The Suppressing Effect of Voltage Distortion by the Fifth Harmonic Current at the Supply Point for Customers with a Middle Voltage Power Supply

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Keywords: harmonics, limit value, customer, three-phase equipment, phase angle

Because the limit values on the harmonic currents that can be emitted by customers of 6.6 kV and higher power supplies are applied to large equipment (those drawing more than 20 A), they typically apply to three-phase equipment.

Transformers in the range of 75 kVA to 500 kVA are required by the Japanese Industrial Standard (JIS) to have a star-delta connection. Single-phase equipment is considered to be equivalent to three-phase equipment with a delta-delta connection transformer in the electric power distribution system, because many home appliances are connected phase-to-phase. Therefore, harmonic currents introduced by three-phase equipment and single-phase equipment cancel each other out.

The authors reached the following conclusions by analyzing harmonic voltage and current data.

1. The limit values for customers with high-voltage power supplies may be unnecessary, because the harmonic currents from three-phase equipment reduce the harmonic voltages. Figure 1 shows the relative frequency of the phase angle of the fifth-harmonic current related to the fundamental phase voltage. The phase angles of single-phase equipment mainly appear between 150 and 180 degrees, and those of three-phase equipment mainly appear between 300 and 330 degrees. As these currents are about 180 degrees out of phase, they should cancel each other out.

2. The harmonic voltages are generally produced by single-phase equipment. Figure 2 shows the relative frequency of the phase angles of the fifth harmonic voltage related to the fundamental phase voltage. The phase angle of the fifth harmonic voltage appears between −30 and +30 degrees. This indicates that the 5th harmonic voltage on the 6.6 kV distribution lines in Japan is produced by single-phase equipment.

3. Figure 3 shows the relative frequency of the phase angles of the fifth-harmonic current related to the fifth-harmonic voltage based on the measurement of 45 customers that had installed a capacitor and a reactor and 23 customers that had installed a capacitor without a reactor. The current of 45 customers, each with an installed capacitor and reactor, mainly appears between 270 and 300 degrees. The fifth harmonic current operates to reduce the fifth harmonic voltage in the 6.6 kV distribution lines. On the other hand, the current of 23 customers with an installed capacitor, but without a reactor, mainly appears between 60 and 90 degrees. The current increases the fifth harmonic voltage. These characteristics of the phase of the fifth harmonic current do not depend upon the amount of the fifth harmonic current emitted by the customer.

Therefore, we conclude that adding a series reactor to the capacitors to improve the power factor is a necessary and sufficient method for suppression of the fifth harmonic voltage.

Fig. 1. Relative frequency of the phase angle of the 5th harmonic current related to the fundamental phase voltage

Fig. 2. Relative frequency of the phase angle of the 5th harmonic voltage related to the fundamental phase voltage

Fig. 3. Relative frequency of the phase angle of the 5th harmonic current related to the 5th harmonic voltage
Assessment of Energy Saving and CO₂ Mitigation Potential by Electric Vehicle and Plug-in Hybrid Vehicle under Japan’s Power Generation Mix

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Keywords: electric vehicle, plug-in hybrid vehicle, optimal power generation mix model, vehicle penetration model

1. Introduction
This paper evaluates the impact of an extensive introduction of electric vehicle (EV) and plug-in hybrid vehicle (PHEV) on energy supply mix in Japan. Energy consumption in Japan’s transport sector has been dominated by petroleum, and CO₂ emissions in this sector accounts for twenty percent of Japan’s carbon dioxide (CO₂) emissions. Therefore, the deployment of clean energy vehicles, such as EV and PHEV, are expected to play a significant role in tackling with energy security and environmental concerns. On these backgrounds, we develop energy system model, explicitly analyzing the impact of EV and PHEV introduction into daily electric load curve considering its specific electricity charging profile by 10 minutes in 365 days.

2. Methodology
For assessing energy and environmental benefits of EV and PHEV, we develop energy system model integrating optimal power generation mix model and vehicle penetration model, considering optimal overnight charging profile of electricity derived from EV and PHEV.

Through the mutual feedback of electricity price and electricity demand of EV and PHEV among both models, vehicle penetration model yields long-term perspective on vehicle penetration mix as shown in Fig. 1 and optimal power generation mix model identifies the best mix of power generation and optimal charging pattern of EV and PHEV as illustrated in Fig. 2.

Sensitivity analysis is conducted on EV and PHEV penetration

3. Estimated Results
Calculated results suggest that massive EV and PHEV penetration serves as energy saving measure in Japan’s whole energy system, due to significant petroleum reduction exceeding the growth of fuel input into power generation sector derived from significant EV and PHEV penetration.

Massive EV and PHEV deployment is estimated to contribute to CO₂ mitigation of the energy system as well. Evaluating CO₂ emissions per mileage by automobile, however, carbon emissions per mileage of EV is almost equivalent to that of gasoline hybrid vehicle (HEV) in the case of decommissioning nuclear after 40 years operation, as shown in Fig. 3, which eventually causes higher carbon intensity of electricity supply.

This paper estimates that EV and PHEV penetration might provide beneficial effect on energy saving and CO₂ mitigation in whole energy system. It is also revealed in this paper, however, that CO₂ regulation and decommission of nuclear cause increase in electricity price and eventually decrease in EV and PHEV introduction, consequently suppressing petroleum demand reduction through those advanced vehicles. These calculated results imply that energy and environmental policy in power sector potentially has inter-sectoral impact on transport sector.

