INTERCONNECTION GUIDELINES AND CONTROL COORDINATION OF REACTIVE POWER SUPPORT FUCTIONS OF DISTRIBUTED ENERGY RESOURCES

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ABSTRACT

This proposal discusses the interconnection guidelines for DER (Distributed Energy Resources), especially reactive power support functions of DER. The existing interconnection guidelines generally prevent active voltage regulation by the DER at the PCC (Point of Common Coupling). Also, they prevent lagging power factor operations of the DER. However, the DER can enhance and support the voltage profiles of distribution networks. However, the optimum operations and advanced voltage regulations are guaranteed only by the proper coordination between distribution automation and DER units. This can be realized by the intelligent supervised and localized control schemes for the DER units. In this proposal, the interconnection guidelines and coordination schemes for reactive power support of the utility interactive DER units are discussed.

INTRODUCTION

The DER, especially large wind turbine and photovoltaic systems, have become more important as an alternative energy resources during the last decades. Currently, the DER (Distributed Energy Resources) will be interconnected in customer areas in distribution networks and operated on its own schedule without communication to the control center of the existing distribution automation system. It is well known that the large penetration of the DER units to distribution networks in rural areas can cause many technical interconnection problems, i.e., voltage regulation, harmonic distortion, protection coordination, short circuit capacity, etc [1].

The DER units have both positive effects and negative effects regarding operations of the distribution networks [2].

With the proper coordination of the DER units in the distribution networks, losses are reduced during normal operations and they support local loads during abnormal conditions. Thus, the positive effects of the DER units need to be enabled in the distribution networks by adopting advanced operation schemes and infrastructures. The positive effects of the DER in the distribution networks are;

1) Quality improvement: a dynamic voltage support, ensuring a voltage profile improvement over feeders, active filters, etc.
2) Reliability improvement: UPS (Uninterruptible Power Supply) functions, local service restoration (intentional islanding), etc.
3) Economic benefits: a relatively high energy efficiency, loss reduction, load leveling, etc.

The well developed intelligent operation algorithms and two way communication network infrastructures must be required to cope with the above mentioned positive effects of the DER. The next generation distribution networks "Smart Distribution Networks" can manage the DER units to achieve the optimum operation in view of the new distribution EMS (Energy Management Systems) concepts.

In existing distribution networks, fully utilizations and cooperation of DER units are difficult to realize due to the incompleteness or uncertainly of information about operation status of the DER units, information about distribution networks status, and etc. This requires above mentioned infrastructures.

Otherwise, without proper coordination and well developed interconnection procedures, the interconnection of DER units to the existing distribution networks cause the technical interconnection problems. The negative effects of the DER in the distribution networks are summarized as follows:

1) voltage variation due to the active power fluctuation of the DER
2) LTC (Load Tap Changer) control disturbances due to the power injection of the DER
3) increases in short circuit capacity of circuit breaker due to the fault contribution of the DER
4) miscoordination of the protection devices due to the reverse power flow of the DER, etc.
5) increases in harmonic distortion due to the increases use of power converter devices, i.e., Photovoltaic, Fuel Cells, etc.

In practice, voltage variations due to the DER units are often a limiting factor for the maximum amount of DER interconnection capacity. Already current wind generation systems and photovoltaic systems with a capacity of MW class or more over can often not easily be connected to existing feeders in typical distribution networks.

The modern power converter technologies "full scale converter" enables the DER can absorb and inject the reactive power without loss of active power generation. This type of DER can regulate the network voltage actively with a technical agreement by a utility.

In this proposal, the technical interconnection guidelines associated with reactive power support functions will be discussed. The existing standard and guidelines should be modified to implementing these positive effects of DER. The reactive power control guidelines and schemes of the utility interactive DER units in existing distribution networks are discussed. As results, it can be seen that the interconnection capacity of DER can be increased without reinforcement of the distribution network equipments and devices. In addition, the optimal voltage control practices for fully automated distribution networks with DER are introduced.

