SCREENING METHOD FOR DG INTERCONNECTION TO DISTRIBUTION SYSTEM

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ABSTRACT

Penetration level of distributed generation (DG) on the grid is increasing worldwide. For the connection of new DG to the distribution network, various factors are considered including technical requirements that ensure the DG does not adversely affect the operation and safety of the network. Distribution system operators (DSO) have to perform impact studies of DG but these studies need cumbersome modeling and simulating of the target distribution network whenever DG is connected and the long time required for technical review. Therefore, utility engineers need the screening methods that can straightforwardly indentify cases with no impact on distribution system or those applications requiring detail studies. This paper presents the screening process and evaluation methods with simple rule on bank level and feeder level, respectively.

IMPACTS OF DG INTERCONNECTION

The voltage management of the existing distribution system presupposes power flow on a unidirectional basis from a transformer substation to load. Likewise, with unidirectional power flow, even though the current through the distribution line depending on load change causes voltage fluctuations, voltage is monotonically decreasing from the output of main transformer through a distribution feeder, resulting in the adjustment of voltage in the feeder according to the following: main transformer ULTC tap controlled by LDC (Line Drop Compensation) method, and; distribution transformer tap setting with a fixed tap. Therefore, the voltage control for the distribution line are determined by the main transformer ULTC tap control using the LDC method with respect to load change.

Sending voltage variation of main transformer

LDC controls the voltage throughout the distribution feeder within a designated range by maintaining the voltage on the centre point of load on which load concentrates at an optimal voltage level. LDC then detects and reacts to the entire load current throughout the distribution line and flowing out of the main transformer bank. The connection of the large capacity of DGs causes load current changes detected by LDC and likely malfunction of LDC. If any renewable enerty such as photovoltaic or wind power whose output characteristics are intermittent and frequent are connected, the load current detected by LDC fluctuates suddenly; thus causing frequent tap changing of ULTC, which in turn result in the shortening of life span and sudden voltage fluctuation experienced by customers, wielding an adverse impact on electric appliances. All DGs connected on main transformer bank affect the sending voltage variation. Therefore, this impact study has to be performed considering cumulative capacity of DG on bank level.

Over voltage on the local section of feeder

One of the main issues is feeder voltage variation with respect to DG's injected current. When DGs are connected to a distribution feeder, feeder voltages increase due to the effect of reverse power flow from the connected DGs. The bigger the output of the connected DGs is, the bigger the whole feeder voltage rise. One can even ascertain that reverse power flow occurs in some sections, resulting in the section of higher voltage than the sending voltage of the substation. Customers in some sections of the distribution network are at risk of being exposed to overvoltage as a result of the output variation of DG. All DGs connected on same feeder affect the voltage variation. When voltage analysis on the feeder, all DGs connected to the feeder has to be considered.

Protection problem

Another main issue regarding the connection of DG to the distribution network is protection problem. Whenever a fault would occur in the distribution network, the power source supplying the fault current was only the power source in a substation; fault current was supplied in a unidirectional manner from the substation to the fault point. Because of this, over-current relaying, which basically does not consider directionality, has basically been adopted for the protection of the distribution network.

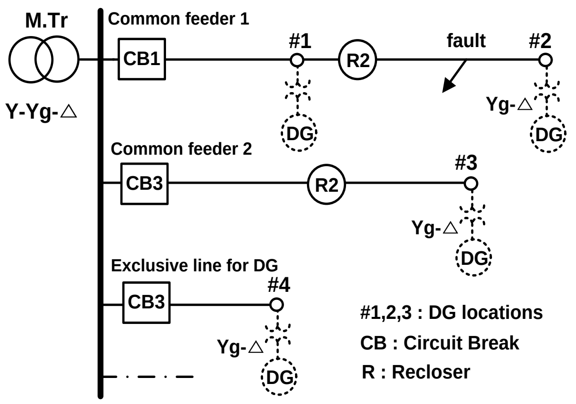

Fig. 1. Sample distribution network with DGs

Table 1. Protection problems due to DGs

DG location	Relay	Short Circuit level	Fault Current Sensitivity
#1	CB1	-△	-△
	RC1	+△	+△
#2	CB1	-△	-△
	RC1	-△	-△
#3, #4	CB1	+△	+△
	RC1	+△	+△

