

# **Performance Improvement of 7 MW DC Photovoltaic Power Plant in Thailand using the Active Power Control**

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## **Abstract**

This paper presents the performance improvement of a grid-scale distributed photovoltaic power plant by using the power control techniques and the battery energy storage system (BESS), in order to increase the power generation and avoid any disconnection due to the voltage problem. The 7 MW Solar PV plant connected with the medium (MV) distribution network that normally used the fixed power factor (PF) control was investigated. The experimental data of the main bus are given to verify the fixed PF method and to evaluate the voltage rise. However, the active power control by using the BESS also evaluated. The simulations have been carried out and demonstrated that the BESS has the potential to improve power quality and performance. Through control of the charging and discharging of the BESS, it is shown that the Solar farm output power can be controlled and can be smoothing of the grid voltage.

## **Keywords:**

*Grid-Connected Inverter, PV Plant, Power Factor, Active Power Control, Reactive Power Control, Energy Storage*

## **1. Introduction**

Energy is vitally linked to environmental, economic development and quality of life. We are now mostly dependent on the mainstay of power generation by burning fossil fuels that have been released gas to the atmosphere caused by climate change [1]. The world is at risk of experiencing extreme weather conditions, such as heat containers and floods. The economic impact is even more significant than decreasing the use of fossil fuels [2]. Due to the environment friendly of renewable energy, the penetration of renewable resources generated the electrical energy into the grid system are growing dramatically in terms of advantageous public and environmental concerns. Currently, many countries are in the early stages of a renewable energy revolution. The solar PV generation capacities in electrical power networks are increasing [3,4]. In Thailand, the Solar PV started over 20 years ago and supported by the government budgets in the rural areas. Since 2000, the private investment was driven by the government's electricity tariff for renewable energy production according to the global trend. There was added \$ 0.27/kWh in the first period, which decreased in early 2010 with added \$ 0.22/kWh support 10 years support duration and changed the scheme in 2013 to be a Feed-in-Tariffs (FiT) \$ 0.21 to \$ 0.23/kWh with 25 years support duration [5].

The target for solar PV in Thailand has been set by Alternative Energy Development Plan 2015-2036 (AEDP 2015) and was approved by the National Energy Policy Council (NEPC). The renewable target is around 30% sharing with the total energy consumption by 2036, so the solar-energy target is 6,000 MWp [6, 7]. Due to big target and lower investment cost, the utility-scale of Solar PV connected to the MV Grid is interested in the power producers, because the PV module is becoming more economical every year. In addition, the balances of the system are more competitive than in the past decade. The annual renewable investment costs are decreased and will lower continuously [8]. The lowest industry-reported system prices for some large-scale utility estimated below \$1000/kW [9].

According to Energy Development Plan of Thailand with the situations of competitiveness, install quickly and efficiency of technology, in 2017, the photovoltaic power plants have been installed in Thailand about 2,669 MW [10]. The utility-scale solar PV systems are connected to medium voltage distribution grids typically, where the inverters are required to convert solar energy into electricity in such a grid-interactive solar PV system. As the traditional source supplied by a centralized power plant based on fossil fuel and transmits to a consumer, the distributed generation (DG) technologies are usually based on the renewable source such as the PV power plant connected directly to the distribution network converting to a decentralized power system with multidirectional power flow [11]. The electrical grid has been designed to deliver a stable supply of power from centrally located power sources, via the distribution lines, to users. However, adding a renewable source that is variable in some areas might not be proper for the connection at the end of line or in the low demand area. Therefore, the additional significant power control is required to ensure that the demand and supply are aligned.

The solar PV power capacity has been expanding rapidly but the grid stability and availability are difficult to maintain. The solar output impacts on voltage variation, the loss level and limit of operation that related to the reliability and performance of the system [4]. Besides, the PV output cannot match the demand due to the changes in irradiation, which is PV input. One of major effect is the voltage problem occurred in distribution networks [12], so the higher voltage can result in de-rating of all insulation of electrical devices while the under-voltage makes the high current in the system. In terms of system availability, the voltage quality problems are the major grid failures of the commercial solar PV power station in Thailand.

