Improvement of Three-phase Unbalance due to Connection of Dispersed Generator by Damper Windings of Synchronous Generator

Junya Matsuki Senior Member (University of Fukui, matsuki@fuee.u-fukui.ac.jp)
Hisao Taoka Senior Member (University of Fukui, taoka@u-fukui.ac.jp)
Yasuhiro Hayashi Senior Member (Waseda University, hayashi@waseda.jp)
Shigeru Iwamoto Student Member (University of Fukui, shigeeeen@yahoo.co.jp)
Akihiro Daikoku Member (Mitsubishi Electric Corp., Daikoku.Akihiro@ab.MitsubishiElectric.co.jp)

**Keywords:** damper windings, three-phase unbalance, dispersed generator, damper current, armature current

It is well known in a numerical simulation that the damper winding contributes to suppress the three-phase circuit unbalance. However, experimental study has not been performed yet. In this paper, authors verify experimentally the suppression of the three-phase unbalance caused by dispersed generator by the damper windings.

Figure 1 shows the experimental power system. A 470 W dispersed generator of single-phase-two-line type is connected to a three-phase laboratory-scale power system that consists of a 6 kVA synchronous generator. Authors measure and analyze line voltages and currents as well as damper bar currents both with and without the dispersed generators. The influence of damper windings to the unbalance of three-phase circuit is also investigated.

The results show that the damper winding contributes to improve the three-phase unbalance. The relation among damper current, armature current and negative-sequence current that appears in the unbalanced state was shown. Figure 2 shows harmonics of damper current at RS-phase connection.

Figure 3 shows negative-sequence current. Figure 4 and Table 1 show unbalance rate and improvement rate with and without the dispersed generator.

<table>
<thead>
<tr>
<th>Connections</th>
<th>Unbalance rate without damper windings (%)</th>
<th>Unbalance rate with damper windings (%)</th>
<th>Improvement rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>5.89</td>
<td>5.70</td>
<td>3.15</td>
</tr>
<tr>
<td>RS-phase</td>
<td>8.56</td>
<td>7.94</td>
<td>7.26</td>
</tr>
<tr>
<td>ST-phase</td>
<td>8.95</td>
<td>8.24</td>
<td>8.00</td>
</tr>
<tr>
<td>TR-phase</td>
<td>1.06</td>
<td>0.99</td>
<td>7.11</td>
</tr>
</tbody>
</table>
Estimating Power Outage Cost based on a Survey for Industrial Customers

Yoshikuni Yoshida Non-member (The University of Tokyo)
Ryuji Matsuhashi Member (The University of Tokyo)

Keywords: power outage cost, industry, survey, input-output analysis

There are two approaches for estimating power outage cost. Survey methods include the direct survey for customers. Proxy methods adopt outage cost proxies such as the ratio of output to electricity consumption or the cost of back-up generators. This study estimates power outage cost for many industrial customers by survey methods. Indirect outage cost, such as production stoppage in related factories, is also estimated by utilizing input-output analysis. Survey data was obtained from 5139 establishments that are designated as the energy management factory. Peak electricity consumption of the establishments accounts for 17 percent of total industry. Hence, this study is beneficial in terms of the survey scale.

The questionnaire includes power outage cost and power consumption during an hour in midsummer afternoon. Unit cost of power outage (Yen/kWh) is calculated as power outage cost divided by power consumption. Medians of unit cost of power outage are shown in Fig. 1 with 95 percent confidence intervals. Sectors that have larger unit cost of power outage are Services for amusement and hobbies (Q-84), Manufacture of information and communication equipment (F-28), Manufacture of petroleum and coal products (F-18), Manufacture of precision instruments and machinery (F-31), Manufacture of electrical machinery, equipment and supplies (F-27), and so on. Median of unit cost of power outage in all sectors are estimated 582 Yen/kWh. A 95 percent confidence interval is 525 to 629 Yen/kWh.

Next, log-logistic distribution is selected as an approximated sample distribution of unit cost of power outage in all sectors. The median of the log-logistic distribution is 672 Yen/kWh, which is larger than the sample median 582 Yen/kWh. Since a good fit for the sample reduces the sample bias, 672 Yen/kWh is adopted as the total median of unit cost of power outage. A 95 percent confidence interval is estimated as 631 to 722 Yen/kWh by bootstrap method.

