



## A power restoration strategy for the distribution network based on the weighted ideal point method



Jing Ma\*, Wei Ma, Dong Xu, Yang Qiu, Zengping Wang

State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 102206, China

### ARTICLE INFO

#### Article history:

Received 17 August 2013

Received in revised form 13 June 2014

Accepted 6 July 2014

Available online 30 July 2014

#### Keywords:

Power recovery

Multi-objective optimization

Rough set theory

Ideal point method

### ABSTRACT

A power restoration strategy for the distribution network based on the weighted ideal point method is proposed in this paper. First, with the power loss, voltage quality and load balancing as the reconfiguration goal, the comprehensive evaluation function is established. And then, the rough set theory is used to calculate the weight coefficients of the sub-objective functions. Finally, the optimal solution of the comprehensive evaluation function is obtained by applying the ideal point method. Simulation tests on the 33-bus and 69-bus radial distribution networks verify that, the proposed method of using multi-objective function instead of single objective function to gain the optimal solution is more comprehensive in different considerations and more in line with the requirement of the actual distribution network power restoration. Furthermore, the uncertainty problem in traditional weight setting due to dependence on experience can be avoided.

© 2014 Elsevier Ltd. All rights reserved.

### Introduction

Power restoration in the distribution network refers to the restoring of power supply to the lost load in the non-fault area by means of network reconfiguration after a fault occurs. Power restoration should meet the constraints of the node voltage and line current, as well as taking into account the economic and reliable operation of the distribution network after the fault recovery. Therefore, power restoration is a multi-objective optimization problem with multiple constraints [1–3].

Currently there are many methods to establish and solve the power restoration objective function and these methods can be sorted into three major categories. (1) Mathematical optimization methods [4–7]. This category of methods is based on a complete mathematical theory, and is not dependent on the initial structure of the distribution network. However, these methods have the ‘dimension calamity’ problem, thus are only applicable to power restoration of systems with relatively small scale and complexity. (2) Heuristic search methods [8–10]. This category of methods is widely used for fault restoration in the distribution network, and is mainly based on switch operation, according to the search mode guided by the heuristic rules. These methods are real-time, and

have good versatility and practicability. However, the search result is easily affected by the initial state, thus the algorithm stability is not favorable. (3) Artificial intelligence methods [11–16]. This category of methods is effective in solving specific power restoration problems. However, parameters such as the penalty coefficient, the initial particle swarm, and the mutation probability are needed. These parameters will directly affect the calculation speed and convergence of the algorithm. And currently there is no clear theoretical basis as to what values the parameters should apply. Continuous grope is needed concerning the specific problem.

The advantage of the above methods is that the power restoration problem can be expressed accurately in the form of objective function with constraints. However, since power restoration is a complicated optimization problem with multiple objectives, and the sub-objectives are conflictingly inter-connected, it is difficult to describe the comprehensive objective function. Besides, the weight setting is often reliant on subjective experience, which makes the solving process complicated. In view of the above problems, a power restoration strategy for the distribution network based on the weighted ideal point method is proposed in this paper. First, with the power loss, voltage quality and load balancing as the reconfiguration goal, the comprehensive evaluation function is established. And then, the rough set theory is used to determine the weight coefficients of the sub-objective functions. Finally, the optimal solution of the comprehensive evaluation function is obtained by applying the ideal point method. Simulation tests on the 33-bus and 69-bus radial distribution networks verify

\* Corresponding author. Address: No. 52 Mailbox, North China Electric Power University, No. 2 Beinong Road, Changping District, Beijing 102206, China. Tel.: +86 10 80794899 (work), mobile: +86 15801659769.

E-mail address: [hdmajing@ncepu.edu.cn](mailto:hdmajing@ncepu.edu.cn) (J. Ma).