Fig. 1. Passenger vehicle ownership in Japan

Fig. 2. Monthly power generation profile in May 2050 at Advance case in vehicle penetration

Fig. 3. CO₂ per mileage in 2050 at Advance case in vehicle penetration
Capacity Planning and Economical Evaluation of a Renewable Power System for Remote Island

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Keywords: remote island, renewable power system, hydrogen storage, capacity planning, economical evaluation

With the shutdown of many nuclear power plants after the Great East Japan Earthquake, how to meet the future power demand is actively discussed in Japan. In the medium- and long-term, it is important to speed up the introduction of renewable energy. In general, it’s easier to introduce renewable energy to remote islands, because renewable power system became more economical competitive to conventional power system (such as diesel engine power generation, usually with a high fuel cost) in remote islands. To prompt the introduction of renewable energy in remote islands, detailed economical evaluation, advantage and disadvantage evaluations are necessary. This paper presents capacity planning and economical evaluation of a renewable power system proposed for Okushiri Island, which is a remote island in the southwest of Hokkaido. Figure 1 shows basic configuration of the renewable power system. In this system, the power demand is mainly provided by photovoltaic (PV), wind turbine (WT). Batteries (BA) are used as short time energy storage, and hydrogen storage system (composed of water electrolyzer (WE), hydrogen storage (TK), and fuel cell (FC)) is used as long time energy storage here. Optimal capacities of these power sources are those meet the required supply reliability, with the lowest cost.

In order to evaluate the supply reliability and economy, evaluation indexes are defined respectively as follow:

1. Loss of power supply reliability ($LPSP$):

$$LPSP = \frac{Annual \text{ power shortage}}{Annual \text{ power demand}}$$

2. Levelized Cost of Energy ($LCE$):

$$LCE = \frac{Annual \text{ system cost}}{Annual \text{ power usage}}$$

As the first step in the capacity planning, mathematical models for characterizing PV, WT, BA, WE, FC, and TK are explained. The second step is to optimize the capacities of the power sources according to the $LPSP$ and the $LCE$ concepts. The configurations, which meet the required $LPSP$ with the lowest $LCE$, give the optimal choices. These calculations are carried out with hourly meteorological data and energy demand data of Okushiri Island.

A capacity planning and economical evaluation result is shown in Fig. 2. We can see that higher power supply reliability means higher cost. With the increasing of $LPSP$, $LCE$ fall down quickly at first because of the decreasing of capacities of TK and FC. However, When $LPSP > 0.02$, the decreasing of $LCE$ became very slow. When $LPSP < 0.02$, system with hybrid storage (combination of battery and hydrogen storage) is the best choice with lowest cost. When $LPSP > 0.02$, system with battery only storage get the lowest $LCE$.

![Fig. 2. Result of Capacity planning and Economical evaluation (BOS: Balance of system, MNT: Maintenance)](image-url)
Improvement of Transient Stability and Short-Term Voltage Stability by Rapid Control of Batteries on EHV Network in Power System

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Keywords: power system, emergency control, short-term voltage stability, transient stability, battery energy storage system, FACTS devices

Recent trends towards deregulation in an electrical power sector and a large penetration of renewable energy resources increase uncertainty in the power system operations, which may lead to deterioration of the power supply reliability. Effective utilization of the existing transmission networks with an advanced emergency control scheme can be a promising approach in terms of economic efficiency and robustness for the uncertainty. Development of the new emergency control scheme applicable to the future grid can be more effective by utilizing advanced electrical power controllers available in the future grid. BESS (battery energy storage system) is one of the attractive equipment for the emergency control since BESSs will be installed on EHV (extra high voltage) networks for demand and supply matching.

In this paper, use of BESSs is studied for the improvement of short-term voltage stability from the viewpoint of the voltage control. Active and reactive power exchanges by the BESS are targets for the emergency control. Based on the stabilizing control scheme proposed in our previous research to improve transient stability, a new control scheme is developed considering a finding that the short-term voltage stability is closely related to the angle stability. The new control scheme changes active and reactive power exchange between the BESSs and the grid to shift the time derivative value of the stability indices, an energy function of the power system and rotor speed of the critical generator, into a desirable direction for the stability enhancement. In this paper, an additional control system that limits active and reactive power absorption from the grid is applied to the stabilizing control system since the power absorption drops the system voltages.

Numerical simulations are conducted on two test systems, where a part of the loads are modified as induction motor loads, to verify the effectiveness of the proposed control system of BESSs for the improvement of the short-term voltage stability. The results on the IEEJ west 10-machine test system are shown in Figs. 1–3. Multiple BESSs are assumed to be installed at load buses. Figures 1 and 2 show comparison of generator rotor angles and bus voltages between the cases without and with control of the BESSs, respectively, under a large-capacity generator trip at G3. The comparison of control action of a BESS at bus 2 is shown in Fig. 3. As shown in the results, control of the BESSs by the proposed control scheme prevents the immediate system collapse. It enables the system operator to add transmission capacitor banks several seconds after the contingency. The active and reactive powers are injected during the period where each control action is effective for the improvement of the transient stability. Therefore, the control action is effective not only for the prevention of voltage collapse but also for the suppression of the rotor angle oscillation as seen from Fig. 1. The robustness of the proposed method is also checked by analyzing other generator outages. As shown in Table 1, the control of BESSs can improve the system stability under all the fault cases assumed here.

Table 1. Results of dynamic simulations under generator outages with and without control of BESSs

<table>
<thead>
<tr>
<th>Disconnected generator</th>
<th>Without BESS</th>
<th>With BESSs</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2</td>
<td>System collapse after 2.0 s</td>
<td>Stable</td>
</tr>
<tr>
<td>G3</td>
<td>System collapse after 1.5 s</td>
<td>Stable</td>
</tr>
<tr>
<td>G4</td>
<td>System collapse after 1.5 s</td>
<td>System collapse after 28.9 s</td>
</tr>
<tr>
<td>G5</td>
<td>System collapse after 1.5 s</td>
<td>Stable (voltages are sinking)</td>
</tr>
<tr>
<td>G6</td>
<td>System collapse after 2.0 s</td>
<td>Stable</td>
</tr>
<tr>
<td>G7</td>
<td>Diverging oscillation</td>
<td>Stable</td>
</tr>
<tr>
<td>G8</td>
<td>Diverging oscillation</td>
<td>Stable</td>
</tr>
<tr>
<td>G9</td>
<td>System collapse after 2.0 s</td>
<td>Stable</td>
</tr>
</tbody>
</table>
Estimation Methods of Short Circuit Current using Normal PMU Measurements and Field Testing

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Keywords: phasor measurement unit (PMU), analog simulator, reference phase, outlier filter, power system monitoring, short circuit current

1. Introduction

This paper proposes estimation methods of short circuit current using phasor measurement unit (PMU) measurements (phasors). The methods follow the basic notion of representing the source side of a power system by an equivalent circuit with a voltage behind back impedance, and employ a set of voltage and current phasors measured at substations during the normal variation of loads in their estimation. In order to improve the estimation accuracy of the proposed methods, the concept of using the changes between the consecutive phasors is introduced. Furthermore, to make the methods applicable to the real world system, a reference phasor concept to remove the effects of system wide frequency variations and a filtering process to filter out the outlier phasors, are proposed and implemented. The validity and effectiveness of the proposed methods were checked and confirmed using experiments and field tests.

2. Short Circuit Estimation Method

The main steps of the proposed short circuit estimation method are described as follows;

(S1) Measure voltage and current phasors during natural load variation using PMU.

(S2) Remove the system wide frequency variation from a set of coherent phasors using a system phasor which is measured at the upper power system.

(S3) Prepare a set of coherent phasors using a reference phasor which is selected from measured phasors at multiple measuring points while filtering out the outliers.

(S4) Estimate short circuit impedance employing a least square or a covariance approach (referred to below as dLS or dCV) on the set of coherent phasors in step S3. In this step, the difference between two consecutive measured phasors is used to estimate the system back impedance.

(S5) Estimate short circuit current using the estimated short circuit impedance and measured phasors.

3. Field Testing Results

The field testing of short circuit current estimation method was performed on the actual power system (Fig. 1) and the testing results for substation B are shown in Fig. 2 (24 hours). Each point in the plots represents the median (300 points for 5 seconds) of the estimation results of each data set. Figure 2 indicates the estimation results with use of the reference phasor and with filtering outliers. These plots show the effectiveness of the proposed method is ample clear and the estimation method suggested in this paper is quite applicable to the real world system as its accuracy is sufficient enough for user in the day-to-day power system planning and operation work.

![Field test system](image)  

Fig. 1. Field test system

![Estimation results](image)  

Fig. 2. Estimation results of dLS and dCV method (with correction/with filtering)
Control of Multistage SVRs using Voltage Sensor in Distribution System with Large Amount of Photovoltaic Generations

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Keywords: voltage control, SVR, photovoltaic generation system, PV, distribution system

1. Introduction

Recently, for reducing greenhouse gas emissions, Photovoltaic generation (PV) is being focused on in Japan. However, since an output of PV depends on weather conditions and climate condition may change rapidly or randomly, voltage in distribution system with many PVs will fluctuate. By contrast, Step Voltage Regulator (SVR), which is located on distribution line to keep voltage within adequate range, has time delay to operate against voltage change. Hence, SVR could not prevent voltage deviation from adequate range when a large amount of PVs are connected to distribution network. From this point of view, several novel equipment that control voltage flexibility such as Static Var compensator (SVC) and Battery are being noted lately. Although, this kind of new device is usually expensive and huge cost is necessary to introduce these devices into many distribution systems. It is necessary to manage voltage properly using established device to control voltage including Load Ratio control Transformer (LRT) and SVR over the next decade. In this paper, the authors focused on SVR and propose the effective control method of SVR to manage voltage fluctuated by PV.

2. Proposed Method

As mentioned above, SVR has time delay against voltage fluctuation caused by PV. For this reason, SVR could not manage voltage within adequate range in case that a large amount of PVs are connected to distribution system. Furthermore, SVR could cause voltage deviation due to its operation. Figure 1 shows voltage deviation caused by SVR. In Fig. 1, SVR changes its tap position frequently to keep voltage within adequate range fluctuated by PV. However, due to delay of SVR, voltage deviation is occurred after the operation. The authors call this phenomenon as Repeat Operation of SVR (ROS). ROS is the main cause of voltage deviation and it is necessary to restrain ROS to prevent voltage deviation. In this paper, the authors expand the dead band of SVR to prevent ROS.

In order to manage voltage using established device, it is assumed that SVR and restricted communication are available in this paper. Hence, SVR operates based on self-terminal information and limited information obtained from voltage sensor. SVR acquires voltage information from voltage sensor and calculates the relation between voltage and sending active power of SVR using least square method like Fig. 2. As a result, SVR can estimate voltage on distribution line and expand its dead band properly.

3. Case Study

Numerical simulation is performed to confirm the effectiveness of proposed method. In simulation, a large amount of PVs are connected to distribution system and voltage fluctuates largely and randomly. By using proposed method, the dead band of SVR can be expanded and ROS can be prevented like in Fig. 3. Figure 3 shows secondary voltage of SVR but voltage is unlikely to deviate from dead band.

Fig. 1. Voltage deviation caused by ROS

Fig. 2. Estimate voltage using sending active power

Fig. 3. Secondary voltage of SVR
An Application of Robust Power System Security to Future Electric Power System and its Evaluation under Uncertainties

——Examination of the N-1 Security——

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Keywords: evaluation index for the N-1 security, high-penetration of PV, smoothing effect of PV output power, storage battery

1. Abstract
In this paper, we explain how the N-1 security will be difficult to keep up and propose the countermeasure under uncertainties in the future. It is a fact that no effective methodologies exist to analyze the N-1 security quantitatively in relation to the PV penetration. Overcoming the present situation, we propose a solution for the subject by using the concept of Robust Power System Security as one evaluation index for quantitative analysis.