Direct power outage cost is calculated as the product of unit power cost and power consumption. In the case of an hour in midsummer afternoon, Wholesale and retail trade (denoted by J in Fig. 1) has the largest power outage cost due to many number of establishments. Services for amusement and hobbies (Q-84) and Manufacture of chemical and allied products (F-17) also have large power outage cost due to their large unit cost of power outage. Sum of the power outage cost in all sectors is evaluated as 77 billion Yen. A method utilizing input-output analysis is proposed for estimating indirect power outage cost. Indirect power outage cost includes repercussions such as production stoppage in related factories. The indirect power outage cost is shown as

\[ (I - A)^{-1}D(I - B^T)^{-1}F \]  \quad (1)

where I is an identity matrix, A is an input coefficient matrix, B is an output coefficient matrix, F is a vector of which elements show the production stoppage in each sector, and D is a diagonal matrix of which diagonal elements show the ratio of final demand to output in each sector.

Substituting data from input-output tables into equation (1), indirect power outage cost in an hour in midsummer afternoon is estimated as 93 billion Yen, which is 21 percent larger than direct power outage cost. Figure 2 shows the direct and indirect power outage cost classified by sectors. Wholesale and retail trade (J) has the largest total power outage cost. One of the sectors with large indirect power outage cost is Manufacture of transportation equipment (F-30), because of the difficulty in procurement of parts due to power outage.
A Suppression Method of Higher Harmonics Resonance in Distribution System

Shouji Sugimura Student Member (Muroran Institute of Technology, s1824061@mmm.muroran-it.ac.jp)
Tadashi Naitoh Senior Member (Muroran Institute of Technology, naitoh@mmm.muroran-it.ac.jp)
Atsushi Toyama Member (Muroran Institute of Technology, toyama@mmm.muroran-it.ac.jp)
Fumihiko Ohta Member (Tokyo Electric Power Supply, ohta.fumihiko@tepco.co.jp)

Keywords: higher harmonics resonance, distribution system, eigen mode, participation factor, suppression method, orthogonal condition

As the DC link wind turbine generators, there are many PWM control apparatuses, which are higher harmonics current sources, in distribution systems. And higher harmonics causes over current by parallel resonance. Figure 1 shows the distribution system, which contains a resonance circuit and is linked the generator. To protect the over current, it is necessary to suppress the resonance.

In this paper, a new suppression method, which uses the effect of source connected point in resonance circuit, is proposed. Figure 2 shows the equivalence circuit of distribution system model. And then, to estimate the suppression effect, a current amplification degree $Q$ is defined as follow:

$$Q = \frac{I_{sp}}{J_p}$$  \hspace{1cm} (1)

where, $I_{sp}$: SC(static condenser) current, $J_p$: source current.

Figure 3 shows the characteristics of source connected point. And an optimal point, in which $Q$ is minimum, exists. Furthermore, the phase angle of optimal point voltage is orthogonal to SC voltage. Otherwise, the differential state equation of equivalence circuit is as follow:

$$\begin{bmatrix} x' \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} x \end{bmatrix} + J_p \sin(\omega t) \begin{bmatrix} b \end{bmatrix}$$ \hspace{1cm} (2)

where, $x$: variable, $b$: constant, $[A]$: coefficient matrix.

Using eigenvector of $[A]$, the participation factor $\varsigma_i,j,R$, where the suffix $i$ is node number of $c_v$ value and a source connects node $j$, is introduced. Since the orthogonal condition is equal to $\varsigma_i,j,R = 0$, the optimal point is given by using with $\varsigma_i,j,R$. Figure 4 shows the distribution system of containing many SC, in which the number in circle means SC node number.

Figure 5 shows the optimal points and the distribution of $\varsigma_i,j,R$ at $f_o = 6.31$ kHz. It is known that multiple optimal points usually exist. Therefore, we can choose the advantageous point as a source connected node.
An Experimental Study on Direct Load Control of Residential Air-conditioning Units from a Viewpoint of Short-period Controllability in Artificial Climate Chamber

Hideharu Sugihara Member (Osaka University)
Tsuyoshi Funaki Member (Osaka University)
Kiyotaka Ueno Member (Kansai Electric Power Co. Inc.)

