บทความวิจัย

การวิเคราะห์ทางด้านการลงทุนและเทคนิคเพื่อการพัฒนาโรงไฟฟ้าพลังงานแสงอาทิตย์กรณีศึกษาในจังหวัดมุกดาหาร ประเทศไทย

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บทคัดย่อ

งานวิจัยนี้นำเสนอการวิเคราะห์ทางด้านการลงทุนและเทคนิคในการพัฒนาโครงการโรงไฟฟ้าพลังงานแสงอาทิตย์ กรณีศึกษาดังกล่าวเป็นโรงไฟฟ้าพลังงานแสงอาทิตย์ขนาด 1 เมกะวัตต์ ตั้งอยู่ที่จังหวัดมุกดาหาร ประเทศไทย งานวิจัยนี้นำเสนอกระบวนการพัฒนาโครงการที่เหมาะสมโดยมีการพิจารณาทั้งทางด้านเศรษฐศาสตร์และทางด้านเทคนิค ปัจจัยที่ทำการศึกษาประกอบไปด้วย ต้นทุนการลงทุน ค่าพลังงานแสงอาทิตย์ ค่าพลังงานไฟฟ้าที่ผลิตได้ ชนิดแผงโซล่าเซลล์ ชนิดของอินเวอร์เตอร์ ผลกระทบจากสภาวะสิ่งแวดล้อมที่มีผลต่อประสิทธิภาพ ขนาดพื้นที่ติดตั้งและระบบโครงข่ายไฟฟ้าที่รองรับ โดยแผงโซล่าเซลล์ที่ใช้ได้ถูกจัดระดับโดยมีดัชนีชี้วัดในระดับ Tier 1 และมีการรับประกันผลิตภัณฑ์มากกว่า 10 ปี โดยมีประกันประสิทธิภาพการผลิตไฟฟ้าตลอดระยะเวลา 25 ปี ซึ่งการลดลงของพลังงานไฟฟ้าอันเนื่องมาจากการเสื่อมสภาพของแผงน้อยกว่า 0.8% ต่อปี หรือรวมกันแล้วไม่เกินกว่า 20% ประเภทอินเวอร์เตอร์ที่ใช้เป็นประเภทที่เชื่อมต่อกับระบบโครงข่ายไฟฟ้าได้ควรมีใบรับประกันเครื่องจากโรงงานการผลิต 5 ปีขึ้นไป และต้องได้รับการรับรองโดยมีดัชนีชี้วัดในระดับ Tier 1 ขนาดพื้นที่ในการติดตั้งโรงไฟฟ้าพลังงานแสงอาทิตย์ที่ได้นำเสนอนี้มีขนาด 7,000 ตารางเมตร ตำแหน่งการติดตั้งโรงไฟฟ้าพลังงานแสงอาทิตย์ต้องไม่ถูกบดบังจากต้นไม้ วัตถุ หรืออาคารจนทำให้เกิดเงาที่แผงโซลาเซลล์ โดยพื้นที่ต้องไม่อยู่ในบริเวณที่มีฝุ่นมากและไม่มีฝนตกชุกเกินไป พื้นที่ควรมีลักษณะราบเรียบและไม่เสี่ยงต่อการเกิดน้ำท่วม โรงไฟฟ้าพลังงานแสงอาทิตย์ต้องอยู่ใกล้ระบบโครงข่ายไฟฟ้าเพื่อง่ายต่อการเชื่อมต่อและยังช่วยลดต้นทุนในการเชื่อมต่อ ขณะเดียวกันต้องมั่นใจได้ว่าระบบโครงข่ายไฟฟ้าบริเวณนั้นมีความต้องการโหลดที่ตรงกับกำลังการผลิต จากผลการศึกษากรณีตัวอย่าง (โรงไฟฟ้าพลังงานแสงอาทิตย์มุกดาหาร) พบว่า พลังงานไฟฟ้าเฉลี่ยที่ผลิตได้คือ 1,506,000 กิโลวัตต์ชั่วโมงต่อปี มีอัตราผลตอบแทนภายใน (IRR) คือ 13.5% ค่าพลังงานแสงอาทิตย์บนพื้นผิวมากกว่า 4.1 กิโลวัตต์ชั่วโมงต่อตารางเมตรต่อวัน ประสิทธิภาพของโรงไฟฟ้าพลังงานแสงอาทิตย์ (Performance Ratio) มากกว่า 76.26%

คำสำคัญ: โรงไฟฟ้าพลังงานแสงอาทิตย์ การลงทุน การพัฒนาโครงการโซล่า

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Research Article

The Investment and Technical Analysis of Solar Power Plant Development Case Study in Mukdahan Province, Thailand

