THREE-STAGE MODEL BASED OPERATIONAL RISK ANALYSIS OF ACTIVE DISTRIBUTION NETWORK

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Abstract: Contraposing to all kinds of distributed energy and load characteristic in active distribution network, this paper establishes a three-stage model of the operational risk analysis in accordance with the time. In this paper, a quick uncertain power flow calculation is completed with joint possibilistic-probabilistic uncertain model based on evidence theory. According to the out-of-limit problems in results, an operation risk analysis system is established considering the power loss. The buses and branches in risk can be located by improved IEEE 33 distribution system model simulation and verifying the necessity of the joint uncertain power flow calculation model and the efficiency of the algorithm. And based on the establishment of the active distribution network security region, excogitate possible guidance of the risk control.

INTRODUCTION

Active distribution network (ADN) has a large scale and a complex structure; in addition, the access points of distributed generations (DG) spread, so controllability and uncertainty problems are increasing, as well as the requirements of operational risk analysis.

Operational risk assessment is focused on the short-term risk assessment and calculation, which should be able to represent system's real-time status and predict short-term risk indexes. Literatures [1] proves that, applying the fast probabilistic power flow calculation can obtain system's operation states based on power flow results.

The solving methods of uncertain power flow (UPF) in power system are divided into two kinds: probabilistic power flow (PPF) and fuzzy power flow (FPF). PPF is used when input variables' probability distribution is known [2]; while in FPF, uncertain input variables are turned into a range subject to certain membership functions by possibility theory, as the output, which can be quantified from a range [3].

In this paper, a three-stage model of the operational risk analysis is established, including the process of solving UPF by joint possibilitic- probabilistic uncertain model wish unscented transformation (UT) method to possibilitic variables and α-cut method to probabilistic variables based on evidence theory, and the foundation of operational risk indexes system and the analysis of the UPF outputs by security region of ADN. And by simulation, the necessity and efficiency of method is proved, and guidance for risk control can be obtained.

THREE-STAGE RISK MODEL IN ADN

There are many uncertain input variables in ADN, thus a probability or possibility distribution model of input variables needs to be established at first stage, as well as to obtain the probability distribution of bus voltage and branch power by UPF; Then analyse the out-of-limit probability of bus voltage magnitude and the branch active power based on the cumulative density function (CDF), as well obtain risk effect indexes combining with the outage loss and load important level coefficient, and establish current security region model of ADN; Finally, sort buses and branches according to operational risk value and discuss the output adjustment direction of controllable variables with large impact factor in security domain model. The whole process above constitutes the three-stage model ADN, and its flow chart is shown in figure 1 below.

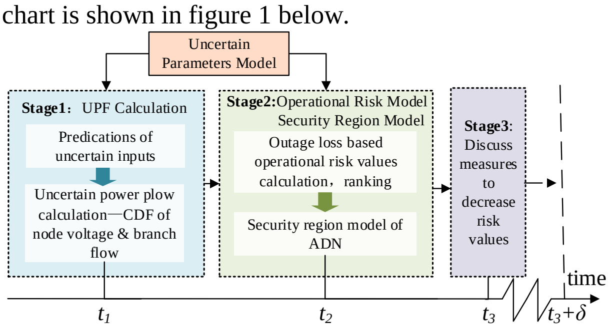


Fig. 1 Three-stage risk analysis flowchart

UPF calculation

The processing of uncertain input variables

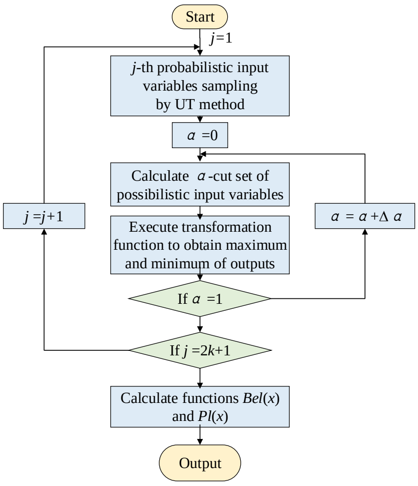
According to whether can be expressed by probability or not, the uncertain input variables are divided into probability uncertainty input and possibilistic uncertainty input. In ADN, wind turbine generations (WTG) and solar cell generations (SCG) are considered as the probability uncertainty input variables; while other controllable DGs, such as the micro turbine (MT), and energy storage system (ESS) are considered as possibilistic uncertainty input, expressed with membership functions.

The solution model of UPF

In order to solve UPF in ADN, considering uncertain input variables of both probability and possibility, this paper adopts joint possibilistic –probabilistic uncertain model based on evidence theory.