The effectiveness of the proposed methods is demonstrated through simulations using a three machines model system.

2. Robust Power System Security
Robust Power System Security (RS) is defined to evaluate the N-1 security under the circumstances where we can’t eliminate uncertainties at the stage of power system operation planning.

This concept is proposed to keep up the N-1 security by arranging some conditions under uncertainties. It consists of four regions and the positioning of each region is determined by the uncertainty condition. The main characteristic of this concept is that RDS, the key region for judging the security, shrinks and finally disappears in accordance with the increase of uncertainties or enlarges in accordance with power supply capacity.

3. Simulation
Based on the amount of insolation, we converted it to PV output power by using the effect of smoothing. By applying RS, we simulated Table 1 indicate the area of RDS.

The N-1 security will be affected by the rate of PV penetration and by installing the storage batteries.

Simulation was done based on the following process.

(1) The area of RDS was computed in accordance with the PV penetration rate and the installation of storage batteries.
(2) PV penetration rate was set from 0% to 30% by 5% unit.
(3) The storage batteries were installed up to completely compensate the PV penetration.

4. Conclusions
The followings are shown that (1) the relation between the PV penetration and the area of RDS is clearly trade-off, (2) the installation of storage batteries is effective to enhance the N-1 security and (3) the power system operators will be able to monitor the N-1 security condition directly by visualizing this concept.
An Insolation Forecasting Method by Partial Least Squares and a Confidence Interval Estimating Method

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Keywords: photovoltaic generation, insolation forecasting, confidence interval, partial least square

This paper presents an insolation forecasting method using numerical weather forecasting data and a confidence interval estimating method. It is planned to introduce photovoltaic (PV) system on a large scale into the power system in order to achieve the low carbon society. However, PV has a negative effect on the power system because the output of PV system depends on weather conditions such as clear fine, cloudy and rainy. Thus, it is necessary to forecast the insolation and evaluate the confidence interval in terms of power system operating and planning.

This paper proposes the insolation forecasting method by Partial Least Squares (PLS) and the confidence interval estimating method considering the forecasting error distributions. In recent years, it is popular to forecast insolation with numerical weather forecasting data as input variables. But it is difficult that the conventional method such as multiple regression equation (MRE) simulates multicollinearity among input variables. PLS handles multicollinear data among those in order to construct proper forecasting models. Also, the conventional method estimates discrete confidence intervals based on each weather condition. The proposed method can estimate continuous confidence intervals by linearly-approximating for representative values of some weather conditions extracted features from forecasting error distributions.

The effectiveness of the proposed method is demonstrated using numerical weather forecasting data and actual data observed by Japan Meteorological Agency. First, to demonstrate the model accuracy of the proposed insolation forecasting method, it is compared with MRE as one of the conventional method. Figure 1 shows the RMSE and MAE of each case. The proposed method by PLS forecasts the hourly insulations as accurately as MRE for large training data, but can forecast more accurately for little training data. Next, to demonstrate the effectiveness of the proposed confidence interval estimating method, Figure 2 shows the example of the insolation forecasting value and confidence interval. In conclusion, almost all of actual data are within the range of ±2σ confidence interval.
A GRBFN-EPSO-based Method for Predicting PV Generation Output

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Keywords: PV systems, forecasting, artificial neural network (ANN), overfitting, metaheuristics, clustering

In this paper, a new method is presented to predicting PV generation output. The method makes use of a hybrid intelligent system of GRBFN (Generalized Radial Basis Function Network) of artificial neural network (ANN) and EPSO (Evolutionary Particle Swarm Optimization) of metaheuristics. RBFN is one of ANNs that have good performance for nonlinear function approximation. GRBFN is an extension of RBFN in a sense that the center and the width of the radial basis functions are determined by the learning process although the conventional RBFN does not update them through the learning process. PSO is one of swarm intelligence techniques that find out solution candidates with multi-point search or a set of agents. However it has a problem to provide local solutions in case where the algorithm parameters are not appropriate. EPSO is used to evaluate better the weights between the hidden and the output layers because it is useful for solving nonlinear optimization problems from a standpoint of global optimization. In particular, EPSO has advantage to adjust the algorithm parameters with the evolutionary strategy to make the search process more diverse by the replication. In addition, DA (Deterministic Annealing) clustering that corresponds to a global clustering technique is employed to evaluate the initial solutions of the center and the width so that the performance of GRBFN is improved. Furthermore, the weight decay (WD) method is utilized at the learning processes to avoid the overfitting to learning data since the conventional methods are inclined to provide erroneous results due to the overfitting to complicated time series data of PV generation output. The proposed method was tested for real data with sampling time of one minute. The number of learning and test data are 2700 and 900, respectively. As the input variables, the following was employed:

\[ x_{1T} \]: PV generation output at time T
\[ x_{2T} \]: temperature of PV panel at time T
\[ x_{3T} \]: variance of \( x_{1T} \) for five minutes at time T
\[ x_{4T} \]: variance of \( x_{2T} \) for five minutes at time T
\[ x_{5T} \]: variance of \( x_{1T} \) for ten minutes at time T
\[ x_{6T} \]: variance of \( x_{2T} \) for ten minutes at time T
\[ x_{7T} \]: first order difference of time series \( \{x_{1T}\} \)
\[ x_{7T} = x_{1T} - x_{1T-1} \]
\[ x_{8T} \]: first order difference of time series \( \{x_{2T}\} \)
\[ x_{8T} = x_{2T} - x_{2T-1} \]
\[ x_{9T} \]: second order difference of time series \( \{x_{1T}\} \)
\[ x_{9T} = x_{1T} - 2x_{1T-1} + x_{1T-2} \]
\[ x_{10T} \]: second order difference of time series \( \{x_{2T}\} \)

\[ x_{10T} = x_{2T} - 2x_{2T-1} + x_{2T-2} \]

For convenience, the following methods are defined:

Method A: MLP
Method B: k-means-GRBFN (conventional GRBFN)
Method C: DA-GRBFN
Method D: DA-GRBFN-PSO
Method E: DA-GRBFN-EPSO
Method F: DA-GRBFN-WD
Method G: DA-GRBFN-WD-PSO
Method H: DA-GRBFN-WD-EPSO (proposed method)

It should be noted that k-means of the conventional clustering is used at Method B and WD stands for the weight decay method. Table 1 shows the results of each method, where the average and the maximum errors, and the standard deviation of errors are given. The values in parenthesis mean the normalized data for MLP results. It can be Method H is better than others in terms of the average, and the maximum errors and the standard deviation of errors. For example Method H succeeded in reducing 43\% average errors of MLP. The trend was applied to the maximum errors and the standard deviation of errors. Therefore, the simulation results have shown that the proposed method outperforms other methods.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Average Error (pu)</th>
<th>Maximum Error (pu)</th>
<th>Standard Deviation of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A MLP</td>
<td>0.0711</td>
<td>0.395</td>
<td>0.0577</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>B k-GRBFN</td>
<td>0.0628</td>
<td>0.286</td>
<td>0.0545</td>
</tr>
<tr>
<td></td>
<td>(0.8821)</td>
<td>(0.7230)</td>
<td>(0.9445)</td>
</tr>
<tr>
<td>C DA-GRBFN</td>
<td>0.0544</td>
<td>0.280</td>
<td>0.0511</td>
</tr>
<tr>
<td></td>
<td>(0.7644)</td>
<td>(0.7087)</td>
<td>(0.8861)</td>
</tr>
<tr>
<td>D DA-GRBFN-PSO</td>
<td>0.0508</td>
<td>0.256</td>
<td>0.0404</td>
</tr>
<tr>
<td></td>
<td>(0.7154)</td>
<td>(0.6488)</td>
<td>(0.6998)</td>
</tr>
<tr>
<td>E DA-GRBFN-EPSO</td>
<td>0.0485</td>
<td>0.249</td>
<td>0.0596</td>
</tr>
<tr>
<td></td>
<td>(0.6813)</td>
<td>(0.6299)</td>
<td>(0.6862)</td>
</tr>
<tr>
<td>F DA-GRBFN-WD</td>
<td>0.0497</td>
<td>0.276</td>
<td>0.0503</td>
</tr>
<tr>
<td></td>
<td>(0.6984)</td>
<td>(0.6990)</td>
<td>(0.8716)</td>
</tr>
<tr>
<td>G DA-GRBFN-PSO-WD</td>
<td>0.0465</td>
<td>0.233</td>
<td>0.0385</td>
</tr>
<tr>
<td></td>
<td>(0.6539)</td>
<td>(0.6396)</td>
<td>(0.6672)</td>
</tr>
<tr>
<td>H DA-GRBFN-EPSO-WD</td>
<td>0.0464</td>
<td>0.228</td>
<td>0.0384</td>
</tr>
</tbody>
</table>

Note) Values in parenthesis denote data normalized by that of Method A.
Experimental Study of Islanding-Prevention Method by Harmonic Injection Synchronized to Exciting Current Harmonics of Pole Transformer

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Keywords: pole transformer, islanding-prevention, synchronized injection of harmonic currents, harmonic voltage detection, photovoltaic system

1. Introduction

When distributed generators (DGs) such as photovoltaic (PV) systems spread widely in distribution systems, it is important to quickly prevent islanding operation caused by power system fault in order to ensure electrical safety. So far, the various islanding protection methods have been used practically. But, the conventional active systems tend to increase the detection time, because mutual interference occurs due to asynchronous state between active signals. On the other hand, the new active islanding detection system that is called “frequency-feedback system with step-injection”, also has possibility of extending the detection time in so called non-detection zone. So, we propose a novel islanding-prevention method by harmonic injection synchronized to exciting current harmonics of the pole transformer in order to avoid mutual interference between active signals.

2. Proposed Methods and Experimental Results

The conceptual block diagram of the proposed method is shown in Fig. 1. The power conditioning subsystem (PCS) can estimate the exciting current harmonics of the pole transformer by observing the line voltage of interconnection terminal, because the exciting current harmonics can be approximated as the functions of the fundamental wave voltage $V_1$. So, as the active signal for islanding-detection, PCS can inject the k-th harmonic current $I_gk$ synchronized to exciting current harmonics of the pole transformer into the distribution network. Where, $I_gk$ is a few percent of the rated current, considering the influence on power quality, and k is 3 or 5.

In order to detect islanding state reliably, PCS changes the active signal amplitude from $I_gk_1$ to $I_gk_2$ after detecting the k-th harmonic voltage change of more than $\Delta V_k$ (0.5%). As the result, since the harmonic voltage under the islanding state will change linearly from $V_k1$ to $V_k2$, PCS can estimate the harmonic components $\Delta Z_k$ of the load impedance in order to avoid miss operations. We confirmed the validity of the proposed detection algorithm by performing the islanding detection tests using the prototype inverters equipped with the proposed method and verified the fast detection of about 0.1 sec (shown in Fig. 2). Further, we have carried out the miss operation tests to clarify the occurrence reason and studied the countermeasure by improving the proposed detection algorithm.

3. Conclusions

We proved the feasibility of detecting the islanding-operation quickly and reliably, even if the islanding state is in non-detection zone. And this proposed method is applicable to the islanding detection system under clustered installation of PV systems because mutual interference does not occur due to synchronous state between active signals.
Development of Estimation Method of Spatial Average Irradiance Fluctuation Characteristics Considering Smoothing Effect around Observation Point

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Keywords: photovoltaic power generation system, irradiance, smoothing effect, spectrum analysis, low-pass filter

In order to estimate the total power output fluctuation of high-penetration photovoltaic power generation system (PVS) by using the data of limited number of points, the smoothing effect around individual observation point should be taken into account. Based on the so-called transfer hypothesis, this study proposed a low-pass filter to estimate the spatial average irradiance fluctuation characteristics by taking into account the smoothing effect around observation point.