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Abstract

This research presents both investment and technical aspects of solar power plant. The one mega-Watt solar power plant, located in Mukdahan province, Thailand, is used as case study. The right process is proposed. Both economic and technical is considered. Interested parameters consist of investment cost, solar radiation, power energy, PV module, type of inverter, environmental impact, area size and the grids connection. PV module must be indexed by 1st tier manufacturing and workmanship warrantee is more than 10 years. Degradation grad warranty must be less than 0.8% per year in the term of long period 25 year. It is not over 20% along period. Inverter type must be pure sine wave grid connected and it should have warrantee from original manufacturing 5 years above and indexed by 1st tier. The area size should be more than 7,000 m^2. The site location must not be obstructed by building, trees, or tall objects. The site must not be prone too dust and rain. The area must be flat and not prone flood. The plant must be near connecting grids and sufficient grid capacity. From the result of case study (Mukdahan plant), it shows average output power energy is 1,506,000 kWh/year. In conclusion, it is found that project has equity internal rate of return (IRR) is more than 13.5%. The surface solar radiation is more than 4.1 kWh/m^2/day. The power energy after Commercial Operation Date (COD) has performance ratio is more than 76.26% (PR ratio).

Keywords: Solar Power Plant, Investment, Solar Project Development

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1. Introduction

The energy is focused more and more because it is needed for all people to run the world [1], [2]. The conventional energy is fossil energy; coal gas oil and etc. [3], [4]. From the data of energy situation [5], [6], it is investigated that the fossil energy is used more therefore it will be gone in a short time; becoming energy crisis. On the other hand, the demand of energy is increased [7]. From data in [8], [9], it is found that energy consumption is higher than the past [10]. Overall the world, the energy consumption is raised at the growth rate of 2.3–2.9% in 2018, nearly twice the average rate of growth since 2010 [11]. Also, the energy consumption had rinsed at the rate of 22% in 10 years in Asia [12]. Considering in the past 10 years, it is found that the energy demand increased three times and the next 10 year will increase 20% including renewable energy source [13], [14]. In Thailand, the energy consumption has been increased at the rate of 1.18% to 2.13% per year on average [15]. The data of Thailand energy situation [16] shows the consumption is higher than 10 years ago by 30%. From data of prediction in Thailand, it is found that the situation of the demand of energy continues to increase while the energy reserve is very little [17]. So, the new choice is renewable energy. The renewable energy suitable for Thailand is solar energy [18].

According to power development plan [17], the solar power plant in Thailand has been developed since 2014. They can be generated at 1419 MW in 2015 [19]. The using target is 10,000 MW in 2033. Now it has the gap far from target. Therefore, government has supporting policies to stimulate the home-use solar panels [20]. However, home used still is small capacity 5–10 kW [20]. But it is not enough for supporting demand. Because the solar system cost has reduced for more than 40% from 5 years ago [21], [22], the beak even point is just 4–5 years. Hence the reasons why several factories which need greater energy consumption have shown interested in installing solar panels for energy saving and solar self-generating energy [23] [24]. Then, understanding of running this operation and maintenance efficiently is utmost important.

Therefore, this research presents investment and technical analysis of solar power plant case study in Thailand. The case study is done in Mukdahan province. The plant was commercially operated for 5 years. The capacity is 1 MW for case study which is sizeable for a factory. The objectives of this research are to summarize the process of development and investment for solar power plant, to analyze economic worthiness of Mukdahan solar power plant. All investment data was collected from Pre financial model and actual operation costs for 5 years. All technical data was collected from SCADA system.

2. Methodology

The objective of this research was to find the most suitable site that maximize the annual electricity output and minimize investment cost. Data collection has been conducted prior and after the commissioning of the power plant from the target area for technical and financial analysis.

2.1 Preliminary assessments of potential location

The factors for choosing locations can be found in Table 1. Firstly, there is no shading effect from tree and building in south direction. In study case of Mukdahan plant, there is no object (building and tree) to obstruct the light. Secondly, the plant must be near grid connections and free of any obstacle to access. The grid should be along the direction of light. For Mukdahan plant, the plant is far from grid, about 200 meters and the grid just placed in front of the plant which is easy to access. Moreover, the grid is along the direction of light. The plant should be on flat area for avoiding from shading effect among PV layer. Studied plant is above flat roof high 20 meter from ground. Another important thing, the plant must avoid flood plain. If flood cannot be avoided, the water flood protection system is prepared. Other techniques include the construction of levees, dikes, dams, reservoirs or retention ponds to hold extra water during time of flooding. In this site is on the roof top so there is no chance of having any flood issue. The suitable solar radiation is 4.2 kWh/m^2 a day which related with the case study plant (4.1 kWh/m^2 a day). The plant must not be in heavily polluted area, generally occurred from transportation system, so the plant should be far from the main road. Furthermore, the rain does not play significant role on solar radiation decreased. Mukdahan solar power plant is on the area which maximum average raining rate in 2009–2019 is just 200–220 mm [25] a year which is less.

