A PLATFORM FOR CASE STUDY OF ACTIVE DISTRIBUTION NETWORK PLANNING

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ABSTRACT

With the distributed energy resources (DER) integrated, the power flow in the distribution network will be changed, and the network will become the active distribution network (ADN), so traditional distribution system planning faces substantial challenges and new requirements, so the impacts of DER integration should be taken into account. A platform for case study of active distribution network planning is revised in this paper, and typical MV distribution network structure and load information of nods are also provided. The working conditions such as network topology and nominal base voltage are adjustable, which can be applied to carry out the tests of DER integration and to research the impact of grid-connected DER on distribution system reliability.

INTRODUCTION

In recent years, as the energy structure adjustment of China is speeding up and the smart grid technologies are developing rapidly, the power flow between MV/LV network and its upgrade network becomes duo-directional through the integration of wind, solar, electric vehicles and other DERs. So the traditional distribution system planning faces substantial challenges and new requirements.

There is much greater uncertain about the load forecasting, planning and operation of the distribution network after the DERs integration. In order to meet the major transitions, it is necessary to study the techniques and methods of ADN [1] planning. It may be observed that currently most attention is paid to the siting and sizing of DER, power optimization planning algorithm and future network structure designing in the area of ADN planning [2-3]. In 2009, one American / Europe MV benchmark for network integrated of DERs was addressed by CIGRE C6. However, the basic research in this area hasn't been carried out well in China. For this reason, the research of platform for case study of ADN planning is chosen from various issues about ADN planning.

In this paper, firstly, the functional requirements are analyzed, secondly the platform structure and network data are provided, and finally multiple functions of the platform are introduced.

FUNCTIONAL REQUIREMENTS ANALYSIS

DER's siting and sizing, investment decision, reliability comparison of feeders and so on should be studied in ADN planning, usually including the evaluation of the impacts of DERs integration under different grid conditions. The situations above are fully taken into account by this study. Network parameters can be adjusted by the platform to provide flexible grid conditions as follows:

- The flexible topology of network can be introduced by means of allocating tie/sectional switches in different locations.
- The nominal base voltage of the platform is 10 kV for China. If the nominal base voltage has been changed, the parameters may all need to be adjusted appropriately.
- The line lengths of urban distribution network is 2~4 km according to load density (5~30MW/km^2) in Chinese cities, which can be modified in order to meet different needs.
- Overhead lines and underground cables are used on the platform. Sections of underground cables or an entire underground network can be used. Similarly sections of overhead lines or an entire overhead network can be used too.
- The load values are obtained from physical system which has been modified in order to suit for the platform. They can be modified as necessary.

STRUCTURE OF PLATFORM

In order to verify the new concepts and methods of ADN planning, there should be a unified simulation and experiment platform. A method of stratification research has been used in this study. It divided the platform into two parts, benchmark system and DERs. Furthermore, the benchmark system is separated into network structure and load information of nodes. All simulation and calculation can be performed on the platform.

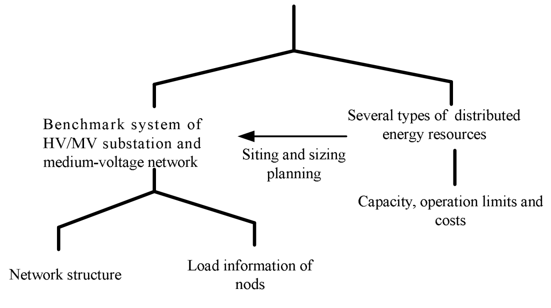

Figure I Structure of ADN Planning Platform

Technical issues of ADN

The technique issues of network integrated of renewable and DER can be divided into two categories in this study, quantity (capacity) and quality. The quantity (capacity) consists of economic capacity series of assets for existing networks and the connecting points of DERs as well as their capacity. The quality includes power quality, customer service reliability and system stability etc. All of the technique issues above can be tested on the platform.

Topology of benchmark system

The benchmark system is built on the platform. It is based on several physical MV networks in China, including some ones which already have the practice in DER integration. The structure consists of a HV/MV substation (110/10 kV, 2×40MW) and part of MV networks (10kV, 5 overhead lines, 2 underground cables, 60MVA).

