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Fault Diagnosis to On-load Tap Changer Using MRBR

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Abstract

For disconnection and poor contact - the fault of on-load tap changer in transformer, there is a new fault diagnosis method in this paper. This method takes the losses caused by different misjudgment into account, on-load tap change is diagnosed with MRBR (minimum risk Bayes and review). This method can process the collected current data in real-time, and be able to determine if disconnection or the situation of poor contact exists accurately.

Keywords: *Minimum risk Bayes, on-load tap changer, fault diagnosis*

1. Introduction

The stability of the power supply circuit is extremely important for users, therefore voltage is a very important quality index in the power system. Just like evening peak and morning rush hour in traffic, there is also the peak users' number of the grid during peak hours, due to the increasing (reducing) users of electricity, the voltage will go low (high), however the users do not want this phenomenon. Tap changer [1] must be used as a voltage regulator so as to maintain a stable grid voltage. On-load tap changer is a key component to transformers, which can not only reduce and avoid large fluctuations of voltage, but also distribute power system load flow to guarantee safe and reliable operation, and enhance grid the flexibility of scheduling. Because of an increase number of users, OLTC accident rate is increasing [2-4]. Statistics [5] show OLTC fault occupies more than 20%[6], and OLTC fault still rises, it causes a great threat to power grid[7].

2. Work Principle and Fault

On-load tap changer is under load regulating transformer winding Tap position, which requires on-load tap changer to ensure continuous load current, not open, but also not short-circuit. So to ensure the continuous current during the process, there must be the time while bridging two taps. The resistors must be connected in series between the bridge to limit circulating current, the circuit to achieve this function called transition circuit. According to the number of series resistors, there are a single resistor, two-resistor and four-resistor, the common is the second one, the Work principle is illustrated as figure 1(R1=R2=R).

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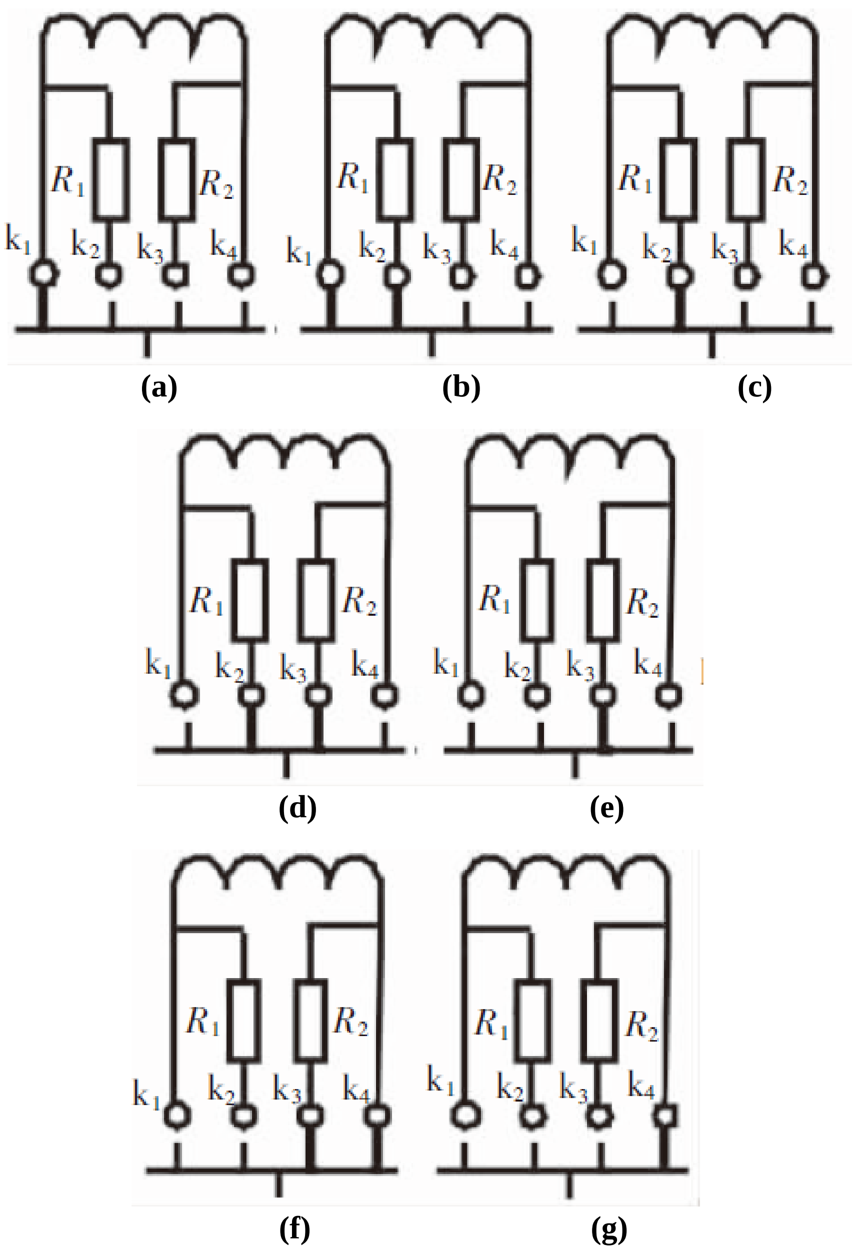

