Reactive Power Adjustment in MV Distribution Systems Integrating with Wind-Turbine Power Plants

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ABSTRACT

This paper illustrates optimal reactive power setting for voltage stability in the power distribution system affected from wind turbine operation. The implementation of disturbance analyzing device to compare the result before and after setting reactive compensator is shown. In this research, to optimize the overall voltage limitation, three decision variables were used i) active/reactive power generated from wind turbine farm plants, ii) specified voltage magnitude all node limitation and iii) power factor control. A Classical optimization technique is well-known and widely accepted for solving optimization problems. "WA-YU″ wind turbine farm project rated 8.0 MW, 22-kV of Provincial Electric Authority (PEA) of Thailand in Nakhon Ratchasima at feeder no. 9 was employed as a case study. The voltage limitation was controlled within 22 kV ±5 % based on the PEA regulation. The result showed that appropriate reactive power is efficiently related to the best power factor. The controlled voltage seemed to provide no effect to consumers from the same feeder circuit.

Keywords: Optimal reactive power flow, Wind turbine farm, Overvoltage limitation.

1. INTRODUCTION

The issue of global warming and the soaring cost of fuel, energy-efficient and environment friendly heating and cooling applications varying from domestic and commercial to industrial sectors are among the promising development from renewable sources [1]. The renewable energy is cooperated and installed in distribution power systems to incorporate two or more sources of power generation to balance each other's strengths and weaknesses [2]. There are many types of energy from renewable energy such as wind turbine power, solar power plant, and biomass power plant. These sources are environmentally friend and use predominant energy carriers that have been installed increasingly all over the world. The sources mentioned above can be divided into two groups: controlled sources and uncontrolled sources. Controlled sources mean that the output power can be easily controlled to the goal power; for example, biogas or biomass power plant. It is evident that output power from uncontrolled sources is unpredictable and independent of human action. Solar and wind power plants are environmentally uncontrolled sources [3]. The wind turbine technology is now actively presented in the electricity market, and it can be seen as a vision of the future. When the wind power plant is installed to serve loads in LV/MV power distribution grids, energy flow in the distribution network must be well managed to minimize total power losses or maximize net energy transaction in the system and voltage stability.

The overvoltage is a source of disturbance in the power systems which can damage the lines and equipment connected to the system. Typically, most of the overvoltage are originated from surges, lightning, and switching of electric loads that may result in sparks and flashes between phase and ground. In weakest point, the relay protection for overvoltage can misoperate which can affect the breakdown strength of insulation, failure of transformers and rotating machines or circuit breaker trip can operate falsely in the network [4-5]. This paper focuses on the over voltages occurred when the wind farm fully generates power to the grid. The problem of fully generated power from the wind turbine is an excessive power to the grid. The reason for this is that the power system protection can shut down the plant connected to the grid which can affect nearby factories in this situation. The protection system of wind turbine energy and voltage control limitation quality on the substation mostly trip by 59 code IEEE/ANSI for overvoltage code. The resulted effects are plant shutdown processes. The other results are inter-log between relay setting criteria in wind turbine protection, and substation in which malfunction may occur on circuit breaker 400V because overvoltage relay is not reset.

Thailand's government has a policy that directs the electric market to generate power from renewable energy resources as alternative energy development plan (AEDP) 2015. The goal of renewable energy source is to supply up to 25% of total demand [6] within 2021. Wind turbine generation is nowadays highly implemented to serve power demand. But the power from the wind turbine is limited regarding suitable areas for the installation, the issue of power quality and the impact on electric power system to other users in the same system such as over voltage problem.

Section two describes an electric power distribution grid with wind turbine power plant, overall power distribution grid and wind power model. Section three is optimal problems structure corresponding to mathematical expressions of its objective and various practical constraints. Section four gives simulation results and discussion.

2. ELECTRIC POWER DISTRIBUTION GRID WITH WIND TURBINE FARM

Various renewable energy generations have been developed to reduce greenhouse gas emissions and increasingly attract in resolving global problems such as environmental pollution and energy shortage. The renewable energy generation, which is impressionable to vary in the environmental conditions and weather, is anticipated to be increasingly connected to distribution systems in the future [7]. However, the disadvantage is that wind power generation is intermittent, depending on weather conditions. Short-term energy storage is essential to get a smooth power output from a wind turbine [8].

Electric power distribution is the final stage to deliver electricity to end users. A distribution system's network carries electricity from high-voltage power transmission systems and therefore offers it to consumers via low-voltage residential power cables. The electric power distribution grid with renewable energy is defined as an integration of electrical loads and generation [9-10] as shown in Fig. 1.