The main permits consist of three types; construction, energy and synchronizing permission license. The construction permit is issued by Provincial Industry Office. The needed evidences include the construction drawings and engineering calculations. The energy permit is issued by Energy Regulation Committee Department. This permit will be approved when the construction proceeding

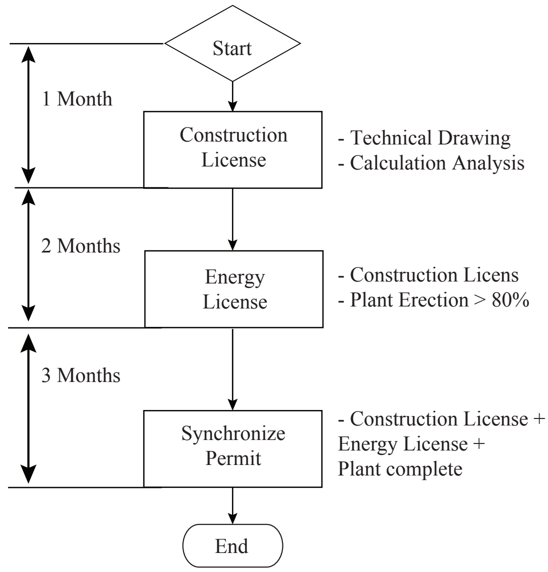


Figure 1 License permission process.

Table 1 The criteria of site selection.

The Considered Lists	Criteria	Mukdahan Plant		
		Condition	Check List	
			No	Yes
1. Shadow Effect	No shading effect from tree and building in south direction	No shading effect		X
2. Grid Connection Distance	The distance should be not too long	< 200 meters		X
	Easy to access	Easy to access		X
	Along the light way	In Front of power plant		X
3. Considered Feature Area	Flat area	Flat roof area		X
4. Water Flood	No water flood	On the roof		X
	Sometime need protection by the land cannel protection	No need		X
5. Solar Radiation	Input upper 5 kWh/m^2 a day	5.2 kWh/m^2 a day		X
6. Dusty	No too dust (vehicle)	Far from 800 M so the dust is less		X
7. Raining	No too must raining	1507.1 mm a year that is less		X

more than 80%. Synchronizing permit is issued by Provincial Electricity Authority (Thailand). To approve this permit, the construction and synchronizing permits must be approved. The process is shown in Figure 1. Finally, to approve grid available capacity, it is checked by Provincial Electricity Authority (Thailand). It is to make sure that the solar power plant is connected to system.

2.2 Technical analysis

2.2.1 Solar module

Presently, the silicon solar module technology consists of two type; thin film and crystalline silicon solar cell. Solar power plant in this research is developed for installing in Mukdahan province, Thailand. The poly crystalline silicon solar cell was chosen because its characteristics are suitable for Thai climate. Durability is its strong advantage, more than 25 years of usage. Most importantly, requited space for installation is less a half of thin film. For example, 1 MW solar power plant, for thin film needs 12000 m^2 while just 6000 m^2 is needed for crystalline type. The reason is that efficiency of module (watt per area) of crystalline is higher than another. Moreover, the total investment cost is lower. [26]–[29].

For case study (Mukdahan power plant as shown in Figure 2), the crystalline is used by considering from Tier 1 manufacturing certified by PV Tech [30]. It is warrantee the degradation percentage decreased not over 20% for 25 years. Degradation grad warrantee must be less than 0.8% per year in the period 25 year and it is not over 20%. Furthermore, workmanship warrantee is more than 10 years. Moreover, the solar module is built according to IEC and UL standard.

Figure 2

Another considered factor is temperature coefficient of maximum power. It should be –0.37% to –0.42% in range at 25°C at nominal operating cell temperature. So, the chosen module is –0.41%/°C for coefficient of maximum power. The installing power is approximately 120% of output power because it is realized the power loss in system. The solar module 250 watt peak amount 4800 modules are installed in studied plant. The comparison between thin film and crystalline silicon solar as shown in Table 2.

Table 2 The comparison between thin film and crystalline silicon solar.

List	Crystalline Silicon	Thin Film
Module Efficiency (%)	13–19%	4–12%
Temperature Coefficients	Higher	Lower (Lower is beneficial at high ambient temperatures)
Types of Technology	crystalline silicon (c-Si)	Amorphous silicon Cadmium Telluride (CdTe)
Module Construction	With Anodized Aluminium	Frameless, sandwiched between glass; lower cost, lower weight

Figure 3 Installed inverter in Mukdahan.

