ELEKTROTEHNIŠKI VESTNIK 87(3): 142-146, 2020
ORIGINAL SCIENTIFIC PAPER

Increasing the Wind Farms Penetration Level using SVC Devices to Ensure Voltage Stability

Mehrdad Ahmadi Kamarposhti

Department of Electrical Engineering, Jouybar Branch, Islamic Azad University, Jouybar, Iran
E-mail: mehrdad.ahmadi.k@gmail.com, m.ahmadi@jouybariau.ac.ir

Abstract. The worldwide approach to use the renewable and wind energy has been considered as the main source of electrical energy production in recent years. Wind power plants are usually created in remote areas and special geographic conditions, and they have a great importance and sensitivity. According to the variable and uneven nature of the wind speed, the induction generator is commonly used to convert the wind kinetic energy into the electrical energy in wind turbines. It is much simpler to manufacture, repair and maintain the induction generator than synchronous generator. Despite certain disadvantages such as their consumption of a large amount of the grid reactive current resulting in a loss of the voltage profile and grid instability, the power grid voltage control has always been one of the most important challenges of the power industry. Therefore, the paper discusses the design and implementation of a SVC reactive-power compensator and compares the use of non-compensator and compensator modes in wind power plants.

Keywords: SVC, reactive power compensator, voltage stability, voltage stability margin (VSM), wind farm.

Povečanje deleža vetrnih elektrarn z uporabo statičnih kompenzatorjev jalove energije

Pri proizvodnji električne energije je v zadnjih letih vedno večji poudarek na uporabi obnovljivih virov. Pri tem imajo veliko vlogo tudi vetrne elektrarne. Glede na spremenljivo in neenakomerno naravo hitrosti vetra se v vetrnih elektrarnah za pretvorbo kinetične energije vetra v električno energijo uporabljajo asinhronski generatorji. Načrtovanje, izdelava, popravilo in vzdrževanje asinhronskih generatorjev so veliko enostavnejši kot pri sinhronskih generatorjih. Slabost asinhronskih generatorjev je poraba jalove moči v elektroenergetskem omrežju, katere posledici sta slabši napetostni profil in nestabilnost omrežja. V članku obravnavamo zasnovo in izgradnjo statičnega kompenzatorja jalove energije in analiziramo njegovo uporabo pri vetrnih elektrarnah.

1 INTRODUCTION

The wind energy is one of the most important renewable sources in the world. By 2020, the share of the wind-generated electrical energy is predicted to be 10% of the total wind energy demand. The excessive increase in the fossil fuel price and environmental considerations are two of the several reasons to use this clean energy. In Iran, steps have been recently taken to build wind power plants and install wind turbines, similar to those operating in the Manjil and Binaloud wind power plants. Power system voltage control has always been one of the most important parameters affecting the power system quality. Yet, due to the use of induction generators and the wind power plant sensitivity, a significant decrease is being noted in the voltage profile at most times of the day (the same applies for the Manjil and Binaloud wind power plants) Therefore, the critical voltage oscillations should be put under control at the soonest possible time. To solve the issue, reactive-power compensators such as capacitive banks, SVCs and STATCOM should be used to adjust and control the wind power plant voltage. In the light of the importance of the reactive-power compensators in a power grid, the paper investigates the application of an SVC reactive-power compensator to improve power system voltage stability and increase its transmission capacity.

2 VOLTAGE STABILITY MARGIN (VSM)

It has been shown in various sources that increasing the wind permeability increases the reactive power demand which, may lead to a voltage instability. [2-5.] By increasing power system wind production penetration and its reactive power demand, the voltage stability constraints have become the most limiting factor in increasing the permeability of the power system wind production [3-5]. The maximum wind power permeability level depends on available VSM2 a of power system [3] and [4]. In order to maximize the wind penetration level in a power system, wind farms a minimized negative effect on VSM should be larger by size. Limiting the wind farm maximum size based on the assumption that a high wind speed occurs simultaneously with the peak-load interval, may not maximize the wind

Received 4 January 2020
Accepted 7 April 2020

penetration level [6], to increase the voltage stability and maximize the farm size.

