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Research on Solutions for Implement of Active Distribution Network

Abstract. *Nowadays, distribution systems are facing the challenge to accommodate increasing quantities of Distributed Energy Resources (DERs), especially based on the intermittent renewable sources. So it is inevitable for distribution systems shifting from passive mode to active mode. This paper discusses some important issues for implementation of active distribution network (ADN) which is capable of allowing high penetration of renewable resources together with optimal operation by its flexible network, including planning for active distribution network considering renewable energy uncertainties, fully utilization of large scale intermittent renewable energy and active network management (ANM). Accordingly, some solutions are proposed to meet requirements of implement of active distribution network, basing on the issues aforementioned.*

Streszczenie. *W artykule omówiono zagadnienie implementacji aktywnej sieci przesyłowej, z naciskiem na wysoki poziom wykorzystania odnawialnych źródeł energii (OZE) poprzez zapewnienie elastyczności sieci. Przedstawiono rozwiązania dotyczące niestabilności generowanej przez OZE energii, optymalizacji pracy, maksymalnego wykorzystania generowanej energii oraz zarządzania siecią aktywną. (**Badanie metod implementacji aktywnych sieci przesyłu energii**).*

Keywords: distributed energy resources; intermittent renewable sources;active distribution network; active network management
Słowa kluczowe: rozproszone źródła energii, nieciągłe odnawialne źródła energii, aktywne sieci przesyłowe, zarządzanie siecią aktywną.

I. Introduction

Nowadays, as environmental and energy shortage awareness has grown, the energy and electricity industry pays extremely attentions to the development and application of distributed renewable resources, together with its integration to the power grid.

As far as can be seen, distribution network is a good choice for high penetration of Distributed Generations (DGs), especially based on the intermittent renewable resources such as wind and solar power. However, increasing amount of DGs will bring about significant impacts on operation of distribution networks despite of the economical benefits for its owners. Power flow and voltage profile for example, are two key factors that would change dramatically when integrating with large amount of DGs [1][3]. Meantime, the intermittent nature of some renewable resources is another notable issue.

As a result, Distribution System is undergoing a challenge of shifting from the passive network to active network. In the past, distribution system is just responsible for delivering power from the high-voltage transmission system to the low-voltage end users in a passive unidirectional way. But in near future, distribution network power flow will becomes bidirectional due to the distributed generators incorporation. Distribution network will face the fluctuation of frequency and voltage caused by the intermittence of renewable resources (Wind, Solar). Additionally, distribution system will allow intend islanding form to secure the power supply of important load. In summary, Distribution System should operate in active way to support large scale integration of intermittent renewable resources, better power quality and higher reliability.

This paper presents some important issues for active distribution network (ADN) [2] implementation which is capable of allowing high penetration of renewable resources together with optimal operation by flexible network and proposes according solutions enabling active distribution network, basing on the issues aforementioned. Section II gives a detail presentation of the important issues which are urgent to be addressed for active distribution network. Section III proposes some effective solutions enabling active distribution network according to the issues described in Section II, including the two-stage stochastic planning for active distribution network, the coordinated control framework of active distribution network along to make full use of renewable energy and the advanced distribution management system. Finally, Section IV summaries the key technologies needed for deployment of active distribution network and looks forward to future smart distribution network.

II. Issues for Implementation of Active Distribution Network

As mentioned, Active Distribution Network is defined as distribution network that has systems in place to control a combination of distributed energy resources (generators, loads, storages) appropriately to assure maximum utilization of renewable generation together with good power quality and high reliability [4]. To Achieve this goal, the following issues are the most urgent to be addressed: (1) Active Distribution Network Planning considering renewable generation uncertainties (2) Technology for absorption of intermittent Renewable Generation (3) Coordinated Control Technology between distributed resources(generation, load, storage) (4) Active Network Management System, which will be represented in details as follow:

A. Active Distribution Network Planning Considering Renewable Energy Uncertainties

Active Distribution Network needs to employ varieties distributed resources such as renewable generations, controllable loads, non-renewable distributed generations, storage devices and compensators etc in good combination, leading to the complexity and uncertainties for the planning of active distribution network [5][6].

The issues of the planning active distribution network consists of determining the placement and the capacity of the distributed generators, the installation of normal open switches, the wiring between MV substations, and the placement and the capacity of reactive power compensators.