Figure 2 shows the flowchart of the algorithm. The algorithm is composed of two loops, internal loop and external loop. The former one considers the possibilistic uncertainty of variables. This paper uses UT algorithm, and shows its advantages through the comparison with the Monte Carlo Simulation (MCS) algorithm. The latter one calculates possibilistc uncertainty of variables, applying α- cut- set method[4-5].

Fig. 2 Flowchart of joint possibilistic-probabilistic uncertainty method



Operational risk assessment model of ADN

Risk analysis of distribution network is designed to measure the potential impact degree of disturbance events on the distribution network. This paper ignores power failure situations, and simply decides the risk of the current buses or branches by predicting out-of-limit through UPF in short-term and its effect.

Risk probability index

(1) Risk probability index $P_r\left(U_i\right)$ of out-of-limit of bus voltage

$$P_r\left(U_i\right)=1-F\left(U_{\max}\right)+F\left(U_{\min}\right)$$

Where, $U_{\max}$ and $U_{\min}$ are the upper and lower limits of the node voltage magnitude respectively; $F\left(u_i\right)$ is the CDF of voltage magnitude of bus i according to UPF calculation results. Usually, the upper and lower limits of the bus voltage magnitude are 105% and 95% of rated value respectively [6].

(2) Risk probability index $P_r\left(P_{ij}\right)$ of out-of-limit of branch active power

$$P_r\left(P_{ij}\right)=1-F\left(P_{\max}\right)$$

Where, $P_{\max}$ is the upper limit of branch active power; $F\left(P_{ij}\right)$ is the CDF of branch ij active power. Usually the allowed active power upper limit of branch ij is set to 1.1 times that of the normal value [7].

Risk effect index

Risk effect index takes two aspects into account: one, to characterize the out-of-limit severity of voltage or active power; two, to characterize economic consequences which is considered to be illustrated by outage loss. And the two parts is linked by load loss function.

(1) Severity index I

The expression of voltage severity is

$$I\left(U_i\right)=\begin{cases}\dfrac{U_i-U_{\max}}{U_{\max}}, \text{if } U_i>U_{\max} \text{ and } 1-F\left(U_{\max}\right)>\delta \\ \dfrac{U_{\min}-U_i}{U_{\min}}, \text{if } U_i<U_{\max} \text{ and } F\left(U_{\min}\right)>\delta\end{cases}$$

The expression of active power severity is

$$I\left(P_i\right)=\frac{P_i-P_{\max}}{P_{\max}}, \text{if } P_i>P_{\max} \text{ and } 1-F\left(P_{\max}\right)>\delta$$

Where, δ is the occurrence probability of small probability events, taken 0.001%.

(2) Outage loss L

This paper uses indirect method, choose the ratio of output value to unit electric energy consumption C as assessment factors, and to distinguish loads by load importance factor. Load importance factor k is simply set to 1, 3 and 5 according to the first class load, secondary class load and third class load in this paper, which can be given by engineer of experience of operation and maintenance of actual distribution network [8]. Outage loss expression is as follows:

$$Loss\left(U_i\right)=k\left(U_i\right)EENS\left(U_i\right)C$$

$$Loss\left(P_{ij}\right)=k\left(P_{ij}\right)EENS\left(P_{ij}\right)C$$

Where, $EENS$ represents the current total load of the bus i or the branch ij.

(3) Load loss percentage P_{load}

To eliminate the out-of-limit of voltage or active power, a load shedding should be proceeded. Load loss percentage P_{load} shares function relationships of severity indexes of out-of-limit of voltage and active power t as shown in Figure 3.

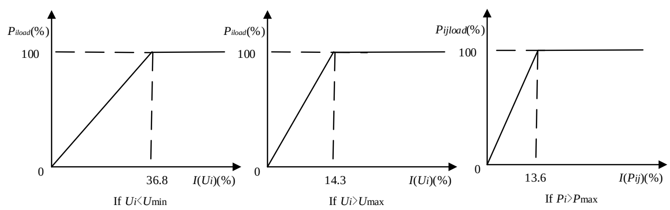


Fig. 3 *I*-*P*load function

Then the risk effect indexes are as below :

$$S_{ev}\left(U_i\right)=Loss\left(U_i\right)P_{iload}$$

$$S_{ev}\left(P_{ij}\right)=Loss\left(P_{ij}\right)P_{ijload}$$

Furthermore, the operational risk value is the product of the risk probability index and the risk effect index of the bus or the branch.

Security region model of ADN

There is no stability problems in conventional distribution network, in which power flow security domain is the only consideration. Because of the fluctuations of DGs and the uncertainties of loads in ADN, the introduction of static voltage security region (SVSR) under small perturbations can effectively narrow the scope of the security domain, and to ensure the stable and secure operation of the system at the time of the prediction.

