. The total harmonic distortion at the connection point is less than 6.5%.

The simulation results obtained from the two scenarios above have shown that the parameters of voltage and harmonics are within the permissible ranges according to the standards. The system frequency fluctuates outside the standard range but is still within the inverter's frequency range and returns to the permissible range (± 0.2Hz) within 1 second after the noise. Therefore, it is necessary to develop more measures to reduce system fluctuations.

4. CONCLUSION

This paper presented design calculations and modeling of a HRES for Tho Chu island including photovoltaic system, diesel generator and energy storage system. PV system is connected to the system at the DC bus. Diesel generator connected to the system at the AC bus. The connection between the DC bus and the AC bus is made through a DC/AC inverter. These models allow the study of the behavior simulation and stability analysis and the responses of HRES in symmetrical 3-phase load mode. After analyzing and assessing the power quality of the HRES, the simulation results show that the design system has operated stably. Frequency, voltage and harmonic parameters are within the permissible range as Vietnam standard. However, there is still a short time (under 1s) of the frequency fluctuation outside the permissible range before returning to a stable value. Therefore, it is necessary to apply more measures to reduce the oscillation of the system such as increasing the inertia constant for the generator by connecting the generator shaft to the flywheel system or using super capacitor storage.

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REFERENCES

[1]. F. John Hay, "*Solar Electric Investment Analysis*", University of Nebraska. Reserved (2016).

[2]. R. Singh, R. C. Bansal, A. R. Singh and R. Naidoo, "*Multi-Objective Optimization of Hybrid Renewable Energy System Using Reformed Electric System Cascade Analysis for Islanding and Grid Connected Modes of Operation,*" in IEEE Access, vol. 6, pp. 47332-47354, (2018).

[3]. Hung-Cheng Chen, Jian-Cong Qiu and Chia-Hao Liu, "*Dynamic modelling and simulation of renewable energy based hybrid power systems,*" 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, Nanjing, pp. 2803-2809, (2008).

[4]. L. A. de Souza Ribeiro, O. R. Saavedra, S. L. de Lima and J. de Matos,

"*Isolated Micro-Grids with Renewable Hybrid Generation: The Case of Lençóis Island*," IEEE Transactions on Sustainable Energy, vol. 2, no. 1, pp. 1-11, (2011).

[5]. M. R. Elkadeem *et al.*, "*Techno-economic Design and Assessment of Grid-Isolated Hybrid Renewable Energy System for Agriculture Sector*," 2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA), Xi'an, China, pp. 1562-1568 (2019).

[6]. IEC Standard 61724. *Photovoltaic systems performance monitoring, guidelines for measurement, data exchange and analysis*, (1998).

[7]. M.Q. Duong, N.T.N Tran, Gabriel Nicoleta Sava, Vladimir Tanasiev, "*Design, performance and economic efficiency analysis of the photovoltaic rooftop system*", Revu Roumaine Science Technology – Energy, vol.64, pp.229-234, (2019).

[8]. Quy phạm trang bị điện phần I (bảng 1.3.3 và 1.3.4 trang 38).

[9]. Electrical Installation Guide 2018, IEC Standards.

[10]. Tiêu chuẩn quốc gia TCVN 7447-7-712:2015 (IEC 60364-7-712:2002) về Hệ thống lắp đặt điện hạ áp-Phần 7-712: Yêu cầu đối với hệ thống lắp đặt đặc biệt hoặc khu vực đặc biệt - Hệ thống nguồn quang điện sử dụng năng lượng mặt trời (PV).

[11]. Lê Thị Minh Châu, Lê Đức Tùng, Nguyễn Thùy Linh, "*Điều khiển điện áp của hệ thống pin mặt trời tích hợp vào lưới phân phối*", Tạp chí Khoa học và Công nghệ Đại học Đà Nẵng, số 9(118), (2017).

TÓM TẮT

THIẾT KẾ VÀ ĐÁNH GIÁ CHẤT LƯỢNG ĐIỆN NĂNG HỆ THỐNG NĂNG LƯỢNG TÁI TẠO LAI CUNG CẤP ĐIỆN CHO ĐẢO THỔ CHU, VIỆT NAM

Sử dụng các nguồn năng lượng tái tạo cung cấp điện cho các khu vực địa lý cô lập là giải pháp hiệu quả về mặt kinh tế-kỹ thuật và đảm bảo môi trường sống. Đảo Thổ Chu, huyện Phú Quốc, tỉnh Kiên giang hiện được cấp điện hoàn toàn bằng các máy phát diesel, gây ô nhiễm môi trường và chí phí phát điện cao. Bài báo này trình bày tính toán thiết kế hệ thống lai bao gồm máy phát diesel, hệ thống điện mặt trời và hệ acquy lưu trữ cho đảo Thổ Chu. Bên cạnh việc tính toán lựa chọn các thiết bị, đảm bảo cung cấp điện cho phụ tải, bài báo còn đánh giá chất lượng tần số và chất lượng điện áp, xem xét độ biến dạng sóng hài của hệ thống cung cấp điện. Các kết quả mô phỏng thu được từ phần mềm PYsyst và Matlab/Simulink minh chứng được tính hiệu quả của hệ thống.

Từ khóa: Đảo Thổ Chu; Hệ thống lai; Hệ thống năng lượng mặt trời; Chất lượng điện năng.

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