ULTC와 SVR이 설치된 배전계통에서 LDC Parameters을 고려한 최대 DG 용량 산정

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The Installable Maximum DG Capacity Considering LDC Parameters of ULTC and SVR in Distribution Systems

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Abstract—For stable and sustainable energy supply, distributed generator (DG) has become an essential and indispensable element from environmental and energy security perspectives. However, installation of DG in distribution systems may cause negative affects on feeders because power outputs of DG could be changed irregularly. One of major negative affects is variation in voltage profile. In general, voltage regulation devices such as under load tap changer (ULTC) at distribution substation and step voltage regulator (SVR) along feeder in distribution system are used to maintain customers' receiving voltage within a predetermined range. These regulators are controlled by line drop compensation (LDC) method which calls for two parameters; the equivalent impedance and the load center voltage. Therefore, consideration of DG outputs in the LDC parameter design procedure may give large impact on the installable DG capacity. This paper proposes a method that estimates maximum Installable DG capacity considering LDC parameters of ULTC and SVR. The proposed algorithm is tested with model network.

1. Introduction

The major problems we face both as an individual and a society are limitation of natural resources and the serious environment pollution such as the global warming. As an alternative, the small-scaled onsite generators called distributed generators (DGs) such as photovoltaic power generation, wind power generation and biomass generation are promising [1]. However, the utilities are nervous with DG interconnection due to its uncertain and volatile output, and have laid operational constraints about power quality. Particularly, the maintenance of satisfactory voltage levels for the customers is the most important concerns of the utility.

In order to mitigate the impacts of DG interconnection on voltage profile, the necessities of cooperated operation between voltage controllers and apparatus such as an ULTC at distribution substation, a SVR on distribution line, a capacitor bank or a static var compensator (SVC) are presented in [1]. Among these voltage regulation devices, ULTC and SVR are operated by LDC method in which the line voltage drop for a varying load current can be estimated and compensated [2]. In the LDC method, these voltage regulators call for two parameters; the equivalent impedance and the load center voltage. When DGs are introduced into a distribution system, voltage regulation by the LDC method using the parameters designed without consideration on DG interconnections may result in voltage violations. That is, consideration of variation in DG outputs in LDC parameters design process may give large impact on maximum Installable DG capacity.

This paper proposes a method for estimating maximum Installable DG capacity considering LDC parameters of ULTC and SVR. The availability of the proposed estimation method is ascertained through DG capacities according to operational constraints about power quality.

2. LDC Voltage Regulation and Its Parameters Design

2.1 LDC voltage regulation

The ULTC and SVR maintain customers' receiving voltage within a proper range. Namely, when the load increases or DG output decreases, these regulators boost sending voltage, and vice versa [2]. This operation is realized by adjusting the sending voltage by the following equation.

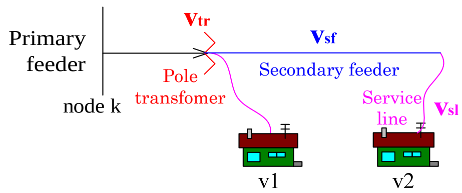
$$V_{send}(t) = V_{ce} + Z_{eq} \times I_{Bank}(t) \times Xmtr(t) \qquad (1)$$

where, $V_{send}(t)$ is sending voltage at time t [p.u.], $Xmtr(t)$ is voltage compensation rate at time t, $I_{Bank}(t)$ is the measured bank current at time t [p.u.]. V_{ce} and Z_{eq} are the LDC parameters called the load center voltage [p.u.] and the equivalent impedance, respectively [p.u.].

Actual tap position of ULTC, however, is discretized and control of voltage regulators usually requires the other parameter called bandwidth extent (±ε). The tap position is changed only when the estimated optimal sending voltage exceeds the bandwidth extent.

