A STUDY OF VOLTAGE STABILITY ENHANCEMENT OF ISOLATED HYBRID DIESEL AND WIND GENERATORS ON PHU QUI ISLAND
NÂNG CAO ỔN ĐỊNH ĐIỆN ÁP CỦA HỆ THỐNG ĐIỆN ĐỘC LẬP KẾT HỢP MÁY PHÁT DIESEL VÀ MÁY PHÁT ĐIỆN GIÓ Ở ĐẢO PHÚ QUÍ

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Abstract - This paper focuses on voltage stability improvement of isolated hybrid diesel and wind generator system with increased wind power penetration in order to reduce the number of existing diesel generators. The system is located on Phu Qui Island, Binh Thuan province, Vietnam, and consists of 6 x 0.5-MW diesel synchronous generators (SG) and 3 x 2-MW wind turbine-based doubly fed induction generators (DFIG) interconnected to the local 22-kV isolated grid. Simulation results are performed to test the stability of the voltage system with different wind energy penetration levels and a static VAR compensator (SVC). It can be concluded that the voltage of the studied system can remain stable with wind energy penetration of 77%.

Key words - diesel synchronous generators, doubly fed induction generator (DFIG), static VAR compensator (SVC), stability.

Tóm tắt- Bài báo tập trung vào vấn đề nâng cao ổn định điện áp cho hệ thống điện độc lập kết hợp giữa máy phát diesel và máy phát điện gió bằng việc nâng cao lượng điện năng phát ra từ máy phát điện gió để giảm số lượng máy phát điện bằng diesel. Hệ thống điệnđược nghiên cứu nằm ở đảo Phú Quí thuộc tỉnh Bình Thuận, Việt nam bao gồm 6 máy phát điện đồng bộ 0,5-MW chạy bằng động cơ diesel và 3 máy phát điện gió 2-MW sử dụng máy phát điện nguồn đôi (DFIG) nối vào lưới 22-kV. Kết quả mô phỏng được thực hiện để kiểm tra tính ổn định của điện áp với các mức độ thâm nhập khác nhau của điện gió và thiết bị bù tĩnh (SVC) được đề xuất. Có thể kết luận rằng điện áp của hệ thống nghiên cứu có thể duy trì ổn định khi nâng cao mức thâm nhập của điện gió lên đến 77%.

Từ khóa - máy phát điện đồng bộ diesel, máy phát nguồn đôi, thiết bị bù tĩnh, ổn định.

1. Introduction

The 6-MW wind farm including 3 x 2-MW wind turbine doubly fed induction generator (DFIG) on Phu Qui Island is the first plant in Vietnam to use both wind energy and diesel oil to generate power. This wind power plant is expected to provide an average of 25.4 million kWh of electricity a year, enough to ensure daily demand on the Phu Qui Island. The configuration of power grid on Phu Qui Island is depicted in Figure 1. The system consists of 36 buses including two main power supplies 3 x 2-MW VestasV80 wind turbine generators and 6 x 0.5-MW Cummin diesel generators connected to a 22-kV isolated grid and 34 load buses. Each wind turbine generator includes a 2-MW DFIG with 0.69 kV terminal voltage; a 2100-kVA 22/0.69-kV transformer, a 0.69-kV circuit breaker; rectifiers, protection controls and communication [1].

Besides, in an isolated power system, diesel generators are usually used to generate electricity since they can meet the basic requirements from power system standards such as frequency demand, voltage control, as well as quickly response with the load change. However, the main disadvantage of diesel generators is that they have to run with at least 30% nominal power.

In the considered system, the total wind generator capacity is higher than that of the diesel generators. The diesel generators will be operated together with the DFIG based wind turbines in the considered isolated system. Maximum demand is about 2.4-MW, which is smaller than the total diesel installed capacity. The considered scenarios are [2]:

- 50% power from wind and 50% power from diesel in case the load is greater or equal than 1.1-MW.
- When the load is smaller than 1.1-MW and the wind speed is greater than 7.2 m/s the generated power of wind generators and diesel generators is 70% and 30%, respectively.

