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An Economic Evaluation under Thailand Feed in Tariff of Residential Roof Top Photovoltaic Grid Connected System with Energy Storage for Voltage Stability Improving

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Abstract

In this paper, Residential roof top photovoltaic system with 9.9 kW design is proposed. The system composed of 200 Watts solar array 33 panels connecting in series 10 strings and parallels 3 strings which have maximum voltage and current are 350 V and 23.8 A. The 10 kW sinusoidal grid-connected inverter with window voltage about 270-350 is selected to convert and transfer DC Power to AC Power at PCC (Point of Common Coupling) of power system following to utility standard. However the impact of fluctuation and uncertainty of weather condition of PV may decrease the voltage stability and voltage collapse of power system. In order to solve this problem the energy storage such 120 V 1200 Ah battery bank and 30 kVAR capacitor are designed for voltage stability control. The other expensed for installing the system such battery charger, cable, accessories and maintenance cost are concerned. The economic analysis by using investment from money loan with interest about 7% and use own money which loss income of deposit about 3% are calculated as 671,844 and 547,044 for PV system with energy storage and non energy storage respectively. The solar energy from PV is about 101,616 Bath per year which evaluated by using the value of 5 kWh/m^2/day from average peak sun hour (PSH) of the Thailand and 6.96 Bath/kWh of Feed in Tariff Incentive. The payback periods of four scenarios are proposed follow as i) PV system with energy storage and use loan money is 15 years ii) PV system with no energy storage and use loan money is 10 years iii) PV system with energy storage and use deposit money is 9 years iv) PV system with energy storage and use deposit money is 7 years. In addition, the other scenarios of economic analysis such no FIT support and other type of economic analysis such NPV and IRR are proposed in this paper.

***Keywords**: Roof Top Photovoltaic System, Feed in Tariff, Economic Evaluation, Energy Storage*

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1. INTRODUCTION

The photovoltaic grid connected is one of popular renewable energy for residential and small building because of simplify and easy to install, clean and no cost of fuel. In Thailand, the potential of solar energy has more than 500 MW and solar radiation is about 16-18 MJ/m^2/day. Eventhough the initial investment cost of photovoltaic system is high but the price of PV system trend are decrease gradually. In addition, Thailand government has launch the policy to support such as adder, Feed in Tariff. From this reason, the residential and also office building are increasing install photovoltaic system to get the revenue price from Feed in Tariff. Then the power system structure is change from the past, the conventional type of power plant is minimize but decentralize small power plant such roof top photovoltaic systems are increase. This type of renewable energy such PV is calls VSPP (very small Power Producer). Because of uncertainty of weather condition such as solar radiation and temperature and also cloudy effect which may have the effect of photovoltaic grid connected in aspect of power quality, reliability and stability. The fluctuation of voltage, frequency and harmonic may about misoperate of equipment in the power system. In order to avoid this situation, the energy storage is one of the solutions. There are various types of energy storage which has different property such as energy density, power density, price, product life time. Two important of energy storage are used to solve this problem; battery is the electrochemical equipment to storage energy in term of chemical and convert chemical energy to electrical energy. The second type of energy storage is capacitor which has property for compensate the reactive power flow and improve the power factor of system. The PV grid connected with energy storage is concerned and both of equipment can solve the power quality problem in their own aspects. It can implied that advantages of PV grid connected with energy storage are including i) Mitigating the stochastic nature of solar power ii) Taking advantage of solar feed-in tariffs to make profit by selling/purchasing electricity to/from grid and iii) Injecting reactive power to improve power quality and support grid during transient disturbances. However, the problem is how to sizing the appropriate energy storage for PV system because when install the energy storage the cost of system is higher. In this paper the PV system with energy storage are designed and sizing. The cost estimation of system are calculated and the economic evaluation by payback period, NPV and IRR of under Feed in Tariff measure are discussed.

2. PV GRID CONNECTED SYSTEM WITH ENERGY STORAGE DESIGN

In this section, the photovoltaic grid connected systems with energy storage and non energy storage are designed. From the Energy Regulatory Commission, which requires homes to install solar power systems with less than or equal to 10 kWp and their feed in tariff rate as shown in Table 1.

Table 1. Feed Tariff Rate of each type of building

Type of Building	Power Capacity	Feed In Tariff Rate
1) Household	< 10 kWp	6.96 Bath/unit
2) Small Business Building	10 – 250 kWp	6.55 Bath/unit
3) Medium/large Business Building/Factory	250 – 1000 kWp	6.16 Bath/unit

To design the system, the three commercial types of solar panels are considered such as single crystalline, poly crystalline and amorphous silicon which have different features and prices as shown in Table 2.