However, DG has been added as supplier of fault current in the distribution network due to the connection of DG to the distribution network; fault current also gets distributed in a bidirectional manner, thereby causing problems in the existing over-current protection system such as false operation, loss of sensitivity of protection device and increasing short circuit level. Fig. 1 is a sample distribution system with DGs. When the fault is occurred at the common feeder 1 as shown fig. 1, table 1 is a result of protection problem such as changes of fault current, short circuit level and sensitivity of the protection devices installed on common feeder 1. When DG located at the fault feeder, which is interest feeder, the fault contribution of DG affect the sensitivity of protection devices. But when DG located at adjacent feeder, the fault contribution of DG does not affect the sensitivity of protection devices installed at the fault feeder. Therefore, the evaluation of loss of sensitivity needs to be performed on feeder level. In case of increasing short circuit level, short circuit level is determined somewhere along the connection point of DGs no matter where fault is occurred at the fault feeder or adjacent feeders. Therefore, the evaluation of short circuit level needs to be performed on bank level.
When the impact studies for DG connection are needed, the consideration level with respect to DG impacts is listed in Table 2.

Table 2. Consideration level with DG impacts

Consideration	Impacts
Bank Level	- Frequent tap changing of ULTC and improper send voltage caused by ULTC abnormal operation - Increasing Short circuit level : especially, large capacity DG connected through exclusive line in the same bank
Feeder Level	- Over voltage : especially, local section where DG connected in the long distance from substation - Loss of Sensitivity : especially, over current ground relay when the ground fault arise with high fault resistance

SCREENING METHOD OF DG IMPACTS

Evaluation of sending voltage variation in the main transformer

In general, the control method for the main transformer ULTC adopts the LDC (Line Drop Compensation) method. The sending end reference voltage is expressed as:

$$V_{ser} = V_{ref} + Z_{eq} \times I_{bank} \qquad (1)$$

Where, V_{ser}: sending end reference voltage (SERV)
V_{ref}: reference voltage
Z_{eq}: compensating impedance
I_{bank}: load current of bank

In equation (1), $Z_{eq} \times I_{bank}$ means the equivalent voltage drop on the distribution line; the sending end reference voltage (SERV) is determined by compensating such voltage drop.
If DGs are connected to the distribution system, the load current of bank (I_{bank}) is changed to the following:

$$\acute{I}_{bank} = I_{bank} - \sum I_{DG} \qquad (2)$$

Where, $\sum I_{DG}$: total injected current by DGs

In other words, after such connection of DGs, the load current of bank ($\acute{I}_{bank}$) detected on the main transformer changes and affects the calculation of the equivalent line voltage drop, resulting in influencing SERV in equation (1). Eventually, SERV due to the connection of distributed generations is changed as:

$$\acute{V}_{ser} = V_{ref} + Z_{eq} \times \acute{I}_{bank} \qquad (3)$$

According to the connection of DGs the fluctuation volume of SERV is calculated as:

$$\Delta V_{ser} = \left|V_{ser} - \acute{V}_{ser}\right| = Z_{eq} \cdot \sum I_{DG} \qquad (4)$$

The variation of SERV due to the connection of DGs is proportional to the DG capacity. Therefore, the capacity of DGs should be limited on the main transformer bank level where ULTC tap movements are not frequent depending on the output fluctuation of such DGs. In other words, the fluctuation of SERV due to the connection of DGs should not be beyond the dead band of the LDC controller. Consequently, the acceptable capacity of DGs on a bank level can be evaluated using above equations

Simple rule on bank level

As seen in equation (4), the larger the compensating impedance of the LDC controller is, the further the fluctuation of the sending end reference voltage (SERV)

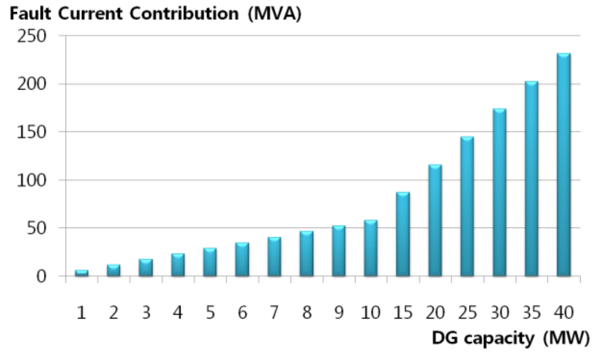

Fig. 2 Fault current contribution of synchronous generator with respect to capacity