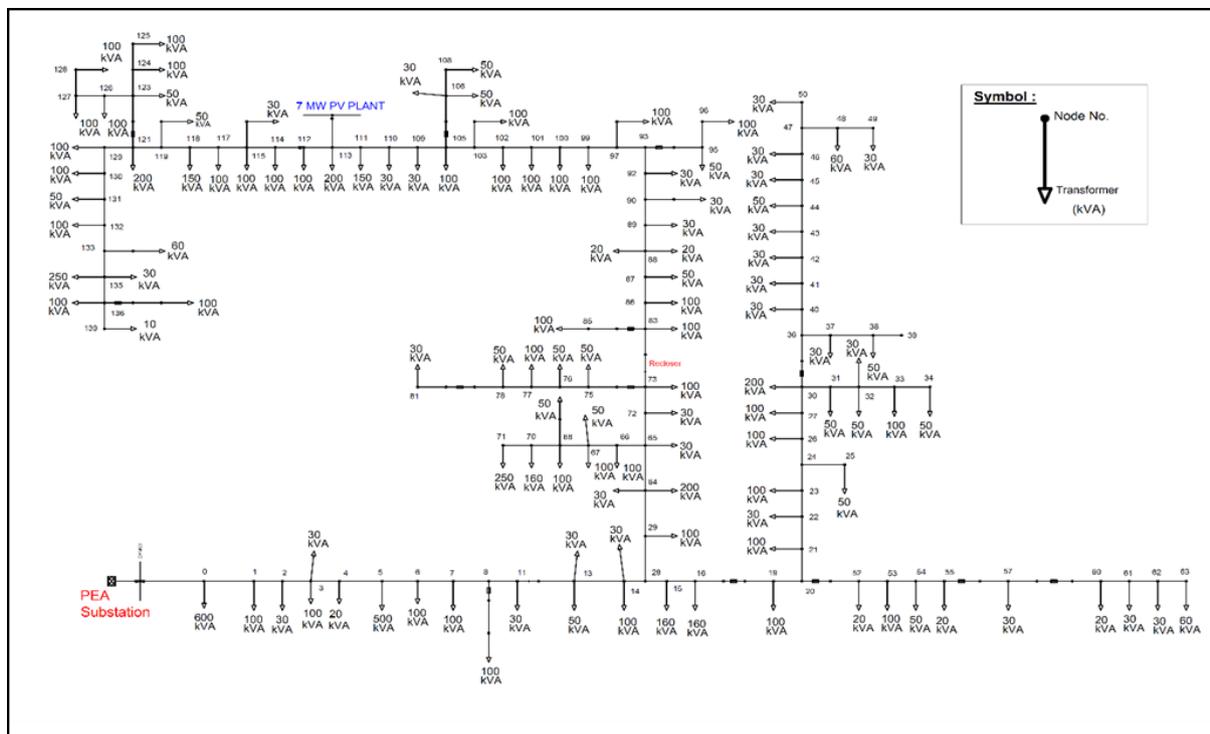


Fig. 1 The distribution network diagram in DlgSILENT PowerFactory software.

## 2. Experiment and Simulation

### 2.1. Case Study Network

The 7MWDC solar PV plant is in Thailand, which the system is connected to the distribution line of Provincial Electricity Authority (PEA). The Power Purchase Agreement (PPA) period is 25 years with the feed-in tariff rate \$0.22/kWh. This plant location is far from the PEA Sub Station about 37 km that the 119 units of transformer and about 9,000 users are connecting with this line. The maximum power generation that flows into the grid is about 6.0 MVA<sub>ac</sub> at 22 kV, while the residential loads are connected to the low voltage side. This plant consists of 22,560 modules of 310 W mc-Si, 45 boxes of PV array, 9 units of the 680kW inverter, 5 units of Ring Main Unit, 5 units of transformer and MV switchgear at the 22kV grid connection point. The distribution network diagram is shown in Fig. 1.