**Nomenclature**

$U_j^{\min}$	lower bound of the RMS value of the voltage at node $j$ .	$f$	decision function
$U_j^{\max}$	upper bound of the RMS value of the voltage at node $j$ .	$\mathbf{C}$	condition property set
$\mathbf{I}^{\max}$	line current constraint matrix	$\mathbf{D}$	decision property set
$I_i^{\max}$	the maximum current allowed in line $i$	$pos_Q(P)$	the set of elements in $U$ that can be accurately divided to $U/P$ through $Q$
$I_i$	the current on line $i$	$\varphi(C_i)$	importance degree of property $C_i$
$D_1$	node voltage constraint	$\gamma_C(D)$	dependence degree of the decision property set $D$ on the condition property set $C$
$D_2$	line current constraint	$\gamma_{C-C_i}(D)$	dependence degree of the decision property set $D$ on the condition property set $C-C_i$
$C_1$	power loss function	$Y$	comprehensive evaluation function
$C_2$	voltage quality function	$w_i$	weight coefficient of the sub-objective function
$C_3$	load balancing function	$H_i(+)$	ideal point vector of the $i$ th index of object $H$
$m$	number of lines	$H_i(-)$	anti-ideal point vector of the $i$ th index of object $H$
$P_i$	active power on the end of line $i$	$C_i(x)$	value of the $i$ th index
$Q_i$	reactive power on the end of line $i$	$g_j(+)$	positive evaluation function
$U_i$	voltage of the end node of line $i$	$g_j(-)$	negative evaluation function
$r_i$	resistance of line $i$	$L_i(+)$	the distance from the evaluation function to the ideal point
$k_i$	state variable of line $i$	$L_i(-)$	the distance from the evaluation function to the anti-ideal point
$P_{i\max}$	maximum capacity of line $i$	$T_i$	the weighed ideal point close degree
$\mathbf{U}_m$	measured voltage vector of the system		
$\mathbf{U}_e$	rated voltage vector of the system		
$\mathbf{S}$	knowledge representation system		
$U$	universe of discourse		
$A$	finite set of properties		
$V$	value range of $A$		

that, the proposed method of using multi-objective function instead of single objective function to gain the optimal solution is more comprehensive in different considerations and more in line with the requirement of the actual distribution network power restoration. Furthermore, the uncertainty problem in traditional weight setting due to dependence on experience can be avoided.

**Constraints and objective functions**

After the fault is located and separated accurately, there will be lost load in the downstream of the fault area. First, all the contact switches in the original network that may help to restore power to the lost load are virtually closed. It should be noted that, this operation may cause branches to interconnect and form loops (the route between two different sources is also equivalent to a loop). On this basis, all the breakable branches in the loops constitute of an operable switch set. And then, virtual breaking of the switches in the operable switch set is done separately, and power flow of the resulting network is calculated to determine whether each virtual breaking meets the constraints of the node voltage and line current. With all the constraints met, the optimal breaking scheme can then be determined by the optimization of the multi-objective function of power loss, voltage quality and load balancing.

*Constraints of node voltage and line current*

The node voltage amplitude constraint is as follows:

$$U_j^{\min} \leq U_j \leq U_j^{\max} \tag{1}$$

where  $U_j^{\min}$  and  $U_j^{\max}$  are the lower bound and upper bound of the RMS value of the voltage at node  $j$ .

In order to meet the thermal stability constraint of the distribution network lines, the line current constraint matrix  $\mathbf{I}^{\max}$  is defined according to the maximum current allowed in each line:

$$\mathbf{I}^{\max} = [I_1^{\max}, \dots, I_i^{\max}, \dots, I_m^{\max}]^T \tag{2}$$

where  $I_i^{\max}$  represents the maximum current allowed in line  $i$ ;  $m$  is the number of lines.

The line current constraint is as follows:

$$I_i \leq I_i^{\max} \tag{3}$$

where  $I_i$  is the current of line  $i$ .

*Power loss function*

The objective function of the distributed system power loss is:

$$C_1 = \sum_{i=1}^m \left( \frac{P_i^2 + Q_i^2}{U_i^2} \right) r_i k_i \tag{4}$$

where  $m$  is the number of lines;  $P_i$  and  $Q_i$  are the active and reactive power of line  $i$ ;  $U_i$  is the voltage of line  $i$ ;  $r_i$  is the resistance of line  $i$ ;  $k_i$  is the state variable of line  $i$ , with  $k_i = 0$  representing that line  $i$  is open and  $k_i = 1$  representing that line  $i$  is closed. The smaller the power loss function  $C_1$  is, the higher the power utilization rate is, and the more energy saving and economic the distribution network proves to be.

*Voltage quality function*

The objective function of the power quality is:

$$C_2 = \|\mathbf{U}_m - \mathbf{U}_e\| \tag{5}$$

where  $\mathbf{U}_m$  and  $\mathbf{U}_e$  are the measured voltage vector and rated voltage vector of the system. The smaller the voltage quality function  $C_2$  is, the closer the bus voltage is to the rated value, and the better the voltage quality is.

*Load balancing function*

Load balancing refers to the ability of the distribution system to match the load distribution with the power supply capacity of each line. It aims to improve operational efficiency of the lines and power supply capability of the distributed system, at the same time reducing power loss and lowering the risk of overloading.

متن کامل مقاله

دریافت فوری ←

**ISI**Articles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات