Voltage Stability Improvement by Optimal Active Power and Reactive Power Output Control of Storage Battery System

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***Abstract*—Future, transmission capacity processing capability may become the limit because of the pursuit of economic benefit and increasing renewable energy. Then, the power system is placed in severe conditions than ever. In addition, it increases the likelihood of voltage instability and voltage collapse. Therefore, voltage stability analysis is a major concern in power system operation. Voltage stability has been analyzed in a variety of ways. However, voltage stability analysis considering simultaneously both the active and reactive power in the analysis is less done because of it is difficult analysis. When considering both the active and reactive power at the same time, it is expected that voltage stability analysis is accurate. In this paper, we propose a method to improve the voltage stability of the power system by using the voltage stability index of the active power information and reactive power information of the transmission line. Installing the battery in the load substation to inject the appropriate amount of active and reactive power can improve the voltage stability of the system as shown in the simulation. In addition, it indicates further improvement of voltage stability by optimal active power and reactive power output with battery.**

I. INTRODUCTION

In recent years, concerns about the liberalization of the electricity market and the depletion of energy resources are increasing, so the introduction of renewable energy sources into the electric power system is increasing. Furthermore, the transition to economic benefits to the electrification system brings about an increase in electricity demand, and the electric power system is operated near the transmission capacity under harsh conditions[1]. By using transmission lines more efficiently, there is a possibility that more parts of the power system will operate near the voltage stability limit. As a result, the possibility of voltage collapse increases[2,3]. Therefore, voltage stability analysis is the main consideration in the stable operation of the power system. Voltage stability has been analyzed in various methods. Several analysis methods among them include P-V analysis related to the relation between voltage and active power in the transmission system and P-Q analysis related to the relation between voltage and reactive power in the transmission system[4∼14]. The proposed indicators of voltage stability include finding the change in active and reactive power with respect to the change in voltage from the P-V and Q-V characteristics, the proximity of the high and low voltage vectors from the P-V characteristics, and the voltage stability margin of the active power that can be consumed by the load. It is difficult to achieve analysis at the same time, there are few studies on voltage stability considering both active power and reactive power. Therefore, it is expected that accurate voltage stability analysis will be carried out simultaneously considering both active power and reactive power. Regarding the transmission characteristics, since the active power and the reactive power are the main values, the P-Q characteristic is considered.We have previously proposed the voltage stability limit index that takes into account the active and reactive power in the transmission. Also, it was realized in this study that the impact of active power on voltage stability is higher when system loads are heavy.

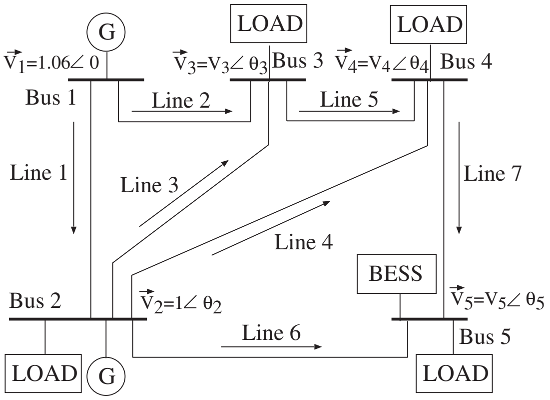

Fig. 1. IEEE 5 Bus System model.

This paper proposes a method of improving power system

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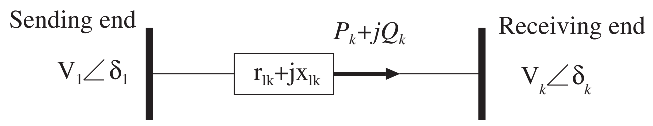


Fig. 2. Transmission line model.

voltage stability using optimal active and reactive power control of a battery storage system. Where, we use particle swarm optimization method (PSO) as an optimization technique. Particle swarm optimization is not to fall into local solutions, it features that it is possible to explore the global solution in many cases. Utilizing an adequately controlled battery storage system installed at the load substation, the voltage stability of the power system is improved.

II. VOLTAGE STAGILITY ANALYSIS

The model assumed in this paper is shown in Fig. 1. The IEEE 5 Bus system is used in this paper[15].