Keywords: demand side management, air-conditioner, direct load control, artificial climate chamber, pay-back phenomena

1. Introduction

Recent years have seen higher demands for electrical power systems to reduce emissions of greenhouse gases, and increased use of renewable energy power sources like photovoltaic systems. However, various concerns over potential adverse implications on the secure operation of the power grid that could result from large-scale installation of PV systems have been identified, such as large-scale PV causing frequency variations et al.

This paper presents findings on performing direct load control in an artificial climate chamber capable of constant outside air temperature control, and focuses on the potential for using load-variable residential Air-Conditioning (AC) units in order to promote the large-scale introduction of photovoltaic systems. Specifically, measurements were taken of power consumption, room temperature, suction air temperature, and blow air temperature while altering the set-point of inside air temperature over 4, 8 and 12 minutes interval, and the variability of AC unit power consumption was evaluated, while also investigating the effects on thermal comfort index inside the room.

2. Experimental Condition of Direct Load Control

The direct load control testing conditions used are indicated in Table 1. Summer conditions were assumed for the outdoor environment, with an air temperature of 35°C, and relative humidity of 60%. Indoor conditions were set at 22°C. Temperature settings were increased 2°C to assess direct load control (from 22°C to 24°C). Repeats for ON and OFF time for load control were each set at 4 min, 8 min and 12 min, respectively. Data was recorded in 10-s intervals.

3. Experimental Results

Result of measured changes in power consumption for AC unit A in the LDK and AC unit B in the bed room, respectively. Figure 1 shows AC suction air temperature and blow temperature in addition to AC power consumption and room temperature in the LDK. Figure 1 indicates that power consumption remains essentially unchanged when the temperature settings are changed (to 24 degree), then falls to near zero after around 3 min. The delay in change is most likely attributable to the unit re-measuring room temperature, but this depends on the AC model involved. As unit power consumption drops, air blow temperature from the unit increases, which in turn increases the temperature of the room. After the room reaches the set temperature of 24°C, the AC unit once again returns to the same operating conditions as in the initial settings with the same amount of power consumption. It was noted that power consumption increased significantly when the temperature settings were returned to 22°C after the third control cycle (the “pay back effect”). The reason for this is assumed to be that the conditions for the coolant inside the unit gradually changed over the last two changes in temperature settings.

Figure 2 indicates PMV indicators during direct load control for unit A. PMV was between −0.5 and −0.4 during the 10 min prior to direct load control, which approximates the lower limits of the comfortable range recommended by ISO-7730. For the nearly 3 min after direct load control was initiated, PMV remained essentially unchanged. Afterwards, PMV increased together with the rise in room temperature, and reached a maximum of +0.1 during the 3rd direct load control event. In summary, the PMV indicator increased 0.53 during the 8 min of direct load control, which is about half the amount of variation allowable by the ISO-7730 standard, so presumed to be within a range permissible by users.

Table 1. Experimental conditions of direct load control

<table>
<thead>
<tr>
<th>Case</th>
<th>Controlled duration time</th>
<th>Uncontrolled duration time</th>
<th>Temperature: controlled</th>
<th>Repeated times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>4 minutes</td>
<td>4 minutes</td>
<td>24°C</td>
<td>3 times</td>
</tr>
<tr>
<td>Case 2</td>
<td>8 minutes</td>
<td>8 minutes</td>
<td>24°C</td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>12 minutes</td>
<td>12 minutes</td>
<td>24°C</td>
<td></td>
</tr>
</tbody>
</table>
Shunt Capacitor Renewal Planning with a Cost Leveling Strategy using the Condition Age Model

Yuta Tanaka  Student Member  (Waseda University)
Ken Suzuki  Student Member  (Waseda University)
Shinichi Iwamoto  Member  (Waseda University)

Keywords: power system planning, asset management, cost leveling, voltage stability L-index

The demand for power had increased sharply during the period of accelerated growth in the economy in Japan. With this situation, the utilities have been installed many Shunt Capacitors (SCs) in their power systems. Therefore, it is necessary to consider the cost increase for a certain period and the failure risk increase during the renewal period by the short term concentration of the renewal periods. Then, to solve these problems, it is important to develop a method which determines a renewal plan with cost leveling while considering supply reliability for the renewal terms.