VOLTAGE REGULATION ISSUES WITH DER

Voltage regulation due to the interconnection of DER

The unexpected undervoltage and overvoltage conditions could be happen in distribution networks due to the interconnection operations of the DER. The main voltage regulation device of the distribution networks is LTC control of the substation main transformer. It is well known that LTC control can be disturbed by the operation of the DER. In addition, the voltage drop characteristics of the distribution line will be changed by the real/reactive power injection of DER [1].

In general, undervoltages at customer terminals can be seen at the end of feeders without DER interconnection and overvoltages at the customer terminals can be seen at the end of feeders with DER interconnection.

The Fig. 1 shows that the changes in voltage profiles over feeder with the changes in power factor of the interconnected DER.

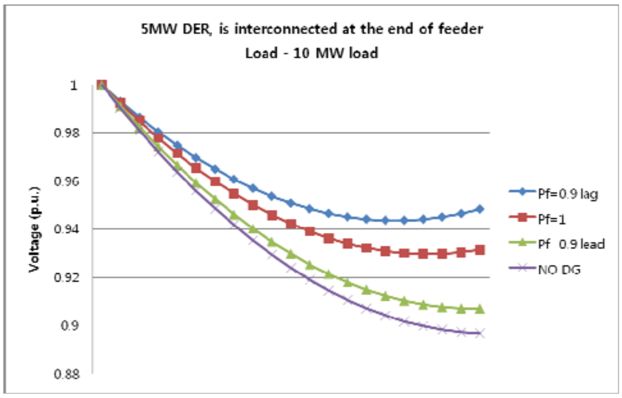

Fig. 1. Changes in voltage profiles over feeder with the changes in power factor of DER

From the Fig. 1, the DER can regulate the voltage profiles over feeder by controlling a power factor. The lagging power factor results voltage rise compared with leading power factor. Note that the lagging power factor of DER represents reactive power production.

However, the IEEE 1547 standard prevent active voltage regulation by the DER at the PCC (Point of Common Coupling) [3]. In addition, some utility interconnection guidelines or practices prevent lagging power factor operations of the DER to prevent undesired overvoltage conditions [4]. In recent, remote command and control of reactive power of DER is mentioned in some technical guideline [5]. But the detailed command/control schemes and localized reactive power control schemes are not described. This reactive power control functions and remote control functions will be essential functions in the distribution networks with a large number of DER units and/or future distribution networks with DER units.

Optimal voltage regulation including DER

In fully automated distribution networks, the optimal voltage control can be achieved by determining the optimal sending end voltage of the distribution bus and optimal reactive power output of the DER units. The generalized voltage coordination formula in distribution networks with DER can be

$$\underset{V_{se},Q_k}{Min} \quad J = \sum_{j=1}^{n} \{(V_j - V_{nom})^2\} \tag{1}$$

Subject to

$$V_{\min} \le V_j \le V_{\max}$$

$$Q_k^{\min} \le Q_k \le Q_k^{\max}$$

where, V_{se} : sending end or distribution bus voltage, Q_k : reactive power output of k^{th} DER, V_j : node voltage, and V_{nom} : nominal voltage

In Eq. (1), the cost function is defined as how close the node voltages (customer voltages) of the distribution networks are to the nominal voltage. The optimal sending end voltage and optimal reactive power output of the DER units can be obtained by solving Eq. (1).

Case study I

The sample case study was done to show the effects of reactive power control of DER units. The 32 bus system was chosen as sample distribution network [6]. The single line diagram of the sample distribution network is shown in Fig. 2. The detailed parameters of the DER units for case study are shown in Table 1. The simulation results for 32 bus system are listed in Table 2.

Case study II

The typical 22.9 kV Korean distribution network was chosen for the case study. The sample system is consists of 23 node, 3 feeders, and 1 tie switch. The PF 0.9 10 MVA load are distributed for each feeder. The single line diagram of the sample distribution network is shown in Fig. 3. The detailed parameters of the DER units for case study are shown in Table 3. The simulation results for 23 bus system are listed in Table 4.

In case study I and II, it is note that the positive value of PF represent lagging PF. In simulation study, it is assumed that the optimal sending end voltage is discreetly changed in 0.01 pu. It is also assumed that the DER can absorb and inject the reactive power without loss of active power generation.