Table 2. Properties of solar cells are made from silicon.

Type of cell	Efficiency	Cost	Space for installation
Amorphous	6%-10%	Cheap	Large
Poly Crystalline	12%-15%	moderate prices	middle
Mono crystalline	16%-18%	Expensive	Small

In addition, the size of the solar panels is also range in size from 10 W to 300 W. Therefore, the design of the system the researcher has used Poly crystalline solar panels, which effectively moderate size selection 295 W. They have important features include: [3] Pmax = 295 W, Vmax = 45 V and Imax = 8.13 A. Solar power system design is divided into 2 systems as follows

1. The solar power system with no batteries back-up.

The 295-watt solar panel is selected to connection in array by 10 panels in series and 4 rows of parallel. The circuit connections of solar panels are shown in figure 1.

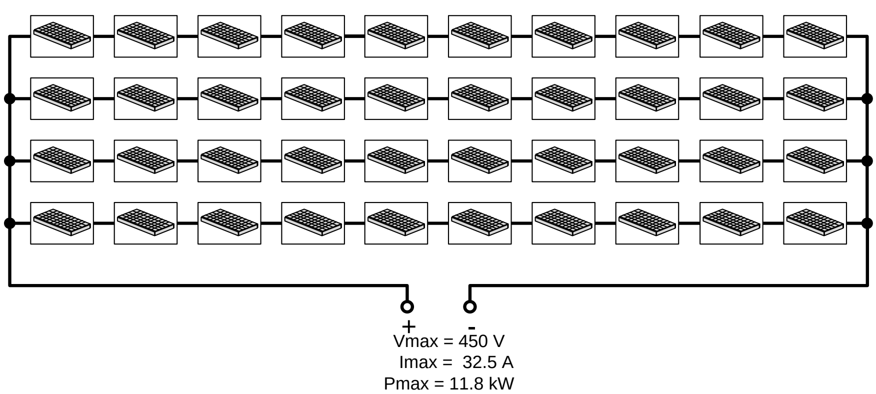

Figure 1. The design of the solar arrays in not used batteries backup system.

The next step is the stage of selection the inverter for DC voltage to AC voltage. Criteria for choosing the inverter can be connected to the grid system of electricity. You need a product that allows EPA to work. The research team chose GROWATT Model 10000 UE 10 kW 3 phase 230/400 volts inverter. The diagram of solar power system with no batteries back-up is shown in Figure 2.

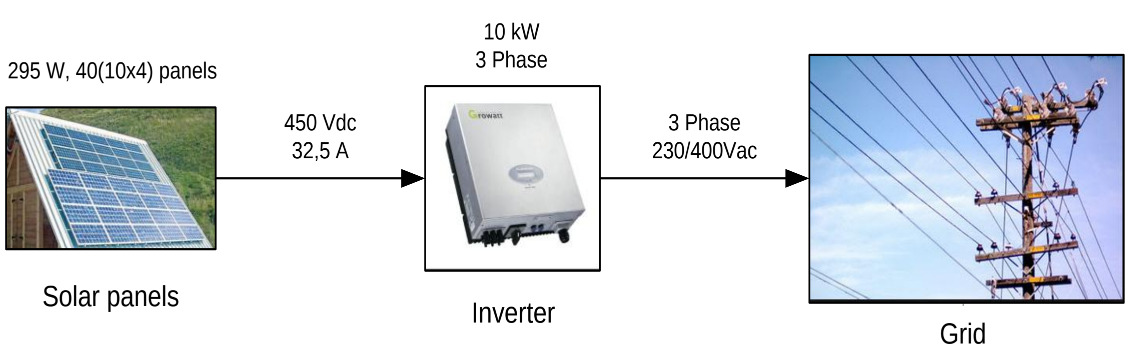

Figure 2. The diagram of solar system with no batteries back-up.

2. The solar power system with batteries back-up.

In Thailand, the average intensity of solar electricity that can be called the Peak Sun Hour is about 5 hours (10.00 AM – 3.00 PM) per day. During this time, the solar cell can generate power fully. However, solar power is dependent on the intensity of sunlight varies with the electricity generated in the panels. So when there is a change in light intensity caused by the sun obscured by clouds on one level. The intensity of sunlight that solar cells cannot be reduced to produce electricity. Such moments occur only briefly. Or it could happen a long time. This resulted in a loss of power and Instability in electricity. The consequently cause an unstable electricity distribution system. Therefore, the PV design system with battery backup power solutions to power unstable is proposed in this paper. The solar panels supply electricity to recharge the battery. Until the battery can supply power needed for the task then. Battery sending power to the inverter to change the DC voltage to AC voltage appropriate for supply to the distribution system. A diagram of the system is shown in Figure 3.