Recently, the concern for the global warming issue has risen. One of the solutions for the problem is to introduce a lot of renewable energies including the use of photovoltaic generation (PV) into power systems. The voltage stability problem will become more important when a large amount of PVs are introduced to power systems in the future. Also, SC is one of the voltage control equipment. Therefore, this paper deals with the replacement of SCs.

Since the SC state in the power system is constantly changing, when the SCs are replaced in the power system, it is important to establish some SCs with an expected increased demand and to remove some SCs which are less effective to the voltage stability in order to reduce the cost. In other words, during the period to update the aging SCs, the important factor is the cost leveling and saving while maintaining voltage stability in the power system. Concerning the cost evaluation, AM has become desirable for use with power systems.

At the point of the asset management, in order to reduce the maintenance costs and maintain the system adequacy and reliability simultaneously, it is necessary to have the evaluation of the SC in the present condition considering the failure rates and an aged SC model that evaluates the equipment conditions to maintain the reliability. Therefore, this paper proposes the so-called SC life cycle cost considering the failure rates and the SC age model using the concept of overhaul, and then analyzes a new renewal planning with this model.

From the point of stability, the feature of the SC voltage control is consumed in close proximity. Therefore, SC renewal with keeping the voltage stability needs the method to know which SCs are important in the power system. This paper deals with the SC grouping method and the voltage stability index L-index.

This paper proposes a new renewal planning method which has the concept of asset management with a cost leveling shown as Fig. 1. Then, this paper confirms the effectiveness of the proposed method using the condition age model. Figure 2 shows the simulation results of the renewal plan cost compared with the conventional method which does not have the strategy of the cost leveling, by using the IEEJ West 30 machine 115 bus system. As shown in Fig. 2, the proposed method contributes to the cost leveling and cost reduction. At the point of the cost leveling, the appropriate time selection of the construct new SCs by the proposed method using the idea of SC grouping, is considered effective. The reason for cost saving is that the timing of establishing the new SCs is delayed, and the total of maintenance cost and repair cost of the SCs are reduced.

The results of the simulations show the proposed method has the validity of the cost leveling under the case of the large amount of SC renewal.
Modeling Method of a Real Earth in an Experiment above a Conductor Plate

Masanori Nishitsuji Student Member (Doshisha University, etk1101@mail4.doshisha.ac.jp)
Akihiro Ametani Fellow (Doshisha University, aametani@mail.doshisha.ac.jp)
Naoto Nagaoka Member (Doshisha University, nnagaoka@mail.doshisha.ac.jp)
Yoshihiro Baba Member (Doshisha University, ybaba@mail.doshisha.ac.jp)

Keywords: surge, characteristic-impedance, real earth, conductor plate, scale model, EMTP

A transient over-voltage analysis is very significant for the insulation design of a power system. A scale model is very useful for an experimental investigation of a transient, when a real power system is too large to carry out an experimental measurement. In the scale model, it is a common practice to use an equivalent conductor plate, i.e., an aluminum (Al) or copper (Cu) plate, to represent a real earth. In this case, voltage measurement becomes very easy, because the conductor plate can be used as a voltage reference. However, it is not clear if the conductor plate can represent the real earth.

This paper investigates representation of a real earth by a conductor plate. Figure 1 illustrates an experimental circuit. Figure 2 shows a comparison of measured results when the ground plane is a real earth and a conductor plate, where the grounding impedance is represented only by a resistance in the conductor plate case. It is clearly observed that there exists a significant difference between the measured results. The waveform is different between the case of a real earth and an Al plate after reflection comes back from the return end. The first reflected wave is affected by the impedance of a grounding electrode. This fact indicates that the grounding electrode should be carefully represented in an experiment above a conductor plate.

To reduce the difference, the effect of the grounding electrode is investigated. Figure 3 shows a measured frequency response a grounding electrode. Included is a frequency response of an RL circuit representing the grounding electrode.

Figure 4 shows a comparison of measurement results above a real earth and above a conductor plate with an RL circuit for representing a grounding electrode. It is observed in the figure that the RL series circuit representing a grounding electrode gives a better result in the case of only a resistance.