A rotor axis of rotation in a turbine that is horizontal to the earthed is called a HAWT (Horizontal Axis Wind Turbine). Nowadays, HAWTs are illustrative of the majority of all large-scale wind turbines. These turbines are utilized in an upwind manner, where the rotor plane is set to be instantly upwind of the tower through the utilization of a yaw motor that rotates the entire nacelle. Wind passing over the turbine blades provides lift, and this then induces a rotational torque. This test system of the wind farm is double fed induction generator (DFIG) on which layout and component of Gamesa type G114- 2.0 MW are shown in Fig. 2 [12].

Wind turbine control is conventionally divided into four primary regions, as shown in Fig. 3. Region 1 spans operation from the start up to the âĂŸcut-
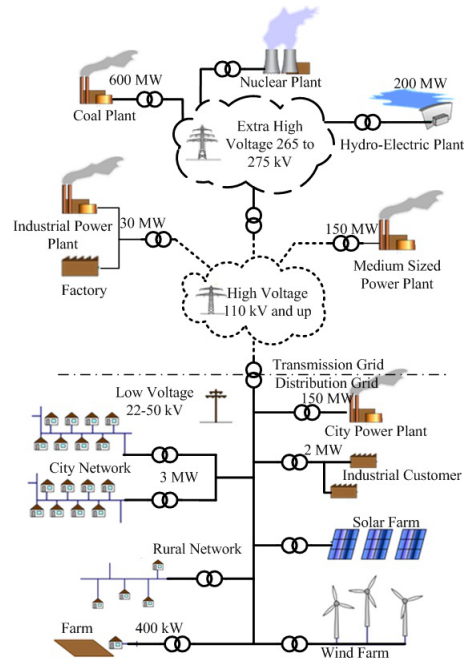

Fig.1: *Renewable energy plant for power distribution grid [11].*
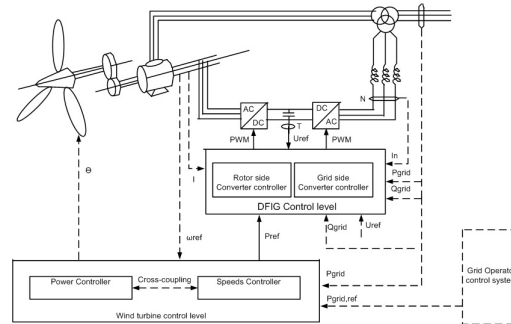

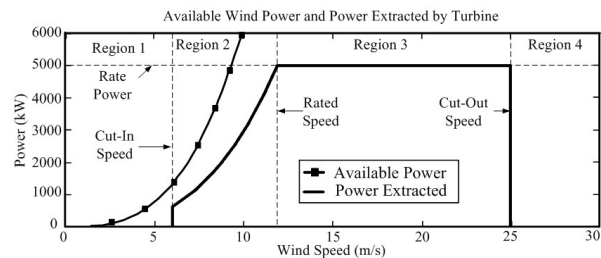**Fig.2:** *Wind Turbine Gamesa type G114-2.0 MW.*

Fig.3: *Wind power, turbine power, and operating regions for an example 5 MW turbine.*

in' wind speed where the generator is turned on and starts generating power. When wind speeds are over cut-in, but still too low to generate maximum power, the turbine is stated to be in Region 2. The objective is to increase aerodynamic efficiency to capture as much energy as possible from the wind stream in this below rated region. In Region 3, wind speed is highly sufficient to operate the generator at its rated power output; the goal is to regulate speed and power safely at rated levels in this case. In Region 4, the turbine shuts down due to high wind speeds to prevent damage to the turbine.

3. OPTIMAL PROBLEM FORMULATION

The optimal problem consists of a nonlinear objective function defined with nonlinear constraints. The general optimal problem can be expressed as a constrained optimization problem as follows.

Minimize   f(x)
Subject to   g(x) = 0, equality constraints
              h(x) ≤ 0, inequality constraints

h(x) ≤ 0, inequality constraints By converting both equality and inequality constraints to penalty terms and hence added to form the penalty function as shown in (1) and (2).

$$P(x) = f(x) + \Omega(x) \tag{1}$$

$$\Omega(x) = \rho\{g^2(x) + [\max(0, h(x))]^2\} \tag{2}$$

Where: P(x) is function of the penalty,
             $\Omega(x)$ is term of the penalty
             ρ is the penalty factor

The transformation of a constrained into an unconstrained optimization problem was achieved by employing a concept of the penalty method in which the penalty function as described above is minimized [13].