2.2 Design of the LDC parameters

The sending voltage provided by ULTC and SVR must be controlled so as to maintain the customers' receiving voltage within a proper range considering the compensation for voltage drops at pole transformer, secondary feeder and service line (see Fig. 1). In other words, the upper and lower limits of primary voltage are specified for each node depending on the conditions of load and DG outputs. The authors have proposed a LDC parameter design method based on these nodal upper and lower limits of voltage and the bandwidth extent [3].



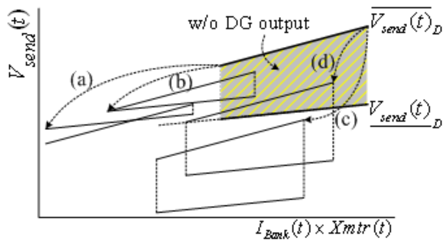
<Fig. 1> Component of voltage drops along the feeder

3. Estimation Method of Maximum Installable DG Capacity

As is well-known, power systems have some operational constraints on power quality level that must be satisfied certainly in any situations; regardless of the amount of DG output. In conventional distribution systems, for example, prohibition of reverse power flow at bank transformer, adequate regulation of customers' receiving voltage, current capacity limit for the feeder and operation range of voltage regulators are considered.

Satisfaction of these operational constraints restricts the installable DG capacity. When we discuss about voltage constraints, two factors should be considered; existence of the available sending voltage ($V_{send}(t)_D$) and existence of the feasible LDC parameters. Here, the available sending voltage means the voltage which can successfully maintain the all customers' receiving voltage within the predetermined admissible range. Fig. 2 shows a schematic image of relationship between the above two factors and DG installation. Let us assume that the bold lines in Fig. 2 represent the available sending voltage limits ($\overline{V_{send}(t)}_D$, $\underline{V_{send}(t)}_D$) when the DG injects no power. The voltage limits are slid left and downward by the power injection from DG. When too much power injection from DG upsets the order of upper and lower sending voltage limits as Fig. 2(a), any sending voltage cannot maintain the proper customers' receiving voltage. In this case, the maximum installable capacity of DG is defined so that the order of upper and lower sending voltage limits can be preserved and available sending voltage can exist (Fig. 2(b)).

When the power injection from DG slides the voltage limits as Fig. 2(c), there are available sending voltages, but we cannot design the adequate LDC parameters since there is no intersection between two parameters ranges. In this case, the DG introduction capacity should be decreased until the common straight line exists as shown in Fig. 2(d). These two factors - existence of available sending voltage and feasible parameters range are the most important concerns in this paper.



<Fig. 2> DG output and upper/lower limits of sending voltage

4. Case Study

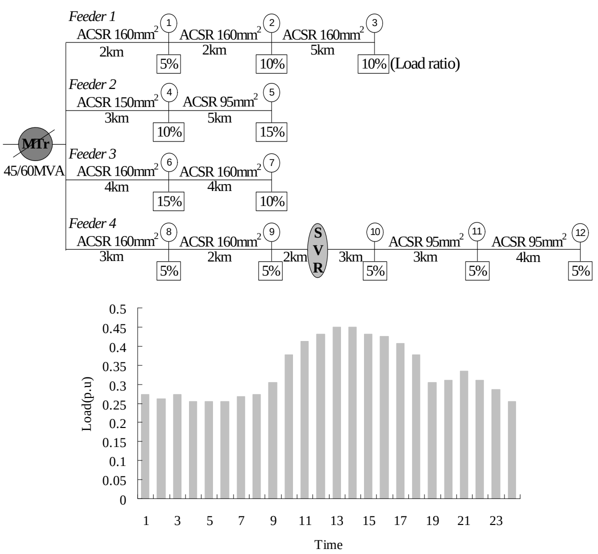
Availability of the proposed DG estimation method for multiple feeders is ascertained through numerical case study using 22.9[KV] model system and load pattern illustrated in Fig. 3.

