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CIGRE US National Committee
2017 Grid of the Future Symposium

Optimization Enabler for a Voltage and Reactive Power Management (OPEN-VQ) System for Smart Operation

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SUMMARY

Integration of renewable energy sources (RESs) and reform of electricity system have been progressing in Japan. Their advances will increase generation uncertainties in power systems. To handle these uncertainties, the authors, in this paper, propose the sophisticated voltage and reactive power management technology that can reduce operating expenditure (OPEX) and/or capital expenditure (CAPEX). In particular, it can expand the range of operational choice and reduce OPEX.

In this paper, the authors introduce the Optimization Enabler for Voltage and Reactive Power Management (OPEN-VQ) system for smart operation. Its architecture consists of a short-term look-ahead operational condition, an optimal voltage profile solver, a control procedure creator, a control procedure selector, an online voltage security assessment, and an enhancement engine. The OPEN-VQ system optimizes key performance indices (KPIs), such as the loss reduction and the transfer capability enhancement, on the basis of the short-term look-ahead operational condition.

To validate the performance of the OPEN-VQ system, a simulator has been developed that can handle multi-period operational conditions considering time series. Simulation results based on the TEPCO 1500-bus model show that the short-term look-ahead operational condition is important for online optimization of voltage and reactive power management. Furthermore, the results also show that multiple control procedures created by the OPEN-VQ system can optimize the KPIs, which indicates that the improvement of the control procedure creator and selector will enable the optimization of multiple KPIs considering time series.

KEYWORDS

Transmission grid, EMS, OPF, Voltage Security Assessment, Voltage Control, Look-Ahead

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1. Introduction

Integration of renewable energy sources (RESs) have been progressing together with the electricity system reform in Japan. The electricity system reform aims to suppress the electricity price by implementing market mechanisms in power systems. These advances will increase the generation uncertainties in power systems. Utilities all over the world are trying to handle these uncertainties by the facility expansion and/or the sophisticated operation technology. Although the facility expansion enhances the grid strength, it requires high cost to deal with all of the uncertainties. Thus, the authors propose an Optimization Enabler for Voltage and Reactive Power Management (OPEN-VQ) system that can reduce operating expenditure (OPEX) and capital expenditure (CAPEX).

Hierarchical voltage control to manage whole grid voltage has been practiced in France and Italy [1]-[4]. Also, there are numerous papers about a centralized or decentralized voltage control methods [5]-[8]. However, in practice, it is difficult to optimize key performance indices (KPIs) by these technologies because they are based on the feedback control from the previous period. Furthermore, increasing the grid size may reduce reliability in the feedback control because of a communication delay in long distance communication or a calculation delay from an excessive number of calculations.

To solve this problem, the authors propose the OPEN-VQ system for smart operation composed of optimization calculation and security assessment. The OPEN-VQ system optimizes KPIs, such as the loss reduction and transfer capability enhancement on the basis of a short-term look-ahead operational condition.

Section 2 introduces the architecture of the OPEN-VQ system, and section 3 describes the simulation conditions to evaluate the OPEN-VQ system's performance and discusses the results.

2. OPEN-VQ Architecture

Figure 1 shows the concept of the OPEN-VQ system, which consists of a security assessment, a look-ahead operational condition, optimal power flow, and scenario analysis. The security assessment evaluates the security of the grid condition and operation plans to improve security. The look-ahead operational condition takes into account the uncertainties to improve the integration of RESs. The optimal power flow maximizes KPIs while maintaining security to minimize OPEX. The scenario analysis rationalizes the asset management of voltage regulators to minimize CAPEX.

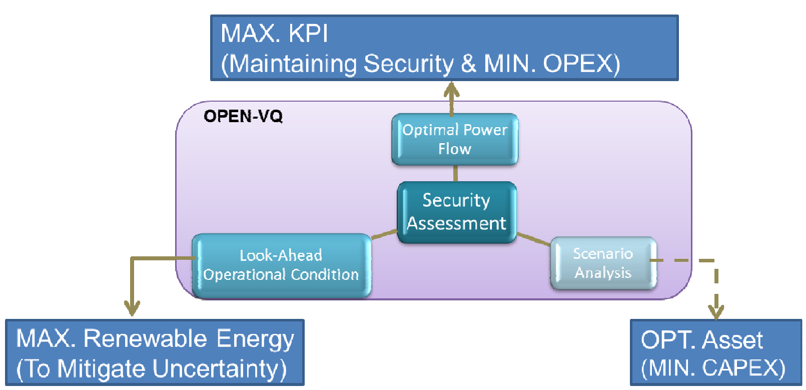

Figure 1. Concept of OPEN-VQ.