2.2.2 Inverter

The inverters in solar power plant consist of two types, central solar inverter and string solar inverter. Central solar inverter is on big size grid inverter. It is suitable for the big plant about 500–2500 kW. It is simple to install but its reliability is low because it is not easy to maintenance.

String solar inverter is small inverter about 2–100 kW which suitable for office and home. Mostly, it is installed on the roof. Because of small size, if some inverter fails, the remaining is still running and not affect the whole system. However, installation is more complex. In conclusion, the 25 kW 44 string solar inverters were installed. Because the size in Mukdahan was 1MW so if some inverters fail, the rest can still generate sufficient power required. The installed inverter in Mukdahan Plant as shown in Figure 3.

2.2.3 The location

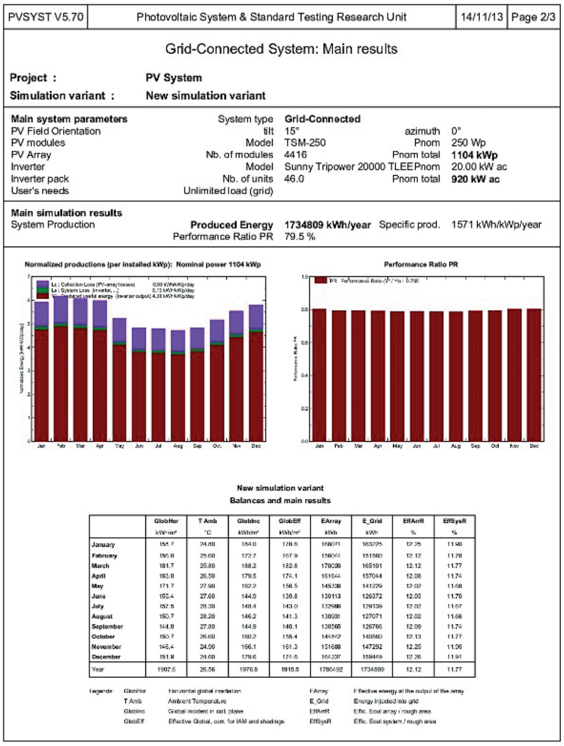
To choose the location, must consider the following factors, it needs to be close to the grid, the land must be flat and the level has to be higher from the riverbank, the solar radiation should not be covered by mountains or obstacles in the south and north direction and the solar modules should be installed facing southward for Thailand. The important factor for high yield is that the solar radiation has to be sufficient all year around. Mukdahan plant is upper than 4.1 kWh/m^2/day and its Global Horizontal Solar radiation is at least is 5.0 kWh/m^2/day [31] in range of Solar radiation. Therefore, it is suitable.

2.2.4 Accessory

The accessories of system consist of SCADA main distribution boards and protection system, service walk way and water pump systems which used to wash modules. SCADA system is supervisory data and acquisition system. The SCADA is used to get online data for analyzing. The online data includes output energy, solar radiation, temperature, wind speed and electrical quantity which these influence on power plant efficiency [32]–[34]. The SCADA is important because it helps to get data for using in warning system, maintenance system and monitoring system. Main distribution board should be installed near transformer because to reduce electrical loss. The service walk way is spare free space about 5–10% to maintenance and protect shading effect. The water system consists of storage tank and piping. The water distribution should cover the site area.

2.2.5 Simulation

The simulation program is PVSyst which is solar power plant design simulation. After information on location, plant size of the model of solar module, and inverter size are selected, plant data can be calculated. The result of simulation is shown in Figure 4.



PVSYST V5.70 | Photovoltaic System & Standard Testing Research Unit | 14/11/13 | Page 2/3

Grid-Connected System: Main results

Project : **PV System**
Simulation variant : **New simulation variant**

Main system parameters System type **Grid-Connected**
PV Field Orientation tilt 15° azimuth 0°
PV modules Model TSM-250 Pnom 250 Wp
PV Array Nb. of modules 4416 Pnom total **1104 kWp**
Inverter Model Sunny Tripower 20000 TLEE Pnom 20.00 kW ac
Inverter pack Nb. of units 46.0 Pnom total **920 kW ac**
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **1734809 kWh/year** Specific prod. 1571 kWh/kWp/year
Performance Ratio PR 79.5 %