By using the transfer hypothesis, first, we estimated the frequency characteristics of ensemble average irradiance fluctuation of 18 points in the Nobi plain. As a result, we confirmed the following two results; 1) the fluctuation characteristics of spatial average irradiance can be estimated by using the frequency characteristics of single point irradiance $S_A(f)$, and 2) the fluctuation cycle $T_x$ from which the random fluctuation factor begins to increase can be formulated when the radius of equivalent circle area is smaller than 30 km.

Based on the fact that the short-cycle fluctuation can be calculated by using the so-called $1/\sqrt{N}$ rule, we calculated the number of lattice point $M$ of a 5 km × 5 km mesh covering the area. Then we modified the transfer hypothesis by using the lattice point $M$, so that the frequency characteristics of spatial average irradiance fluctuation $S_{cenM}(f)$ considering the smoothing effect around observation point can be presented as a function of $S_A(f)$ and $T_x$. Based on $S_{cenM}(f)$ for various area sizes, we formulated $T_x$ as a function of the area size $S$ as shown in Fig. 1. $T_y$ in Fig. 1, which is calculated by using $T_x$ and the number of lattice points $M$, shows the cycle from which the fluctuations in the different points become independent each other.

$S_{cenM}(f)/S_A(f)$ corresponds to a low-pass filter gain $G(f)$ for calculating the frequency characteristics of spatial average irradiance fluctuation by taking into account the smoothing effect around observation point. Besides, $T_x$, $T_y$, and $M$ are formulated as a function of area size. Therefore, we proposed the calculation procedures regarding $G(f)$ for a given area size. Figure 2 shows the calculated $G(f)$ for various area sizes.

Finally, we calculated $G(f) \cdot S_A(f)$ as shown in Fig. 3. $G(f) \cdot S_A(f)$ is almost the same as the frequency characteristics $S_{cenM}(f)$ of the spatial average irradiance fluctuation calculated by using the multi-points observation data. Consequently, the spatial average fluctuation characteristics of various area sizes within the radius of 20 km can be estimated successfully by applying the dedicated low-pass filter according to the area size.

![Fig. 2. LPF gain for smoothing effect around observation point](image)

![Fig. 3. Frequency characteristics of spatial average irradiance fluctuation estimated with LPF for smoothing effect around observation point](image)
New Method of Calculating Temperature Distribution on Solid Substances

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Keywords: temperature distribution, thermal conduction, thermal resistance, time constant, reflection ratio

1. Introduction

There was a useful and classical equation for the trend of temperature which was an original equation of an equation applied to this paper, and used thermal resistance corresponding to electric resistance inverse proportional to square and heat source regarded as fixed one. As the result, this equation was not developed for the calculation of temperature distribution. And the old mindset on a classical equation caused unreasonable. Thus, a heat conduction equation and the finite element method became widely used for the calculation of a temperature distribution. However, if a heat conduction equation was applied to calculate a temperature distribution, its result was not agreed with measured one. The method of calculating temperature distribution using the finite element method was a tentative technique due to simulating a natural phenomenon through repeating process with the computer. This proposed method of calculating temperature distribution used the new concepts of thermal resistance proportional to the volume and moving heat source, based on a classical equation, and as a result, existing unreasonable was dispelled perfectly.

2. Calculation of Temperature Distribution

We studied a sodium-sulfur (NaS) battery. The temperature difference $\theta$ was distributed proportionally to $r^2$, where $r$ was the distance from the center of the battery. This $\theta$ distribution was simulated by using thermal resistance $\Delta R = \psi \Delta V$, where $\psi$ and $V$ were a factor and volume. The differential equation of time constant $\tau$ was calculated by numerical analysis, but its solution included an unknown value of the total number of layers $m$, which was solved by assuming as $m=1$. The heat source $\Delta P_w$ was located in the $n$th layer, and the heat source $\Delta P_{w'}$ heated its layer, resulting in the $P_{flow}$ of moving $P$ passing through its layer. $\Delta P_{w'}$ was not equal to $\Delta P_{w}$. The concept of $P_{flow}$ was needed to represent the heating of layers that did not have a heat source. And $P = P'w$ was established, because $P_{flow}$ was consumed completely by heating the layers and did not flow to the outside of this heating system, thus differing from the thermal current $W = \Delta \theta/\Delta R$. Time constant $\tau$ was unitary throughout the substance and the temperature difference $\Delta \theta$ was divided evenly, so $\Delta \theta$ equation had to be in the same form as the $\tau$ equation to allow the substitution $\rho'$ for $\rho$ in the $\tau$ equation. Also, $\rho'$ was distributed evenly due to $\rho$ being distributed evenly, where $\rho'$ was the heat source $P'$ per volume, and the volumetric specific heat $\rho$ was thermal capacity $C$ per volume and a constant. If the $\theta$ and $W$ distributions were calculated on a composite substance constructed with many layers, $\psi$ proportional to $P_w$ was established by changing $\psi_e$ due to the unitary existence of $\tau$, where $\psi_e$ was a constant $\psi$. Equations for calculations of these distributions included terms of $n'/m$ with $n'$ using $m$, so that $m$ was allowed to take any values to lead to the assumed $m=1$. Also, these distributions differed by the method of selecting $m=1$, as a result, the smallest value of $W$ was allowed to flow, because $W$ was a flow depending on $W \propto \sqrt{m}$, and $\psi_e$ changed by compounding was not smaller than $\psi$, which was the original value for each layer, leading to the largest $\tau$.