Generally, planning depends on two basic parameters: technical constrains and the optimization targets [6]. As for the active distribution network, there are some new contents. On one hand, besides the conventional technical constraints (equipment capacity, voltage profile, reliability indices, power flow, etc), the maximum utilization of renewable generation raises a new challenge of capacity match between renewable sources with other non-renewable generators and storages. On the other hand, the assessment of the active distribution network benefits [7] is

a new task concerning not only the cost reduction due to energy efficiency improvement, but also the environmental benefits due to utilization of large scale renewable generation.

Essentially, active distribution network planning is multi-objective and stochastic programming [8] due to the intermittence and uncertainty of renewable generation production, which needs to introduce probabilistic assessment into the algorithm.

B. Technology for making full use of large scale intermittent renewable energy

Active Distribution Network is characterized as making full use of high penetration renewable sources such as wind, solar. At present, micro-grid is considered as a good choice for utilization of renewable energy. Micro-grid can be seen as a small distribution system consisted of distributed generators, energy storage device, loads, energy conversion devices and protection devices, which can realize self-control, protection and autonomous management [9].

Nevertheless, with high penetration and large scale implementation of distributed sources, micro-grid is inadequate to completely absorb large scale renewable energy in terms of its capacity and scale. The new technology for utilization of large scale intermittent renewable energy should be based on MV distribution network allowing decentralized locations of distributed renewable sources not as well as micro-grid. Furthermore, the new technology based on active distribution network gives priority to complete utilization of renewable energy, leading to the coordinated control [10] between renewable sources with other non-renewable sources and storages. Additionally, the new technology should resort to active network management system to assure the technical constraints within reasonable limits during the process of completely using renewable energy.

C. Active Network Management

Active Network Management (ANM) should operate a distribution network with high DGs share without violation of the constraints on nodal voltages and line currents. As a result of high DGs share, especially renewable sources, distribution power flow shifts from unidirectional to bidirectional inevitably. Secondly, the intermittence and uncertainty of renewable energy results in complexity of charge-discharge strategy for energy storages and voltage fluctuation. Last, ANM should assure maximum utilization of renewable generations. All above makes ANM optimal schedule and coordinated voltage regulation [11] more complicated.

III. Solutions Enabling Active Distribuiton Network

On the basis of the issues for active distribution network implementation discussed above, this paper proposes some solutions enabling implement of active distribution network as follows:

- Two Stage Stochastic programming
- Multilevel hierarchical control framework for fully utilization of intermittent renewable energy in active distribution network
- Advanced Distribution Management System

A. Two Stage Stochastic programming

Active Distribution Network Planning involves numerous variables including distributed generators siting and sizing, distributed energy storages siting and sizing, compensators sitng and sizing and normal open switches location complying with such constraints as power balance, line currents limits, nodal voltage limits, radial structure of MV feeders neglecting distributed generators and zero active power curtailment of renewable generations. Besides investment cost, operation cost, maintenance cost, network loss cost, capacity adequacy cost, the objective function of active distribution network planning should incorporate the benefits of renewable generations due to dioxide emission reduction.

The process of active distribution network planning is related to plenty of uncertainties which is listed in Table1.

Table1 Uncertainties of Active Distribution Network Planning

No	*Uncertainties*
1	Future Load Growth
2	Output Power Of a Wind Generation Unit
3	Output Power Of a Solar Generation Unit
4	Fuel Price Used By Fuel Cell Or Gas Turbine
5	Electricity Prices
6	Incentives For Renewable Generation

For the analysis given above, the variables involved in the process of active distribution network planning are basically discrete. Hence, GA can be seen as an effective way to solve stochastic programming by introducing probabilistic assessment into the algorithm. Considering the "charge-discharge" feature of energy storages, active distribution network planning can be summarized as two stage stochastic programming. The first stage considers the charge feature of energy storages corresponding to the valley time. By contrast, the second stage concerns about the discharge feature of energy storages corresponding to the peak time.

Obviously, the principles for renewable generation uncertainties vary with the type of renewable sources.

For example, the output power of a wind generation unit can be unified expressed as equation (1) without considering the difference between two stages:

$$P_{wind} = \int_0^\infty P_w(v) f(v) dv \tag{1}$$

Where $P_w(v)$ and $f(v)$ are, respectively, the wind power function of wind speed v and the probability density function of wind speed v. However, the solar generation is closely related with the time stage due to its regular intermittence. Hence, the output power of a solar generation unit can be expressed as equation 2 for simplicity:

$$P_{solar} = \begin{cases} 0 & \text{stage 1} \\ \int_0^\infty P_s(S) f(S) ds & \text{stage 2} \end{cases} \tag{2}$$

Where $P_s(S)$ and $f(S)$ are, respectively, the solar power function of solar radiation S and the probability density function of solar radiation S.