Here, the architecture of the OPEN-VQ system for smart operation is explained. Figure 2 shows its architecture consisting of a short-term look-ahead operational condition, an optimal voltage profile solver, a control procedure creator, and a control procedure selector. The architecture is established based on the finding that there are multiple control procedures to optimize specific KPIs, normally with the highest priority, and the best control procedure can be selected out of the multiple control procedures in order to optimize multiple KPIs. The short-term look-ahead operational condition simulates the operational conditions of look-ahead periods. The optimal voltage profile solver optimizes the voltage profile based on the short-term look-ahead operational condition. The control procedure creator creates multiple candidates for the control procedure. The control procedure selector selects the most preferable candidate from the viewpoint of security and/or system economy.

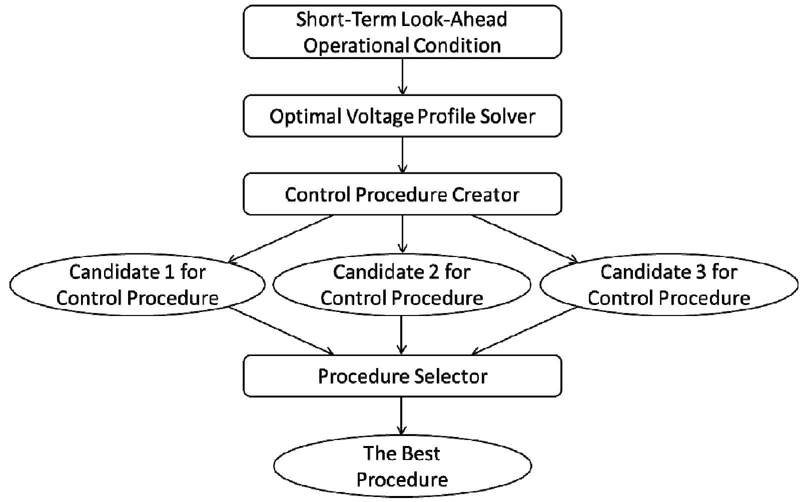

Figure 2. Architecture of an OPEN-VQ system for smart operation.

3. Evaluation of OPEN-VQ System Performance

To evaluate OPEN-VQ system performance, the authors have developed an OPEN-VQ simulator. This section explains the simulation conditions for the simulator and the evaluation results for the OPEN-VQ system performance. The evaluation points include the necessity for short-term look-ahead operational conditions and the consideration of multiple control procedure candidates.

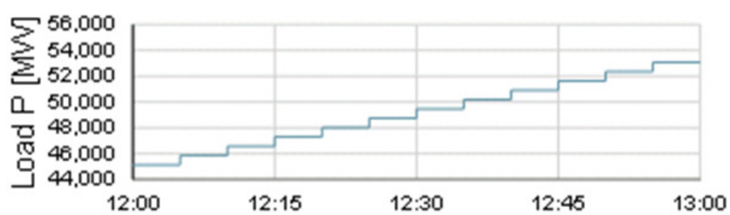

Figure 3. Total demand variation.

The simulation scenarios are set as described below. The loss reduction and the load margins are set as the KPIs. The voltage regulator targets are the generator terminal voltage, the on/off status of the shunt devices, and the tap position of the transformers. Figure 3 shows the total demand variation. The demand variations of all buses were proportionally distributed with the initial demand distribution. On the basis of the simulation conditions, two scenarios were evaluated.

a. Scenario 1

In scenario 1, to evaluate the necessity of the short-term look-ahead operational condition, two simulations with different intervals for the one hour look-ahead windows were carried out. The interval for case 1 is one hour. In other words, the status of the voltage regulators is fixed for a representative time (12:20). The interval for case 2 is five minutes. In other words, the status of the voltage regulators is optimized every 5 minutes.