New simulation variant
Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	155.7	24.80	184.0	178.6	168071	163725	12.25	11.90
February	156.0	25.60	172.7	167.9	156044	151560	12.12	11.78
March	181.7	25.80	188.2	182.8	170020	165101	12.12	11.77
April	183.0	26.50	179.5	174.1	161644	157044	12.08	11.74
May	171.7	27.90	162.2	156.5	145338	141229	12.02	11.68
June	155.4	27.60	144.9	139.8	130113	126372	12.05	11.70
July	157.5	28.30	148.4	143.0	132988	129139	12.02	11.67
August	150.7	28.20	146.2	141.3	130881	127071	12.02	11.66
September	144.0	27.80	144.9	140.1	130565	126766	12.09	11.74
October	150.7	26.60	160.2	155.4	144842	140580	12.13	11.77
November	146.4	24.90	166.1	161.3	151688	147292	12.25	11.90
December	151.8	24.60	179.6	174.6	164237	159449	12.26	11.91
Year	1907.6	26.56	1976.8	1915.5	1786492	1734809	12.12	11.77

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

Figure 4

2.3 Investment analysis

2.3.1 Financial feasibility

The financial feasibility analysis of Mukdahan solar power plant is shown in Table 3. All data has been obtained in 2015. The total investment cost is 1.91 Million U$. The project operation time is 25 years. Mukdahan power plant is a government backed power plant. It's subsidized and a part of feed-in tariff policy at the purchase rate of 0.19 U$ per unit. The goal is to stimulate growth of renewable energy investments in private sector. This project is working in accordance to Public Policy Doctrine, 2015 Power Development Plan. The total income is 7.24 Million U$. The operational expenses are 1.71 Million U$. The net profit is 3.27 Million U$. The project IRR in 25 years is 11.50% and equity IRR is 16.51%.

Table 3 The economic analysis of solar power plant.

Item	Quantity
Project Investment CAPEX (DC)	1.91 Million U$
Project Operation Period	25 years
Feed in Tarif (FIT)	0.19 US /kWh
Total Project Income	7.24 Million U$
Total Operational Expenses	1.71 Million U$
Net Profit Yr1-Yr25	3.27 Million U$
Project IRR in 25 Years	11.50%
Equity IRR in 25 Years	16.51%

After one year in operation, it is found that the investment cost exceeds the target about 5%. Therefore, the output power energy per year decreased 4%. The project IRR reduce down to 10.05% and equity IRR is 13.50%.

Beside aforementioned variables, solar radiation is the most important factor that affects Internal Rate of Return (IRR). According to Table 4, it clearly shows that values of project IRR and equity IRR will rise in accordance to the rise of solar radiation. Scenario case will show this plant operating within projected range after a year of commercially operation.

Table 4 The Project Internal Rate of Return (IRR) sensitivities.

Scenario Case	Solar Radiation (kWh/m^2/day)	Project IRR (%)	Equity IRR (%)	Payback Period (Years)
Worst Case	3.50	8.72%	11.02%	9.62
	3.60	9.22%	11.93%	9.25
Base Case	3.70	9.70%	12.85%	8.91
	3.80	10.19%	13.79%	8.59
	3.90	10.66%	14.75%	8.29
	4.00	11.14%	15.73%	8.01
	4.10	11.60%	16.73%	7.76
	4.20	12.07%	17.76%	7.51
Best Case	4.30	12.53%	18.82%	7.29
	4.40	12.98%	19.90%	7.07

2.3.2 Bank funding

To form the investment, the PPA contact will completed. The land will be permitted for 25 years. The construction permit will be approved. The solar power plant should be operating within planned budget, not corporate loan. The owners will gain an equity of at least 30% of total investment. Loan from lenders will be finance 70–80% maximum. The yearly expense includes operation cost mandate and spare part maintenance for solar equipment. In term of financial projection, the project IRR is more than 10%. The equity IRR is more than 12%. This decision depends on investor policy.

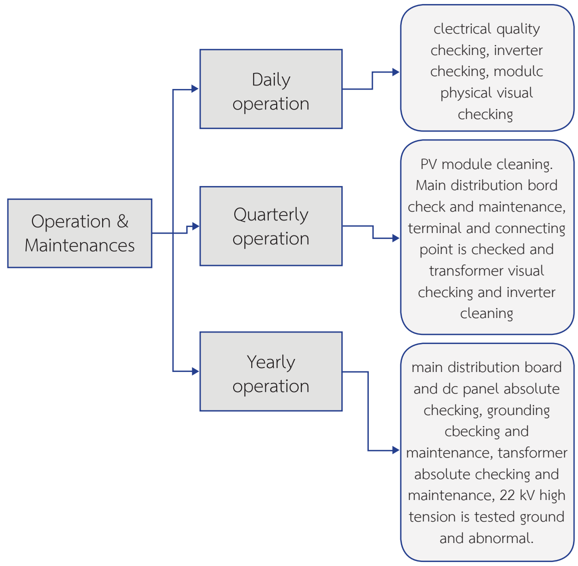


Figure 5 Operation & Maintenance diagram.