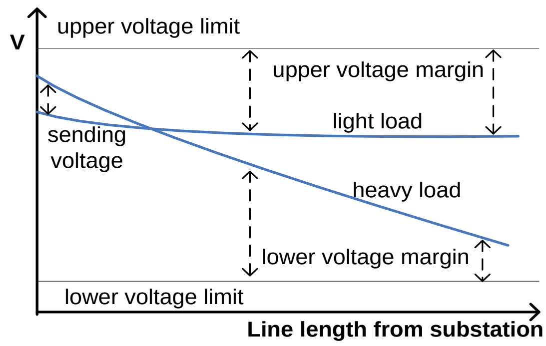

Fig. 3 Voltage Variation Margin

increases for DGs with the same capacity. Toward that end, the interconnection capacity of distributed generations as calculated using equation (4) by reflecting the largest compensating impedance in the distribution system can serve as a simple rule for determining whether or not it is possible to connect the main transformer bank without any specific technical calculation. As a result, 15 % of the main transformer capacity is determined as simple rule of bank level.
The capacity of most main transformer of KEPCO is 60MVA, that is, 15% of the main transformer is 9MVA. Fig. 2 shows the fault current contribution of the synchronous generator. The short circuit level increase below 50 MVA when 9MVA synchronous DG installed. 50MVA is about 5% of CB breaking capacity and 10% of recloser breaking capacity of KEPCO. This means that 15% of main transformer capacity has no impact on the short circuit level of the distribution system. The DG capacity less than 15%(simple rule) of main transformer need not calculate any specific technical calculations on bank level such as sending voltage variation and also short circuit level.

Evaluation of voltage violation in the feeder

There is a need to find a method of evaluating the capacity of DG that is acceptable without modification of the infrastructure of the distribution feeder by considering an electric power company's distribution network design and voltage management method.
Fig. 3 shows the voltage profiles with respect to the load amount of the distribution network and the voltage variation margin. Deriving the allowable capacity of DG in terms of maintaining the suitable voltage of the distribution feeder requires calculating whether a deviation from the suitable voltage range occurs due to the output of DG under the condition of load wherein the distribution network has the minimum voltage margin.
DG generally causes the voltage of the feeder to rise. The worst case condition is said to be the condition of minimum load and maximum generation. As such, we can consider the evaluation of the allowable capacity of DG for its connection to the distribution feeder by checking whether a deviation from the suitable voltage maintenance range occurs in a MV-level distribution feeder by calculating power flow under the conditions of the minimum load of the feeder and the maximum generation of DGs. As mentioned in above section, the main transformer controls the sending voltage by adjusting the ULTC according to the load amount for each time range to maintain the overall voltage of the distribution lines within the suitable voltage range. Therefore, the distribution feeder can be said to have the minimum voltage margin under the conditions of maximum sending voltage condition.
Therefore, the allowable interconnection capacity of DG for the distribution feeder to which DG will be connected can be calculated by checking whether the voltage of the distribution network deviates from the upper voltage limit or not by calculating power flow under conditions 1, 2, and 3.

Condition 1: Minimum load
Condition 2: Maximum generation
Condition 3: Maximum sending voltage
Constraint: Upper voltage limit

Simple rule on feeder level

The numerous studies have been performed to determine the specified simple rule which is suitable for the KEPCO distribution. All technical interconnection issue, i.e. voltage regulation, slow/fast voltage variation, protection, harmonic distortion, short circuit levels, has been studied for distribution network that is designed with the planning specifications of the KEPCO.
After the study, the critical technical requirements for determination of the specified percent rule are voltage issue and protection coordination issue. Above them, it can be seen that most critical impacts are voltage regulation and slow/fast voltage changes impacts in KEPCO distribution networks. Because KEPCO already have the solution for protection coordination issues, this technical solution has been developed and field test has been done. As a result, the 15 % Rule is selected for simple interconnection process.