Figure 4 shows the simulation results. The upper and lower graphs show active power loss and load margin, respectively. Red and yellow lines indicate the results for cases 1 and 2, respectively. After 12:20, the active power loss is smaller and load margin is larger in case 2 than in case 1. The active power loss reduction can contribute to reducing OPEX, and the load margin increase indicates an improvement in voltage security. Before 12:20, although the active power loss is smaller in case 1 than in case 2, the load margin in case 1 is insufficient even though the load amount is 10% less than that in the representative condition. At 12:55, load margin in case 1 is also insufficient. These results show that the short-term look-ahead operational conditions are important for the online optimization of voltage and reactive power management.

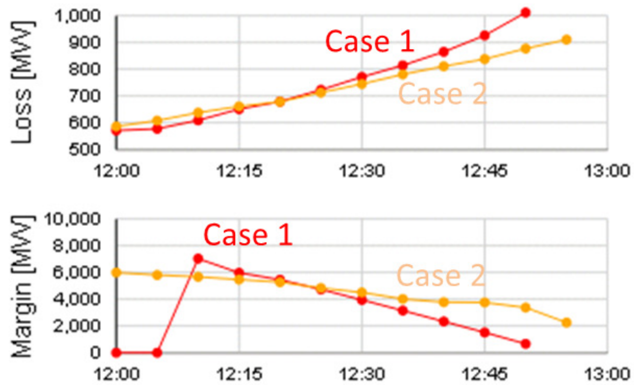

Figure 4. Simulation results for scenario 1.

b. Scenario 2

To validate the consideration of multiple control procedure candidates, two simulations with different voltage regulation candidates were carried out in addition to the two cases of scenario 1. Cases 1 and 2 are the same as scenario 1. Cases 3 and 4 have limited voltage regulation candidates. Figure 5 shows the simulation results. The top graph shows the change in generator terminal voltage from a previous time. The middle and bottom graphs show the active power loss and the load margin, respectively. Cases 2, 3, and 4 have almost the same active power loss and load margin although they have different control procedures as seen in the top graph. These results show that multiple procedures can achieve an optimal voltage profile.

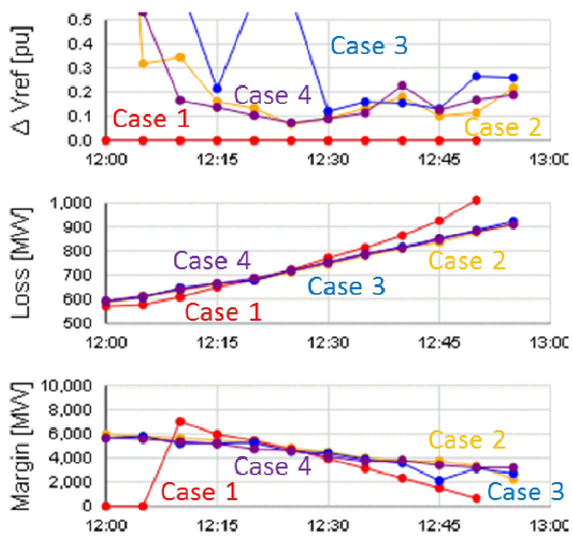

Figure 5. Simulation results for scenario 2.

4. Conclusion

The OPEN-VQ system is proposed for optimizing multiple KPIs, such as the reduction of losses without infrastructure expenditure and the enhancement of available transfer capability. Its architecture consists of a short-term look-ahead operational condition, an optimal voltage profile solver, a control procedure creator, a control procedure selector, a voltage stability assessment, and enhancement engine.

To evaluate its performance, a simulator has been developed that can handle multi-period operational conditions. Simulation results based on the TEPCO 1500-bus model show that the short-term look-ahead operational condition is important for online optimization of voltage and reactive power management. Furthermore, results show that multiple control procedures created by the OPEN-VQ system can optimize the KPIs, which indicates that the improvement of the control procedure creator and selector will enable the optimization of multiple KPIs considering time series.

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