This paper focuses on increasing the penetration levels of wind power to the system to reduce the generated power from the diesel generators in order to reduce electricity tariff.

2. Case Study on Phu Qui Island

With the operating modes mentioned above, when the load is greater than 1.1-MW the power sharing between diesel and wind generators is 50% and 50%, respectively. It can be seen that the generated power of the wind farm is relatively small compared to the 6-MW installed capacity. Thus, this paper studies the effects on voltage stability due to increased wind energy penetration level in the isolated power grid on Phu Qui Island. The simulation results which are performed in PSAT toolbox considering the different wind speed conditions measured on Phu Qui Island are shown in Table 1. The detailed parameters of loads are shown in Table 2 in the Appendix.

Table 1. Wind speeds in Phu Qui Island (m/s)

Month / Height	1	2	3	4	5	6	7	8	9	10	11	12	AVE
60m	7,7	7,0	7,7	5,5	5,7	7,5	6,7	6,9	6,1	4,7	6,2	8,9	6,7

According to the values of power demand shown in Figure 2, the load demand of Phu Qui Island in June 2013,

for example, is around 2.2-MW which is selected as a base case to study different wind energy penetration levels.

Figure 3 shows the voltage at all buses (a) and active power of the generators (bus 1 for wind turbine generators and bus 7 for diesel generators) and the loads (b) with the generating power of diesel generator is 50% and wind turbine generator is 50%. It can be seen that the voltage at each bus reaches the maximum grid code limit (± 5%).

For testing the penetration levels of wind energy to power system, in these cases, electric power from wind turbine generators is increased from 1.1-MW to 1.8-MW and electric power from diesel generator is decreased from 1.1-MW to 0.4-MW respectively with a step change of 0.1-MW. A droop control technique is used for power sharing [3].

The voltage levels obtained with PSAT software [4, 5] and different penetration levels are shown in Fig. 4. However, when the wind energy increases up to 1.8-MW the voltages at bus 26 (DA_DEN) and bus 27 (XOM_RAY) drop under 0.95 p.u. To solve this problem, shunt FACTS devices such as SVC or STATCOM [6] can be used to improve the voltage magnitude of these buses. However, anSVC is proposed due to the financial reason [7].