### 2.2. Experiment Data

An objective of this dissertation is to analyze the real case. Therefore, the daily data that selected for each month must be in a healthy condition. The impact factors such as irradiation, weather condition, PV power generation, utility grid condition, demand, and other factors should be the same as a normal condition of each month. The vital parameters consist of the active power/reactive power of the common coupling point (CCP), grid status, and PV power plant component statuses were measured and recorded with one-minute interval time by the solar power monitoring system. All measured data are recorded in the server of the PV power station monitoring system.

### 2.3. Voltage Simulation

DIgSILENT PowerFactory software provides a range of load flow calculation methods [13]. The load flow calculation methods including a full AC Newton-Raphson technique [14,15]. This software was used to model the network component for calculating the system voltage. The power flow can be decided by the equation (1) and (2). The voltage at typical bus  $i$  of the system is given in the polar coordinates and the voltage at another bus  $j$  is similar written by changing the subscript from  $i$  to  $j$ . The net current injected into the network at the bus  $i$  in terms of the element  $Y_{ij}$  [14, 15].

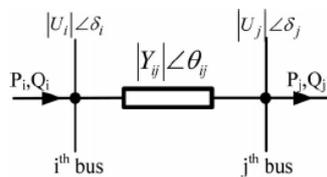


Fig. 2 Two-bus load flow demonstration.

$$P_i = |U_i| \sum_{j=1}^n |U_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (1)$$

$$Q_i = |U_i| \sum_{j=1}^n |U_j| |Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

Where:

$P$	=	Active Power
$Q$	=	Reactive Power
$U$	=	Voltage Magnitude
$I$	=	Current
$Y$	=	Admittance
$\delta$	=	Voltage angle

The distribution power network details in Fig. 1, consists of 7 MWDC PV plant that connected at the node no. 113. The 118 units of the transformer are connected in the distribution line, which is the PEA bus considered as the slack bus. The remaining nodes were considered as  $PQ$  buses in the load flow program, but there were only the load points. The photovoltaic bus was defined as the connecting bus, which can be controlled the active power by BESS. Type data required for simulation consist of voltage at PEA substation, all connected loads (this simulation is transformer rated), load consumption in the 15-minute time interval, PV power generation and BESS charge or discharge power in a one-minute time interval. The PV power generation was calculated by using the experiment data, but the power changed to be the unity power factor when any inverter was working. For example, power 5,000 kW with 0.975 power factor was equal to 5,000/0.975 kW at the unity power factor according to the equation of tri-angle power [14]. Type data required for simulation by program consist of the voltage at PEA substation (consider as a slack bus) and all connected load (for this simulation is transformer rated), together with % Load, PV generated and charge or discharge of BESS in each time interval.

#### 2.4. Simulation Scenario

The voltage at the connection point behavior was studied by using the real PV generation data from the experimental data (1 Minute Interval Time) and the forecasting demand (15 Minutes Interval Time) that provided by PEA. The inverters were operating at unity power factor and using the BESS to control the active power in order to limit the voltage. The maximum power and minimum power could be fed into the grid in each demand situation have to be calculated. The voltage range control mode was used by following flow chart in Fig. 3.

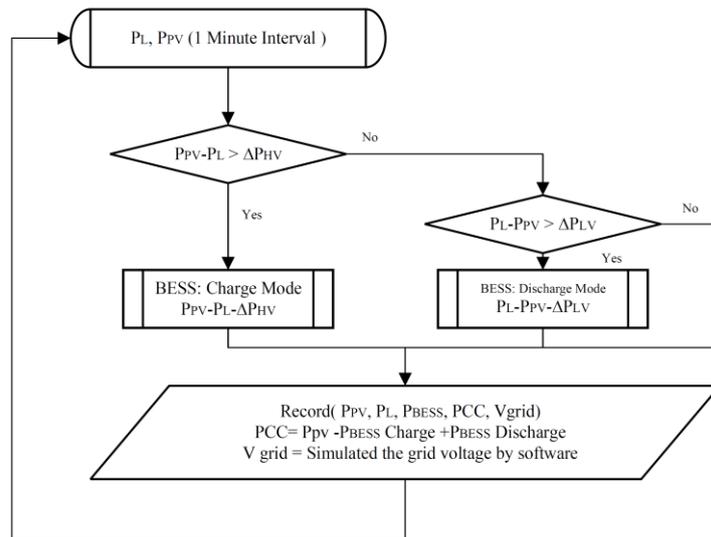


Fig. 3 Flow Chart for the calculation of the battery sizing and grid voltage of the voltage range-active power control.