Figure 1. Work Principle

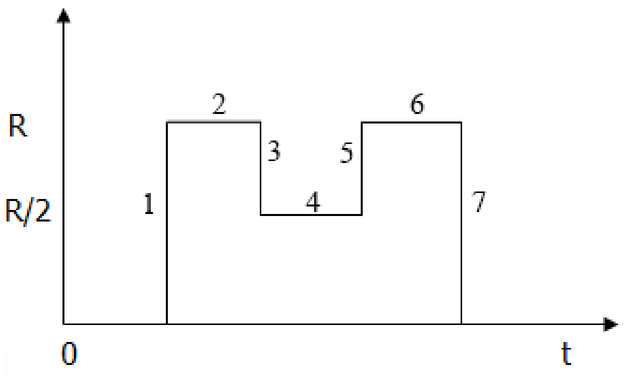

Figure 2. Resistance Variation

(1) Switch to turn on k1 and k2, then disconnect k1, it is the process in figure 1(a-c).The resistor R1 accesses to the load circuit, the resistance changes from 0 to R. It is the process 1 in figure 2;
(2) Switch to turn on k3 and k2, there is a loop between the registers, as shown in figure1(d).The resistance changes from R to R/2, as shown in figure2(3);
(3) Switch to turn off k2(as shown in figure 1(e)), the resister R3 has been disconnected, the resistance changes from R/2 to R(as shown in figure2(5));
(4) Switch to turn on k4, then turn off k3, shown in figure1 (f-g).The resistance changes from R to 0, shown in figure 2(7).

In order to ensure safe and reliable operation of the power grid, Fault Diagnosis to on-load tap changer is very necessary. Its main task is to monitor the status and determine whether the tap switch is faulty [8].

Here is the actual monophasic waveforms of on-load tap change [9], which are studying in this paper (The abscissa is sampling point, and the ordinate is current (mA)):