3 EXPECTED VOLTAGE STABILITY EVALUATION

A power system experiences a state of voltage instability when there is a progressively decreased or uncontrollable voltage level, following a disruption, an increase in the load demand or a change in the system operating state. For a stable voltage system, increasing the reactive power "Q" leads to an increase in the bus "V". For an unstable voltage system, increasing reactive power "Q" leads to a decrease in the voltage in the bus V [7]. The curved V-Q method used to calculate VSM has many advantages over other stability analysis static tools, especially for each stage where the lack of reactive power "Q" causes the power systems to reach the point of collapse. In this paper and in accordance with the local tool criteria, no bus voltage should fall below 0.9 p.u.

EVSM described in [1] is used to measure the effect of a wind farm size on the system voltage stability. When considering the probabilistic nature of wind speed, EVSM is a sum of the VSM of each wind speed multiplied by the probability of its occurrence (Equation 1):

$$EVSM = \sum_{i=1}^{n} VSM(V_{wind}) * \text{probability}\,(V_{wind}) \quad (1)$$

Where VSM (V_{-wind}) is the voltage stability margin calculated for the wind speed V_{-wind} measured at a wind farm site V_{-wind} is the probability of the wind speed occurrence and n is the number of different wind-speed intervals included in the EVSM calculations. To evaluate the effect of increasing a wind farm size on the voltage stability, new index of the expected voltage stability L_i indicates that the system is strong and its stability is not significantly affected by changing the wind farm size.

L_i is calculated from the difference between the final initial system EVSM divided by the system initial EVSM. The L_i index is given with Equation 2.

$$L_i = \frac{\text{EVSM}_b - \text{EVSM}_a}{\text{EVSM}_b} \quad (2)$$

Where, EVSM_b is the expected system stability margin before increasing a wind farm size and EVSM_a is the expected system voltage stability margin after increasing a wind farm size.

The value of the L_i index is between 0 and 1, the 0 value shows that the expected system voltage stability is not affected by increasing a wind farm size. L_i when equal to 1 shows that by increasing a wind farm size the expected system stability is unstable.

4 STATIC VAR COMPENSATORS (SVC)

One of the methods of the wind power plant reactive compensation is to use a SVC which is a reactive-power static var generator or absorbent connected in parallel to the grid with its output is controlled for the exchange of the capacitive or inductive current. Using SVC, the voltage is maintained and controlled within the permissible limits. There are different SVC types, such as:

- Thyristor controlled reactor (TCR)
- Thyristor switched capacitors (TSC)
- Thyristor-controlled Constant and reactive capacitors (TCR / FC)
- Thyristor-Controlled capacitor and reactive Thyristor-controlled reactive capacitor (TSC / TCR)

In wind power plants, fixed capacitive compensators and thyristor-controlled reactors controlled are used (TCR / FC) [9]. These compensators act as a dynamic reactive power controlling device. Their capacity is set to permissible maximum and minimum value to maintain an adequate reactive power thus assuring the wind power plant voltage stability. SVCs are designed and constructed so that they continuously and smoothly respond to sudden voltage changes thus preventing the voltage to collapse. These compensators are usually installed in a communication bus of a local grid of a wind power plant and to increase the reliability. A block diagram of an SVC control system is shown in Figure 1.

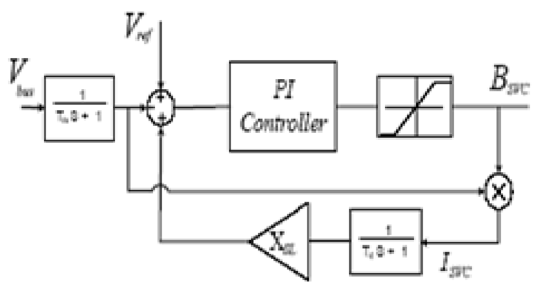

Figure 1: Block of diagram of a conventional control system (SVC) [9]

Using SVC considerably improves the voltage profile compared to using a capacitive non-compensator mode and minimizes the destructive effect of the capacitor bank steps changes on the wind turbine mechanical equipment.

5 SIMULATION RESULTS

The method used to measure the observed wind farm is applied to an IEEE 14-bus grid (see Fig. 2. 2). For optimal measurement two new wind farms are studied in two separate areas placed in a similar area and their internal connections have the same transmission equipment on the 8, 13 KV voltage level. They are connected on the network at 8, 13 KV network level, and are modeled as PQ bus at the connection point with a constant power coefficient of pre-phase/post-phase (0.95). The calculated VSM is generated based on a realistically assumed wind-power composition.