Where:

$P_L$	=	Load Demand (kW)
$P_{PV}$	=	solar PV generated (kW)
$PCC$	=	point of common coupling
$\Delta P_{HV}$	=	the delta between PV power generated and the higher power that generated at the maximum voltage
$\Delta P_{LV}$	=	the delta between PV power generated and the lower power that generated at the minimum voltage
$V_{grid}$	=	the voltage at the grid connection

### 2.5. Battery Capacity Calculation

The BESS can control the power and limit the level of fluctuation for smoothing in the network system by charging and discharging operation [16-21]. The power conversion system (PCS) would be selected from the maximum power of charged or discharged of BESS. The BESS capacity is defined as the ratio of a difference between the maximum and the minimum of battery energy to the maximum DOD.

$$\text{Battery size (kWh)} = \frac{|E_{BESSmax} - E_{BESSmin}|}{DOD_{max}} \quad (3)$$

The state of charge (SOC) is using for managing the BESS during charging or discharging. The SOC should not exceed the  $SOC_{min}$  that can be simply calculated as follows

$$SOC_{min} = 1 - DOD_{max} \quad (4)$$

## 3. Results and Discussion

### 3.1. The Voltage Magnitude Simulation

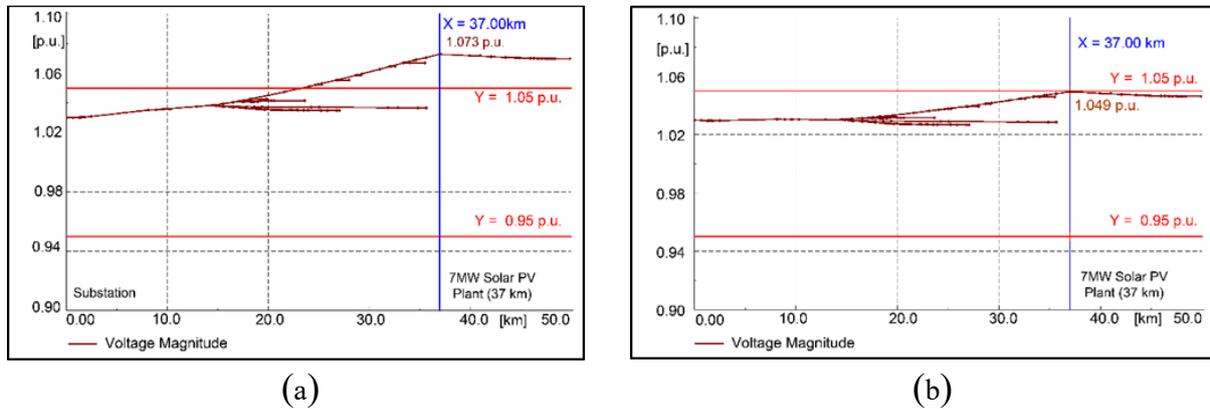


Fig. 4 (a) The 6MW from the PV plant is generated to the grid while the 25% of demand is connected,  
 (b) The power generation from the PV Plant must be limited by the voltage regulation.  
 (The Connected Load is 9,050 kW, PF 0.88)

Fig. 4 (a) shows the voltage at the grid connection that is the highest and out of the PEA regulation would occur at the solar PV plant when the PV was maximizing with the unity power factor. The voltages of all locations in this distribution line were affected. Moreover, the voltage of the locations that closed to the PV plant less than 12 km were higher than PEA regulation. On the other hand, the PV plant was limited the power at 3,500 kW to reduce the voltage in order to maintain the reliability, as shown on Fig. 4 (b).