Furthermore, the operation cost of objective function should be calculated separately corresponding with two stages, which are illustrated as follows:

$$C^{op} = C^{op}_{stage1} + C^{op}_{stage2} \tag{3}$$

where C^{op}_{stage1} and C^{op}_{stage2} can be respectively expressed as equation (4) and (5):

$$\begin{aligned} C^{op}_{stage1} = {} & C^{op}_{wt} \times P_{wind} \times T_{stage1} + C^{price}_{valley} \times P_{charge} \times T_{stage1} \\ & + C^{op}_{other} \times P_{other} \times T_{stage1} \end{aligned} \tag{4}$$

where C_{wt}^{op} represents the operation cost for per kwh of wind turbine power production, C_{valley}^{price} represents the electricity price for per kwh at valley time, C_{other}^{op} represents the operation cost for per kwh of non-renewable generation power production, and T_{stage1} is the time period of stage 1.

$$C_{stage2}^{op} = C_{wt}^{op} \times P_{wind} \times T_{stage2} + C_{solar}^{op} \times P_{solar} \times T_{stage2} + C_{other}^{op} \times P_{other} \times T_{stage2} - C_{peak}^{price} \times P_{discharge} \times T_{stage2} \quad (5)$$

where C_{solar}^{op} represents the operation cost for per kwh of solar generation , C_{peak}^{price} represents the electricity price for per kwh at peak time, and T_{stage2} is the time period of stage 2. Similarly, it will have the same process when calculating network loss cost. In general, the two stage stochastic programming method for active distribution network can be described as Fig 1.

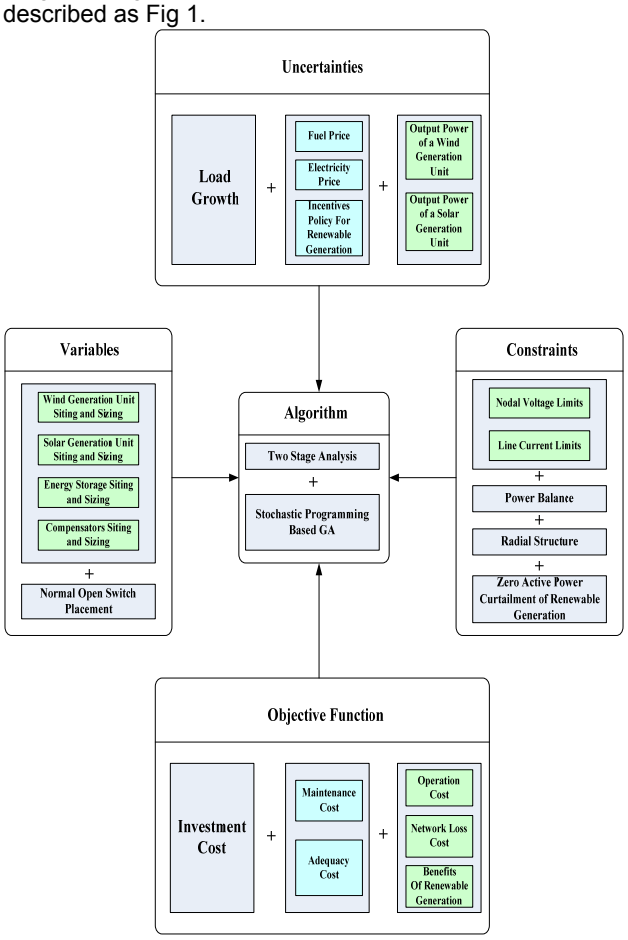

Fig.1. Two-Stage Stochastic Programming Method For Active Distribution Network

B. Multilevel hierarchical control framework for fully utilization of intermittent renewable energy in active distribution network

With the progress of renewable energy technology and the incentive policy for renewable energy, it's necessary for active distribution network to make full use of high penetration renewable energy allowing bidirectional power flow between DGs with grid, which gives rise to a series of technical challenges comprised of how to accommodate varieties of DGs, how to coordinate control between DGs with grid and how to make full use of renewable energy.