4.1 Simulation conditions

- Base voltage=22.9(kV), Base power=100(MVA)
- Acceptable customer receiving voltage: 207~233(V)
- Voltage drops at peak time
  From the primary feeder to the nearest customer: 8(V)
  From the primary feeder to the farthest customer: 16(V)
- Tap step and bandwidth extent of regulators: 0.0125(p.u.)
- DG injects the power through 24 hours at single node.
- Ratio of pole transformer (ΔV_{feeder}):

$$\Delta V_{feeder} \le 5(\%) : 22.9(kV)/230(V)$$

$$5(\%) < \Delta V_{feeder} \le 10(\%) : 21.8(kV)/230(V) \rightarrow \text{node } 5$$



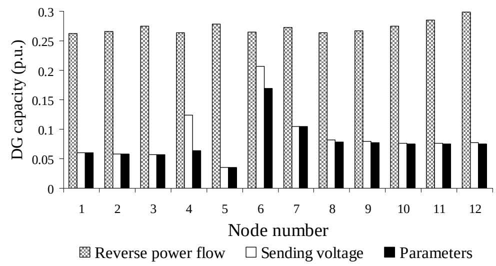
<Fig. 3> Model network and load pattern

4.2 Maximum installable DG capacity in the model system

In this case study, prohibition of reverse power flow at bank transformer, existence of available sending voltage and existence of LDC parameters are considered as operational constraints. Fig.4 shows the estimated nodal maximum installable DG capacities dominated by each operational constraint.

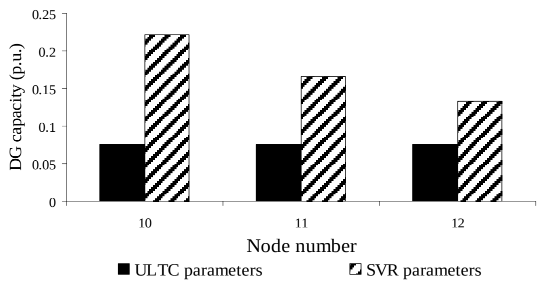
Maximum installable DG capacity dominated by the reverse power flow prohibition depends on the distance from the distribution substation. That is, the installable DG capacity at node closer to the distribution substation becomes smaller and severer. However, the prohibition of reversal power flow arrows larger installable DG capacity comparing to the other two operational constraints. In other words, we can say that the existence of available sending voltage or LDC parameters constraint has significant influence on installable DG capacity.

In fact, the maximum installable DG capacity is decided by existence of available sending voltage at node 1, 2, 3, 5 and 7, and is decided by existence of feasible LDC parameters at node 4, 6, and 8~12 even if the order of voltage limits can be preserved. Especially, installable capacity at node 5 having high pole transformer tap ratio is considerably small.



<Fig. 4> Maximum DG capacity according to each constraint

In the applied distribution system model, installable DG capacity at the nodes in the SVR control area (node 10, 11 and 12) is limited by existence of feasible LDC parameters of ULTC (see Fig. 5) since the ULTC has smaller flexibility in LDC parameter design than the SVR.



<Fig. 5> Dominant regulator for maximum DG capacity

5. Conclusion

This paper proposes a method to estimate maximum installable DG capacity considering LDC parameters of ULTC and SVR, and also revealed the importance of consideration for the existences of feasible LDC parameters in that estimation process.

In conclusion, we can say that the maximum installable DG capacity depends on the LDC parameters of voltage regulators, DG installation place and pole transformer tap ratio.

[Reference]

[1] Yoshiyuki Kubota, et al., " Influence of distribution voltage control Methods on maximum capacity of distributed generators," *Electrical Engineering in Japan*, vol. 150, No 1, pp.8-17, 2005. (in English)

[2] Jae-eon Kim, et al., " Methods of determining introduction limits of dispersed generation systems in a distribution system," *Electrical Engineering in Japan*, vol. 120, No 4, pp.48-58, 1997. (in English)

[3] KIM Miyoung, et al., " Design of the optimal ULTC parameters in distribution system with distributed generations," *The International Conference on Electrical Engineering* (ICEE 2007), No ICEE-454.