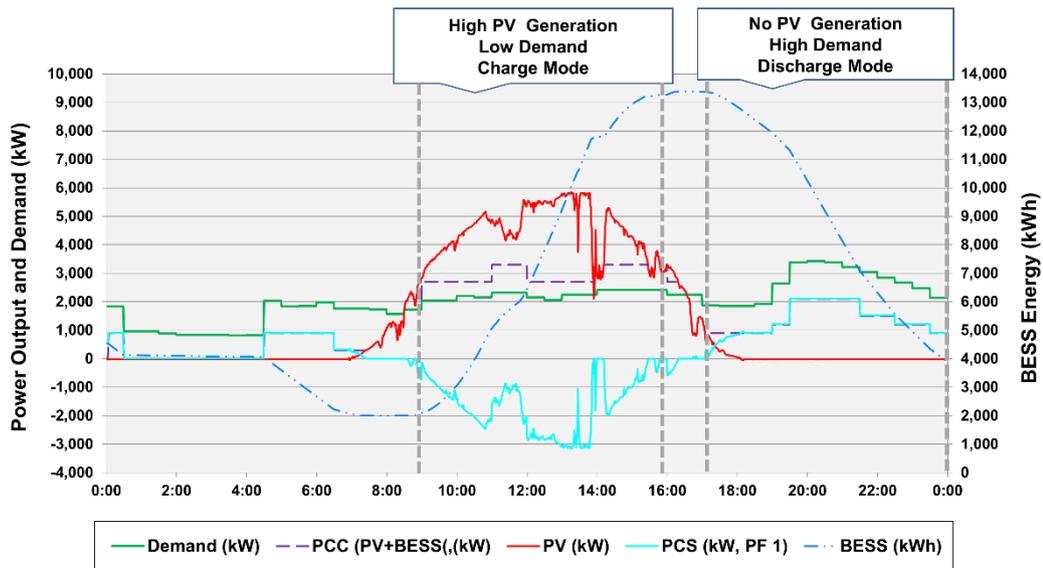


Fig. 5 (a) Daily power output of the PV Plant integrating with the BESS.

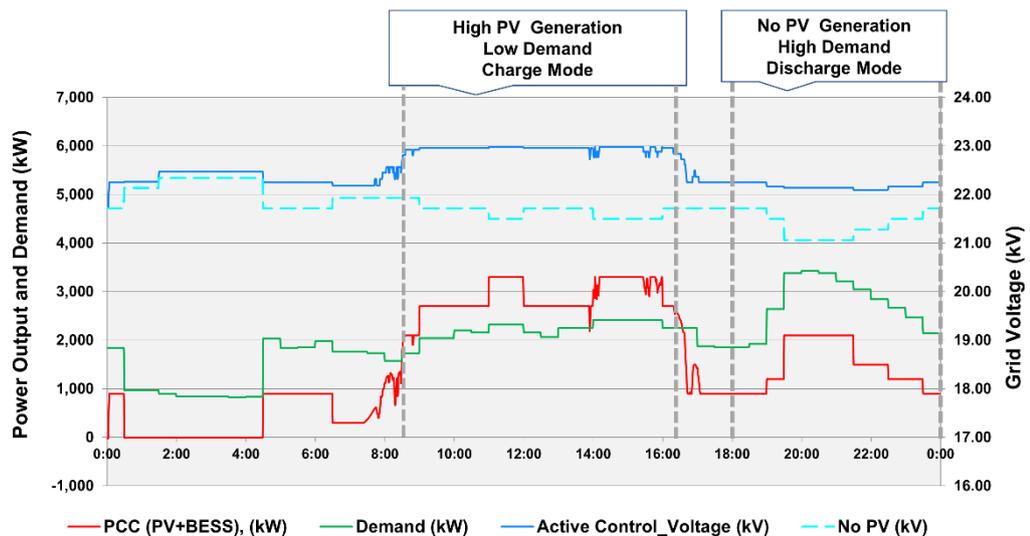


Fig. 5 (b) The simulation of grid voltage for the PV Plant integrating with the BESS were generated.

Table 1 The comparison between experimental data and the simulation of using the BESS for limit the voltage.