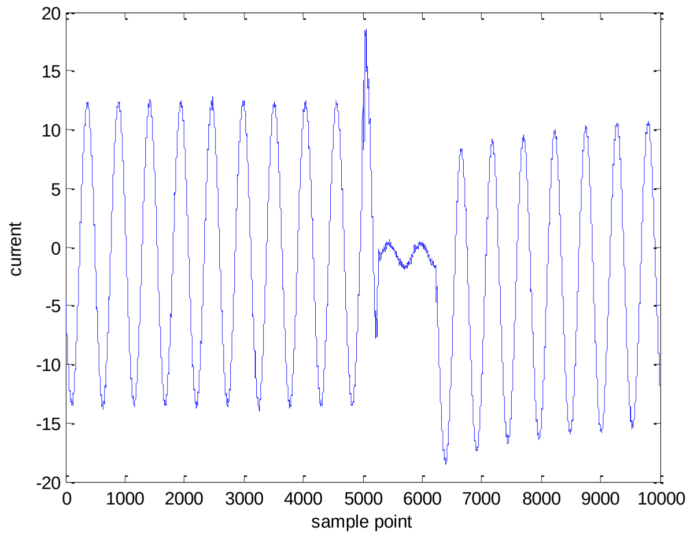

Figure 3. Disconnection

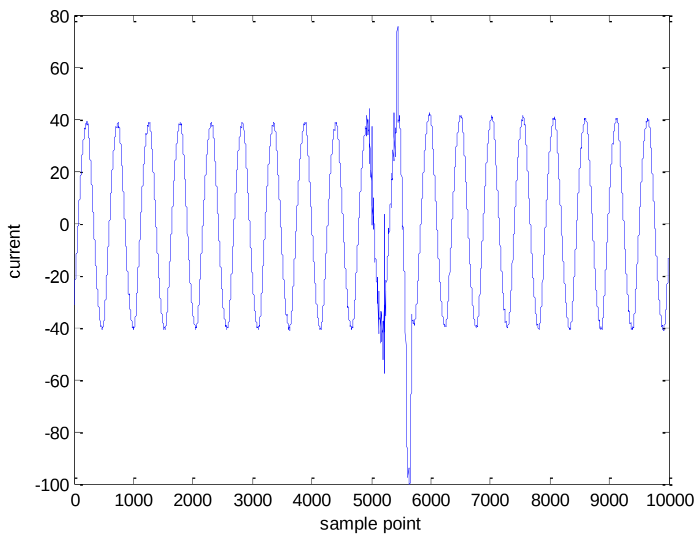

Figure 4. Poor Contact

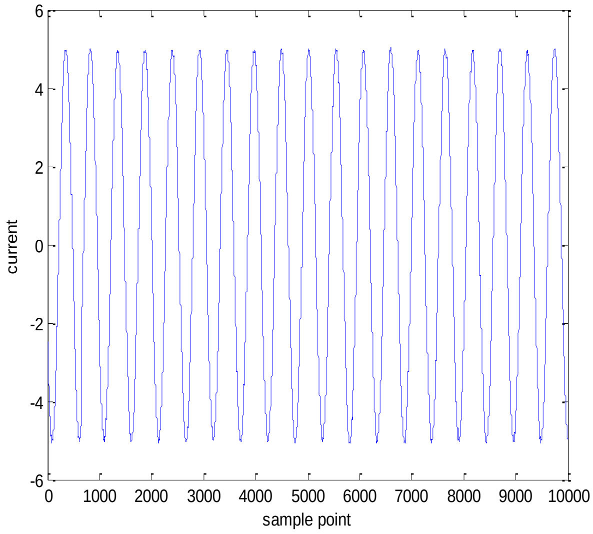

Figure 5. Normal Condition

3. Minimum Risk Bayes[10]

Due to various identification methods have certain error rate [11], and for on-load tap-diagnosis, it need care about more than just the error rate[12,13], but also concern about the loss caused by an error. The losses of judged the normal one as a trouble one and judged the trouble as the normal are different, the former loss is just a tap cost, and the latter may be not a constant amount of money [14-16]. Therefore, on the basis of the traditional Bayesian, this paper proposes Bayesian decision based on minimal risk, and uses this decision to diagnose if on-load tap change is out-of-order.

Here are some definitions used in this paper:

1. There are 70 samples, each sample has about 10,000 sample data, sample vectors represents as follows:

$$\begin{aligned} x_1 &= [y_{1,1}, y_{1,2}, \cdots, y_{1,10000}] \\ x_2 &= [y_{2,1}, y_{2,2}, \cdots, y_{2,10000}] \\ &\vdots \\ x_{70} &= [y_{70,1}, y_{70,2}, \cdots, y_{70,10000}] \end{aligned} \quad \text{-------------------------------------} (1)$$

Where x_i is the sample number, $y_{i,j}$ is the samples data.