Therefore, an RL circuit model of a grounding electrode is an approach to represent a real earth by a conductor plate, when an experiment is carried out above the conductor plate.
A New Design Method of AC Filter for Static Var Compensator

Yuji Tamura  Member  (Toshiba Corporation)
Shoichi Irokawa  Senior Member  (Toshiba Corporation)
Hideo Takeda  Member  (Toshiba Corporation)
Kikuo Takagi  Member  (Toshiba Corporation)
Yasuhiro Noro  Senior Member  (Toshiba Corporation)
Akihiro Ametani  Fellow  (Doshisha University)

Keywords: AC filter, static var compensator, HVDC, harmonic analysis

1. Introduction

When the SVC (Static Var Compensator) for power network system consists of TCR(s) (Thyristor Controlled Reactor(s)) or TCT(s) (Thyristor Controlled Transformer(s)) and of AC filter(s), it is required to design the AC filter(s) carefully to meet regulation level of harmonic voltage and current at the connection point of the SVC. In general the AC filter design may require many iterative calculations of the harmonic performance by changing electrical parameters of the AC filter(s) until all the harmonic voltage and current performances at the connection point of the SVC meet the regulation level on various conditions in terms of the filter de-tuning cases and the AC system conditions. In this respect a new AC filter design approach has been proposed, which is innovative on evaluation method of the performance on the complex impedance plane.

2. Proposed Method

Harmonic distortion voltage and current at SVC connection point at a certain harmonic order 'n' are calculated by the simplified circuit as summarized in Fig. 1. Harmonic impedance of AC system impedance Zsn can be represented by an envelope on a complex plane as indicated in Fig. 1 taking consideration of all possible AC system conditions. Permissible range of Yfn and Zfn on the complex plane which realize harmonic distortion voltage and current to be within the regulation levels are calculated by the Zsn and the regulation levels of harmonic voltage/current. Besides the total harmonic impedance of the applied AC filter distribute in a certain range on a complex plane depending on the capacitance deviation due to ambient temperature etc. Comparing with the said permissible ranges and the filter performance ranges, the required filter parameters can be determined looking down on complex planes efficiently.

3. Example of Actual Evaluation

Figure 2 is an actual example of evaluation results on Yfn and Zfn permissible ranges at n = 5th of an SVC. Susceptance and impedance ranges of Yfn and Zfn are all within the permissible ranges of which border lines are comprised of Y' or Z' in the diagrams.

Figure 3 is a simplified evaluation diagram by filter reactance values for all harmonic orders. Xl (Upper limit) and Xc (Lower limit) are reactance values of the permissible range at R = 0 and/or G = 0. Filter reactance Xn are of the applied filter impedances for the three de-tuning cases. The upper limits and lower limits exist at 5th and 7th order, and the applied filter reactance values are all within the permissible range.

4. Conclusion

By using this method, the iterations of the calculation can be reduced. It enables more efficient process of the design providing clear accountability of the decision of AC filter parameters.
Fundamental Study for Introduction of Renewable Energy into Syowa Base

Shogo Nishikawa Member (Nihon University, National Institute of Polar Research)
Haruhiko Abiko Non-member (Misawa Homes Institute of Research and Development)
Junichi Kurihara Non-member (Misawa Homes Institute of Research and Development)
Kenji Ishizawa Non-member (National Institute of Polar Research)
Nobuhiko Endo Non-member (National Institute of Polar Research)

Keywords: antarctica, syowa base, renewable energy, PV system, WG system, heat pump

National Institute of Polar Research (NIPR) conducts a lot of observations relating to the earth, the environment, life, space and other fields. Syowa base in Antarctica is important base to study them. In Syowa base, the diesel engine generator (DG) supplies electrical energy and thermal energy at the same time, and the boiler supplies supplementary thermal energy. Most fuel for DG and boiler is light oil. To reduce the volume of fuel consumed in Syowa base, we study the proper renewable energy system (RE) to supply both electrical and thermal energy. Though a lot of photovoltaic power generation systems (PV) and wind power generation systems (WG) have already been installed all over the world, climate at Syowa base is quite different from other area and we have few experiences on renewable energy system in Antarctica. Moreover, though thermal load (TL) is much bigger than electrical load (EL) all the year round, both PV system and WG system generate only electrical energy.

As the first step of this research, we studied the introduction effect of a hybrid RE composed of PV, WG and heat pump (HP) by a simple simulation. Figure 1 indicates system configuration and power flow. Since TL is always bigger than EL, we proposed the use of a HP to convert all or a part of electrical energy from RE into thermal energy. In this report, we reported the simulation results of the influence on performance of RE by various conditions of RE.