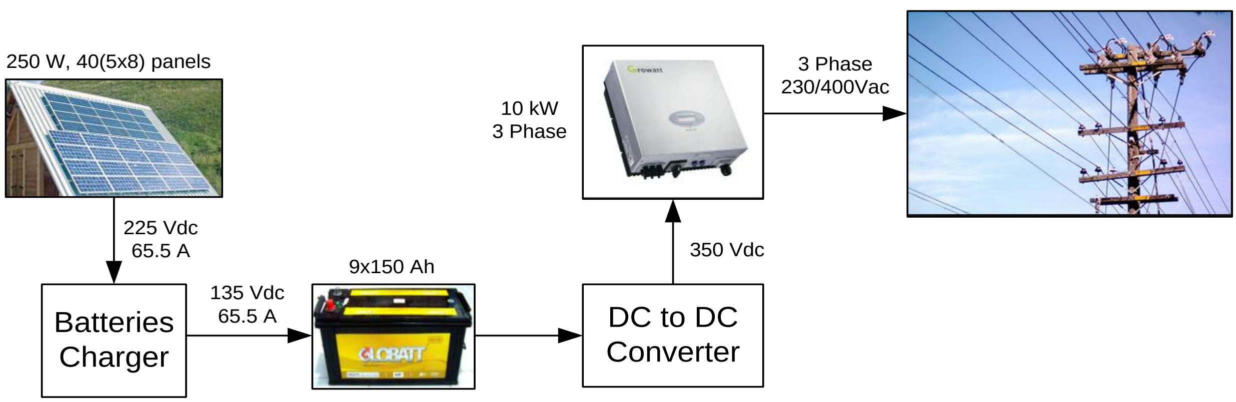

Figure 3. The diagram of solar system with batteries back-up.

The circuit solar panel for charging the high current required but not high voltage. Therefore the solar panels and photovoltaic panels in series 5 to 8 rows parallel to serial Figure 4 gives a voltage equal to 225 V and a current of 65.5 A.

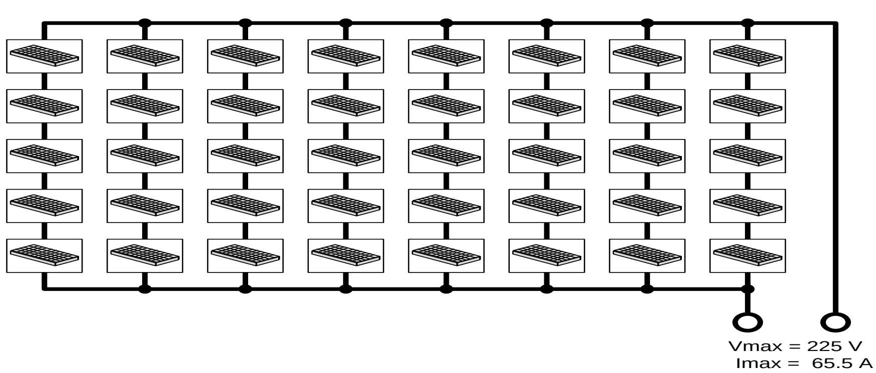

Figure 4. Design of a solar panels power system with power backup.

The charger is charging the battery pack will need a circuit that can reduce voltage from 225 V down to a voltage of 135 V, which is the appropriate voltage to charge the battery. Also must be able to withstand the current size of 65.5 A, which is the maximum current that the solar panels can be supplied to the system. This system researcher use deep cycle batteries 12 V 9 set by both batteries connected in series. As a result, the voltage at the terminals of the batteries is 12 x 9 = 108 V. In addition, the Ah of the battery can be calculated from the equation Ah = Wh / (VBattx0.8x0.85). The numbers 0.8 is the percentage of the current in the battery (Type Deep Cycle) and 0.85 is the efficiency of the inverter. Which will result in the calculation is 161 Ah, so the research team chose to use the battery 150 Ah. When the battery's power until it can recharge from the power supply to the inverter already. Power is supplied to the DC to DC Converter circuit to adjust voltage suitable for supply to the inverter. To send to the distribution system of electricity distribution. The power system with solar energy, no energy reserves when the price survey can then be estimated installed as shown in Table 3, the case of electricity systems with solar backup battery power, then an estimate to install such a system is shown in Table 4.

Table 3. Price estimates to install a solar power system with no backup power.