In the considered peak month, the load reaches its peak in the afternoon at 4 to 6 pm. (see Fig. 3 where the peak is marked in orange). Most loads are irrigation, small commercial and residential loads. The wind infusion into the base model leads to a decrease in VSM for all hours of the day.

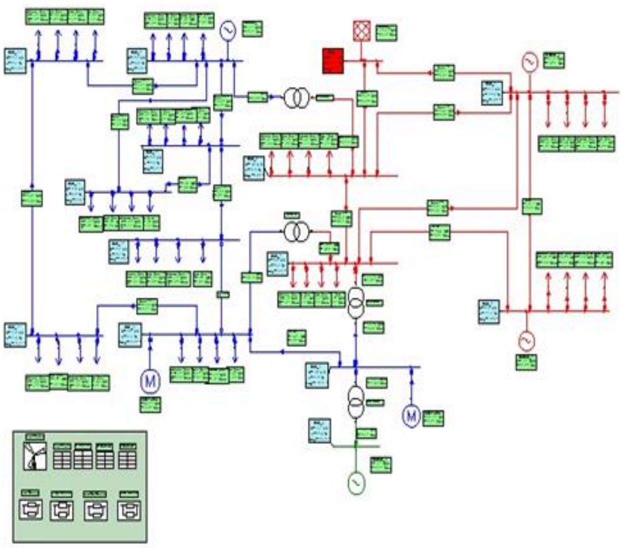

Figure 2: IEEE 14-bus in the NEPLAN software

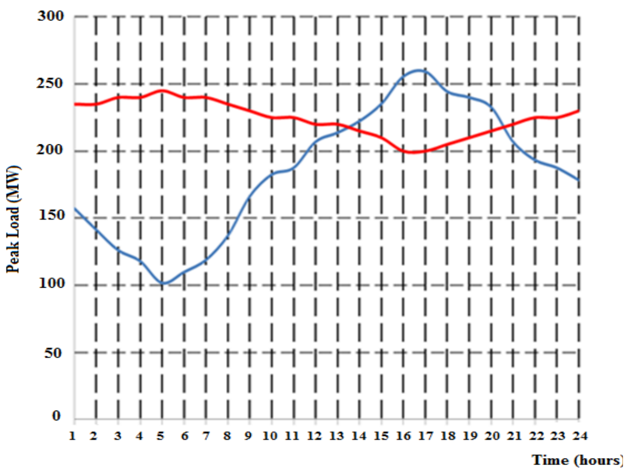

Figure 3: Maximum hourly peak load for the peak month and the maximum wind farm size of the IEEE 14-bus

The maximum wind infusion shown in blue in Figure 3 is the maximum wind farm size that can safely be injected into a system without causing any voltage instability for any hour of the day. The maximum wind farm size at this hour of the day is the measuring the voltage stability. If the maximum wind farm size does not exceed 240 MW, there will be no definite hour of the expected wind. The 4 p.m. and 5 p.m. hours are the lowest maximum limit for such wind farm. In the interval from 1 a.m. to 8 a.m. the wind farm limit size is maximal.

5.1 Grid investigation in a non-SVC mode

In order to investigate the effect of the increase in the wind farm size above the stable size of 200 MW. VSM and EVSM, four new sizes are investigated. i.e. 250, 300, 350 and 400 MW. There is no significant difference in the increase in the number of definite hours between samples 4 and 5 (see Fig. 2), as many of the expected waiting hours of a wind farm are between 90% and 100% of the wind farm characteristics or around 0% to 10% of the categorized license plate. This complies with [4] where it is shown that wind farms are exploited mainly at their highest point or near the lowest output due to the wind speed relationship.

To determine the effect of the increase in the wind farm size above the stable size of 200 MW, the four new sizes are investigated. Increasing the number of definite hours, does not significantly change between samples 4 and 5, because many of the expected working hours of a wind farm are classified between 90% and 100% of the plaque of the characteristic of the farm wind or around 0% to 10% of the plaque of characteristics. This is in compliance with reference [4], where it is shown that the power of a wind farms is exploited mainly at its highest limit or near its lowest output according to the wind speed relationship.