3. Thermal Conduction in Wave

3.1 Reflection Ratio of $W$ and $P_{flow}$

If $W$ flowed from $\psi_1$ to $\psi_2$, its reflection ratio $\lambda_w = (\psi_1 - \psi_2)/(\psi_1 + \psi_2)$ was represented. Similarly to $\lambda_w$, the reflection ratio of $P_{flow}$ was $\lambda_w = (c_1 \rho_1 - c_2 \rho_2)/(c_1 \rho_1 + c_2 \rho_2)$. The numerals of $\psi$, and $\rho$ represented their layers of the composite substance. For $\psi_1 < \psi_2$, reflection waves $\psi'$ in phase inversion due to $\lambda_w < 0$ and transmitted waves $\psi''$ occurred on the contact surface of $\psi_2$, resulting in that, $W_{after}$ after reflection being smaller than the input waves $W$ was equal to $W''$. $W$ occurred not only on the boundary but also throughout the whole substance, resulting from diffraction of waves. That is, an increased temperature corresponding to smaller $W_{after}$ caused by $W'$ on the boundary was continuously spread throughout the whole substance, because it meant a higher potential energy level causing the spread of waves. As a result of this spread, even if the reflection of $W$ occurred, $W_{after}$ caused the existence of $\tau$ by the shifting of the position of each divided layer to establish the $W_{after} \propto \sqrt{n}$ curve. Also, $P_{flow-after}$ after reflection was smaller than the input $P_{flow}$ by this reflection because thermal energy was transmitted by the combination of $W$ and $P_{flow}$, and it heated a smaller number of divided layers than at no reflection, thus making the heated system separate. For reflection with $\lambda_w > 0$ under $\psi_1 > \psi_2$, $W'$ in phase cause $W_{after}$ to be larger than $W$. Also, $P_{flow-after}$ was larger than the input $P_{flow}$, becoming too large to heat divided layers in $\psi_2$ and flowing to the outside of this heated system. This was an unreasonable result, because $P_{flow-after}$ had to be consumed perfectly within this system. Thus $W_{after} = W$ and $P_{flow-after} = P_{flow}$ flowed through the boundary just as at no reflection. $\lambda_w$ was equal to $\lambda_w$ because $\psi$ was proportional to $\rho$.

3.2 Method for Conduction in Waves

Electrostatic induction and electromagnetic induction did not accept the reflection theory. Thus, thermal energy was transmitted from ions at a higher potential energy level to other ions at a lower potential energy level through coupling by electromagnetic waves, because thermal energy emitted in every direction by an ion was compensated for by receiving thermal energy emitted from neighboring ions. Thermal energy was transmitted by the repeated process of sending and receiving between ions. Thermal energy in electromagnetic waves transmitted in the spaces between the ions in the substance. The reason was that, ions taking on a positive or negative electric charge were vibrated by receiving thermal energy and then they emitted electromagnetic waves like airwaves.

4. Conclusion

(1) If the substance was a composition, temperature distribution was reasonably and perfectly calculated by using thermal resistance proportional to volume and the numerical analysis.

(2) The thermal current flowed proportionally to the square root of the number of divided layers, which caused the thermal resistance to change and resulted in selection of the largest time constant.

(3) When the reflection ratios of the thermal energy were calculated and applied, no problem occurred.
Application of the Type-C Constrained Interpolation Profile Method to Lightning Electromagnetic Field Analyses

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Keywords: constrained interpolation profile method, electromagnetic field, finite-difference time-domain method, lightning

In this paper, the type-C constrained interpolation profile (CIP) method has been applied to analyzing lightning electromagnetic fields. The CIP method is one of the finite-difference methods. Differently from the finite-difference time-domain (FDTD) method, however, it considers not only electric- and magnetic-field values at each discretized points in a working space but also their spatial-derivative values there. Therefore, in principle, it can compute fields accurately even when a relatively coarse grid and a relatively large time increment are used.

Figure 1 shows CIP-, FDTD-, and theoretically-calculated waveforms of vertical electric field on flat perfectly conducting ground surface at horizontal distances 3 and 6 km from a simulated lightning channel. The lightning channel is represented by an engineering transmission-line (TL) model, and along it a subsequent lightning return-stroke current whose magnitude is 10 kA and risetime is 1 µs propagates upward at the speed of light. The CIP and FDTD calculations are performed in a three-dimensional working space of 20 km × 20 km × 9 km, which is divided uniformly into cubic cells of 100 m × 100 m × 100 m. Time increments in the CIP and FDTD calculations are set to 190 ns and 173 ns, respectively.

Figure 2 shows CIP-, FDTD-, and theoretically-calculated waveforms of electric field on flat perfectly conducting ground surface at horizontal distance 300 m from the TL-represented lightning channel. Along the channel, a Gaussian-pulse current whose magnitude is 1 kA and half-peak width is 1 µs propagates upward at the speed of light. The CIP and FDTD calculations are performed in a three-dimensional working space of 1.4 km × 1.4 km × 0.7 km, which is divided nonuniformly into rectangular cells of 7 m × 7 m × 10 m in the vicinity of the channel and 60 m × 60 m × 10 m in the rest of the space. Time increments in the CIP and FDTD calculations are set to 19 ns and 8.1 ns, respectively.

It appears from Figs. 1 and 2 that CIP-calculated waveforms in both uniform and nonuniform grids agree well with the corresponding theoretically calculated ones, while the FDTD-calculated waveforms do not. This indicates that the CIP method is effective in calculating high-frequency electromagnetic fields in a relatively coarse grid and in a nonuniform grid in which the ratio in sizes of large and small cells is relatively high.

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Fig. 1. CIP-, FDTD-, and theoretically-calculated waveforms of vertical electric field on flat perfectly conducting ground surface at horizontal distances 3 and 6 km from a simulated lightning channel. Along the lightning channel, a subsequent lightning return-stroke current of magnitude 10 kA and risetime 1 µs propagates upward at the speed of light. Both the CIP and FDTD working spaces are divided uniformly into cubic cells of 100 m × 100 m × 100 m.