According to the definitions of SVSR in cut-set space in literature [9], similarily a SVSR of ADN in cut-set space can be obtained as follows after choosing numbers of cut-set by ranking the risk values :

$$\partial\Omega_{ADN}\left(i\right)=\left\{ i_{CS}\left|\begin{array}{l}\ni x,st.\text{the real parts of eigenvalues}\\ \text{of }\left[\partial f_i\left(x\right)/\partial x\right]_{i_{CS}}\text{ are negative}\end{array}\right.\right\}$$

And the space can be approximated by the following hyperplane formula:

$$\sum_{i\in C}\left(\alpha_i P_i+\beta_i Q_i\right)=1$$

Where, C representsthe critical cut-set, P_i is the active power in the branch of critical cut-set, Q_i is the reactive power in the branch of critical cut-set.

When the voltage stability boundary is represented by hyperplane, the original nonlinear problem of static voltage stability will be converted to linear constraints, which is easy and convenient in online application, available for online dispatch personnel to provide guidance of risk aversion.

CASE STUDY

In this paper, an improved IEEE 33-bus distribution systems is proposed, which is considered to represent a conventional ADN model, as shown below:

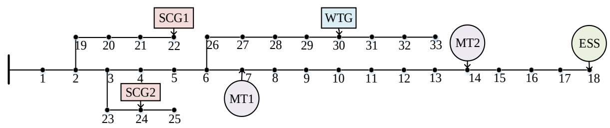


Fig. 4 Improved IEEE 33-bus distribution systems

The parameters of additional DERs are shown below.

Table 1 Parameters of DERs

Node No.	DER	Node type	Capacity (kW)	Model type
30	WTG	PQ	100*5	Probability model
22/24	SCG1/SCG2	PV	200/300	Probability model
7/14	MT1/MT2	PQ	100/100	Possibility model
18	ESS	PV	30	Possibility model

Stage 1

To obtain the UPF of improved IEEE 33-bus distribution systems at a certain prediction time t, assume that the probability of possibility distribution parameters of loads and DERs are as follows.

Table 2 Parameters of uncertain input variables

Uncertain inputs	Distribution model	Relevant model parameters		
Loads	Normal distribution	$\mu(\mathrm{MW})$ load forecasting value at time t		σ $5\%\times\mu$
Wind speed	Weibull distribution	α_w 2.2	$\beta_w(\mathrm{m/s})$ 11	$V_i/V_r/V_o(\mathrm{m/s})$ 3/12.5/25
Solar radiation	β distribution	α_β 0.7	$\beta_\beta(\mathrm{W/m^2})$ 2.2	$r_{STD}/r_c(\mathrm{W/m^2})$ 1000/150
Output of MT	α-cut distribution	$[P_{\min},P_l,P_u,P_{\max}](\mathrm{p.u.})$ [0,0.1,0.9,1]		
Output of ESS	α-cut distribution	$[P_{\min},P_l,P_u,P_{\max}](\mathrm{p.u.})$ [-1,-0.6,0.6,1]		

Assume IEEE standard load values represent the present predicted load values.

Proceed a simulation by joint possibilistic-probabilitic uncertainty model in MATLAB R2014a, in which probabilistic model is solved by MCS and UT method respectively. Figure 5 shows the UPF results of the voltage magnitude of bus 6.

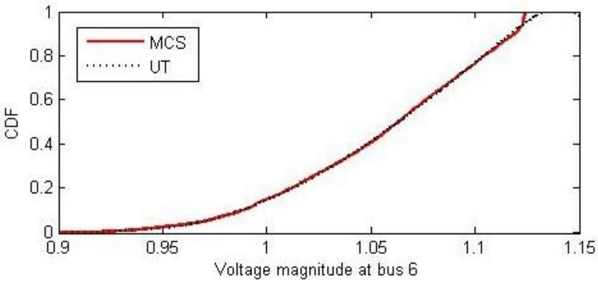


Fig. 5 CDF of voltage magnitude at bus 6

For more accurate output data, some nodes or branches are selected as in Table 3 below.

Table 3 Output and relative errors of improved IEEE 33-bus distribution systems

Output (p.u.)	Mean value MCS	UT	ε%	Standard deviation MCS	UT	ε%
U_2	1.0282	1.0282	0.0004	0.000107	0.000102	4.5723
$P_{21\text{-}22}$	-8.5263	-8.5265	0.0018	0.008692	0.008580	1.2824
$Q_{19\text{-}20}$	-5.6051	-5.6050	0.0015	0.005779	0.005778	0.0037

Where, $\varepsilon\%$ represents the relative error percentage between the outputs of MCS and UT method.

The result shows that UT and MCS method share a small error with less than 0.0028% in mean value and less than 4.5723% in standard deviation among the given nodes or branches. However, the running time consumed by MCS method is 16539.029, with only 88.354s by UT method. Then a great advantage of UT method shows in accelerating computation, which meets real-time engineering requirements.