There is a single radial overhead line connected to bus II_A, and four three-sectionalized overhead lines connected to bus IV、V of switching station. One of them is connected to a bus of station B by a tie switch and forms single loop structure but keeps operating in open-loop. The long OH line represents a feeder in rural area with a comparatively low load density and the other four represent feeders in urban district and towns with a medium load density. Meanwhile there are two UG cables connected to bus II_B, one is double radio source structure, the other is single loop structure. The two cables represent feeders in urban centre with a high load density. The detailed structure as follows:

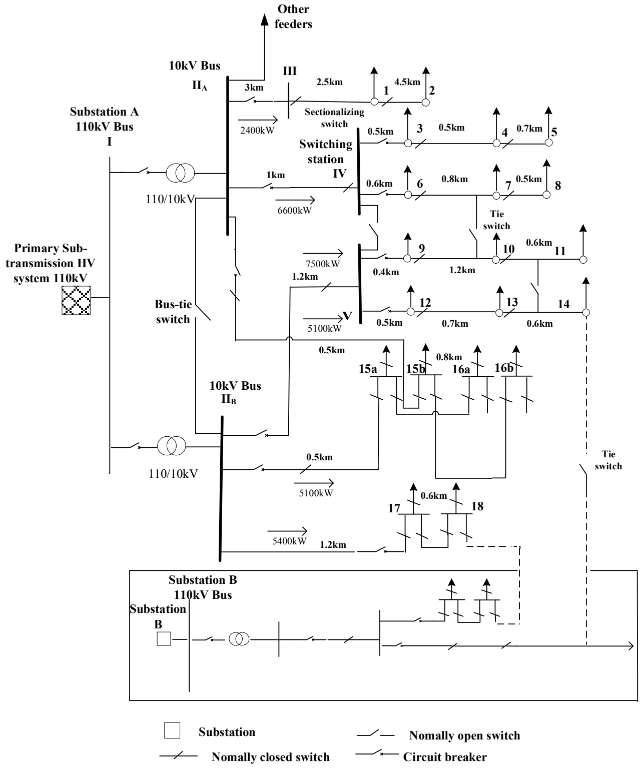

Figure II Network Topology of MV Distribution Benchmark System

TYPICAL DATA OF THE BENCHMARK

Line parameters

The economic principle is applied for the selection of benchmark system assets [4], by which suitable grid-components are chosen for each node. Two parts of costs are considered when selecting the line types. One is fixed cost (capital equipment, labor costs, fixed operating and ownership costs); the other is the variable cost (annual power losses costs), which takes into account the annual load curve shape. Then the total costs is added and converted into present worth value over a 30-year period. The linear economic loading range is shown in Tab.I.

Table I Economical Ranges of OH Lines Evaluated for Capital and Losses Economics - Peak MW

Line Conductor	Low	High
LGJ-50	0	1.3
LGJ-120	1.3	1.8
LGJ-185	1.8	4.5
LGJ-240	4.5	5.2
LGJ-300	5.2	6.7
LGJ-400	6.7	12

Table II provides the length of lines in Fig.II. Line parameters such as positive sequence resistance R'_{ph}, reactance X'_{ph} and susceptance B'_{ph}, zero sequence resistance R'_0, reactance X'_0 and susceptance B'_0 are also provided. Line type consists of OH line and UG cable.

Table II Connections and Line Parameters for Benchmark System

Line ID	Node from	Node to	Installation	Attribute	l [km]
1	II_A	III	overhead	trunk line	3
2	II_A	IV	overhead	main outlet	1
3	II_B	V	overhead	main outlet	1.2
4	III	1	overhead	rural lateral	2.5
5	1	2	overhead	rural lateral	4.5
6	IV	3	overhead	town lateral	0.5
7	3	4	overhead	town lateral	0.5
8	4	5	overhead	town lateral	0.7
9	IV	6	overhead	town lateral	0.6
10	6	7	overhead	town lateral	0.8
11	7	8	overhead	town lateral	0.5
12	V	9	overhead	town lateral	0.4
13	9	10	overhead	town lateral	1.2
14	10	11	overhead	town lateral	0.6
15	V	12	overhead	town lateral	0.5
16	12	13	overhead	town lateral	0.7
17	13	14	overhead	town lateral	0.6
18	II_B	15a	underground	trunk line	0.5
19	15a	16a	underground	trunk line	0.8
20	II_A	15b	underground	trunk line	0.5
21	15b	16b	underground	trunk line	0.8
22	II_B	17	underground	trunk line	1.2