Power flow studies show that, when the load demand is higher than 1.1MW, wind energy penetration can be increased to 77%(i.e. 1.7-MW of 2.2-MW) by means of a 0.5 MVArSVC connected to bus 27 (XOM_RAY) since this bus has large load capacity than bus 26 (DA_DEN) (see Table 2 for more details).
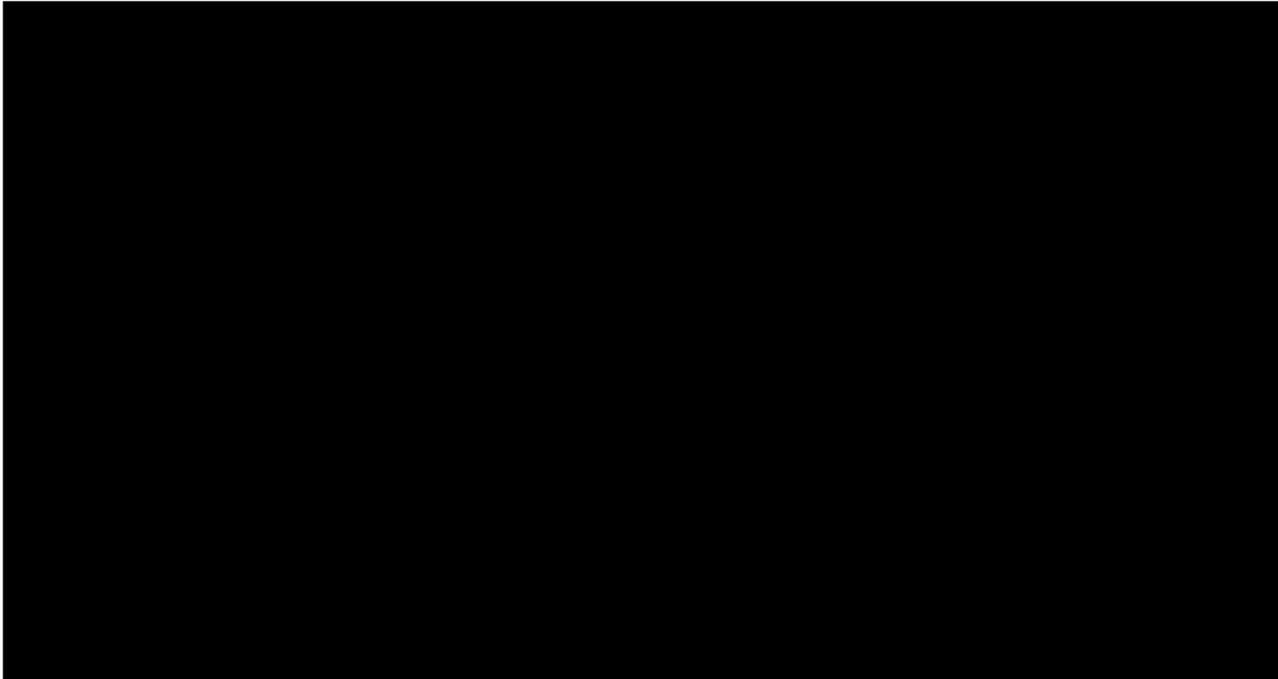

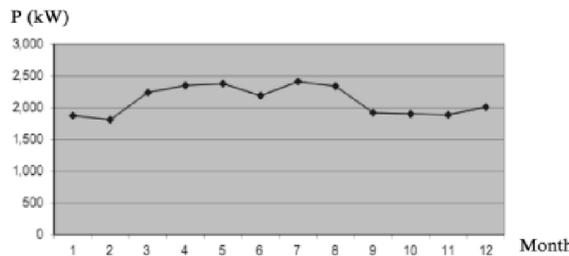*Figure 1*. *One line diagram of the isolated grid in Phu Qui Island*
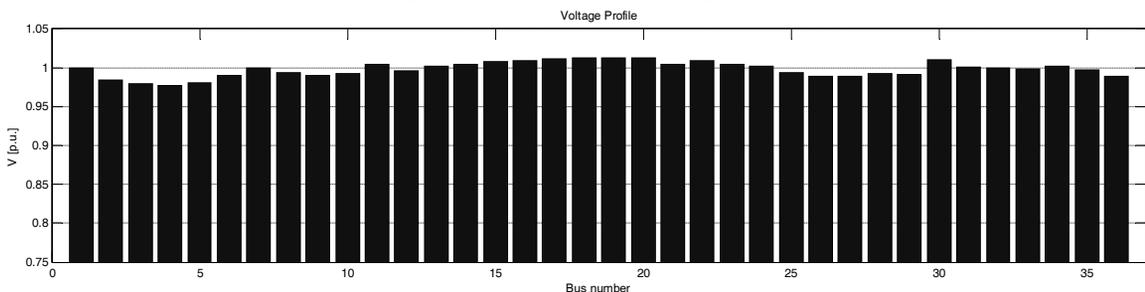