3. Results

3.1 Simulation and 1 year yield operation

After surveys and studies, the main equipment will be put in the simulation software. In this research PVSyst is used. The result from simulation is shown in Figure 4. It is found that specific production is 1571 kWh/kWp/year. The performance ratio is 79.5%. However, the real operation of Mukdahan solar power plant is operated for a year. It is investigated that specific production is 1506 kWh/kWp/year. The performance ratio is 76.26%. It is shown that the simulation result is greater than actual operation. However decision is done on the simulation. The real operation depends on the environmental factor for each season and yearly cycle. It does not mean that next year output will drop. When better climate condition occurs, the energy production is higher. Therefore, from the simulation, the investor decided to move forward.

3.2 Construction

The structure is constructed from anodized aluminum because it is light weight and oxidation protection. The connection point is used strip type. This project foregoes the use of stainless screw type to protect the leak from water damage. To promote cooling and air circulation between panels and rooftops, gaps should be approximately 10 cm. The solar panels are set facing south and the angel should be set 15–18 degree [35]. In case of the research, it is set at Mukdahan province on the roof of warehouse building. Because the structure will be fitted to the characteristics of building.

3.3 Operation and maintenance

In case of operation and maintenance, from Figure 5, it consists of daily, quarterly and yearly operation. The daily operations include electrical quality checks, inverter checks and module physical visual checks. Quarterly operation includes PV module cleanings, main distribution board check and maintenance, terminal and connecting point checks and transformer visual checks and inverter cleanings. Yearly operations and maintenance include main distribution board and dc panel absolute checks, grounding checks and maintenance, transformer absolute checks and maintenance. The 22 kV high tension is ground tested and yearly replacement of miscellaneous parts.

However, the solar power plant should be strictly doing the routine maintenance. An operator needs more experiences and competencies. The other major cause is faulty equipment and human error. Power system equipment is rated to operate under specific conditions and durations before periodic checks or planned maintenance. These issues must be emphasized in power systems and adhered to standards. Then the competency base training [36], [37] necessaries for operator human before working in power plant.

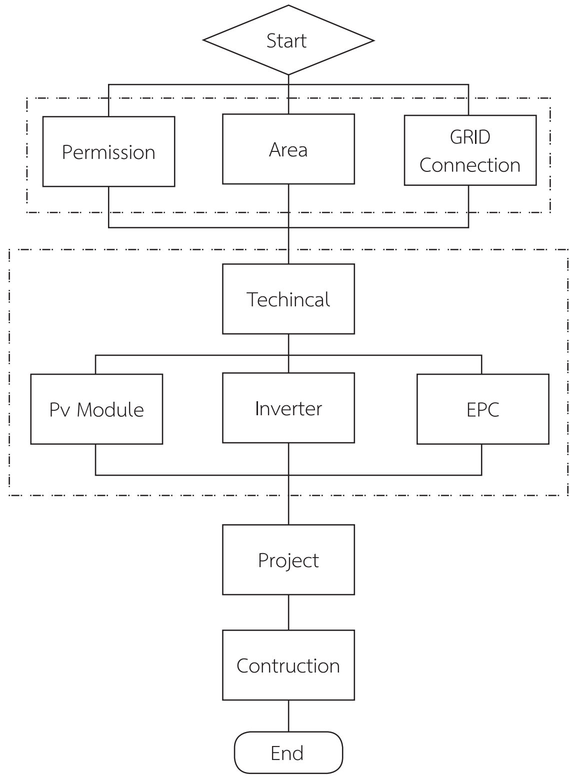


Figure 6 The proposed process model for solar investment.

4. Discussion and Conclusions

The right process model is shown in Figure 6. It should start with 3 criteria such as area survey, grid connection availability and permits.

The next step, technical analysis which includes PV module, Inverter and engineering design and construction firm consideration are performed. Then financing processes which are feasibility study and bank funding. And the next step is construction. Finally, operation phase includes long term 25 years plant's operation and maintenance.

For future research, the data of solar module efficiency will be collected for 10 years to compare with solar module replacement costs for decision making of economic worthiness.

From the results gathered, it can be concluded in following;

1) The solar module suitable for Thailand is crystalline for the reasons of technical characteristic and economic worthiness. The global horizontal solar radiation is more than 5.00 kWh/m^2/day. The power energy after Commercial Operation Date (COD) must perform with Performance Ratio more than 78% (PR ratio). PV module must be indexed by 1st tier manufactures and workmanship warrantee is more than 10 years. Degradation limit warrantee must be less than 0.8% per year in the term of long period 25 year and it cannot reach 20% degradation for the term.

2) The string inverter is suitable to use on the

roof solar power plant because it is high reliability. While central inverter is simpler for installation, when damages occur, the power loss will be greater. Inverter type must be pure sine wave inverter grid connected type at least 5-year warranty from first tier manufacturers.