Fig. 2. CIP-, FDTD-, and theoretically-calculated waveforms of electric field on flat perfectly conducting ground surface at horizontal distance 30 m from the simulated lightning channel. Along the lightning channel, a Gaussian-pulse current whose magnitude is 1 kA and half-peak width is 1 µs propagates upward at the speed of light. Both the CIP and FDTD working spaces are divided nonuniformly into rectangular cells of 7 m × 7 m × 10 m in the vicinity of the channel and 60 m × 60 m × 10 m in the rest of the space.
Identification of Metallic Particle Defect in GIS Based on Partial Discharge Mechanism

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Keywords: GIS, partial discharge, metallic particle defect, SF₆ gas, insulation diagnosis

1. Introduction
A metallic particle defect seriously degrades an insulation performance in gas insulated switchgear (GIS). Therefore, the estimation of property and risk of the metallic particle is important to maintain the reliability of GIS. In this paper, based on a partial discharge (PD) mechanism, we suggest the progressive method to indentify the shape of metallic particle defect from some physically characteristic PD properties.

2. Experimental Setup
The electrode setup simulating the metallic particle defect in GIS is set in a chamber filled with 0.2 MPa SF₆ gas. The metallic particle made of stainless steel is put on parallel electrode system with 30 mm gap. The diameter of particle \( \phi \) is 0.6–1.0 mm, the particle length \( \ell \) is 13–19 mm, and the gap length \( g \) is 11–17 mm. The tip shape of metallic particle is hemispherical. We applied the ac voltage to this electrode setup, and observed PD current and light emission image by an oscilloscope and high-speed video camera, respectively.

3. Estimation of Maximum Electric Field on the Metallic Particle
PD inception voltage (PDIV) will be very useful for the identification of the shape of metallic particle. However, under actual operating condition of GIS, the applied voltage to the metallic particle is constant to the operating voltage and is not variable. In other words, we need to construct the method for the estimation of PDIV from some PD properties under various voltage levels.

We measured the instantaneous PD inception voltage for each polarity with its distribution for various applied voltage. And, we found that the minimum instantaneous voltage of positive PD extinction and the average instantaneous voltage of negative PD inception agrees with the positive and negative PDIVs, respectively. The former is because the minimum instantaneous voltage of positive PD extinction represents the PD voltage without corona relaxation probabilistically. The latter is because the negative PD is based on Torricelli pulse mechanism.

Inceptive PD occurs when the maximum electric field of metallic particle exceeds the PD inception electric field strength. Therefore, the estimated PDIV will correspond to the maximum electric field strength, which is decided by the shape of metallic particle.

4. Identification of the Shape of Metallic Particle
Assuming that the metallic particle exists on the conductor or the tank in GIS, the gap length between the conductor and the tank, corresponding to the gap length of parallel electrodes in our electrode system, is unique. In this case, the maximum electric field \( E_{\text{max}} \) normalized by applied voltage gives the combination of diameter and length of the metallic particle. In addition, we found that the negative PD pulse number strongly depends upon diameter and length of the metallic particle, and this relationship is opposite to that of the maximum electric field. So, we can estimate diameter and length of the metallic particle from negative PD pulse number and normalized electric field \( E_{\text{max}} \) as shown in Fig. 1.

In Fig. 2, we summarize the proposed method of the identification of the shape of the metallic particle defect.
Gas tungsten arc welding (GTAW) is a high quality and welding which is one of the GTAW has been used as a high quality joining case. Because the inert gas is used as a shielding gas, the arc is not contaminated by surrounding gas. Therefore, this joining process is very clean to join the materials. However, the weld defects are occurred, such as lack of penetration and overlap because of low heat transfer to the anode. Some researchers have researched the weld defect. However, the view point of radiation loss has not been researched. Especially, the TIG welding is contaminated with metal vapor from anode material. In this case, the heat transfer to anode is affected by radiation emitted from metal vapor, because of the net emission coefficient emitted from metal vapor is very high. In this paper, the radiation loss of gas tungsten arc welding affected by current increment is elucidated. When the current increases, the heat transfer to the anode increases, and then the contamination ratio of metal vapor increases. When the contamination ratio of metal vapor increases, the arc temperature changes, and then the heat transfer to the anode changes. Therefore, that energy balance of heat transfer to anode and radiation loss should be considered in the TIG welding. As a result, the radiation loss increases with increasing the current. When the metal contamination ratio and its distribution change, the radiation loss changes. In addition, the current increase to 300 A, the radiation loss is saturated. Therefore, the radiation loss is obtained by the complex condition between the current, temperature, metal contamination distribution. And the heat transfer to the anode is affected by this radiation loss.
Control of Spectrum for Improvement of Color Rendering Spectrum Affected by Scandium Vapor Mixed with Argon Arc

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Keywords: arc lamp, metal vapor, scandium, radiation, large-scale lighting

The arc lighting to obtain the environment to evacuate, save the life, keep the safety and be comfortable are focus on. The lack of radiation intensity and color rendering spectrum is problem because of inappropriate energy balance. This paper elucidates the improvement of color rendering spectrum with control of spectrum affected by scandium vapor mixed with argon arc. The temperature with keeping the color rendering increases with increasing the contamination ratio of metal vapor because of $x$, $y$ chromaticity diagram. In addition, the volume increment of low temperature region; periphery of the arc is effective for the color rendering. The radiation power increases with increasing the metal vapor even if the temperature is low. Especially, the maximum radiation power with metal vapor is 10 times as high as that without one. The radiation power increases with keeping the color rendering and the radiation power increases when the appropriate temperature is chosen under consideration of $x$, $y$ chromaticity diagram. The improvement of color rendering spectrum is expected by the control of balance between the broad continuous spectrum of argon and line spectrum of scandium with temperature distribution derived from current increment and/or arc pinch.