Figure 2. *Power demand in Phu Qui Island*

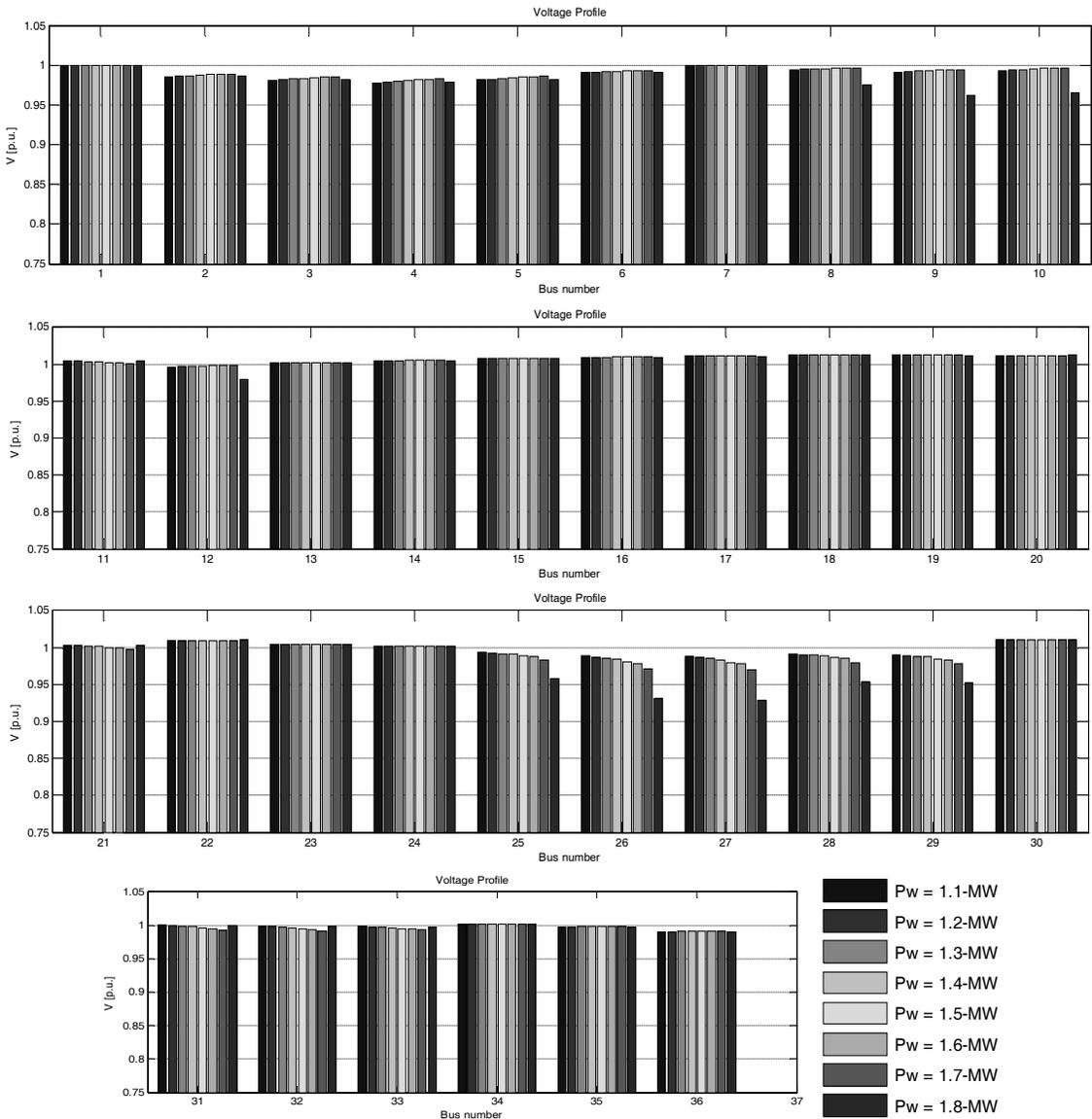*Figure 3.* *Voltage profiles at 36 buses*

Figure 4. Voltage profile at 36 buses with different penetration levels of wind energy

3. Time Domain Simulation

This section utilizes the nonlinear system model to compare the damping characteristics contributed by the proposed SVC [8]. The single-phase equivalent circuit of the SVC with thyristor-controlled reactor-fixed capacitor (TCR-FC) type and the control block diagram for the equivalent susceptance (B_{SVC}) of the SVC are shown in Figure 5 and Figure 6, respectively [9].