3.1 Objective Function and Constraints

The objective was set to control the reactive power which later has the influence to the appropriate bus voltage. Analysis of Power flow was performed to determine the appropriate value using adjustment value to analyze the reactive power compensation of wind farm. The objective function is load voltage derivation (LVD) shown in equation (3).

$$Min \quad f_1(x, u) = \sum_{k=1}^{n} \left(\frac{V_k^{ref} - V_k}{V_k^{ref}} \right)^2 \tag{3}$$

Where: V_{ref} is a reference voltage or nominal voltage (1 p.u./22 kV), V_k is voltage at bus k, x is the

state of the system, and u is the variable change. For the case of the wind farm, reactive power can be controlled by adjusting the real power related with power factor which shown in equation (4).

$$Q_i = F * P_{Gi} * \tan(\cos^{-1}(PF_i)) \tag{4}$$

Where: Q_i is reactive power (MVAR), P_{Gi} is the real power from a wind turbine, F is a constant operate mode; (+1) for (+Q) and (-1) for (-Q) and PF_i is the power factor.

3.2 System Constraints

Quantities of the controllable system are generator MW, controlled voltage magnitude and reactive power injection from wind turbine farm related with the power factor. Hence, no violation on other quantities (e.g. Generator MVAR, load bus voltage magnitude, MVA flow of transmission lines) occurs in normal system operating conditions. These are system constraints to be formed as equality and inequality constraints as shown below.

Equality constraint: Power flow equations are shown in (5) to (6) [14].

$$P_{G,i} - P_{D,i} - \sum_{j=1}^{N_B} |V_i||V_j||Y_{i,j}| \cos(\theta_{i,j} - \delta_i + \delta_j) = 0 \tag{5}$$

$$Q_{G,i} - Q_{D,i} + \sum_{j=1}^{N_B} |V_i||V_j||Y_{i,j}| \sin(\theta_{i,j} - \delta_i + \delta_j) = 0 \tag{6}$$

Where: $P_{G,i}$ is the real power generation at bus i,
         $P_{D,i}$ is the real power demand at bus i,
         $Q_{G,i}$ is the reactive power generation at bus i,
         N_B is the total number of buses,
         $Q_{D,i}$ is the reactive power demand at bus i,
         $\theta_{i,j}$ is the angle of bus admittance element i, j
         $Y_{i,j}$ is the magnitude of bus admittance element i, j

Inequality Constraint: Variable limitations are given in (7) to (10) [15].

$$V_i^{\min} \leq V_i \leq V_i^{\max} \tag{7}$$

$$PF_{WT,i}^{\min} \leq PF_{WT,i} \leq PF_{WT,i}^{\max} \tag{8}$$

$$Q_{WT,i}^{\min} \leq Q_{WT,i} \leq Q_{WT,i}^{\max} \tag{9}$$

$$P_{WT,i}^{\min} \leq P_{WT,i} \leq P_{WT,i}^{\max} \tag{10}$$

Where: V_i^{min}, V_i^{max} are upper and lower limits of voltage magnitude at bus i

$PF_{WT,i}^{\min}, PF_{WT,i}^{\max}$ are the upper and lower limits of the power factor of wind turbine farm module i

$Q_{WT,i}^{\min}, Q_{WT,i}^{\max}$ are the upper and lower limits of reactive power of wind turbine farm module i,

$P_{WT,i}^{\min}, P_{WT,i}^{\max}$ are the upper and lower limits of power generated by wind turbine farm module i

The penalty function can be formulated as expressed in (11), and sub-equation of penalty term is shown in (12) to (17).

$$P(x) = f_1(x,u) + \Omega_V + \Omega_{PF} + \Omega_Q + \Omega_{WT} \quad (11)$$

$$\Omega_P = \rho \sum_{i=1}^{N_B} \left\{ P_{G,i} - P_{D,i} - \sum_{j=1}^{N_B} |V_i||V_j||Y_{ij}| \cos(\theta_{i,j} - \delta_i + \delta_j) \right\}^2 \quad (12)$$

$$\Omega_Q = \rho \sum_{i=1}^{N_B} \left\{ Q_{G,i} - Q_{D,i} + \sum_{j=1}^{N_B} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \right\}^2 \quad (13)$$

$$\Omega_{Q,WT} = \rho \sum_{i=1}^{N_C} \left\{ \max\left(0, Q_{WT,i} - Q_{WT,i}^{\max}\right) \right\}^2 \\ + \rho \sum_{i=1}^{N_C} \left\{ \max\left(0, Q_{WT,i}^{\min} - Q_{WT,i}\right) \right\}^2 \quad (14)$$