Screening and evaluation process

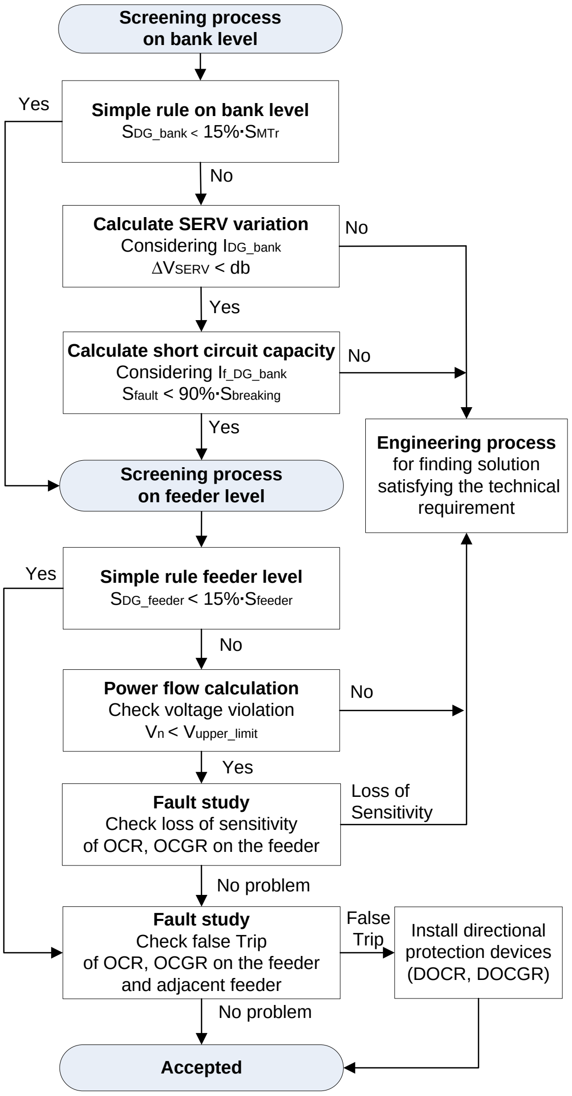

Fig. 4 Flow chart of screening and evaluation process for DG interconnection

The screening and evaluation process for DG interconnection is proposed in fig. 4. The proposed screening process consist of 3 step as following

Simple & fast process

If cumulative DG capacity below than simple rule, 15% of transformer capacity and 15% of feeder normal operation capacity, which DG applicants can be accepted except for checking false trip of protection devices.

Detail study process

If cumulative DG capacity over than simple rule, it needs to be detail study. When DG applicants can not satisfy the technical criteria throughout the detail study, they go to engineering process and have to find a solution satisfying the technical requirements.

Table 2. Indication of index of flow chart

Index	Indication
S_{MTr}	capacity of the main transformer bank
S_{feeder}	normal operation capacity of the feeder
S_{DG_bank}	total capacity of DGs connected on bank
S_{DG_feeder}	total capacity of DGs connected on feeder
I_{DG_bank}	total current of DGs connected on bank
$\triangle V_{SERV}$	Sending end reference voltage
db	dead band of Line Drop Compensator
$I_{f\_DG\_bank}$	total fault current of DGs connected on bank
S_{fault}	short circuit capacity of the system
$S_{breaking}$	breaking capacity of protection devise
V_n	node voltages of the distribution line
V_{upper_limit}	upper voltage limit of the feeder

CONCLUTION

We have discussed the issues of voltage variation, false trip of the protection device, sensitivity loss, and increasing short-circuit capacity arising from DG, affecting the existing distribution network. And we categorized the DG impact study into bank level and feeder level consideration, respectively. Next, we present the equations for evaluating of sending voltage variation on a bank level and the voltage analysis method for evaluating of voltage violation on a feeder level. In addition, the simple rule of KEPCO is introduced that allows intuitively evaluating the interconnection capacity of DG without performing any complicated calculation such as power flow and fault study.

Finally, the screening and evaluation process for DG connection is proposed which process is consist of simple process and detail study process, and the proposed method divided into bank level and feeder level screening process.

This screening and evaluation process is introduced for fast inter-connection process to save the engineering efforts and time consuming. Therefore it will be useful to utility engineers, consultants and also IPPs (independent power producers) in their planning stage of DG installation.

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