In this section, a multilevel hierarchical control framework for fully utilization of intermittent renewable energy in active distribution network is proposed to tackle these challenges aforementioned, which is depicted in Fig 2.

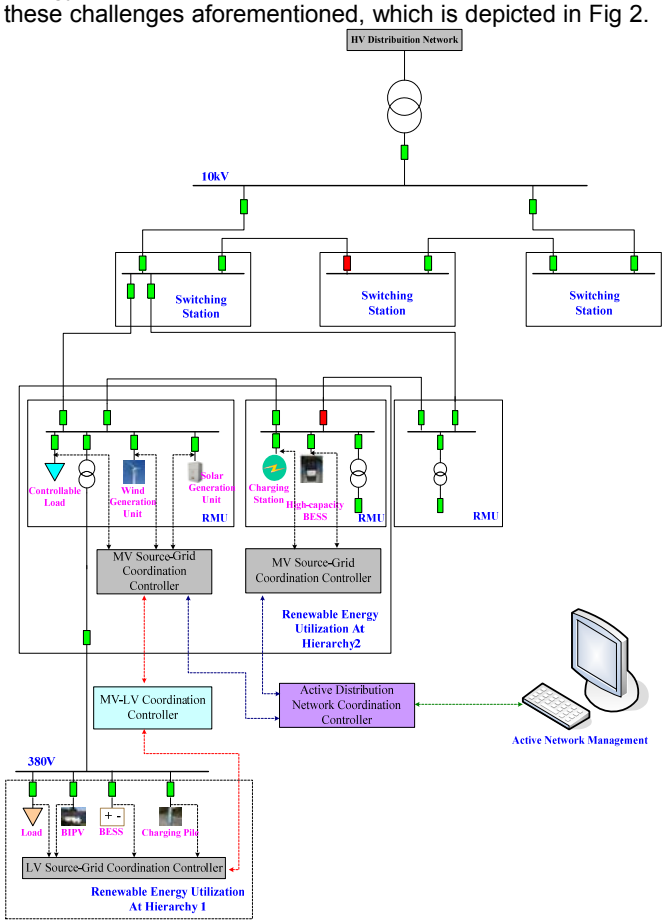

Fig.2. A Multilevel Hierarchical Control Framework For Fully Utilization Of Renewable Energy In AND

As depicted in Figure 3, the control framework used for making full use of renewable energy in active distribution network can be decomposed into 5 levels together with 2 hierarchies, which will be presented in details as follow:

- Low Voltage Source-Grid Coordination Controller: it is responsible for monitoring the operation states of all distributed energy resources connected to the low voltage bus and guaranteeing completely utilization of renewable energy by combined regulating other controllable resources such as micro-turbine, battery energy storage and controllable load etc. Besides this, it sends information to medium voltage coordination controller or receives instructions from medium voltage coordination controller by interacting with medium/low voltage coordination controller.
- Medium/Low Voltage Coordination Controller: it acts as courier between low voltage source-grid coordination controller with medium voltage source-grid coordination controller. It receives the surplus power information from low voltage source-grid coordination controller and transfers the information to medium voltage source-grid coordination controller when existing surplus renewable energy on low voltage level. By contrast, it receives the control instruction information from medium voltage source-grid coordination controller and transfers the information to low voltage source-grid coordination controller when under emergency state.
- Medium Voltage Source-Grid Coordination Controller: it involves in monitoring the operation states of all distributed energy resources in an individual ring main unit (RMU) and

regulating them to assure fully utilization of renewable energy within the RMU and the surplus renewable energy coming from the low voltage level. Additionally, it will resort to the distributed energy resources of neighboring RMU when existing surplus renewable energy by means of active distribution network coordination controller.

- Active Distribution Network Coordination Controller: it functions as a processing unit to handle the utilization of renewable energy in medium voltage level. First, it collects information about the renewable energy utilization from each medium voltage source-grid coordination controller in the charge of it. If there is at least one RMU having surplus renewable energy, it will ask active network management system for an optimal coordination control strategy. Then it gives instructions to its related medium voltage source-grid coordination controller according to the strategy.
- Active Network Management System: it gives the optimal schedule and coordinated voltage regulation solution to ensure no occurrence of voltage violation and economical efficiency of the renewable energy utilization process.