Month	Load Forecast (kWh)	Daily Experiment			Daily Simulation				PV Generation Comparison	
		Reactive Power Control			Active Power Control				The PV Plant using BESS > PV Plant using PF control.	
		Energy	Maximum	Power	PCC	PV	PCS	ESS		
(kWh)	Reactive Power	Factor	Energy	Energy (PF1)	Maximum Power	85% DOD	(kWh)	%		
Jan-18	48,947	35,561	1,008	0.984	36,121	36,121	3,268	13,992	560	1.57
Feb-18	50,816	37,693	1,390	0.978	38,536	38,536	3,090	14,620	843	2.24
Mar-18	56,737	34,713	1,168	0.987	35,188	35,188	2,421	9,341	475	1.37
Apr-18	58,435	31,607	976	0.981	32,203	32,203	3,022	5,080	596	1.89
May-18	57,866	30,726	1,070	0.985	31,184	31,184	2,420	6,868	458	1.49
Jun-18	55,038	27,736	1,336	0.981	28,269	28,269	2,452	5,495	533	1.92
Jul-18	52,447	25,519	1,148	0.986	25,888	25,888	2,790	2,972	369	1.45
Aug-18	51,622	26,084	1,381	0.980	26,625	26,625	3,412	4,995	541	2.07
Sep-18	51,960	27,685	1,115	0.983	28,175	28,175	3,341	6,355	490	1.77
Oct-18	50,694	31,606	1,399	0.983	32,138	32,138	3,333	10,463	532	1.68
Nov-18	52,331	32,672	1,324	0.980	33,338	33,338	3,256	11,058	666	2.04
Dec-18	51,348	32,997	1,389	0.981	33,639	33,639	3,402	10,493	642	1.95
Average	53,187	31,217	1,225	0.982	31,775	31,775	3,017	8,478	559	1.79
Electricity tariff Structure			- \$1.7 /kVAR [22]						\$0.197 /kWh	

In Fig 5 (b), the voltage was low in the evening when the PV plant was connected and the demand was higher. Therefore, the power from BESS was fed in. From the power profiles shown in Fig. 5 (a), the BESS was required to maintain the voltage level, in accordance with the PEA regulation. As such, the BESS can help maintain the voltage between 1.00 p.u. and 1.05 p.u. The BESS was charged from 10:00 AM to 3:35 PM. However, from 5:00 AM to 8:40 PM, the battery got also discharged even during when PV generation peaked, to support high demand in the evening. In this simulation, the reduction in the peak charging and the discharge power was almost equal. The minimum voltage and maximum voltage of the battery were 1.00 and 1.04 p.u., respectively, as shown in Fig. 5 (b).

The annual energy production was estimated by calculating the daily average multiplied by 365 days. Thus, the reactive control lost 203,944 kWh and used the reactive for 2,159,340 kVAR per year. The total revenue loss was estimated to be 40,194.90 USD and for the Var charge at 24,990 USD. On the other hand, with the PV system having an integrated e BESS, the power flow towards the distribution line can be limited and the voltage maintained until the SOC of batteries is minimized at 15%.

Moreover, this can be used for managing the overall power output in order to follow a pre-defined power output at a set point. In combination with a PV generation forecast, this application can allow the PV plant operator to guarantee specific power output for a certain period. For example, the output in February is better than the fixed PF mode about 2.24 %, but the 14,620kWh ESS is needed.

#### 4. Conclusion

This 7 MW DC solar PV plant is the real plant in Thailand. The Power Purchase Agreement (PPA) period is 25 years. Presently, the fixed power factor control is using to maintain the grid voltage. In this work, the experiment showed the simulation of the active power control by using the BESS. The use of BESS has improved the power quality and to increase the power generation with low losses. Through control of the charging and discharging of the BESS can absorb from the Solar farm for a given the smoothing of grid voltage until the SOC is the minimum setting. However, BESS is a high investment due to the battery cost today. The price of the BESS in the grid-scale application market is about 500–2500 \$/kWh for Li-ion [23]. According to the Solar PV policy in many countries, the purchase rate tends to decrease, and the battery will be the most competitive in the future. Therefore, the existing

plant, which gets a better feed-in tariff rate, should consider improving the output by using the BESS instead. These investigations will improve the performance of PV generation that flows through the MV distribution network.

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