In Fig. 2 the sending end voltage is V_l and the receiving end voltage is V_k, P_k is the active power being sent to the receiving side and Q_k is the reactive power being sent. The power flow equation between two bus system is represented by the following equation.

$$P_k - jQ_k = (V_k\angle\delta_k)^* \frac{V_l\angle\delta_l - V_k\angle\delta_k}{r_{lk} + jx_{lk}} \tag{1}$$

Considering sending end voltage (V_l) and receiving end voltage (V_k) is greater than zero, the following equation is obtained.

$$V_k = \sqrt{-(r_{lk}P_k + x_{lk}Q_k - \frac{V_l^2}{2}) \pm\ A} \tag{2}$$

$$A = \sqrt{\left(r_{lk}P_k + x_{lk}Q_k - \frac{V_l^2}{2}\right)^2 - (r_{lk}^2 + x_{lk}^2)\,(P_k^2 + Q_k^2)}$$

There is a limit to the possible transmit power for any given time; that power is called the power stability limit and the voltage is called the voltage stability limit. The power stability limit and the voltage stability limit occurs when A in Eq. (2) becomes zero. therefore, the stability limit conditions can be represented as follows[16].

$$\sqrt{\left(r_{lk}P_k + x_{lk}Q_k - \frac{V_l^2}{2}\right)^2 - (r_{lk}^2 + x_{lk}^2)\,(P_k^2 + Q_k^2)} = 0 \tag{3}$$

$$Q_k = \frac{\pm\sqrt{x_{lk}^2V_l^4 + r_{lk}^2V_l^4 - 4x_{lk}^2r_{lk}V_l^2P_k - 4r_{lk}^3V_l^2P_k}}{2r_{lk}^2} + \frac{2x_{lk}r_{lk}P_k - x_{lk}V_l^2}{2r_{lk}^2} \tag{4}$$

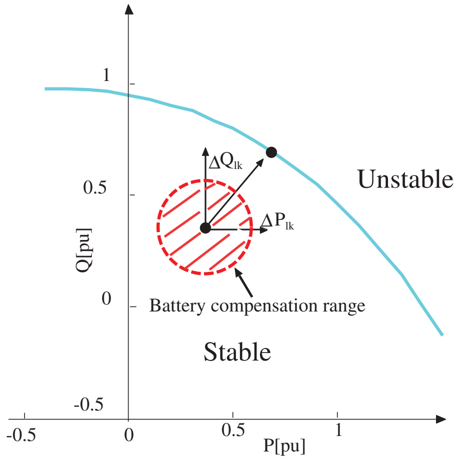


Fig. 3. $P-Q$ characteristics.

The $(P,Q)-V$ characteristics of the power stability limit from Eqn. (4) are shown in Fig. 3. From Eqns. (2) and (4), the relationship between V_k and P_k at the voltage stability limit is shown. The voltage stability index for the power transmission line $l-k$ is calculated as the shortest distance from the current operating point to the P-Q voltage stability limit curve. These are demarcated by ΔP_{lk} and ΔQ_{lk}, and the Critical Boundary Index (CBI) can be evaluated as follows:

$$CBI_{lk} = \sqrt{\Delta P_{lk}{}^2 + \Delta Q_{lk}{}^2} \tag{5}$$

Where, the sending end bus number is l, the receiving end bus number is k. The CBI can be used to the index of voltage stability of the transmission line. The voltage stability of the given transmission line. The voltage stability (CBI) of the transmission lines worsens approaches zero [1]. Moreover, CBI define the objective function to be a maximum.

objective function:

$$max : CBI_{max} = \sqrt{P_{lk}{}^2 + Q_{lk}{}^2} \tag{6}$$

In this paper, optimization is done by using the particle swarm optimization algorism (PSO).

III. BATTERY CONTROL METHOD

For management of the voltage stability of a power system, rather than using just reactive power, additional active power control can further improve the voltage stability of the system. In this research the voltage stability limit is used. The apparent power S_{Bk} of battery output power is described in the following equations:

$$S_{Bk} = \sqrt{P_{Bk}^2 + Q_{Bk}^2} \tag{7}$$

$$S_{Bk} = S_{Bkmax} \exp\left(\frac{\alpha_k - CBI_{lk}}{\xi_k}\right) \tag{8}$$

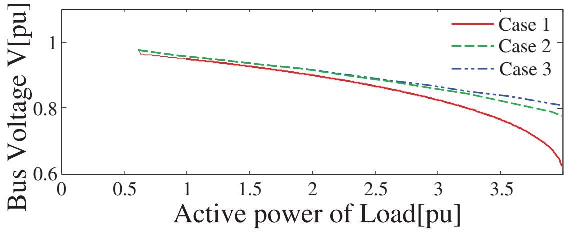
Table 1. Simulation conditions

Case	Simulation condition
Case 1	1) The active power requirements of the load at bus 5 are increased until a voltage collapse occurs.
Case 2	2) The same load scenario as case 1; however, optimal reactive power compensation is applied from a battery connected at bus 5.
Case 3	3) The same load scenario as case 1; however, optimal active and reactive power compensation is applied from a battery connected at bus 5.