$$\Omega_{PF} = \rho \sum_{i=1}^{N_T} \left\{ \max\left(0, PF_{WT,i} - PF_{WT,i}^{\max}\right) \right\}^2 \\ + \rho \sum_{i=1}^{N_T} \left\{ \max\left(0, PF_{WT,i}^{\min} - PF_{WT,i}\right) \right\}^2 \quad (15)$$

$$\Omega_V = \rho \sum_{i=1}^{N_B} \left\{ \max\left(0, V_i - V_i^{\max}\right) \right\}^2 \\ + \rho \sum_{i=1}^{N_B} \left\{ \max\left(0, V_i^{\min} - V_i\right) \right\}^2 \quad (16)$$

$$\Omega_{P,WT} = \rho \sum_{i=1}^{N_G} \left\{ \max\left(0, P_{WT,i} - P_{WT,i}^{\max}\right) \right\}^2 \\ + \rho \sum_{i=1}^{N_G} \left\{ \max\left(0, P_{WT,i}^{\min} - P_{WT,i}\right) \right\}^2 \quad (17)$$

N_G is the total number of generators,
N_C is the total number of reactive power sources
N_T is the total number of transformers

4. A CASE STUDY OF DAN KHUN THOT SUBSTATION

A 12-node test system with is "WA-YU" wind turbine farm project was employed as a special case to study the effectiveness and performance of the system. The wind turbine is located in Dan Khun Thot District, Nakhon Ratchasima, Thailand (see Fig. 4) and installed in feeder no. 9 at Dan Khun Thot substation in the 22 kV distribution system. The turbine is Sap Phlu Project wind farm number one rated 8.0 MW, Doubly Fed Induction Generator(DFIG) Gamesa type G114-2.0MW (2.0MWx4units, so the total rate is 8.0 MW). This wind farm contracted on VSPP-PEA-052/2555 for low voltage side and started on 10 July 2012. The relay setting for protecting wind turbine and substation are shown in Table 1. The relay setting was set to function in under voltage by relay code no. 27 (ANSI/IEEE code) which is set at 5% for voltage drop and can delay for 3.0 second with the alarm activated, 10% for voltage drop can delay for 1.0 second with the trip command to operate the circuit breaker. On the other hand, over voltage operates by relay code no. 59 which is 5% and can delay for 3.0 second with alarm, 10% can delay for 0.25 second with the trip command to operate the circuit breaker.

Table 1: *Relay setting criteria of voltage limitation*

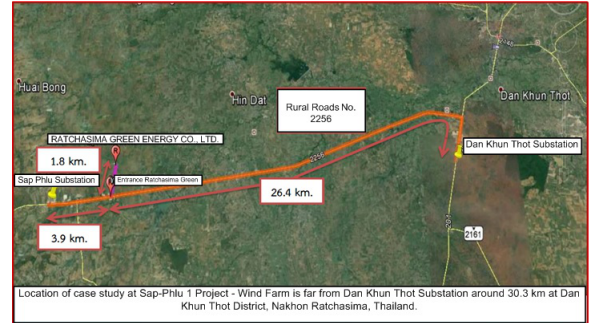| Function	Setting
Under Voltage: 27 U1<	95%, 3.00 sec. =Alarm
U2<	90%, 1.00 sec.=Trip
Over Voltage: 59 U1>	105%, 3.00 sec. =Alarm
U2>	110%, 0.25 sec.=Trip

Fig.4: *Location of a wind turbine for a case study in Dan Khun Thot, Nakhon Ratchasima, Thailand.*

5. SIMULATION RESULTS

The case study of a wind turbine was simulated by using the same computer which is an Intel, Core(TM) i5-6200U, CPU@ 2.3 GHz, 4.0 GB RAM. The results from the disturbance analyzer hardware device were collected and compared. The Digsilent software package was also used to solve power flow problem in the distribution network.

The relay settings were done by PEA team to take into account the grid codes which do not impact to

customers. The criteria of voltage limitation for PEA to control the quality of electricity are given in Table 2. For medium voltage level, normal operation is 5%, while the emergency operation is 10%. The low voltage level is 10% for both (normal and emergency operate)

Table 2: *The voltage's limitation to operate each voltage level*

Voltage Level	Normal Operate		Emergency Operate	
	Max.	Min.	Max.	Min.
115 kV	120.7 (5%)	109.2 (5%)	126.5 (10%)	103.5 (10%)
69 kV	72.4 (5%)	65.5 (5%)	75.9 (10%)	62.1 (10%)
32 kV	34.7 (5%)	31.3 (5%)	36.3 (10%)	29.7 (10%)
22kV	23.1 (5%)	20.9 (5%)	24.2 (10%)	19.8 (10%)
380 V	418 (10%)	342 (10%)	418 (10%)	342 (10%)
220 V	240 (10%)	200 (10%)	240 (10%)	200 (10%)

Practically, power factor control mode was adjusted by the discrete setting value of reactive power which is stepping of reactor and capacitor by 0.9 Mvar per step device. Fig. 5 illustrate typical reactive capability curve. The variable limits given in Table 3 were used as system constraints.