Stage 2

Assume loads connected at bus 4,5 are first class loads and at bus 9,11,29 are second class loads, otherwise are third class loads. Compute risk values of buses and branches by electricity than 8 yuan/kWh and outage time 2h and pick the largest 5 presenting in the following Table 4.

Table 4 Risk values of improved IEEE 33-bus distribution systems

	Out-of-limit buses/branches	Risk probability index	Risk effect index (yuan)	Risk value (yuan)
Bus voltage magnitude	14	1	553.597	553.597
	8	1	480.828	480.828
	7	1	457.968	457.968
	13	1	253.512	253.512
	9	1	249.065	249.065
Branch active power	6-7	1	1658.762175	1658.762175
	31-32	0.9845	1254.454389	1235.010346
	7-8	1	1142.640288	1142.640288
	29-30	0.9845	1116.847949	1099.536806
	28-29	0.9845	1080.888916	1064.135138

By analysing the risk probability and risk effect index, the risk order is not complied with risk probability, while risk effect index contributes a lot to operational risk values. The results calculated by UPF satisfy time-sensitive risk trend and could reflect real risks of buses and branches, which provides a basis for follow-up risk treatments and regulations.

Stage 3

By analysing the growth of load points and changes of allocations of DGs, as well as selecting the 5 branches as cut-set, a relevant coefficient table can be obtained as bellow. Easily a hyperplane can be drawn by cut into sections and an security region is shown.

Table 5 Parameters of uncertain input variables

Branch active power.	coefficient α	Branch reactive power	coefficient β
$P_{5\text{-}6}$	0.0093	$Q_{5\text{-}6}$	0.0083
$P_{6\text{-}26}$	-0.0261	$Q_{6\text{-}26}$	-0.0298
$P_{6\text{-}7}$	0.0023	$Q_{6\text{-}7}$	0.0453

CONCLUSIONS

In this paper, a three-stage model of the operational risk analysis of active distribution network is established in accordance with the time, including a quick uncertain power flow calculation completed with joint possibilistic- probabilistic uncertain model based on evidence theory, the operation risk analysis system and the simple introduction of security region of ADN to guide the risk aversion. Simulations is proceed in an improved IEEE 33-bus distribution systems which verifies the feasibility of the three stage model and the practicability of the relevant methods or algoriths.

ACKNOWLEDGEMENT

This work is financially supported by 2016 Beijing Natural Science Foundation (No.3161002) and Science and Technology Project of State Grid Corporation of China, “Energy Internet Oriented Application Researches of Multi-source Coordination Optimization Operation”.

REFERENCES

[1] Duan Yao, Zhang Buhan, Liu Yifang, 2014, “Power system security risk assessment based on fast stochastic power flow”, *Chinese Electrical Engineering Science*, vol.34: 3784-3790.

[2] Zheng Haifeng, 2006, “Random load flow calculation of distribution system with distributed generation”, *Tianjin University*.

[3] Liu Ruoqin, Wang Shouxiang, 2000, “Power flow calculation of distribution network based on fuzzy interval algorithm”, *Automation of Electric Power Systems*, vol.24, 19-22.

[4] Aien M, Rashidinejad M, Fotuhi-Firuzabad M, 2014, “On possibilistic and probabilistic uncertainty assessment of power flow problem: A review and a new approach”, *Renewable & Sustainable Energy Reviews*, vol.37(3):883-895.

[5] Julier S J, Uhlmann J K, 2004, “Unscented filtering and nonlinear estimation”, *Proceedings of the IEEE*, vol.92(3):401-422.

[6] Li Gengyin, 2006, “The basis of power system analysis” , *China Electric Power Press*,16-18.

[7] Hu Huan, 2012, “Study on the risk assessment of distribution network considering the influence of wind power and electric vehicle access”, *Huazhong University of Science and Technology*.

[8] Li Rui, Li Yue, Su Jian, et al, 2011, “Power loss and emergency response strategy for power users in distribution network”, *Power System Technology*, vol.10, 170-176.

[9] Wang Dongtao, 2007, “Probabilistic safety and risk assessment of power transmission system based on security domain”, *Tianjin University*.

[10] Li Huiling, Yu Yixin, Han Qi, et al, 2005, “The practical boundary of static voltage stability region in power space of cut set”, *Automation of Electric Power System*, vol.29, 18-23.

[11] Yang Fan, 2011, “Construction and analysis of typical system of active distribution network for distributed energy access”, *China Electric Power Research Institute*.

[12] Hu Wenjie, 2010, “Multi objective optimization of power flow calculation and operation of micro grid with high permeability”, *Beijing Jiaotong University*.