When the system voltage is lower than the reference value, the value of B_{SVC} of the SVC is positive to inject reactive power to the system; when the system voltage is higher than the reference value, the B_{SVC} of the SVC is negative to absorb reactive power from the power system.

Assuming a balanced and fundamental-frequency operation, the equivalent B_{SVC} of the SVC is a function of the firing angle α as shown below.

$$B_{SVC}(\alpha) = \frac{2\alpha - \sin 2\alpha - \pi\left(2 - \dfrac{X_L}{X_C}\right)}{2\pi X_L} \quad (1)$$

where X_L and X_C are reactance of reactor and capacitor of SVC, respectively.
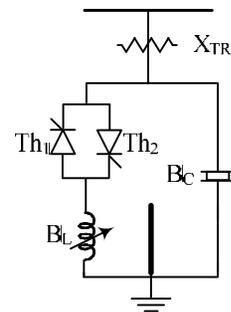

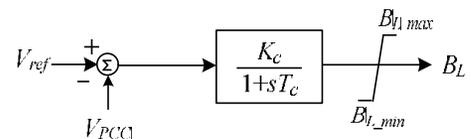*Figure 5. The single-phase equivalent circuit of the SVC*

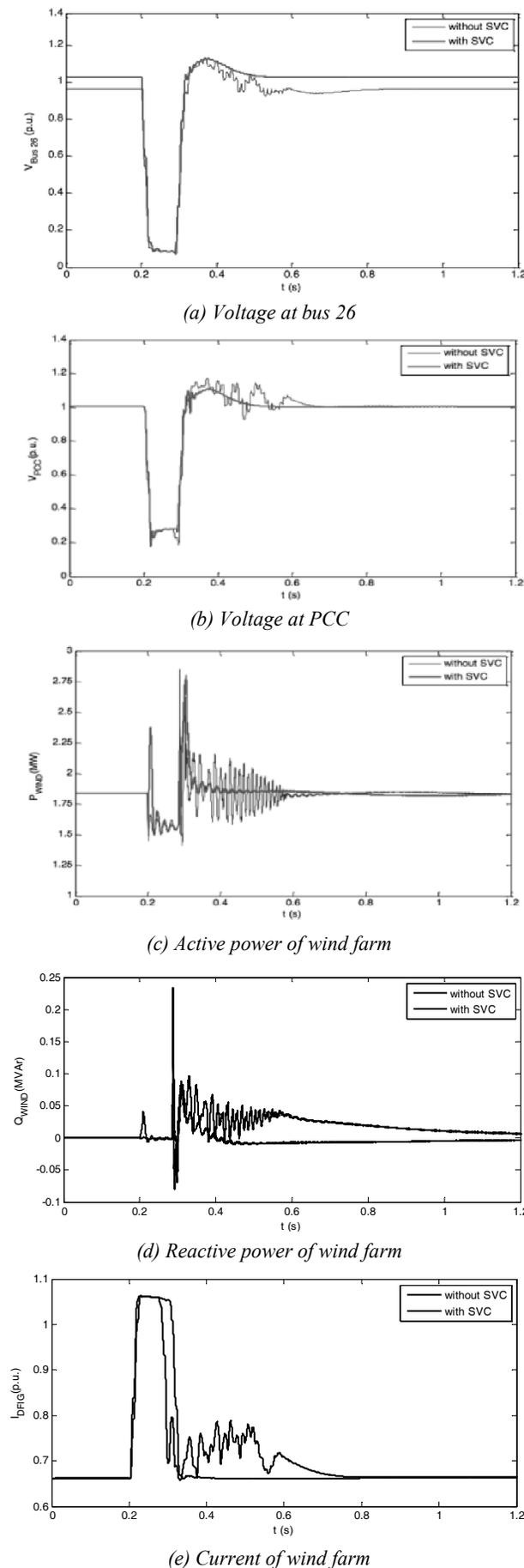*Figure 6. Control block diagram of the employed SVC*

