Impact of Large-Scale Installation of Renewable Energies on Power System

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SUMMARY

Recently, introduction of Distributed Generation (DG) represented by renewable energy sources such as PV (photovoltaic) or wind turbine into power system is increasing rapidly. These renewable energy sources, however, have features that their power outputs are significantly influenced by climate or fault conditions. Therefore, it is anticipated that SPS (Special Protection Scheme) function of transient stability control will be affected because of excluding the rapid power flow fluctuation. Also it is not well understood how DG affects the transient stability in the event of fault so far.

Therefore the investigation on the fluctuation of DG output or its dynamic characteristics of transient domain has been conducted and, consequently, it's revealed that the control (generator tripping) amount of SPS for maintaining transient stability is influenced by these factors. Dealing with this, the real-time calculation method using pre-fault and post-fault data is expected, but control time is delayed because it requires data acquisition period especially in post-fault condition. Hence pre-calculation method is adopted for the primary control which requires high speed performance, and real-time calculation method is adopted for the secondary control. Amount of the primary control for each pre-setting fault case is determined by digital simulation using online data from SCADA system and generator tripping is conducted immediately when the fault concerned occurs. The secondary control conducts additional generator tripping if the amount of the primary control is insufficient to prevent transient stability problem. The amount of the secondary control is determined by the Equal-area method based on the power-angle curve of the equivalent one-machine system, which is estimated using real-time data in both pre-fault and post-fault condition. This new control scheme, developed by Chubu Electric Power Company (CEPCO) and Mitsubishi Electric Corporation, will be applied to the next generation SPS, so-called Integrated Stability Control (ISC) system, for the CEPCO's main power system.

KEYWORDS

PV - Distributed Generation - Transient Stability - SPS - ISC
1. Introduction

Recently, introduction of Distributed Generation (DG) represented by renewable energy sources such as PV (photovoltaic) or wind turbine into power system is increasing rapidly. These renewable energy sources, however, have features that their power outputs are significantly influenced by climate or fault conditions. Therefore, it is anticipated that SPS (Special Protection Scheme) function of transient stability control will be affected because of excluding the rapid power flow fluctuation. Also it is not well understood how DG affects the transient stability in the event of fault so far. This paper shows how the dynamic characteristic of DG affects the power system transient stability and proposes the new SPS solution as a measure against the issue.

2. Impact of DG on transient stability

The main renewable energy source in Japan is PV, so three cases of combination between regular load and PV were assumed as shown in Figure 1. Digital simulations were carried out to investigate the impact of DG on power system transient stability in these cases. Figure 2 shows the dynamic model of PV in Case C. The simulation in Case B revealed that as the power output of PV increased (80→100%), the stability got worse as shown in Figure 3. It is recognized that increased PV output causes a swell of power flow on the transmission line, which increases the voltage phase angle; thus the transient stability is affected. Also, the simulations show that transient stability is most decreased in Case B, after this, Case C and Case A is following. This is interpreted as follows.

Figure 1: Three cases of load and PV model

Figure 2: Dynamic characteristics model of PV

(a) PV power output level at 80%

(b) PV power output level at 100%

Figure 3: Difference of the transient stability between two levels of PV power output

The fluctuation of PV power output changes the gross load and subsequently the power flow on transmission line. Since the PV power output is always constant and the gross load is low in Case B, synchronous generators are most accelerated and the stability is the worst consequently. In case C, the PV output is interrupted by the gate-block due to voltage dip during fault, the gross load is larger than that of Case B and the acceleration of synchronous generators is restrained. Therefore the stability is better than Case B. Case A does not have any PVs, so the stability is the best.
Even in Case C, if the fault location is far from PV and voltage dip during fault does not reach the threshold of gate-block, the stability will be worse as shown Figure 4. Accordingly the extent of DG impact on power system stability depends on the fault location.

3. Development of solution

3.1 Selection of calculation method type

In general, SPSs are classified into two types by calculation method, namely pre-calculation method type based on pre-fault data and real-time calculation method type based on pre/post-fault data. In case of using the pre-calculation method type for transient stability issue, amount of the control for each contingency (pre-setting fault case) is determined based on online data from SCADA system in certain cycle (for instance 30 seconds). So there is a difference in time between the measurement of data from SCADA and the control of SPS. As mentioned above, transient stability of power system is affected by the changes of gross load due to PV output fluctuation involving gate-block in post-fault condition. If the PV output at the control timing is higher than that at the measurement timing, the control amount of pre-calculation method type will be insufficient to prevent transient stability problem. Vice versa, it will exceed appropriate amount. Consequently, this pre-calculation method is hard to be applied to SPS independently.

On the other hand, the real-time calculation method type is expected to deal with the stability problem caused by DGs. However, since this type requires the data acquisition period in post-fault condition, control timing is delayed and the control amount of SPS tends to increase. So this real-time method is also hard to be applied to SPS independently. Evently, an appropriate solution has been developed by adopting advantages of both types, the primary control is based on pre-calculation method which has high speed performance and the secondary control is based on real-time calculation method which has good adaptability. Amount of the primary control is pre-calculated based on severe condition like Case B in Figure 2 for fail-safe.

3.2 Calculation scheme for the primary control based on pre-calculation method

Amount of the primary control to maintain transient stability is determined by digital simulations using online data from SCADA system such as telemeter (TM) and supervision (SV). Digital simulations are carried out for all the contingencies expected. Generators are subsequently classified into unstable (accelerating) group and stable (decelerating) group by center of angle criterion as shown in Figure 5 to support the secondary control.
3.3 Calculation scheme for the secondary control based on real-time calculation method

When an expected fault occurs in power system, generator tripping is carried out immediately as the primary control. Then, real-time calculation is conducted for the secondary control. The secondary control consists of three functions: power-angle curve estimation, transient stability decision and control amount calculation.

