Realization of Information Visualization of Electric Power Monitoring System for MV/LV Distribution Customers

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Abstract - Recently, switchboards for MV/LV distribution customers have been united and digitalized rapidly. This paper proposes the effective information visualization method for the data measured from cubicle switchboards for MV/LV distribution customers. We developed the algorithm that analyzes abundant data measured by switchboards and displays them to overall users, such as fire information index, power condition index, switchboard safety index, and power diminution index. Using a touch screen made users to operate it easily. User interface was also improved by taking graphic visualization. We guess the information visualization method suggested in this paper shows the new direction that heavy electrical equipments including switchboards are going to develop in the future.

Keywords: Power Monitoring Systems, Switchboards, Information Visualization, Touch Screen

1. Introduction

Recently, an electric industry has been rapidly changed from an analog era to a digital era. It is also not exception in power system part of heavy electrical equipments. In the latest situation, the development of remote inspection using digital relay and digital watt-meter could easily show that the digitization of devices for heavy electrical equipments has rapidly been installed.

All management of switchboards had been passively done by manner of analog in former days. However, unification and digitization of the system have rapidly been progressed since mid 90's. After all, switchboards have had microprocessor, and this equipment can deal with many data.

As rapid development of computer, there is numerous data which is impossible for human to recognize in data storage system.

Therefore, these data need to be formed as a group and classified in order to control the equipment properly. It is necessary to administer numerous data effectively for system of embodiment.

Hence, information visualization is a new field of research, so detail fields related of these researches are being studied constantly. [1-4, 17] In addition, the study can be expected educational effects by introducing graphical techniques.

Even though grasping and sharing information are important for both user and developer, the development of domestic switchboards was not more in level that showed a measurement value.

Switchboards have combined several facilities such as transformers. So, there are some factors which can make transformer trouble by over-voltage or by deterioration of insulator. However, switchboards are specialized and developed on the user's desire in the days go by, and there is no special operator in actual switchboards for MV/LV distribution customers. Also, the transmission of effective information is actually difficult for spot operator.

Before an accident makes hazardous factor, preventing the factor is most important. In the case of established switchboards, if emergency happens, spot operator was hard to grasp the state and take an action. Therefore, extension of accident have dangerous factor which can spread more and more. In purpose which is to show real time information of electric power state of switchboards effectively and to prevent accidents before their occurrence, information visualization of switchboards is a problem that must be made up definitely.

In foreign cases, the study concerning about information visualization has been accomplished for long time. [1-4, 17] However, in domestic cases, a systematic study about

information visualization is almost lacking in compositing heavy electrical equipments of distribution system.

This paper focuses on information visualization of switchboards for MV/LV distribution customers to consider this situation. Also, this paper suggests 4 points algorithm that can make supervisor to measure data and to diagnose switchboards.

2. Algorithm of Information Visualization in Switchboards

An algorithm of information visualization in switch-boards suggested by this paper consists of 4 points of logic such as fire index, power quality condition index, switchboards safety index and power diminution index.

2.1 Fire Index

In domestic, electricity fire accidents are increasing dramatically every year. This fire index can be used as the purpose to prevent accidents as the index expresses electricity fire occurrence probability to user.

In fire index algorithm, there are 5 factors such as a leakage current, an over-voltage, an open-phase, an inferiority of contact and a highest temperature of transformer's isolator. The quantity of leakage current is measured by ZCT. Additionally, important factor is the highest temperature permitted in transformer's isolator. Also, over-voltage and open-phase can be the factor of fire.

Except place grounded to wiring for safety of electrical device, all instruments have to be insulated from earth. If insulation of instruments is unsatisfactory, a danger of fire or an electric shock by leakage current is possible to be occurred. In case that the leakage current measured by ZCT is more than limitation, hazardous probability of fire is judged 100%.

Switchboards for MV/LV distribution make low electric power level, 380[V] or 220[V], to 22.9[kV] receiving though a transformer and supply a low power. So, inferiority of connection is very dangerous on account of high voltage in switchboards. In case that temperature more than standard is measured in sensor as leakage current, fire hazard probability is decided 100[%].

In the overload criterion of domestic distribution transformer, a rating for short term is permitted to maximum probability 130[%]. For efficient and economical application of transformer, however, overload of short term have to be considered. Also, transformers should set its' category that cause abnormal dissipation life. Foreign regulations such as IEEE, IEC, JEC, etc. present maximum allowable temperature of facility as kind of insulator. Therefore, the regulations are differently applied

in case of short term overload for 1~2 hours [7]. In this paper, we regarded criteria of abnormal dissipation life of transformer as allowable temperature of insulator.