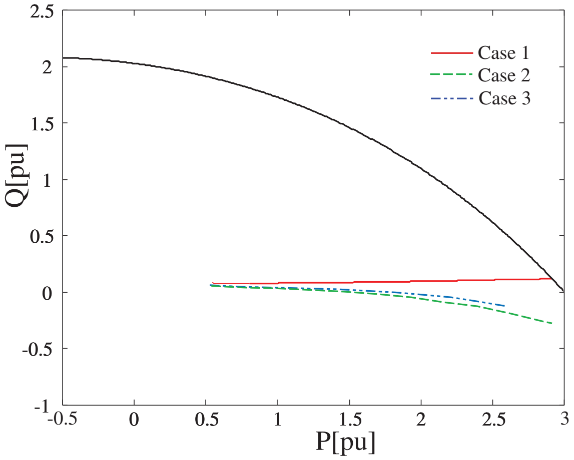
S_{Bkmas} is the inverter capacity interfacing the battery, α_k is the CBI_{lk} at which the output power of the boundary reaches the maximum output, ξ_k is used to modify the rate of exponential decay for the relationship of the apparent power output of the battery to the CBI_{lk}.In this paper, the maximum apparent power output of the battery S_{Bkmas} is 100MVA. Furthermore,for the battery connected to bus 5, values of $\alpha_k = 0.1$ and $\xi_k = 0.5$ are used. Also, perform optimum control is performed by using the active power and reactive power control of storage battery system. In this paper, we set eq.(7) and eq.(8) as a constraint condition of storage battery system. Here, it can move the operating point in the storage battery compensation range as shown in Fig. 3 by the storage battery compensation.

IV. SIMULATION

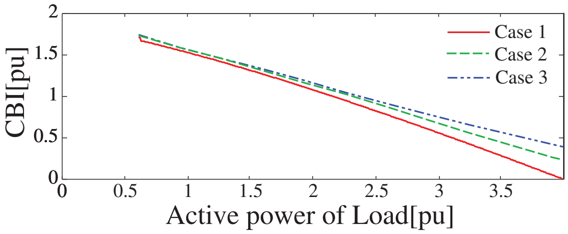
In Table 1, the simulation parameters for the 3 cases used in this study are described. The results of simulations for Cases 1, 2 and 3 are shown in Fig. 4. The results for bus voltage of each cases are shown in Fig. 4(a). The relationship of the load active power and voltage of Bus 5 are shown. As the active power of the load connected to Bus 5 is increased, the bus voltage decreases. Fig. 4(b) shows the (P, Q) characteristics of line 6. As the active power and reactive power of the load increases, the active power and reactive power of the line increases. From this it can be seen that the distance of the operating point to the voltage stability limit curve decreases. For Case 1, no battery was connected to Bus 5. The operating point of the system exceeded the voltage stability limits, leading to a voltage collapse. In Fig. 4(c) the CBI_{lk} is shown. At the time of the voltage collapse, the CBI_{lk} is equal to 0. The results for Case 2 and 3 are shown in Fig. 4(d). As the load active power increases, the amount of battery active power and reactive power increases. From Fig. 4(b), it can be seen that in comparison with Case 1, there is an improvement on the distance of the operating point to the voltage stability index due to battery reactive power compensation. As a result, it can be determined that use of a battery during drops in voltage can protect the system from voltage collapse. From Fig. 4(d), it can be seen that as the load active power increases, the active and reactive power compensation from the battery increases. Fig. 4(c) presents a comparison and shows that the CBI_{lk} of Case 2 and 3 is higher than Case 1. Furthermore, the CBI_{lk} of Case 3 is higher than Case 2. Fig. 4(d) shows that there is the required active and reactive power requirements from the battery of each cases. From these figures the results of Cases 1, Case 2 and Case 3 are shown. In Case 2, optimal reactive power are only used. In Case 3, optimal active and reactive power are used. Through the use of simulations, it has been shown that using both active and reactive power compensation is effective. Voltage stability is a strict condition, and their



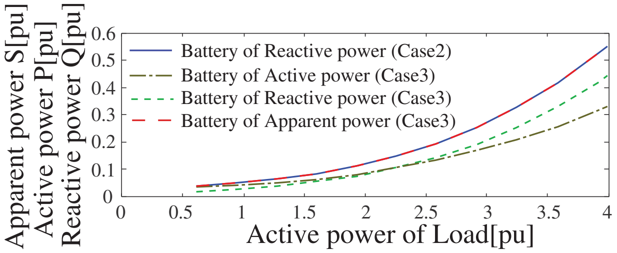
(a) Bus 5 voltage.



(b) $P-Q$ characteristics(Line 6).



(c) Voltage stability index CBI_{lk} (Line 6).



(d) A compensated power (Bus 5).

Fig. 4. Simulation results.

improvement effect is achieved by the optimal active power and reactive power output control of the battery.

V. CONCLUSION

In this research, battery power compensation control through the use of the voltage stability index is used to improve the voltage stability in a power system. Through the use of simulations, it has been shown that using both active and reactive power compensation is effective. Voltage stability was improved by performing optimization. Further research should entail the use of an acceptable range of output active and reactive power, as well as optimizing placement of the battary. With the addition of these techniques, better voltage stability techniques are possible.

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