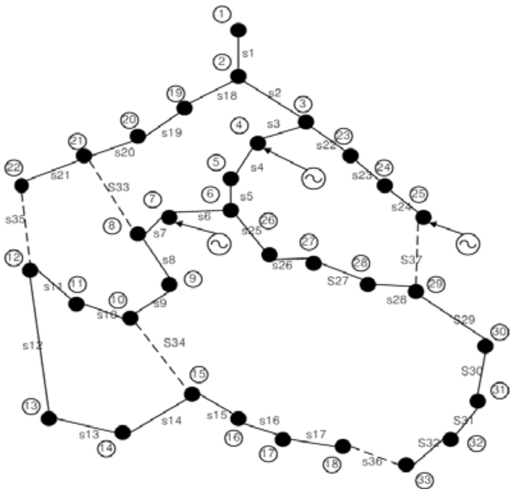

Fig. 2. Sample distribution network (32 bus test system).

Table 1. Detailed parameters for the case study I

DER	Installation node	Installation Capacity (kW)	Operation range of PF
Case 1	4 7 25	50 100 200	-0.9 ~ 0.9
Case 2	4 7 25	100 200 400	-0.9 ~ 0.9
Case 3	4 7 25	200 400 800	-0.9 ~ 0.9
Case 4	4 7 25	300 600 1200	-0.9 ~ 0.9

Table 2. The optimal sending end voltage and reactive power output of DER units for the case study I.

Case	V_{se}	Losses (kW)	PF of DER		
			4	7	25
1	1.04	163.92	0.9	0.9	-0.9
2	1.04	143.36	0.9	0.9	-0.9
3	1.04	131.14	0.9	0.9	-0.9
4	1.04	120.18	0.9	0.9	-0.9

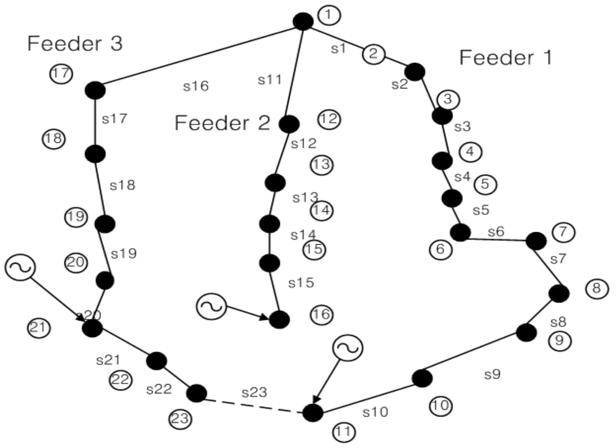

Fig. 3. Sample distribution network (23 bus test system).

Table 3. Detailed parameters for the case study II

DER	Installation node	Installation Capacity (MW)	Operation range of PF
Case 5	11 16 20	2 1 1.5	-0.9 ~ 0.9
Case 6	11 16 20	4 2 3	-0.9 ~ 0.9
Case 7	11 16 20	6 3 4.5	-0.9 ~ 0.9

Table 4. The optimal sending end voltage and reactive power output of DER units for the case study II.

Case	V_{se}	Losses (kW)	PF of DER		
			4	7	25
5	1.01	190.00	0.9	0.9	0.9
6	1.01	112.49	0.9	0.9	0.9
7	1.01	94.67	0.99	0.96	0.92

From the case study I, it can be seen that the optimal power factor of the DER units are reach to its maximum and minimum values. For DER connected at node 25, it absorbs the maximum reactive power from the utility grid. While the DER units connected at node 4 and 7 inject the maximum reactive power to utility grid.

From the case study II, the optimal power factors of the DER units are limited a certain limits for case 7. It can be seen that the reactive power output of the DER units are limited to achieve the optimal voltage profiles at nodes.

Autonomous reactive power control schemes of DER in the existing network

For voltage regulation at the, existing standard and guidelines prevent the active voltage regulation at the PCC by the voltage/reactive control of the DER [3 - 5].