A cause of over-voltage is various kinds such as lightning strike, line accident or breakdown, sudden change of load, capacitor switching etc. in system. Because an insulation of winding is broken by high-voltage taken in line, finally it can make winding damage. However, an insulation can be easily broken by over-voltage generated by various reasons. So, over-voltage is also important factor that user of switchboard must stare necessarily.

At the conclusion, it is about open-phase. Definition of open-phase is that current does not pass even for any phase. If an open-phase is occurred in three phase, an over-current can be made, which also makes great risk of fire. Hence, an open-phase is detected, and used in the fire index.

The limit standard on 5 factors was established in this paper. The standard of each factor same with table. 1. A Fig. 1 shows flowchart of fire index algorithm.

Table. 1 The boundary for the data of fire index

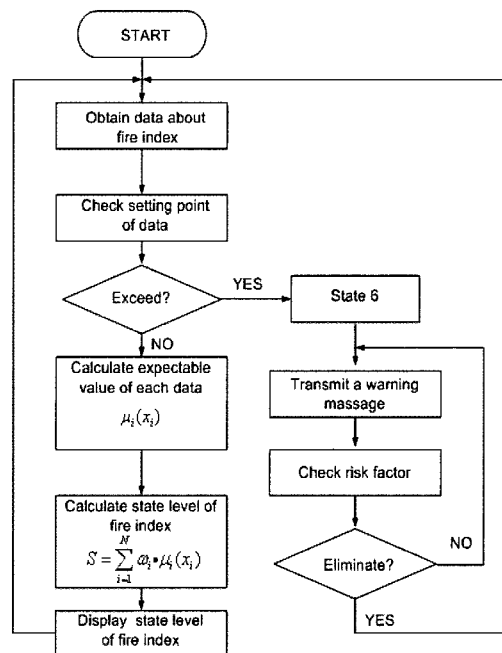| Data Limit norm	Leakage current	Contact badness	Maximum heat point of transformer	over voltage	open -phase
Boundary value	According to capacity of trans- former	80 ℃	According to kind of insulator	130%	One phases' current is zero in three phase

Fig. 1. A flow chart of fire index algorithm

We expressed accuracy of risk in each state, and possibility of fire rises as state goes by state 1 to state 5. State 6 is level of fire alarm.

A fuzzy membership function was also applied to handle uncertainty of the boundary of each factor in this paper. The membership function of S class was used to establish a more effective membership degree. The membership function is defined with equation (1). [13]

$$\mu(x) = \frac{(1-v)^{\lambda-1}(x-a)^{\lambda}}{(1-v)^{\lambda-1}(x-a)^{\lambda} + v^{\lambda-1}(b-x)^{\lambda}} \tag{1}$$

In this formula, 'a' is the lowest limit, and 'b' is the highest limit. Also, λ is gradient, and 'v' is reflective point. A result value is yielded to multiply suitable weight 'ω' by each calculated '$\mu(x)$'. An equation (2) expresses fire risk index.

$$S = \sum_{i=1}^{N} \omega_i \mu_i(x_i) \tag{2}$$

In equation (2), 'S' is probability of fire risk, and 'ω_i' is weight factor of i-th data. Also, '$\mu_i(x)$' is expected value of i-th data, and 'x_i' is input value of i-th data.

2.2 Power Condition Index

To operate switchboards, among the most useful data may be electric charges and power quality data. In other word, facilities' power quantity and quality could be usually wondered.

The purpose of the power condition index is to show the most useful data for switchboard administrator. The index consists of several factors such as voltage, current, power factor, frequency, unbalance factor and total harmonic distortion (THD) of voltage.

A current of transformers' second winding is measured by CT, and overload ability is also expressed as percentage of overload current and steady state current. The overload could be coefficient of utilization of transformer. Hence, to consider unbalance factor, equation (3) expressing to divide the biggest phase current by rated current of transformer is defined as maximum utilization factor 'k_0'.

$$k_0 = \frac{\max(I_a, I_b, I_c)}{I_{T\max}} \times 100 \tag{3}$$

In equation (3), '$I_{T\max}$' is allowable current of transformer, and 'I_a', 'I_b' and 'I_c' are current of each phases.

Table 2 shows voltage maintenance range based on electric industry lows' enforcement regulations article (quality level of electricity) in domestic cases.[14]. When a standard voltage is more than the range, each state is displayed by normalcy, attention and check. For instance, when distribution voltage of transformers' second winding

is 220[V], the state is normalcy in case the present voltage is between 213[V] and 227[V].

Table 2. The range of voltage maintenance in distribution system of Korea

nominal voltage [V]		range of voltage maintenance [V]
low tension	110	104 ~ 116
	220	207 ~ 233
	380	342 ~ 418
	440	414 ~ 466
high tension	6,600	6,000 ~ 6,900
extra-high tension	13,200	12,000 ~ 13,800
	22,900	20,800 ~ 23,800

A power factor of load have to be kept more than 90[%] in domestic. If a power factor is kept 90[%], user does not receive disadvantage to electric charge. For that reason, the power factor 90[%] is named a standard power factor. For maintaining standard power factor, establishing condenser of optimum capacity in each equipment according to [condenser establishment capacity standard table] is necessary. Also, the condenser must be switched at the same time with the equipment.[5]. At this time, user prescribe that the power factor does not become leading power factor by establishing blanket-switchgear or condenser.

At the algorithm, a power factor between 100[%] and 90[%] (standard power factor) is marked as normalcy, and a power factor between 90[%] and 70[%] is marked as attention. Therefore, if power factor is lower than 70[%], warning message is displayed and an alarm works at the moment. If the power factor becomes leading power factor, a message as "Cut off capacitor" is also displayed and an alarm works at the moment.

A current unbalance is defined as deviation of current of each phase about an average current of all phase. Also, the unbalance can be calculated by equation (4). In other word, the unbalance is defined by using symmetrical component, and the unbalance factor is expressed by ratio of negative phase sequence component ('I_2') on positive phase sequence component ('I_1'). The definition of symmetrical component is the same as equation (5).

$$U_1 = \frac{3\max(|I_a|, |I_b|, |I_c|) - \min(|I_a|, |I_b|, |I_c|)}{(|I_a| + |I_b| + |I_c|)} \times 100[\%] \tag{4}$$

$$U_1 = \frac{I_2}{I_1} \times 100[\%] \tag{5}$$

The domestic current unbalance rate is prescribed less than 30[%] in three-phase four-wire system. Also, the rate should not exceed 40[%] in single-phase three-wire system. Consequently, the unbalance rate is set up a boundary, the rate of 30[%] in three phase and the rate of 40[%] in single phase. Then, the rate is displayed.

At side of frequency, the fundamental cause of frequency change is that a demand discord with supply in part of every instantaneous time. If power supply is insufficient, the frequency is dropt. Also, the frequency is risen if power supply is sufficient. If there is customer who has sensitive load with disturbance, a stable voltage having regular frequency and magnitude is necessary. Hence, the range of change limitation is prescribed as ±0.2[Hz] in rated frequency 60[Hz]. In consequence, a threshold value of frequency is ±0.2[Hz], and a change of frequency is visually displayed.

An origination of harmonic current happens in device that use almost power electronic element. A higher harmonic is a frequency having constant magnification of fundamental harmonic. And, THD and containment rate can be shown by value revealing quality of distortion wave. According to KEPCO, the THD is prescribed as 3[%] for customer receiving from substation which has overhead line and underground cable fewer than 66[kV]. The THD of 3[%] is established as a limitation, and THD is displayed visually.

The algorithm of power condition index is a main point how effectively to express power condition for user visually. Therefore, the algorithm of power condition index decides critical condition to 5 factors. Such method as the fire index algorithm, the condition yielded by expected value of each data is displayed.

2.3 Switchboard Safety Index

Even though various devices are integrated in switch-boards, the safety of transformer is equally considered with the safety of switchboards because a transformer is kernel device in switchboards. A normal life of transformer is anticipation value in event of successive drive under ambient temperature and condition of rating drive. Driving transformer. in overload and ambient temperature more than the standard connotes some of danger and accelerates deterioration. If the deterioration is continued, a transformer can spout insulation oil and explode. The main reason of transformer deterioration is overload, ambient temperature of transformer. Accordingly, switchboards' safety index is expressed to compound 3 factors, such as rising temperature of transformer oil, allowable temperature of transformer insulator and transformer overload. To find this index, Dombi's fuzzy membership function is used as fire index.

When each factor exceeds a standard, an alarm works, and the condition is displayed at the same time. Also, an overload state of transformer would be defined in state that transformer life (as ordinary 30 years) has a loss. The rise of transformer oil temperature or maximum allowable temperature of insulator can not be over standard, even if the overload rate exceeds a standard. Usually, a winding temperature and oil temperature rise though overload state continued for long hours, but it is different according to measure of immediate load. That is, transformer can drive if the overload rate is continued for short time.[6]. Hence, the rise of transformer oil temperature or maximum allowable temperature of insulator should be considered without only decision by overload simply by current.

First, when the factor exceeds standard, we should consider which factor influence safety of switchboards. In case the maximum allowable temperature of insulator exceeds more than standard preferentially, this case should be cared because a deterioration of insulating material can occur, and furthermore be extended to accident. Secondly, the rise of transformer oil temperature means that a winding temperature of winding has increased continuously due to the overload. In case of overload for short time, it's no great effect.[6] Consequently, if a temperature of top floor oil or rising temperature is over the standard, we decide that this case influence the safety of switchboard and conclude state 6. Otherwise, we decide the state of this case to multiply weight by each expected value yielded by substituting each element in the membership function.

2.4 Power Diminution index

The power diminution index is embodied as a measurement that shows declining output rate of transformer by disturbance factor such as harmonics in switchboard. For yielding the power diminution index, the utilization factor of transformer and feeder is used. These elements consider harmonics, a maximum heat temperature of transformer and a temperature line.

When the harmonic of power happens in transformer, an eddy current is occurred. So, a loss of eddy current is expressed as equation (6) by k-factor. Also, reducing factor of transformer can be calculated with equation (7).[16] The algorithm expressing power diminution index which use reducing factor of transformer is embodied.

$$k = \sum_{n=1}^{N} (\frac{I_n}{I_1} \times n)^2 \tag{6}$$

In equation (6), 'I_n' is a R.M.S (Root Mean Square) of n-th harmonic current, 'I_1' is R.M.S of fundamental harmonic of load, and 'n' is degree of harmonic.

$$D_{tr} = \sqrt{\frac{1+P_{ec}}{1+P_{ec} \cdot k}} \qquad (7)$$

In equation (7), the 'D_{tr}' is the reducing factor of transformer capacity. The 'k' is k-factor, and the 'P_{ec}' is a loss of eddy current.

Terminally, utilization factor of transformer 'L_{tr}' is defined as equation (8). The equation (9) shows actual load current i-th measured.

$$L_{tr} = \frac{i_{tr}}{I_{tr}} \times 100 \qquad (8)$$

$$i_{tr} = f(\max(i_{ta}, i_{tb}, i_{tc})) \qquad (9)$$

$$I_{tr} = f(I_{\max}, D_t, T_{tr}) \qquad (10)$$

Above the equation (10), the '$I_{\max}$' is a rated current of transformer. 'I_{tr}' is organized by functions '$I_{\max}$', 'I_t' and 'I_{tr}'. So, it means that utilization factor of transformer is considered the harmonics and temperature of transformer.

Also, a utilization factor of feeder is calculated with same as utilization factor of transformer.

This index is displayed on same method as power condition index to find expected value depending on an utilization factor of feeder and an utilization factor of transformer.