EVSM of the Li index is calculated for a maximum increased in the wind farm size. When a wind farm size increases, the Li index increases too. This shows that the system VSM decreases when more wind is injected into a system. The highest Li index is found with sample 5 at 5 p.m. At this time of the day, the system is at its lowest stability point. The change in EVSM of the Li index between samples 4 and 5 is much less than the case of sample 2, 4, and 5.

This shows that increasing the wind farm size above 200 MW decreases the voltage stability. A 400 MW wind farm tends to have the highest value of the Li index, the worst state is analyzed of the five cases. The average Li index for the 400 MW case reaches 0.534 MVar which is 1.40 times higher than the average Li index calculated for the 250 MW case (case 2). Table 3 shows the effect of increasing the maximum wind farm size on the system expected voltage stability. Note that VSM does not predict the daily hour with the worst stability calculation. In case 5, the worst EVSM is calculated at 5 p.m. and is 11.22 MVar with EVSM of the Li index of 0.534 MVar, which is the worst value of all cases.

The number of definite hours is determined by counting the number of hours of the wind farm production above 200 MW. Figure 4 summarizes Table 3. The expected number of the definite hours increases with the increase in the maximum wind farm size. Increasing the wind farm size from 200 MW to 250 MW makes the definite hour to be at 2 p.m.. The definite hour has become doubled by increasing the wind farm size. In cases 4 and 5, the probable definite hour increases to 34 and 36, respectively. This increase is due to the reduced system VSM resulting from the wind infusion.

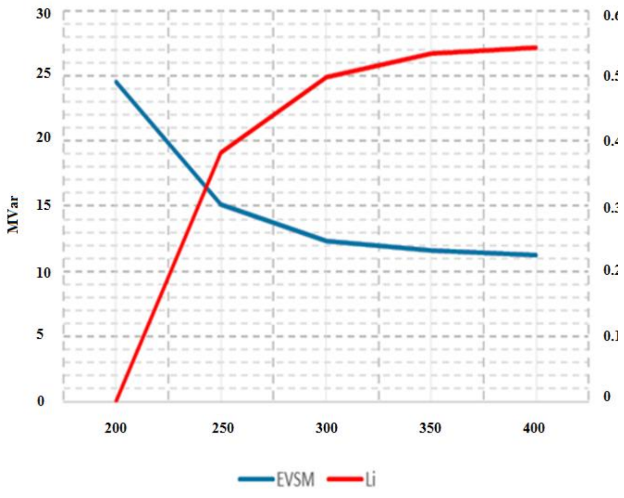

Figure 4: Average EVSM and the Li index at 4 p.m. and 5 p.m.

5.2 Grid investigation the in the SVC mode

In this section, the grid is investigated at 4p.m. and 5 p.m., when the load is the highest, after adding SVC to the grid. SVC is added at the weakest bus in terms of the voltage stability.

Table 1: Expected voltage stability Li index as a function of the variations in the maximum wind farm size after adding SVC

17	Daily Hours	Peak Month
18.34	EVSM	Mode 1. 260 MW
12.87	EVSM	Mode 2. 300 MW
0.298	Li	
12.18	EVSM	Mode 3. 350 MW
0.335	Li	
11.40	EVSM	Mode 4. 400 MW
0.378	Li	

In the considered grid the lowest voltage stability is at bus 14. The SVC size is 45 MVar. The reason for choosing SVC value is that the injection power of 260 MW is reached at the grid peak hour. This is the highest injection value to the grid at a peak month without using SVC.

To investigate the effect of the increase in the wind farm size above the stable size of 260 MW at a peak hour, on VSM and EVSM, the new size investigated with our load dispersion model are 300, 350 and 400 MW. Details of the EVSM calculation for a 260 MW wind farm at its peak hour is at 5 p.m. are shown in Table 1. EVSM is calculated by multiplying the VSM output power probability, which is related to the wind farm output power.

The calculated data, shows that the value of the Li index obtained by adding SVC significantly changes and declines at 5 p.m. as shown in Figure 5 of the peak month. Adding SVC reduces definite hours from 36 hours to 26 hours upon a 400MW injection.