2. This article is about diagnosis disconnection and poor contact, without considering other cases, so the state space consists of three possible states: the normal, disconnection and poor contact, the formula is as follows:

$$\Omega = \{\omega_1, \omega_2, \omega_3\} \cdots\cdots (2)$$

ω_i is an element of the state space.

3. Three kinds of results, which are the normal, disconnection and poor contact. And decision space   is composed by three decisions.

$$\square = \{\beta_1, \beta_2, \beta_3\} \cdots\cdots (3)$$

4. Provided for the actual state of sample vector x_j is ω_i, and the decision taken is β_k, risk generated is $\alpha(\beta_k, \omega_i)$,$i$=1,2,3, k=1,2,3, where β_i is an element of the decision space, ω_i is an element of the state space.

Table 1. Risk Factors

decision	natural state		
	ω_1	ω_2	ω_3
β_1	$\alpha(\beta_1, \omega_1)$	$\alpha(\beta_1, \omega_2)$	$\alpha(\beta_1, \omega_3)$
β_2	$\alpha(\beta_2, \omega_1)$	$\alpha(\beta_2, \omega_2)$	$\alpha(\beta_2, \omega_3)$
β_3	$\alpha(\beta_3, \omega_1)$	$\alpha(\beta_3, \omega_2)$	$\alpha(\beta_3, \omega_3)$

5. For some sample ω_i, the posterior probability of it belonging to each state is $P\left(\omega_j \mid x\right), j=1,2,3$, Expected risk to take decisions $\beta_k, k=1,2,3$ is

$$R\left(\beta_k \mid x_i\right)=E\left[\alpha\left(\beta_k,\omega_j\right) \mid x_i\right]=\sum_{j=1}^{3}\alpha\left(\beta_k,\omega_j\right)P\left(\omega_j \mid x\right), i=1,2,\cdots 70,\quad k=1,2,3 \quad \text{------------ (4)}$$

Provided for decision for the whole is $\delta(x)$, expected risk caused by decisions taken in the feature space of all possible samples x is

$$R(\delta)=\int R\left(\delta_i \mid x\right)p\left(x\right)dx \quad \text{-------------------------------------- (5)}$$

In this paper, it needs to make the expected risk minimized, that is min($R(\delta)$), determine the most likely tap-state from this minimum value.

4. Experiments

Researches show that the size and shape of search template affect not only the speed of motion estimation, but also the algorithm performance directly. This section will prove the above conclusion through the analysis of TSS, NTSS and DS, and provide theoretical support for the improved diamond search.

4.1 Experimental Procedure:

The flowchart in this paper is as Figure 6:

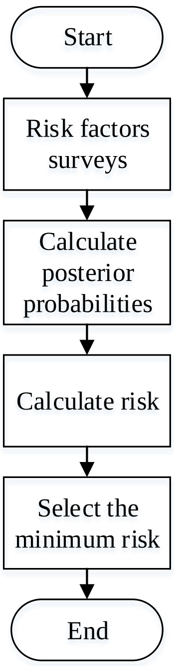

Figure 6. Flowchart

1. Determine the actual power of the risk factors through surveys,
2. Calculate posterior probabilities using Bayesian formula,

$$P\left(\omega_j \middle| x\right) = \frac{p\left(x \middle| \omega_j\right) P\left(\omega_j\right)}{\sum_{i=1}^{3} p\left(x \middle| \omega_i\right) P\left(\omega_i\right)},\ j = 1,2,3 \text{ ------------------------------ } (6)$$

3. By the designed decision table, calculate risk under this decision,

$$R\left(\beta_k \mid x\right) = \sum_{j=1}^{3} \alpha\left(\beta_k \mid \omega_j\right) P\left(\omega_j \mid x\right), i = 1,2,\cdots 70 \text{ --------------------- } (7)$$

4. Decision: Select the minimum risk from a variety of decisions,

$$\chi = \min_{i=1,\cdots,70} R\left(\beta_i \middle| x\right) \text{ -- } (8)$$

4.2. Experimental Process

Because of the grid load, the actual period is 21ms, and the sampling interval is 40us, that is, 525 points in a cycle. In this paper, select 525 points after 35 spaced points, for each cycle calculating different characteristic values respectively.