The power generator of wind plant is Doubly Fed Induction Generator (DFIG). To adjust the voltage at the point connection by controlling the reactive power function to optimal the real power produced is called "PF Control". Fig. 6 shows wind turbine is rated 2 MW per module, have four modules for "WA-YU" wind turbine farm project. Each module can receive and provide reactive power (Q) ranged between + 625kVar (provide) to 625kVar (receive) at power factor = 0.95 (inductive/capacitive). The rated electric power of 2.0 MW can manage active power on the graph control features of the PQ wind turbine generation in Fig. 7. The method is accordance with the increase or decrease of the voltage at the point of connection of power systems.

Table 3: *Variable Limits Used for load voltage derivation*

Variable	Limit	
	Min.	Max.
V1-V12 (p.u.)	0.95	1.05
WT(Q1-Q4) (kVAR)	-625	625
PF (WT1-WT4)	0.8	1.0
WT(P1-P4) (W=MW)	0	8.0

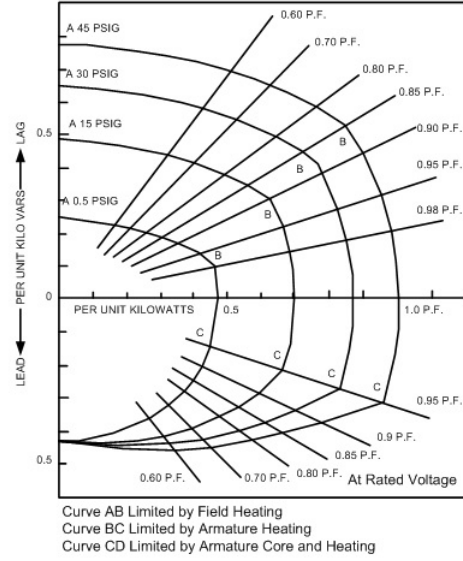The criteria are defined in the analysis as follows:

Fig. 5: *Curve power factor control on reactive power control of wind turbine.*

- The reference bus voltage is 22.6 kV (1.027 p.u).
- The total load on the distribution system is 2.0 MW.
- The conditions are light load and wind turbine generates power to grid at full capacity with 8.0 MW generation.
- The voltage of connection point at the industry is defined not exceed 22.80 kV in full generate capacity 8.0 MW of wind farm. Because over voltage will affect to neighboring plant higher than the standards set at 23.1 kV in the factory when not operating the production line
- The power factor translates diversion on the reactive power (Q) entered by capacitors (+ Q) or inductor (-Q) of the power plant, the rest of the distribution system PEA into the power system (Absorb Reactive Power).
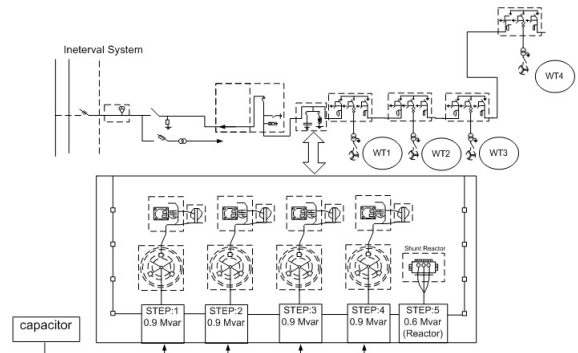