3. System Composition for Information Visualization

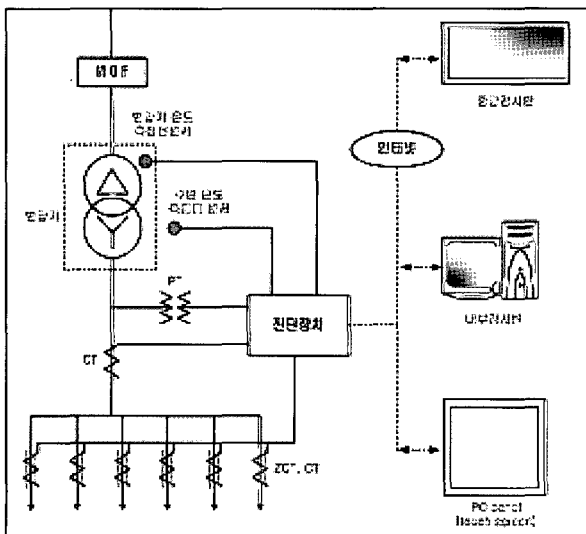### 3.1 Hardware System Composition

Fig. 2. A hardware construction of the switchboard

A Fig. 2 shows whole hardware system composition of switchboard which is embodied in this paper. A transformer oil temperature of the top floor and ambient temperature is measured by temperature sensor. Also, a current and a voltage are measured through CT/PT in second winding of transformer. Also zero phase sequence current and leakage current are measured by ZCT. All measured data are stored in diagnosis equipment, and 4 indices introduced in this paper is calculated by algorithm. In addition, a touch-screen is set in output part of diagnosis equipment. So, the screen can make that observing whole data is possible for spot operator in real time. Also interior observation and central management are possible through internet as Fig. 2.

3.2 Composition of PC Panel

There is a research that visualization techniques improve the faculty of comprehension and original idea about any problem.[17] Especially, this research shows that a visualization techniques is highly effective in part of understanding complicated problem. That research about visualization is continuously studied.

A PC panel in a Fig. 2 should be visualization with graphic techniques so that spot operator can easily grasp data about power condition. All of 4 indices suggested in this paper can be confirmed through a PC panel. Also, a PC panel is totally composed of touch screen. The touch screen has many advantages than other pointing device. Firstly, the touch screen is directly consisted in forms of handling that can learn easily and reduce time. Secondly, the touch screen is one of pointing device reacting greatly fast. Also, there is another advantage that other additional equipments such as keyboard do not need. Of course, there is disadvantage such as possibility that the panel does not perceive user's hand. Also its' price is higher than other equipments. There is, however, no pointing device better than touch screen in side of convenience and management.

Because of these advantages, the touch screen is very effective in public information. We can know the touch screen is very effective coping rapidly in an emergency when we operate facilities which consist complexly of many devices such as the latest switchboard.

A Fig. 3 is a touch screen of PC panel embodied actually. The convenience of user is the most important thing in a screen composition. The screen right top portion composed to 4 indices sequentially, and there is button which can easily stop driving of switchboard at the crisis situation. The information which is measured in real time was composed in center of main screen. The standard administration menu integrated all datum measured such as self-diagnosis of switchboard, power, voltage, current etc. with exception of 4 indices is included.
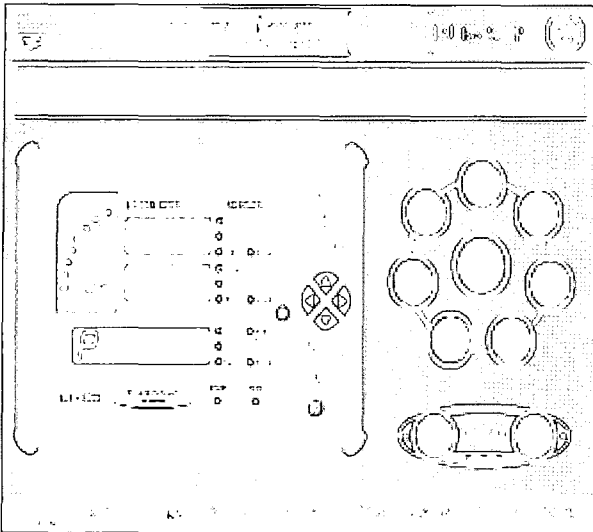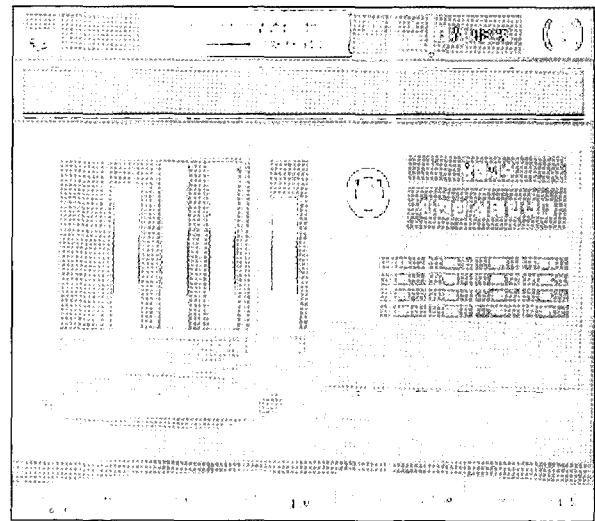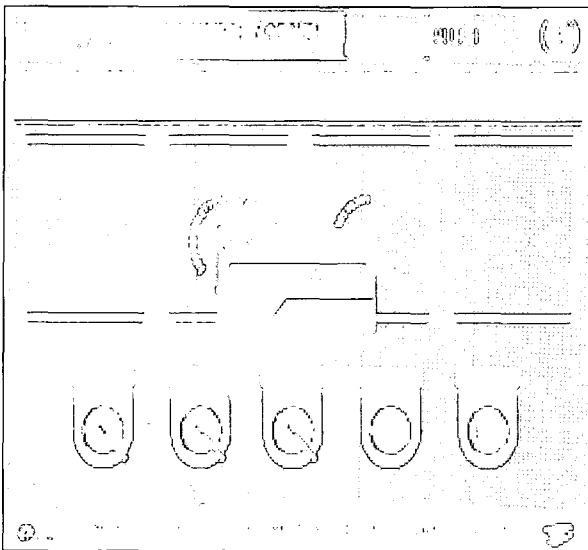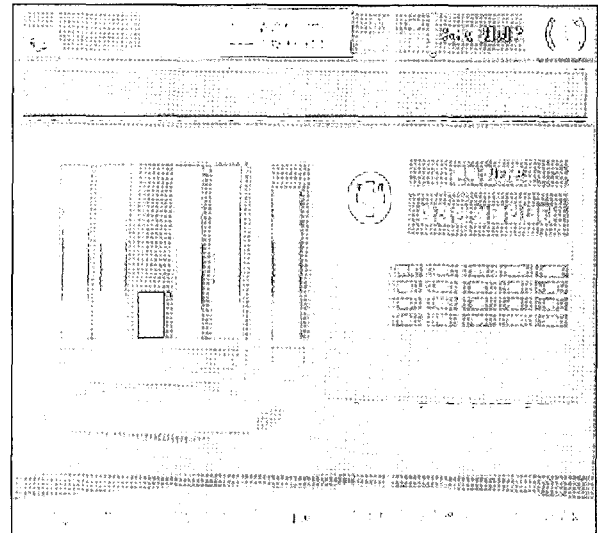
Fig. 3. A PC panel screen for measured information