ITEM	DESCRIPTION	QUANTITY	UNIT	AMOUNT (baht)
1	Solar panels poly crystalline 295 W	40	panels	416,000.00
2	Inverter (GROWATT10000 UE)	1	Set	94,000.00
3	Accessories	1	Set	75,000.00
4	Vat 7%	1	Set	40,950.00
5	Labour cost	1	Set	40,000.00
	Total			**665,950.00**

Table 4. Price estimates to install a solar power system with backup power.

ITEM	DESCRIPTION	QUANTITY	UNIT	AMOUNT(baht)
1	Solar panels poly crystalline 295 W	40	Set	416,000.00
2	Inverter (GROWATT10000 UE)	1	Set	94,000.00
3	Solar Charger	1	Set	18,000.00
4	Batteries Deep Cycle 12V 150Ah	9	Set	58,500.00
5	Accessories	1	Set	80,000.00
6	Vat 7%	1	Set	46,655.00
7	Labour cost	1	Set	40,000.00
	Total			**753,155.00**

The comparison of the theoretical value of economic payback period for the duration of the payback of the investment in the installation of solar power systems to compare the number of years of payback of the two models. In addition, Net Present Value (NPV) is calculated as the difference between the present value of the savings from the measure in billion is expected to be awarded each year. Over the life of the project The present value of the money paid out under this program are considered at lower rate (discount rate) or the cost of capital (cost of capital) of the definition given above. Finally, it uses an Internal Rate of Return (IRR), which represents the rate of decrease (discount rate) that makes the present value of cash flows expected to be paid on the investment equal to the present value of cash flows expected to be derived from Energy savings throughout the project life. This research team will compare the value of economics. Solar power system installed on the roof with great power with a battery and no battery is compared. The payback of cost from selling power back to the electrical system in the event the Feed in tariff (Fit) revenues in the base tariff of PEA divided in the event of a bank to borrow money to invest. Paying 7% interest to banks and investment funds which case the opportunity cost of interest on deposits in banks 3% .

1. Calculating with payback period method can calculated by use the equation 1.

$$Payback\ Period = Net\ investments / Cost\ savings\ per\ year \quad (1)$$

The profit of PV system is calculated by the Feed in tariff (Fit) from government which is paid about 6.96 baht per unit. Estimated that the system can produce up to *kW x PSH x eff*. The variable of *kW* is the power of the system, *PSH* is the hour that the system can produce up to 1 day (Peak Sun Hour) in Thailand found that 5 hours and *eff* is the efficiency of producing power equals 0.8. So the energy that the system can be produced in one day was 47.2 kW/day or equivalent to 16,922 kW/year, representing an income of electricity equal to 117,777 baht /year. Whereas each year shall be the cost of the annual maintenance was 2,000 baht, so the revenue from electricity equal to 115,777 baht per year. The cases are being sold by the base tariff of PEA distribution at 3.5 baht per unit charge rates can be calculated revenues from the electricity produced is equivalent to 57,472 baht per year. Payback period of such a system are shown in Table 5. It showed that the payback period of the electric charge with electricity base tariff by the PEA. And loan banks will invest the time to payback over 61 years, which is longer than the lifetime of the equipment used in the power system, so this method can’t be invested. In case of using solar power system with battery backup power. Make the power more stable. Thus, the power send to the electrical distribution can then be paid the full 10 kW during Peak Sun Hour. As a result, the electric power system in the Feed in tariff equal to 50 kW / day, equivalent to 18,000 kW / year revenue from the sale of the electricity distribution was 125,280 baht.

Table 5. The payback period of a solar power generation system with no backup power.

Feed in tarriff		Base tariff by the PEA	
Bank loan	**Private investments**	**Bank loan**	**Private investments**
9 yaer 8 month	6 year 11 month	61 year 4 month	17 year 9 month

The solar power system with battery backup power has the cost of maintenance over the years due to depreciation of the battery, which has a period of about 5 years. Therefore, the maintenance costs will total approximately 13,700 baht. As a result, the revenues from the production of electricity Feed in tariff is equal to 111,580 baht per year. Most cases accounted for the base tariff by the PEA. The solar power system will have to minus the cost of maintaining it is 49,300 baht per year. And to calculate the payback period will get the results shown in Table 6.

Table 6. The payback period of a solar power generation system with backup power.

Feed in tarriff		Base Tariff by the PEA	
Bank loan	**Private invesments**	**Bank loan**	**Private invesments**
12 year 10 month	8 year 6 month	Can't payback	28 year 2 month

Table V showed that the electric charge distribution of the base tariff by the PEA is not a payback period of the useful life of the equipment of the electric power produced by the solar system for 25 years.