Fig. 6: *Wind turbine power plant 8.0 MW, 22 kV for the test system.*

The data of quality measurement analysis from the electrical disturbance analyzer device are shown for the period before and after corrective action. In Fig 8
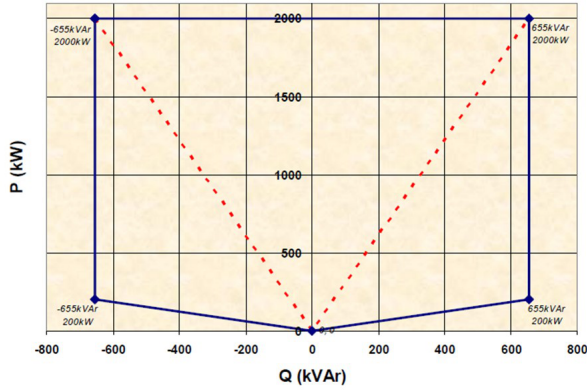
Fig.7: *P-Q characteristic of electricity power by wind turbine.*
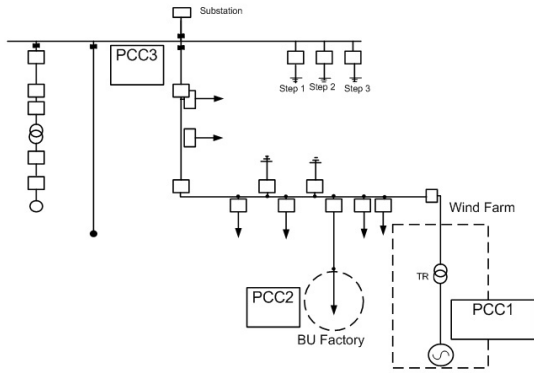

Fig.8: *The 8.0MW rated of wind power generation system connected to the distribution system of 22kV PEA.*

Fig.9: *State voltages exceeded at the power plant (PCC1).*
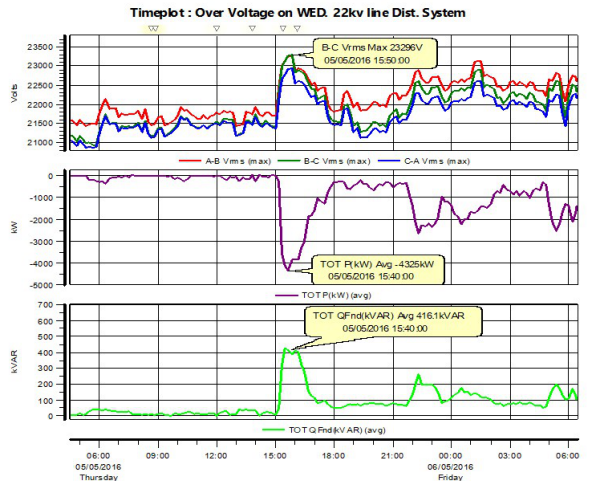
Fig.10: *Overvoltage conditions at the industry area as plant side (PCC2).*

the power plant is in PCC1 position, affected factories are in PCC.2 and power stations is in PCC.3 (PEA source).

Fig. 9 shows the voltage, real power and reactive power at PCC1. The conditions of overvoltage occurred due to the suitable feeding of real power from the wind farm to the grid level of about 5 MW and absorbed reactive power approximately 400 kVAR. On the other hand, the PCC2 point is the factory area which uses real power demand of 2 MW so the real power of wind turbine is excessive and high voltage effected. The overvoltage in factory area is shown in Fig 10.

Fig. 11 shows the low voltage side of service transformer at the substation is about 418.8 V which is higher than normal voltage in 10% (considered 380 Vrms of normal voltage) for support load demand about 2.2 MW while the wind turbine generated real power at 5 MW.

Table 4 shows that the wind turbine farm provides power to 22 kV distribution grid of the PEA. Capacity ranging from 60% of the installed capacity (8.0MW) begins to impact the excessive voltage in the distribution system. The entire electric power distribu-
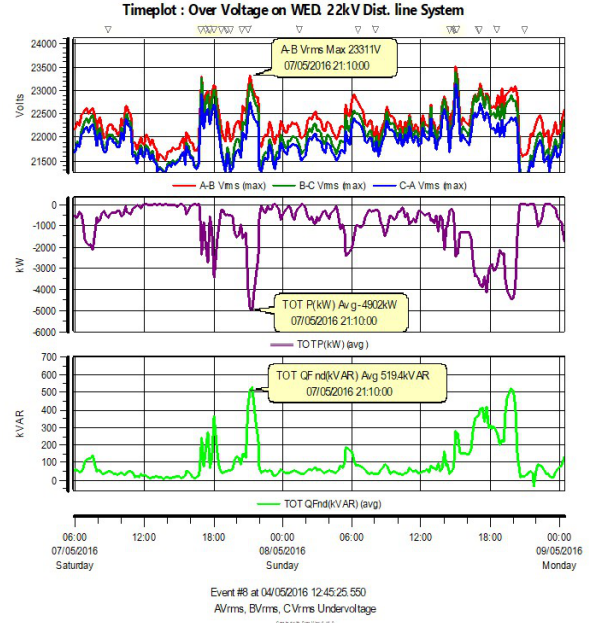
tion network is experienced with overvoltage because the wind turbine is connected to the same feeder at the 22-kV circuit. The protection device at the point of connection such as over voltage relay detected an overvoltage and commanded the Circuit Breaker in the MV switchgear to be operated, and this led to the severe impact on consumers (factory area).