(a) Before breaker works

(b) After breaker works

Fig. 4. A PC panel screen for switch control

(a) Screen for total index in PC panel

(b) Screen for power condition index in PC panel

Fig. 5. A PC panel screen for displaying all indices

A Fig. 4 shows the menu of switch operation. A switch for operating switchboards can be easily operated with clicking the menu of screen without troublesome works to cut off switch directly.

A Fig. 5 shows how 4 indices are composed in screen. Each index expressed in bar graph form so that beginner can easily grasp the present state. For person who doesn't have electrical knowledge, the screen is embodied to add explanation about 4 indices in detail like (a) of a Fig. 5.

A Fig. 6 is the output report screen of each measurement datum that is measured from switchboards established in actuality spot by time zone. For user, the system is composed to offer various function such as power observation, self-diagnosis, alarm condition, data analysis and report output about power condition etc. through internet.

4. Conclusion

This paper performs research about information visualization of switchboards for user's service and an efficient data administration.

In order to analyze and compound data measured with real time whoever does not have professional knowledge, 4 algorithms are embodied. For preventing electricity fire, a probability of fire is expressed as the fire index, and we attempt new concept by which diminishing rate of transformer output by harmonics is expressed. In order to operate complicated function of switchboards conveniently, the touch screen is introduced. So, user's interface is improved. As the result, power observation systems that possess self- diagnosis function is developed.

In the future, it is considered that heavy electrical equipments of distribution system will rapidly be the unification and the digitization. Accordingly, the development of information visualization technique which is more effective will be done. These power observation systems can greatly divide to algorithm, hardware and software part. So, the simulation and the research should definitely be taken for development and practicality of algorithm, which is important part of diagnosis system. In this paper, a development direction of heavy electrical equipments same as switchboards is suggested. Therefore, this paper is expected to be used as reference data in similar field.

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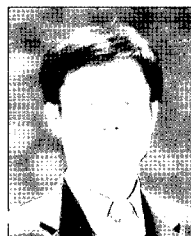
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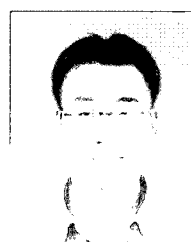
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