3) The site will be flat area and free of shade shadow effect and minimal amount of dust or pollutions, not on the flood plain or flood hazard region. The plant must be near connection grid and enough grid available capacity. The area size should be more than 7,000 m^2. The area the plant will be in is approved by town planning department.

4) The layout design has the modules facing to the south direction with 15 degree of angle. And the main distribution board and control room have to be near the grid.

5) In the case of central inverter, the inverter is installed at the centre of plant with the maintenance space area about 15% of the plant for.

6) The project internal rate of return (IRR) is more than 10%. Equity IRR is more than 12%, its best.

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References

[1] H. Ritchie and M. Roser. (2018, Nov.). *Energy Production & Changing Energy Sources*. [Online]. Available: https://ourworldindata.org/energy-production-and-changing-energy-sources

[2] World Energy Council. (2019, Jan.). *World Energy Issues Monitor 2019*. world energy council insights brief [Online]. Available: https://www.worldenergy.org/wp-content/uploads/2019/02/1.-World-Energy-Issues-Monitor-2019-Interactive-Full-Report.pdf

[3] C. Zou, Z. Qun, G. Zhang, and B. Xiong, "Energy revolution: From a fossil energy era to a new energy era," *Natural Gas Industry*, vol. 3, no. 1, pp. 1–11, 2016.

[4] V. S. Ediger, "An integrated review and analysis of multi-energy transition from fossil fuels to renewables," *Energy Procedia*, vol. 156, pp. 2–6, 2019.

[5] S. Glück, "Making energy cultures visible with situational analysis," *Energy Research & Social Science*, vol. 45, p. 45, 2018.

[6] G. Q. Chen, X.D. Wu, J. Guo, J. Meng, and C. Li, "Global overview for energy use of the world economy: Household-consumption-based accounting based on the world input-output database (WIOD)," *Energy Economics*, vol. 81, no. c, pp. 835–847, 2019.

[7] Enerdata. (2019, Jan.). *The global energy efficiency and demand database*. [Online]. Available: https://www.enerdata.net

[8] International Energy Agency (IEA). (2018, Nov.). *World Energy Outlook 2018*. [Online].Available: https://www.ethz.ch/content/dam/ethz/speci al-interest/mavt/process- engineering/separation-processes-laboratory-dam/documents/education/ccs%20notes/Wo rld%20Energy%20Outlook%202018.pdf

[9] International Energy Agency. (2018, Mar.). Global Energy and CO2 Status Report: The latest trends in energy and emissions in 2018. *International*

Energy Agency [Online].Available: http://www.indiaenvironmentportal.org.in/file s/file/Global_Energy_and_CO2_Status_Report _2018.pdf

[10] World Energy Council. (2018, Jan.). *World Energy Trilemma Index 2018*. [Online]. Available: https://www.worldenergy.org/wp-content/uploads/2018/10/World-Energy-Trilemma-Index-2018.pdf

[11] Exxon Mobil Corporation (2017, Nov.). 2019 Energy & carbon summary. *Exxon Mobil Corporation* [Online]. Available: https://corporate.exxonmobil.com/-/media/Global/Files/energy-and-carbon-summary/Energy-and-carbon-summary.pdf

[12] BP Statistical Review of World Energy BP p.l.c. (2019, Jan.). BP statistical review of world energy 2019: 68th edition. *BP Statistical Review of World Energy*. London, UK [Online]. Available: https://www.bp.com/content/dam/bp/busine ss-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

[13] The Global CCS Institute. (2018 Jan.). *Energy Demand in 2020*. [Online]. Available: https://hub.globalccsinstitute.com/publications/uk-renewable-energy-strategy/energy-demand-2020

[14] U.S. Energy Information Administration. (2019 Jan.). Annual Energy Outlook 2019 with projections to 2050. International Energy Agency. Paris, France [Online]. Available: https://www.iea.org/weo2018

[15] S. Traivivatana, W. Wangjiraniran, S. Junlakarn, and N. Wansophark, "Thailand energy outlook for the Thailand integrated energy blueprint (TIEB)," *Energy Procedia*, vol. 138, pp. 399–404, 2017.