We calculated RE output energy, thermal output energy of HP, disposal thermal energy and consumed fuel volume by DG and boiler every an hour throughout a year. And three conditions of RE were assumed for simulation. They were total RE capacity, the ratio of PV annual output energy to RE output energy and the ratio of HP capacity to RE capacity. Both Fig. 2 and Fig. 3 shows the influence of ratio of PV annual output energy to RE output energy (PV ratio), and RE capacity are 100 kW and 200 kW, respectively. HP capacity is the half of that of RE system. In the both figures, C is the best ratio of HP driving energy to RE output energy, and ΔFU is the annual reduction volume of fuel consumed by DG and boiler. From these figures, it is cleared that PV ratio does not influence C and ΔFU so much in RE of 100 kW but RE of 200 kW influences them very much. Because the output energy of RE of 100 kW is too small to influence them. It is also cleared that ΔFU is maximum at 0% of PV ratio in both figures. Because, though thermal load is the biggest in winter, PV cannot generate in winter. On the other hand, WG output energy is big in winter. However, when the capacity of RE system is 300 kW, proper combination of PV and WG is important to decrease disposal energy.

Though we did not consider solar thermal collector as a component of RE, we will study performance of RE with solar thermal collector. And, to increase the accuracy of simulation, we will conduct the demonstrative test of RE in near future.

![Fig. 1. System configuration and power flow](image1)

![Fig. 2. Influence of PV annual output energy ratio (RE: 100 kW, HP: 50 kW)](image2)

![Fig. 3. Influence of PV annual output energy ratio (RE: 200 kW, HP: 100 kW)](image3)
Transition of Progressing Aspect of Negative Creeping Discharge along Aerial Insulated Cable

Toshiyuki Nishi Member (Toyama National College of Technology, nishi@nc-toyama.ac.jp)
Ryoichi Hanaoka Member (Kanazawa Institute of Technology, hanaoka@neptune.kanazawa-it.ac.jp)
Shinzo Takata Member (Kanazawa Institute of Technology, takata@neptune.kanazawa-it.ac.jp)

Keywords: aerial insulated cable, negative creeping discharge, behavior of positive ions, lightning impulse, discharge progressing model

When a stroke of lightning happens in the vicinity of the high voltage aerial distribution lines, they are exposed to danger of a punch-through breakdown of the insulated coating and melting or snapping accidents of the cable by the creeping discharge along the cable surface. To prevent these disasters, it is important to clarify the progressing mechanism of creeping discharges. The aspect of the negative creeping discharge along the cable surface depends on the peak value of surge voltage and its progressing process is extremely complicated. In the previous paper, we observed in detail the negative creeping discharge using an image converter camera and the progressing process was clarified photographically. In this paper, we propose the progressing models of the negative creeping discharge on the basis of our previous observations and consider the progressing mechanism.

Figure 1(a) to (c) show the progressing models of sticking and arch jumping types which appear in the negative creeping discharge at \( V_m = 50 \text{ kV} \). The discharge of the sticking type A shown in Fig. 1(a) is plasma column with positive ions and electrons. Electrons B are supplied to the discharge tip from the binding wire. Electrons C are emitted from the discharge tip and collide with nitrogen molecules \( N_2 \). Then, electron D and positive ion E are produced by collision ionization. Electrons D are attracted to the positive potential of the central line and they are adsorbed on the wire surface. Positive ions E are repelled by the positive potential of the central line and they move toward the binding wire by the electric field. The positive ions F and G, however, are attracted to the group of electrons H on the cable surface as shown in Fig. 1(b). Therefore, these positive ions progress to an opposite direction from the progressing direction of discharge, and the discharge of arch jumping type is formed. An arch shape is completed when the discharge of arch jumping type I arrives in the group of electrons H on the cable surface as shown in Fig. 1(c).

Figure 2 shows the electric field distribution near the binding wire tip at \( V_m = 80 \text{ kV} \). This is obtained by solving Laplace’s equation. When the positive impulse voltage is applied to the central line of the cable, the electric fields distribute toward the binding wire tip from the central line and describe a large circular arc at the position separating from the binding wire tip. The positive ions produced by collision ionization will move along the electric field distribution. The arch jumping type arises from this electric field shape.