2. Calculating with Net present Value : NPV method

How to calculate the Net Present Value or NPV. That is calculated to equal the profit of the project within the project over the life of the project. This system is generating electricity with solar energy equipment will last for about 25 years. Thus, when considered in Table IV and V showed that the payback period of the power system that uses the Feed in tariff will have backup power or not, will have a payback period of less than 25 years. However, considering the way the base tariff. Found to have a power system that no energy reserves and invest the money themselves only with a payback period of less than 25 years. Therefore, to calculate the NPV method is only available by the case only. The equation for the NPV is shown in Equation 2.

$$NPV = \sum_{t=1}^{n} \frac{ES_t}{(1+i)^t} - I_0 \tag{2}$$

The variable n refers to the age of electricity, the is 25 years ESt is income from the electricity supply. Divided into first case of no backup power systems and electric charge in all aspects Feed in tariff by a bank loan, which is equal to 69,160.50 baht. In second case, as is the case at first, but with private money investment, which is equal to 95,798.50 THB. Third case of the system without backup power and charge voltage according to the power base and using private money investment, which is equal to 37,493.50 THB. Fourth cases of the system has a battery backup power in the Feed in tariff and bank loan which is equal to 58,859.15 THB. And the final case as well as fourth case, but private investment which is equal to 88,985.35 THB by the end of Year 1 to n. I_0 is investment in the electricity system, which is divided into two cases, the first case is a power system that does not back up power. The total investment in Table II. And final case, with battery backup power. Aggregate investment as shown in Table III. The variable i is the devaluation caused by inflation each year, according to Statistics Thailand the average percent inflation rate from year 2536 to year 2556 were 3.36 percent, the result of the calculation with NPV method will shown in Table 7.

Table 7. Profits from the production of electricity using solar energy over time to 25 years.

No Batteries storage System			Batteries storage System	
Feed in tarriff		Base Tariff by the PEA	Feed in tarriff	
Bank loan(THB)	Private invesmant (THB)	Private invesmant (THB)	Bank loan(THB)	Private invesmant (THB)
530,324.70	991,084.31	-17,421.93	264,936.42	786,031.71

Table 6 showed that power generation system with battery backup power that is used to charge the base tariff by the PEA can't make a profit from the sale of electricity on the duration of lifetime and 25 years.

3. Calculating with Internal Rate of Return :IRR method

Internal Rate of Return method used for calculating percent rate of return within one year, calculated using equation 3.

$$-I_0 + \sum_{t=1}^{n} \frac{ES_t}{(1+IRR)^t} = 0 \tag{3}$$

The rate of return from the sale of electricity produced from solar systems in various cases shown in Table 8.

Table 8. yields from the production of electricity using solar energy.

No Batteries storage System			Batteries storage System	
Feed in tarriff		Base tariff by PEA	Feed in tarriff	
Bank loan(%)	Private invesment(%)	Private invesment(%)	Bank loan(%)	Private invesment(%)
10.54	16.36	0.03	6.68	12.63

Table VII showed that the power system that does not back up power to charge the unit using the base tariff by the PEA. The yield has been the year of 0.03%, which is lower than the average rate of inflation occurred. 20 years of Thailand (3.36%) to making this system the values in table VI is negative or no gain there.

4. DISCUSSION AND CONCLUSION

By comparison of the value of economic used theory Payback Period, Net Present Value (NPV) and Internal Rate of Return (IRR). Found that the electricity produced by the Feed in tariff has made investments in solar power system that will power the battery backup system or not. The payback and profit in the last 25 years as the age of equipment, which is the period of payback slowest up to 13 years. The profits from the sale of electricity to the electrical distribution system by the Feed in tariff in 25 years will be at least 264,000 THB profit. Electric power system with no solar power backup system and use private investment can pay for itself quickly. Approximately up to 7 years, and have gained the most in 25 years, about 990,000 THB. The solar system with has backup power. Although the power to make more stable and produce more power. But that will not slow payback and profit when entering 25th year at least. Is caused is to increase the cost of investing in alternate energy systems and the maintenance of backup power. Most cases use the electricity produced by the base tariff by the PEA, it is found that it can’t pay for itself in 25 years, be it power generation system with battery backup or not. However, this research has not led to a variable cost of the loss of power associated with unstable electricity from solar energy, which is likely to affect the power of electricity. These costs which are currently the burden of distribution utility. So in the future if such a burden to manufacturers may also profit from the sale of electricity in the system that do not have the energy reserves decrease.

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