The proposed method in this paper can find optimal reactive power related to the power factor to minimize the load voltage derivation as its objective function. The result showed that the voltage at a wind farm is controlled by the power factor setting at 0.98 lagging, where reactive power is set to feed into
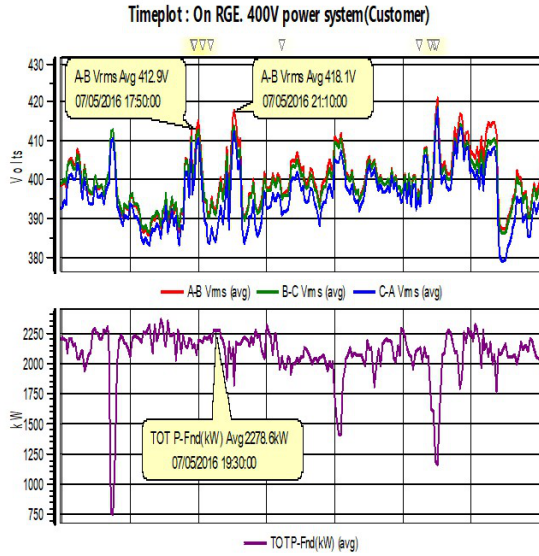
Fig.11: *The overvoltage of low voltage side transformer at PEA's power substation (PCC3).*

Table 4: *The data record of the electric parameter at wind turbine farm.*

Date	Time	P (MW)	Q (MVar)	PF.	Voltage (kV)	Overvoltage (% $22kV_{nor}$)
5/5/2016	15.40	-6.45	+0.65	0.997	23.30	5.9
11/5/2016	15.00	-7.35	+0.68	0.999	23.21	5.5
20/5/2016	19.30	-7.59	+0.91	0.998	23.60	7.2
21/5/2016	12.20	-7.81	+0.94	0.999	23.72	7.8
22/5/2016	06.00	-7.76	+0.92	0.998	24.05	9.3

the grid at 1.6 Mvar (inductive) with the maximum real power generation of 8 MW. The load voltage deviation for this case reduced to 0.0002 and confirmed its efficiency. The load voltage deviation becomes 0.0002.

The result of setting power factor at wind turbine site using optimization can regulate voltage magnitude of the wind farm, and the low voltage side is referring to the local PEA standard which is 22 kV+5% [16] as shown in Fig. 12. The result of voltage limitation is controlled related to wind turbine real /reactive power as illustrated in Fig. 13.

6. CONCLUSIONS

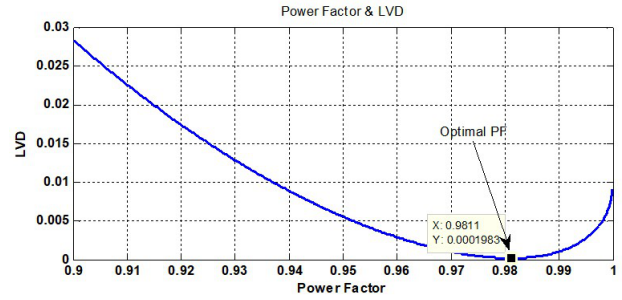The severity of overvoltage in the 22kV distribution system of PEA has an impact to the factory area

Fig.12: *Optimal power factor setting related to load voltage derivation of wind turbine power plants.*
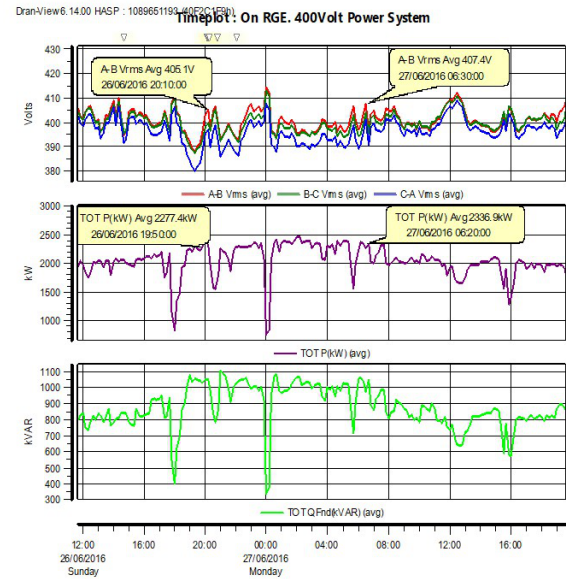