1. There are four selected eigenvalues collected after the tap-data carefully analyzed, in the table the first 10 are trouble-free, the last 5 are disconnect, the other 5 are poor contact.

Table 2. Feathers in Different Status

feature / actual status	mean	square wave	differential coefficient	effective value
normal	-2.31685	46.48008	0.129965	7.194103
	2.543097	69.45378	0.208461	8.705314
	0.659098	40.23721	0.153986	6.371131
	-0.23414	17.32926	0.049287	4.165272
	0.221146	17.61571	0.052452	4.198745
	0.156065	18.46474	0.049018	4.295607
	2.025238	44.33192	0.150477	6.953059
	0.885078	60.98711	0.235676	7.851671
	-2.69566	62.06302	0.140406	8.318998
	1.849524	52.36553	0.137844	7.462021
poor contact	1.22277	16.33561	6.225316	0.279526
	1.241229	16.85282	6.275798	0.616342
	1.215951	16.55263	6.241289	0.6196
	1.218105	16.30468	6.213684	0.582984
	1.222158	16.37879	6.239604	0.625164
disconnection	0.327267	4.922899	0.06958	2.241983
	0.330701	4.926063	0.264377	2.243192
	0.324016	4.970308	0.268137	2.252054
	0.325311	4.968705	0.26914	2.251885
	0.287454	4.922899	0.076465	2.866623

2. These are the results through traditional Bayesian algorithm compare with the actual status as follows:

Table 3. The Bayes Decision and Actual Status

Bayes	1	3	3	3	1	3	1	1	1	3
actual status	1	1	1	1	1	1	1	1	1	1
Bayes	1	1	1	2	2	1	1	1	3	3
actual status	1	1	1	1	1	1	1	1	1	1
Bayes	3	1	1	3	2	1	2	1	3	1
actual status	1	1	1	1	1	1	1	1	1	1
Bayes	3	2	3	1	3	1	2	3	3	3
actual status	3	3	3	3	3	3	3	3	3	3
Bayes	2	2	2	3	2	2	2	2	1	1
actual status	2	2	2	2	2	2	2	2	2	2

In the table 3, number 1 is normal; number 2 is poor contact; number 3 is disconnection. The white are the difference between Bayes algorithm and actual status. There are 50 group data, of which 29 are right, correct recognition rate is 58%.

Due to the recognition rate of traditional Bayesian algorithm is too low, the misjudgment will have incalculable consequences:

a) When the normal tap is identified as faulty, the worst case is the cost of switch;
b) When a faulty tap identified as normal, for the grid, there may have caused power outage in the short term; and for grid power users whose machine cannot be power cut, once the power failure is likely to cause unpredictable loss.

Taking the different misjudgment producing different loss into account, Therefore, when using the improved Bayesian algorithm, the gap between the two sides of coefficient is very large, it shows as follows:

Table 4. Risk Factors

decision	Natural status		
	normal	Poor contact	disconnection
normal	0	100	10000
Poor contact	10	0	10
disconnection	10	100	0

According to decision risk factors given in the above table, compare the results using the modified Bayesian algorithm with the actual status of the switch:

Table 5. Comparing between Minimum Risk Bayes Results and Actual Status

Minimum risk Bayes	1	1	2	1	1	1	1	1	1	2
actual status	1	1	1	1	1	1	1	1	1	1
Minimum risk Bayes	1	1	1	1	2	1	1	1	1	1
actual status	1	1	1	1	1	1	1	1	1	1
Minimum risk Bayes	3	1	1	1	2	1	1	1	3	1
actual status	1	1	1	1	1	1	1	1	1	1
Minimum risk Bayes	3	3	3	3	3	3	3	3	3	3
actual status	3	3	3	3	3	3	3	3	3	3
Minimum risk Bayes	2	2	2	3	2	2	2	2	1	1

actual status	2	2	2	2	2	2	2	2	2	2

In the table there are 9 misjudgments, and recognition rate is 82%. The white are the misjudgment places using traditional Bayesian.