It can also be analyzed that low voltage source-grid coordination controller and medium/low voltage coordination controller transact the process of renewable energy utilization at low voltage hierarchy while medium/low voltage coordination controller, medium voltage source-grid coordination controller, active distribution network Coordination Controller, active network management system deal with the utilization of renewable energy at medium voltage hierarchy in cooperation. Another important issue should be paid attention to is that the medium/low voltage coordination controller only links a medium voltage source-grid coordination controller of an individual RMU with the low voltage source-grid coordination controller of the low voltage bus which is energized by the RMU. Similarity, active distribution network coordination controller is in charge of all medium voltage source-grid coordination controller in the same feeder.

C. Advanced Distribution Management System

Advanced distribution management system (ADMS) [12] is the brain of active distribution network, which makes all control decisions to manage the distribution network actively. Advanced distribution management system is able to manage all controllable resources such as the OLTC, DERs and compensators etc to minimize energy losses, improve power quality and maximum renewable energy utilization while traditionally distribution management system (DMS) simply decide to disconnect DGs or not. The structure of ADMS can be illustrated as Fig 3.

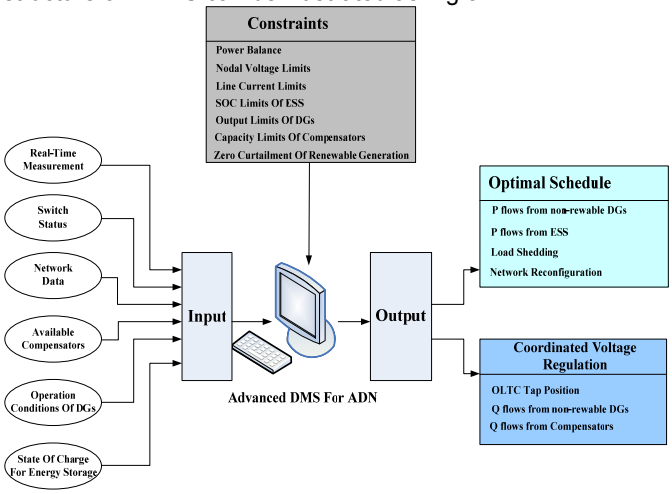

Fig 3. The Structure Of Advanced DMS For AND

As can be seen in Fig 4, advanced distribution management system (ADMS) collects information about real-time measurements, switch status, operation condition of DGs including non-renewable units and renewable units, state of charge (SOC) for energy storage system and gives an optimal solution of schedule for DGs and voltage regulation within the technical constraints comprised of power balance, nodal voltage limits, line current limits, SOC limits of energy storage system, topological limits, output limits of DGs, capacity limits of compensators in the process of fully utilization of renewable energy that is described in previous section. The output decisions made by ADMS can be summarized as follows:

- Output power from non-renewable DGs
- Charge or discharge strategy for energy storage system
- Compensators capacity put into operation
- Load shedding
- Network reconfiguration

As for ADMS optimal schedule, the limit of SOC for energy storage system leads to complication of the algorithm, which can be attributed as correlation between power and energy. As for ADMS coordinated voltage regulation, ancillary services from non-renewable DGs play an important role besides conventional regulation approach such as OLTC and Compensators. It is also noteworthy that the optimal schedule and the coordinated voltage regulation should be taken into account simultaneously to ensure nodal voltage within scope of standard in process of economic schedule.

Generally speaking, renewable generation is always equipped with maximum power point tracking (MPPT). So it is reasonable to keep power balance by adjusting the active power of non-renewable DGs, energy storage system, load shedding and even reconfiguring network if necessary rather than renewable generation curtailment when existing surplus renewable generation power so as to make full use of renewable energy.

IV. Conclusion

Active Distribution Network is the advanced stage of smart distribution grid, encouraging and accommodating high shares of distributed generations, especially renewable energy. Active Distribution Network operates the distribution system in an active mode to make full use of renewable energy accompanied with improved power quality and high reliability. This paper indicates the evolution of distribution network and takes an overview of some important issues for implementation of ADN, which contains ADN planning considering renewable energy uncertainties, the technology for fully utilization of renewable energy and active network management. Ultimately the paper proposes some solutions to tackle the issues aforementioned, which consists of two-stage stochastic programming, multilevel hierarchical control framework for fully utilization of intermittent renewable energy and advanced distribution management system. So it will be brilliant to carry out active distribution network for future smart distribution network along with the key technologies mature.

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