Fig.13: *Result of voltage limitation controlled related to wind turbine real/reactive power.*

caused by the wind turbine power plant. The over voltage is depended on the real power feed to the grid and effective control voltage. In this paper, purposes of power factor control combine power flow analysis was considered in the limitation of node voltage. The Digsilent software and disturbance analysing device were applied to find optimal power factor and reactive power from wind turbine farm with load voltage deviation as an objective function. The aim was to control the voltage at 22kV + 5% equals to 23.1kV based on PEA's standard definition which does not affect customers. Test results showed power factor setting at 0.98 (lagging) could provide an optimal active power from a wind turbine and feed to 22kV's distribution system of PEA. The best setting of reactive power was more intelligent control the voltage at the connection point not so high depend on the standard of PEA. The benefit of optimal voltage control is direct to wind turbine farm who sell electricity, to continually provide electricity to their customer. The over voltage relay as a protection device on 22kV's

switchgear showed an effective operation with the reduced effect to the nearby customers.

7. ACKNOWLEDGEMENT

References

[1] A. Bracale, P. Caramia, G. Carpinelli, A.RD. Fazio and G. Ferruzzi, "A Bayesian Method for Short - Term Probabilistic Forecasting of Photovoltaic Generation in Smart Grid Operation and Control," *Journal of Energies*, vol.6(2), pp. 733-747, 2013.

[2] B. Ozerdem and H.M. Turkeli, "Wind energy potential estimation and micrositting onIzmir Institute of Technology Campus," *Renewable Energy*, pp.1623-1633, 2005.

[3] Y. Zhang, L. Kang, B. Cao, C.N. Huang and G. Wu, "Renewable energy distributed power system with wind power and biogas generator," *Conference on Transmission and Distribution*, pp. 1-6, 2009.

[4] Y. L. Xin, L. Luan, W. H. Tang, G. Y. Chen and H. Wu, "Overvoltage protection on high-frequency switching transients in large offshore wind farms," *IEEE Power and Energy Society General Meeting (PESGM)*, pp. 1-5, 2016.

[5] K. Luewattana and A. Pruksanubal, "Effects of overvoltage on a ground grid system of high voltage substation," *International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, pp. 1-4, 2015.

[6] Regulation PEA on the terms of network connectivity, the year 2008.

[7] B. Ko, N.P. Utomo, G.J.J. Kim, and J. Cho, "Optimal Scheduling for the Complementary Energy Storage System Operation Based on Smart Metering Data in the DC Distribution System," *Journal on Energies*, Vol. 6, pp. 6569-6585, 2013.

[8] J. Aho, A. Buckspan, J. Laks, P. Fleming, J. Yunho, F. Dunne, M. Churchfield, L. Pao, and K. Johnson, "A tutorial of wind turbine control for supporting grid frequency through active power control," *American Control Conference (ACC)*, pp. 3120-3131, 2012.

[9] F. Katiraei and M.R. Iravani, "Micro-Grid autonomous operation during and subsequent to islanding process," *EEE Transaction on Power Delivery*, Vol. 20, pp. 248-257, (2005).

[10] F. Katiraei and M.R. Iravani, "Power management strategies for a Micro-grid with multiple distributed generation units," *IEEE Transaction on Power System*, Vol. 21, pp. 1821-1831, 2006.

[11] Power distribution, From Wikipedia, the free encyclopedia, June 2014.

[12] J. Zhenhua and Y. Xunwei, "Modeling and control of an integrated wind power generation and energy storage system," *Power and Energy Society General Meeting*, pp.1-8, 2009.

[13] P. Dutta and A. K. Sinha, "Voltage Stability Constrained Multi-Objective Optimal Power Flow using Particle Swarm Optimization," *1st International Conference on Industrial and Information Systems*, pp. 161-166, 2006.

[14] N. Sinsuphun, U. Leeton, and Kulworawanichpong, T. "Optimal power flow solution using improved harmony search method," *published by ELSEVIER Applied Soft Computing*, Vol. 13, Issue 5, pp. 2364- 2374, 2013.

[15] U. Leeton, D. Uthitsunthorn, U. Kwannetr, N. Sinsuphun; and T. Kulworawanichpong, "Power loss minimization using optimal power flow based on particle swarm optimization," *The 2010 ECTI International Confernce on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON2010)*, pp. 440-444, 2010.

[16] Energy Regulatory Commission, "the purchasing power of private," sources: http://www.eppo.go.th/power/powerN/PICP/File/(1).pdf online:11/08/2558]

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