(1) Power-angle curve estimation

An equivalent generator is modelled using supporting information from pre-calculation. Equivalent generator’s output \( P_E \) is calculated from eq. (1). And an angular velocity deviation \( \Delta \omega \) and a phase angle deviation \( \Delta \delta \) (\( \delta = \delta(t=0) + \Delta \delta \)) of the equivalent generator are calculated from eq. (2) and eq. (3).

\[
P_E(\Delta \delta) = P_1 \sin \Delta \delta + P_2 \cos \Delta \delta
\]

\[
\frac{M}{\omega_0} \frac{d\Delta \omega}{dt} = P_M - P_E
\]

\[
\frac{d\Delta \delta}{dt} = \Delta \omega
\]

Where \( P_1 \) and \( P_2 \) are coefficients of power-angle curve, \( M \) is inertia of equivalent generator and \( P_M \) is mechanical input of equivalent generator. Post-fault data of \( P_E \) can be measured and \( \Delta \delta \) is calculated using swing equation. Therefore, \( P_1 \) and \( P_2 \) are calculated by least square method using time-series data in eq. (4) and eq. (5).

\[
y = Ax
\]

\[
A = \begin{bmatrix} \sin \Delta \delta(t_s) & \cos \Delta \delta(t_s) \\ \vdots & \vdots \\ \sin \Delta \delta(t_f) & \cos \Delta \delta(t_f) \end{bmatrix} \quad x = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} \quad y = \begin{bmatrix} P_E(t_s) \\ P_E(t_f) \end{bmatrix}
\]

\[
x = (A^T A)^{-1} A^T y
\]

(2) Transient stability decision

At the time of secondary control calculation \( t_c \), acceleration energy \( ACC \) and deceleration energy \( DCC \) are calculated from eq. (6) and eq. (7).

\[
ACC = \frac{1}{2} \frac{M}{\omega_0} \Delta \omega(t_c)^2
\]

\[
DCC = \int_{\Delta \delta(t_c)}^{\Delta \delta} (P_E(\Delta \delta) - P_M) d\delta
\]

Using Equal Area Criterion, stability of equivalent generator can be determined from eq. (8).

\[
ACC \geq DCC \quad : \quad \text{Unstable}
\]

\[
ACC < DCC \quad : \quad \text{Stable}
\]

(3) Control amount calculation

When stability decision result indicates that power system is unstable as shown in Figure 6(a), acceleration energy \( ACC_1 \) and deceleration energy \( DCC_1 \) at post-control condition are calculated from eq. (9) and eq. (10). And minimum amount of generator tripping which requires the condition in eq. (11) is calculated. Where suffix “1” means post-control (assumed) value. (Figure 6(b))

\[
ACC_1 = \frac{1}{2} \frac{M}{\omega_0} \Delta \omega(t_c)^2
\]
Generators selected in real time calculation are tripped immediately for the secondary control. 

\[
DCC_1 = \int_{\Delta\delta_C}^{\Delta\delta_D} \left( P_E(\Delta\delta) - P_{M1} \right) d\delta \\
ACC_1 < DCC_1
\]  

\[P_E(\Delta\delta) = P_E \sin \Delta\delta + P_E \cos \Delta\delta\]

\[P_E(\Delta\delta) = P_E \sin \Delta\delta + P_E \cos \Delta\delta\]

3.4 Case study for secondary control

Figure 7 shows the simulation result of route cut-off fault (3-phase 6-line-to-ground fault) on 500kV looped power system in CEPCO. It can be clearly seen from this figure that transient stability becomes worse due to load drop and PV power fluctuation, and generator tripping of secondary control is effective for power system stabilization.

![Figure 6: Secondary control calculation based on Equal-area Criterion](image)

![Figure 7: Simulation result for case study](image)
4. Outline of SPS as the applied solution

In this section, the outline of ISC system as the applied solution is described. Figure 8 illustrates the configuration of ISC system. ISC system consists of ISC-P (Processing equipment), ISC-C (Controller), ISC-S (Sensing equipment) and ISC-T (Transfer trip equipment). ISC-S is divided into two type based on its function; ISC-S (fault detecting) and ISC-S (generator output measurement). ISC-P has the function which determines the targeted generators as the primary control for each contingency and makes these results into a table based on the digital simulations. The simulations are calculated using detailed model of CEPCO’s trunk power system. Also it has supporting function for ISC-C’s secondary control, which classifies generators into two groups; unstable and stable. This pre-calculated information is sent from ISC-P to ISC-Cs in certain cycle (for example 30 seconds). ISC-Cs are located in major substations and when they receive the fault detecting signal from ISC-S (fault detecting), they send the primary control signal to ISC-Ts immediately based on the table. ISC-Ts trip generators in accordance with received signal within 150 milliseconds of fault occurrence. ISC-C carries out real-time calculation for the secondary control just after fault occurrence. Amount of the secondary control is determined by the Equal Area Criterion based on the power-angle curve which is estimated using real-time power flow data from the ISC-Ss (generator output measurement) classified as unstable group. If the amount of the secondary control is not zero, additional control signal is sent from ISC-C to ISC-Ts, which trip generators.

On-line Transient Stability Control System [1], which covers CEPCO’s bulk power system, will be replaced with this ISC system. The ISC system is now under development to commence operations in 2017.

BIBLIOGRAPHY