[16] International renewable Energy agency (2017, Apr.). *Renewable Energy outlook Thailand 2017*. Ministry of Energy. Bangkok, Thailand [Online]. Available: \https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Outlook_Thailand_2017.pdf

[17] Ministry of Energy of Thailand. (2018, Apr.). *Power Development Plan 2018*. Ministry of Energy. Bangkok, Thailand [Online]. Available: http://www.eppo.go.th/images/Infro mation_service/public_relations/PDP2018/PD P2018.pdf

[18] Solar Magazine. (2019, Mar.). *Thailand Solar Energy Profile*. [Online]. Available: https://solarmagazine.com/solar-profiles/thailand/

[19] Energy Research Institute Chulalongkorn University. (2015, Dec.). *Scaling Up Solar PV: A RoadMap for Thailand*. Chulalongkorn University. Bangkok, Thailand [Online]. Available: http://www.dede.go.th/ewt_dl_link.php?nid=42059

[20] Asian Development Bank. (2015, Mar.) *Handbook for Rooftop Solar Development in Aria*. Asian Development Bank. Manila, Philippines [Online]. Available: https://www.adb.org/sites/default/files/public ation/153201/rooftop-solar-development-handbook.pdf

[21] The International Renewable Energy Agency (IRENA) (2012, Jun.). *Renewable Energy Technologies: Cost Analysis Series*. IRENA Secretariat. Abu Dhabi, United Arab Emirates [Online]. Available: https://www.solar-united.org/wp-content/uploads/2017/02/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf

[22] Eclareon. (2014, Mar.). Pv rooftop development in Thailand analysis of regulations and challenges. *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*. German [Online]. Available: http://www.thai-german-cooperation.info/download/20140408_pdp_th_report_pv_regulations.pdf

[23] S. Tongpong. (2017, Mar.). *Solar Rooftop Power Generation Encouragement by Using Solar Hero Application*. Provincial Electricity Authority (PEA). Bangkok, Thailand [Online]. Available: http://eit.or.th/paperseminar/National%20Engineering%202017.pdf

[24] Solar Power Europe. (2018, Mar.). *Renewable Self-Consumption: Cheap and Clean Power at Your Doorstep*. [Online]. Available: http://www.solarpowereurope.org/wp-content/uploads/2018/06/Self-consumption_final1507.pdf

[25] World weather online. (2018, February). *Mukdahan Monthly Climate Averages*. [Online]. Available: https://www.worldweatheronline.com/Mukdahan-weather-averages/Mukdahan/th.aspx

[26] M. Kaur and H. Singh, "A review comparison of silicon solar cells and thin film solar cells," *International Journal of Core Engineering & Management (IJCEM)*, vol. 3, no. 2, 2016.

[27] M. Imamzai, M. Aghaei, Y. Hanum Md Thayoob, and M. Forouzanfar, "A review on comparison between traditional silicon solar cells and thin-film cdte solar cells" in *Proceedings National Graduate Conference 2012 (NatGrad2012)*, University Tenaga National, Putrajaya Campus, 2012, pp. 1–5.

[28] C. Kalu, E. Isaac, and U. Mfonobong Anthony, "Comparative study of performance of three different photovoltaic technologies," *Mathematical and Software Engineering*, vol. 2, no. 1, pp. 19–29, 2016.

[29] A. phowan and P. Sriphadungtham, "Performance analysis of polycrystalline silicon and thin film amorphous silicon solar cells," presented at the 8th Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI), Khon Kaen, Thailand, May, 2011 (in Thai).

[30] F. Colville. (2019, Jan.). Top 10 solar module suppliers in 2018. PV-Tech & Solar Media Ltd., Solar Media. London, United Kingdom [Online]. Available: https://www.pv-tech.org/editors-blog/top-10- solar-module-suppliers-in-2018

[31] Global solar Atlas. (2019, Apr.). *Map info Global Horizontal irradiation* [Online]. Available: https://globalsolaratlas.info/?s=16.53833,104.715&m=sg:ghi&e=1

[32] C. Thongchaisuratkrul, "Studies and analysis the affecting factors for solar power," In Research Report. Bangkok: King Mongkut's University of Technology North Bangkok. 2016.

[33] W. Srisuriyajan and C. Thongchaisuratkrul, "The solar power plant prediction: A case study in Phitsanulok, Thailand," The 2nd International Conference on Power and Energy Engineering (ICPEE 2018) Xiamen, China, Sept 3-5, 2018.

[34] W. Srisuriyajan and C. Thongchaisuratkrul, "The model of solar power plant efficiency improvement: A case study in Lampang, Thailand," The International Conference on Advanced Mechanical and Electrical Engineering (AMEE 2018) Beijing, China, December 26–28, 2018.

[35] M.Z. Jacobson and V. Jadhav, “World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels,” *Solar Energy* vol. 169, pp. 55–56, 2018.

[36] P. C. Acquah, “The Competency base training (CBT) concept of teaching and learning in the technical universities in GHANA: Challenges and the way forward,” *Asia Pacific Journal of Contemporary Education and Technology*, vol. 3, no. 2, pp. 172–182, 2017.

[37] W. Srisuriyajan and C. Thongchaisuratkrul, “The competency based training for aintenance technicians of solar power system focusing on solar modules,” in *the 11th International conference on Technical Education*, March 19–20, 2019.