Line ID	Node from	Node to	Installation	Attribute	*l* [km]
23	17	18	underground	trunk line	0.6

Continued Table II

Line ID	*R*'ph	*X*'ph	*B*'ph	*R*'0	*X*'0	*B*'0
	[Ω/km]	[Ω/km]	[μS/km]	[Ω/km]	[Ω/km]	[μS/km]
1	0.17	0.377	3.03	0.32	1.471	1.842
2-3	0.105	0.404	2.81	0.225	1.445	2.728
4-5	0.33	0.371	2.87	0.48	1.617	3.086
6-17	0.27	0.365	2.92	0.42	1.613	3.124
18-23	0.0788	0.0885	117.9	0.239	2.286	117.9

Note: Zero sequence parameters of UG cable are decided by structure, operation environment and layout style, where reference values are provided in Tab. II.

Table III OH Line and UG Cable

Cond. ID	Attribute	Type	Size	GMR	Current rating
			[mm^2]	[m]	[A]
OH	Substation outlet	LGJ-300	300	6	700
	trunk line	LGJ-185	185	3	560
	lateral	LGJ-120/95	120/95	2	380/305
UG	trunk line	YJV22 XLPE-3×300	300	0.016	455

Transformer parameters

Transformer parameters are provided by Tab. IV. The impedances calculated are referred to the secondary side.

Table IV Transformer Parameters

Connection	*V*1	*V*2	*Ztr*	S_{rated}
	[kV]	[kV]	[Ω]	[MVA]
3-ph Y-Y Both grounded	110	10.5	0.011+j0.289	40

Note: Transformer parameters refer to s9 series 110kV transformers.

HV equivalent network parameter

Parameters of HV equivalent network are given by Tab. V, which is connected to the primary side of the transformer. S_{SC} is given as range to provided flexibility for considering of DERs on power system voltage: large values correspond to stiff networks, while small ones to weak networks.

Table V HV Equivalent Network Parameters

Nominal system voltage	Short circuit capacity (S_{SC})	R/X ratio
[kV]	[MVA]	
110	100	0.01

Load parameters

The values of the peak loads for each node of the benchmark are provided in Tab.VI. The N-1 principle should be met when configurating the main transformers of the substation. The peak load of the substation should not exceed the 150% of the single transformer's capacity, .i.e. 60MW. The load values of nodes II_A and II_B are much larger than that of other nodes. These loads represent additional feeders (not actually part of the feeder) served by the transformer. This is made clear by the topology in Fig.II.

Table VI Load Parameters

Line ID	※$P_{ER\text{-}min}$	$P_{ER\text{-}max}$	※$P_{thermal}$	Node	Apparent power [kVA]	
	(MW)				Residential	Commercial /industrial
—	—	—	—	II_A	7800	5500
—	—	—	—	II_B	5000	11000
1	1.8	4.5	9.7	1	500	1550
				2	450	1200
2	5.2	6.7	12	3	700	0
				4	300	1800
				5	800	1200
				6	0	2650
				7	300	500
				8	800	950
3	5.2	6.7	12	9	1000	1500
				10	850	2000
				11	300	700
				12	900	1500
				13	620	0
				14	0	1800
18	4	6.5	9	15a	2200	2250
20	4	6.5	9	15b	800	2800
—	—	—	—	16a	1200	2400
—	—	—	—	16b	1000	3200
22	4	6.5	9	17	0	3000
				18	850	4500
Total	**24.2**	**37.4**	**60.7**	—	**26370**	**52000**

Note: (1) ※ER refers to line economic range; ※thermal refers to line thermal limit.
(2) The coincidence is 0.75 when calculate the peak load.
(3) The power factor for residential load is 0.85, and for commercial and industrial load is 0.95.

In an actual distribution system, distribution load behaviour is dominated by coincidence, due to the fact that the peak loads do not occur simultaneously. According to the load characteristics and the number of users, proper load parameters are revised in this paper. Typical daily load profiles in summer are given in Fig.III and Fig. IV.