(3) In order to further improve the recognition rate, on the basis of using a modified Bayesian identification, if the recognition result is disconnected state, review the variance , and determine whether the variance is close to 0:

If the variance is close to zero, it is the disconnection;

If the variance is not close to zero, judge again, and choose the second small of the risk.

Table 6. Comparing between MRBR and Actual Status

MRBR	1	1	2	1	1	1	1	1	1	2
actual status	1	1	1	1	1	1	1	1	1	1
MRBR	1	1	1	1	2	1	1	1	1	1
actual status	1	1	1	1	1	1	1	1	1	1
MRBR	1	1	1	1	2	1	1	1	1	1
actual status	1	1	1	1	1	1	1	1	1	1
MRBR	3	3	3	3	3	3	3	3	3	3
actual status	3	3	3	3	3	3	3	3	3	3
MRBR	2	2	2	2	2	2	2	2	1	1
actual status	2	2	2	2	2	2	2	2	2	2

In the table, MRBR is minimum risk Bayes and review. Review the results are disconnection, and improve the correct judgment rate. There are six false positives, because there is no misjudgment about disconnection, reducing the losses caused by the judge greatly. It shows as follows:

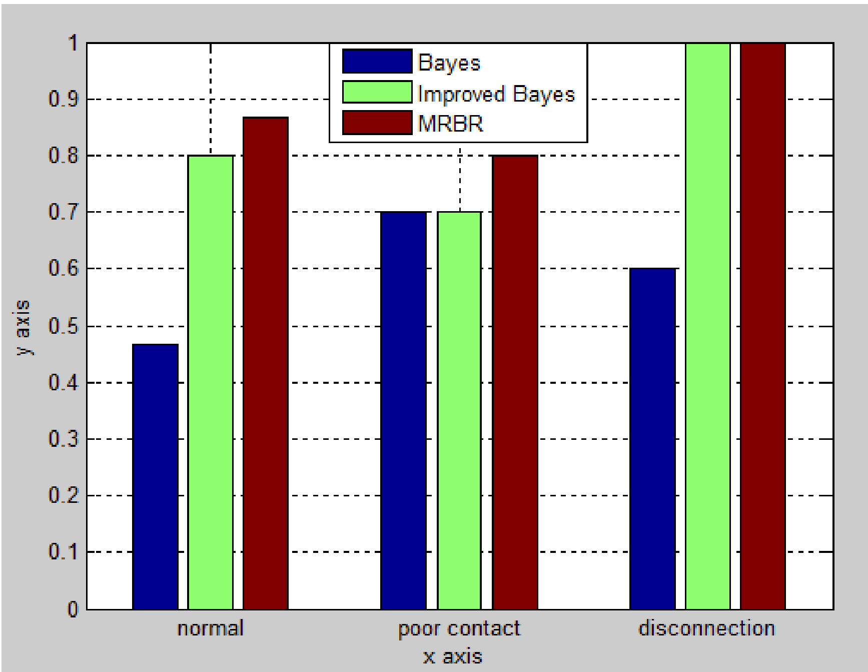

Figure 7. Comparison of Different Methods

5. Conclusion

For on-load tap changer, the results using MRBR are significantly better than traditional Bayesian algorithm:

1. For all users the load tap changer in the use of power is critical, thus the loss of the switching state caused by misjudgment will be different, misjudgment risk is introduced into the algorithm in this article. Introduce the risk to change the proportion of different features, which improves the recognition rate greatly.
2. Through the use of the special nature of disconnection - variance tends to 0, the algorithm reviews the results and raise the recognition rate.

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