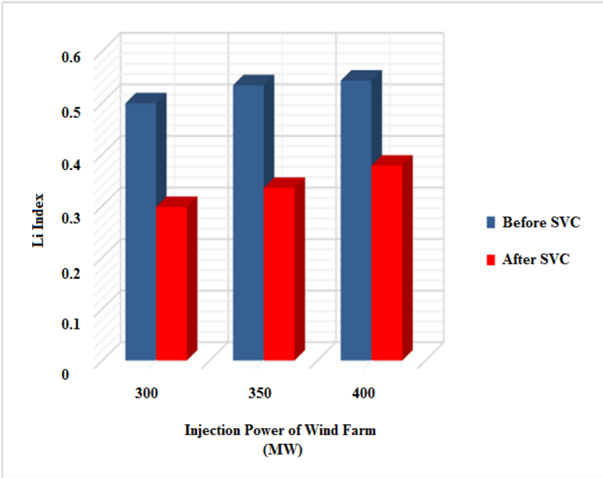

Figure 5: Difference in the Li index value before and after adding SVC at 5 pm

After adding SVC, at an increased injection power from 200 MW to 260 MW, the average Li index value is reduced by 45% at a 400 MW power injection.

6 Conclusion

The method presented in this paper determines the effect of increasing the maximum wind farm size above the stable voltage size. If the wind farm size increases, there is more wind energy injected. To investigate the size effect on stability margin, the system of wind speed patterns are analyzed. The number of the definite hours may be very large, when the power system EVSM is low.

A qualitative analysis is effectively used when maximizing the wind penetration levels of wind in a weak grid by identifying the best location for the wind power injection. When the found location for a new wind field in buses minimally affects the system voltage, wind penetration can be increased without using external voltage supporting devices.

To increase the wind penetration levels of wind by placing external voltage supporting devices in particular buses two options are given for the system to re-increase the maximum wind farm size. The SVC location is important for increasing the wind penetration level. By placing SVC on the weakest system bus rather than on the bus of wind energy production, the highest wind penetration level is obtained, which significantly reduces both the EVSM value and Li index, which altogether would increases the system voltage stability.

REFERENCES

[1] Transmission Reliability Evaluation of Large-Scale Systems (TRELSS), EPRI research Project 3833-1, Final Report, October 1994.

[2] C. Taylor, Power System Voltage Stability, McGraw-Hill, 1994.

[3] N. T. Linh, T. T. Chuong, "Voltage Stability Analysis of Grids Connected Wind Generators", ICIEA 2009. 4th IEEE Conference on 25- 27 May 2009 Pages 2657-2660.0.

[4] G. Coath, M. Al-Dabbagh, "Effect of Steady State Wind Turbine Generator Models on power Flow Convergence and Voltage Stability Limit".

[5] M. Chinchilla, S. Arnalte, J.C. Burgos, and J.L. Rodrigues, "Power Limits of Grid-Connected Modern Wind Energy System", Renewable Energy, September 2005, pp. 1455-1470.

[6] Kansas Energy information Network October 2009.

[7] Y. Li, H.D. Chiang, H. Li, Y.T. Chen, D.H. Huang and M. G. Lauby, "Power System Load Ranking for Voltage Stability Analysis", IEEE trans., 2006.

[8] H. Li, H.D. Chiang, H. Yoshida, Y. Fukuyama, Y. Nakanishi, "The generation of ZIP-V Curves for Tracing Power System Steady State Stationary Behavior Due to Load and generation Variations", IEEE Transaction on Power System, Vol 10, No. 2, May 1999.

[9] Narain. G, Gyugyi. Laszlo, understanding FACTS: Concept and Technology of flexible AC Transmission system,book pp: 208 to 215, 2000.

Mehrdad Ahmadi Kamarposhti received his B.Sc. degree from the Mazandaran University and M.Sc. degree from South Branch, Islamic Azad University, Tehran, Iran, in 2006 and 2008 respectively, both in electrical power engineering, and also Ph.D. degree in electrical power engineering from the Science and Research Branch, Islamic Azad University, Tehran, Iran, in 2015. He is currently an Assistant Professor with the Department of Electrical Engineering, Jouybar Branch, Islamic Azad University, Jouybar, Iran. His research interests are in FACTS devices, allocation of disturbed generation, renewable energy, optimization algorithm, micro grid and reactive power compensation.