In practices for DER interconnection, unit capacity and accumulated capacity of the DER units are regulated to the certain limits in most utilities. In most interconnection guidelines, the % voltage variations ($\Delta V_{\max}$) by the DER can be limited and therefore the interconnection capacity of DER is limited [4 - 5].

$$\Delta V_{\max} < 2\% \qquad (2)$$

To increase the interconnection capacity in the existing distribution networks without any reinforcement, the DER units should be actively and/or autonomously operated. When a DER can actively regulates voltage of the PCC within an acceptable voltage limits, larger capacity of DER can be interconnected into the existing networks without voltage regulation problems. In this case, the highest priority is to maintain the voltage within an acceptable voltage limits. To achieving this goal, simple algorithms to maintain the PCC voltages will be presented in this proposal. The active and reactive power outputs of the utility interconnected DER are influence on voltage drops on the feeders. Thus, the regulation of the active and reactive power outputs of the utility interconnected DER results in changes in voltage drop on the feeder. Between them, the reactive power has great influence on voltage drops due to the high X/R ratio of the distribution overhead lines. And the curtailment of the active power is not favorable since it is very critical factor for the economics of the DER operator. Fortunately, the DER which use full scale converter, can absorbs and injects reactive power without changes in active power output.

Therefore, the reactive power control schemes of the utility interactive DER are proposed to reregulate the distribution voltage within permissible limits. The proposed autonomous reactive power control schemes of the utility interactive DER are shown in Fig. 4.

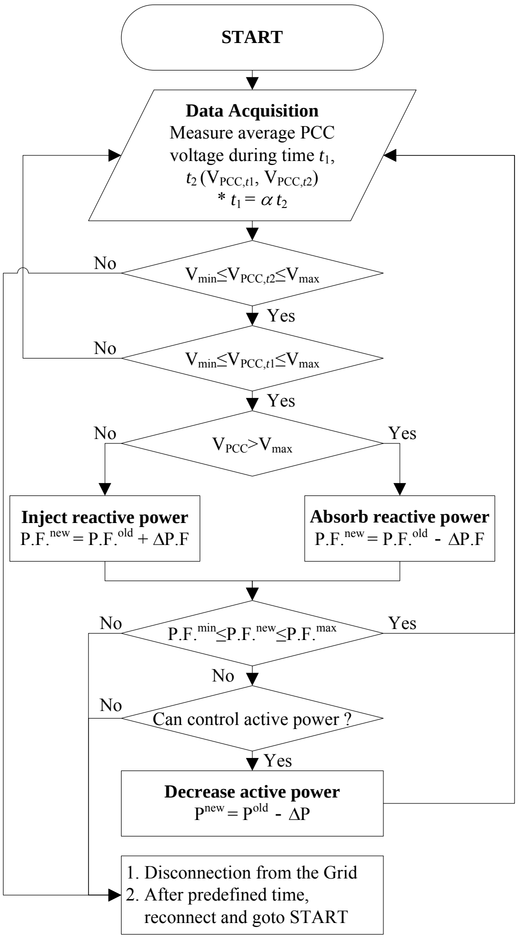

Fig. 4. The algorithms of the proposed autonomous reactive power control schemes of the utility interactive DER.

The proposed autonomous reactive power control schemes of the utility interactive DER will be appeared in newer version of the KEPCO interconnection guidelines. From this technical requirement, it is expected that the interconnection capacity of the DER will be increased without reinforcement of the existing distribution networks and changes of existing operation practices.

CONCLUSION

In this proposal, the methodologies and case studies for remote control of the reactive power of the DER units at the fully automated distribution networks are presented. In the proposed optimal voltage regulation including DER units, the cost function is only formulated by the voltage regulation performances. However, the loss reduction should be also considered into the cost function. The further development of formulation of the cost functions will be remained.

In addition, the autonomous reactive power control schemes of the DER in the existing distribution network are proposed. This would be a new feature for the new version of the interconnection guidelines. In the proposed schemes, it is note that the time intervals t_1 and t_2 of average voltage value of PCC are carefully selected for utility voltage regulation practices and standards. The detailed analysis and study for these parameters will be studied in the near future.

Acknowledgments

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