The progressing models proposed in this paper are caused by the behavior of positive ions. The progressing lengths of positive ion are estimated by taking account of the electric field at near the cable surface and positive ion mobility. They gave roughly agreement with the values that had been obtained by experimental observations, which revealed the validity of developing models.
The Mechanisms and Countermeasures of Failure in Low-Voltage Electronic Watt-Hour-Meters Caused by Lightning

——A Study on Effective Method to Prevent Electromagnetic Disturbance——

Akira Asakawa Member (Central Research Institute of Electric Power Industry, asa@criepi.denken.or.jp)
Seiji Hurukawa Member (Kyushu Electric Power Co., Inc, Seiji_Furukawa@kyuden.co.jp)
Akihisa Takahashi Member (Chugoku Electric Power Co., Inc, 262620@pnet.energia.co.jp)
Kazuyuki Ishimoto Member (Central Research Institute of Electric Power Industry, ishimoto@criepi.denken.or.jp)

Keywords: lightning, distribution line, electronic watt-hour-meter, lightning protection design

1. Introduction
In the near future, it seems that a smart meter with the metrological function, telecommunication facility, and opening and shutting function spreads widely by applying the smart grid. The metrological function of a smart meter doesn’t roughly have the change with the function of electric watt hour meter (E-WHM). It is easy to receive the damage of lightning compared with past machine typeWHM because E-WHM is composed of the electric circuit. However, any mechanisms of these breakdowns have not been clarified, and the counter measures are not examined at all in a past research. From the above-mentioned viewpoint, the purpose of the present study is to clarify the lightning-proof ability value and the method of counter measures of E-WHM experimentally.

2. Experimental Study of Breakdown Mechanism of E-WHM
The experimental study of four items shown in Table 1 for E-WHM was executed by using 12MV impulse generator at Shiohara testing yard in CRIEPI.

(1) Influence of magnetic field
The breakdown of the meter occurs if the current of 3 kA flows to the line (1s-1L) arranged near the operation processing unit. The meter doesn’t break down even if the current of 18 kA (Shiohara’s maximum current) flows to a line left from the operation processing unit. The cause of the breakdown is to receive the influence of the magnetic field by the current to which the operation processing unit flows in the line in the meter. The meter breaks down when the induced voltage of the operation processing unit flows in the line in the meter. The cause of the breakdown is to receive the influence of the magnetic field by the current to which the operation processing unit flows in the line in the meter.

(2) Influence of energy
The breakdown of E-WHM occurred by 5 kA when having passed lightning current to ZnO element established in meter. As for the breakdown aspect, the power failure display was confirmed, and line that supplies power to operation processing unit had been disconnected by the energy of the current.

(3) Influence of lightning overvoltage
The influence of the overvoltage generated when sparkover was caused between the outside walls of house and E-WHM was examined. However, the breakdown did not occur even by the current of 18 kA. Therefore, the overvoltage doesn’t influence it so much.

(4) Influence of lightning current
The influence of the current that flowed when sparkover was caused between the outside walls of house and E-WHM was examined. The breakdown did not occur when the terminal on the power supply side of E-WHM was connected with the meter case. However, the breakdown occurred when the terminal was connected with the case on the load side. When 1L is connected to case, the value is 3 kA. And when 2L or 3L is connected to case, the value is 8.5 kA.

3. Counter Measures to Breakdown of E-WHM
It proposed the following three items as counter measures of the breakdown of Chapter 2.

(1) Measure to magnetic field
It proposed the application of the magnetic shielding as a measures that decreases the influence of the magnetic field. The arrangement of the shield material should be insufficient only in the operation processing part, and enclose the operation processing part and the entire electric circuit substrate that accompanies it.

(2) Measure to energy of lightning current
It proposed to move the varistor between lines in the meter to meter outside terminal on the power supply side as a fusion measures of the power supply line to the operation processing unit.

(3) Measure to reduce the current flowed into the line in meter
It proposed to establish the varistor between meter terminal and the case, and to connect the case and earth of SPD established by customer as a measure that decreases the lightning current that passes the power line in the meter.

4. Directionality in the Future
A lot of breakdowns of E-WHM occur compared with a past machine type meter. Therefore, it is important to accumulate the crest value and the waveform data of the lightning current, and the data of magnetic field strength generated in operation processing unit of meter by current that invades into the meter by an actual lightning. It is thought that developing the standard examination device based on the observational result, and reflecting it in the standard are important.