(a) Voltage at bus 26

(b) Voltage at PCC

(c) Active power of wind farm

(d) Reactive power of wind farm

(e) Current of wind farm

Figure 7. *Comparative transient responses of the studied system*

Clearly, the included SVC does improve the voltage profile. In order to ascertain the improvement on transient voltage stability, the system response to a three phase fault is studied. The short-circuit fault is located at LTD 472.3 and starts at t = 0.2 s and the fault is cleared after 5 cycles. In this case, the considered wind power generation is 1.8-MW.

Figure 7 shows the comparative transient responses of the system. It is clearly seen from Figure 7(a) that, when the SVC is in service, the voltage at bus 27 is increased and the damping of the system is better. The voltage at the PCC, the active, the reactive and the current of wind system are also presented to demonstrate the effect of SVC on improving the voltage quality of the studied system in Figures 7(b) to (e), respectively. From the simulation results in Figure 7 we can see that the penetration level of wind energy can be improved up to 82% (1.8-MW of 2.2-MW).

4. Conclusions

This paper has presented a study of voltage stability of an isolated hybrid diesel and wind generator system by increasing the penetration of the wind power into system. It can be seen from the simulation results that for all operation situations the penetration of wind power can be improved up to 77% to supply power to grid for reducing electricity tariff. In case of low voltage buses, an SVC can be used to improve the voltage profile and optimize the wind power extracting to power grid. Moreover, it has been shown that the use of the proposed SVC does improve the transient voltage stability of the complete system.

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Appendix

Table 2. *Rated Load Parameters*

No.	Load name	S_{rated} (KVA)	P_{rated} (KW)	Q_{rated} (KVAR)
1	TU_DUNG	45	40.5	19.575
2	CANG_PHU_QUI	150	135	65.25
3	LINH_QUANG	50	45	21.75
4	XA_TAM_THANH	150	135	65.25
5	TAM_THANH_2	25	22.5	10.875
6	CHO_TAM_THANH	150	135	65.25
7	TT_PHU_QUI	50	45	21.75
8	TAM_THANH_1	150	135	65.25
9	NN_NONG_NGHIEP	45	40.5	19.575
10	DAI_TRUYEN_HINH	112.5	101.25	48.9375
11	TTVH_HUYEN	150	135	65.25
12	BUU_DIEN	45	40.5	19.575
13	TT_Y_TE	95	85.5	41.325
14	NHA_MAY_NUOC_1	250	225	108.75
15	NGU_PHUNG_5	125	112.5	54.375
16	NGU_PHUNG_1	150	135	65.25
17	NGU_PHUNG_2	125	112.5	54.375
18	NGU_PHUNG_4	75	67.5	32.625
19	NGU_PHUNG_3	112.5	101.25	48.9375
20	HUYEN_DOI	50	45	21.75
21	UB XA_LONG_HAI	175	157.5	76.125
22	LONG_HAI_2	50	45	21.75
23	LONG_HAI_3	112.5	101.25	48.9375
24	LONG_HAI_1	150	135	65.25
25	CAO_CAT	15	13.5	6.525
26	DA_DEN	37.5	33.75	16.3125
27	XOM_RAY	250	225	108.75
28	XOM_COI	112.5	101.25	48.9375
29	PHU_THANG	150	135	65.25
30	QUANG_HAI	320	288	139.2
31	NHA_MAY_NUOC_2	250	225	108.75
32	GO_MAY	45	40.5	19.575
Total		**3772.5**	**3395.25**	**1641.04**

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