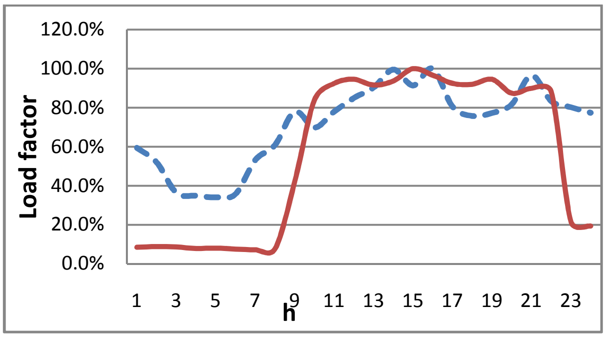

Figure III Residential (node3 blue-dashed) and Commercial (node6 red-solid) Load Profile

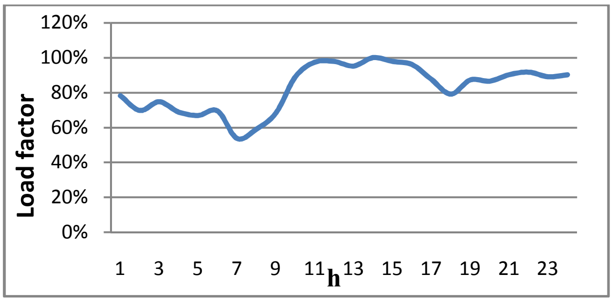

Figure IV Load Profile of Benchmark System

FUNCTIONS OF PLATFORM

Siting and sizing of DER analysis

The criterion about the line is that it should operate within economical range and voltage drop limits when it carries on peak load. Several candidate sites and sizes of DERs for integration are given by Tab.VII.

Table VII Candidate Nodes for DERs Integration

Nodes	Minimum integrated cap. [MW]	Criteria not satisfied
2	——	voltage drop limits
3、4、5	1.5	economical range
6、7、8	1.6	economical range
9、10、11	2.4	economical range
12、13、14	1.4	economical range
18	——	voltage drop limits

In addition, besides the annual load curve shape, marginal cost-effectiveness for DERs integration and the energy forecast of candidate nodes (maximum load availability hours) should be considered too.

The type of DERs includes wind energy resource (WER), solar energy resource (SER), Electric Vehicle (EV), demand side integration (DSI) and energy storage system (ESS) etc.

A small testing was carried on the platform in which a 1.5 MW wind turbine was connected to the node 3. The simulation result shows that the improvement of voltage on node 3 by integration of WT is 2.6% in14:00 (the peak load period of a day in summer).

Integration of storage system analysis

Under the condition of relative low load availability hours of DG, the ESS is necessary to be installed and its capacity is up to 50%~100% of DG capacity in the ideal case .The total costs of DG and ESS in life cycle should be compared before they are installed. HV or MV side in the platform is the recommended site for ESS.

Network reliability analysis

Typical failure rates and repair time of grid components are provided in the study. When the capacity, access locations, failure rates and other parameters of DERs are given by users in their own, with which the reliability of lines and load points can be measured before and after the DERs integration. Associated parameters are provided in Tab.VIII and IX.

Table VIII Reliability parameters of line components

Component	Annual failure rate (f/km·yr)	Repair time (h)
10kV OH	0.04~0.06	2~4
10kV UG	0.03~0.05	5~7

Table IX Reliability parameters of Assets

Device	Annual failure rate (f/·yr $\times 10^{-2}$)	Repair time (h)	Switch time (h)	
			No automation	Automation
Distribution transformer	0.13	4	/	/
Breaker	0.01	7.5	1~1.5	0.2
Switch	1.24	4	1~1.5	0.2

CONCLUSIONS

This study proposed a platform with a certain degree of flexibility, sensitivity and discrimination, where various conditions for DERs integration could be tested. Furthermore, the technical and economical comparison of the sites and sizes of DERs for integration can be performed on the platform.

REFERENCES

[1] C.D'Adamo, S.C.E. Jupe and C. Abbey, "Global survey on planning and operation of active distribution networks-update of CIGRE C6.11 working group activities", *20th International Conference on Electricity Distribution*, Prague, CZ, June 2009

[2] LU Yong, GAN De-qiang, John N. Jiang, 2010, "Issues of Smart Grid and Distributed Generation Development in the United States", *Automation of Electric Power systems*, Vol. 34, 12-16.

[3] SONG Yong-hua, SUN Jing, 2008,"Development of European Power Grid and Relative Technologies in Future", *Electric Power Technologic Economics,* Vol.20, 1-5.

[4] H. Lee. Willis, 2004, *Power Distribution Planning Reference Book (the second edition)*, CRC Press, Boca Raton, America, 389-418.