An Actual Design of AC Filter for Static Var Compensator and Verification Results from the Field Test

Yuji Tamura Member (Toshiba Corporation)
Shinji Takasaki Member (Kyusyu Electric Power Co., Inc.)
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

The conventional AC filter design method for SVC requires many iterative calculations of the harmonic voltages and currents until the calculation results become within the regulation levels by changing filter parameters based on the experience. In this respect, a new improved design method is proposed, which enables efficient evaluation on the complex impedance plane to confirm as to whether the proposed filter impedance is in the permissible range.

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. Since AC system impedance $Z_{sn}$ are represented by envelopes, the permissible $Z_{fn}$ to obtain voltage and current distortions within the regulation levels can be calculated and determined as envelopes on complex planes. Actual design procedure by using this new method is proposed in this paper.

3. Actual Design Reference

This method was applied to an actual project, Okuura SVC of Kyusyu Electric Power Co., Inc. Figures 2(a) and (b) are actual evaluation results using the new method on the permissible ranges of the filter impedance at 5th harmonic order. It was confirmed that the impedance of the applied AC filter configuration is within the permissible range.

4. Verification by the Measurement Results at the Field Test

Figures 3(a) and (b) are the comparison between field test results and calculation results at 5th harmonic order. The calculation results with consideration of influence of background harmonics are almost consistence with the field test results.

5. Conclusion

A new AC filter design procedure with a new method is proposed and was applied to an actual project. The calculation results and the filed measurement results are almost consistent with each other, thus the validity of the new design method is verified on its accuracy and effectiveness.
A Two-Stage Stochastic Mixed-Integer Programming Approach to the Smart House Scheduling Problem

Shunsuke Ozoe Non-member (Kyoto University, ozoe@amp.i.kyoto-u.ac.jp)
Yoichi Tanaka Member (Toho Gas Co., Ltd., ytanaka@tohogas.co.jp)
Masao Fukushima Non-member (Kyoto University, fuku@i.kyoto-u.ac.jp)

Keywords: smart house, optimal scheduling, stochastic programming, recourse cost

A “Smart House” is a highly energy-optimized house equipped with photovoltaic systems (PV systems), electric battery systems, fuel cell cogeneration systems (FC systems), electric vehicles (EVs) and so on. Smart houses are attracting much attention recently thanks to their enhanced ability to save energy by making full use of renewable energy and by achieving power grid stability despite an increased power draw for installed PV systems.

In this paper, we formulate the smart house scheduling problem, where the total operation cost of a smart house during a certain period is minimized under the constraints on electrical equipments, energy balances and electricity trading. Moreover, we propose a mathematical model based on the assumption that solar power and demands for electricity and heat are uncertain. We formulate this model as a mixed-integer programming problem by applying two-stage stochastic programming. The smart house considered in this paper is shown in Fig. 1.

Two-stage stochastic programming is an optimization method which adds penalties to the objective function when the constraints which contain random variables are not satisfied. For example, the constraints on power balance contain solar power \( s(h) \) and electricity demand \( E(h) \). Since we must make our schedule before we know the realizations of \( s(h) \) and \( E(h) \), the power balance constraints do not always hold when the realizations become known. In such cases, we add recourse variables \( e^-(h) \) and \( e^+(h) \) to the constraints in order to keep them holding. Furthermore, we add the term of the expectation \( \mathbb{E}(C^-e^-(h) + C^+e^+(h)) \) to the objective function, where \( C^- \) and \( C^+ \) are the unit costs of \( e^-(h) \) and \( e^+(h) \), respectively. Similarly, the constraints on heat demand and the constraints associated with solar power and electricity sale contain random variables \( \Theta(h) \) and \( s(h) \), respectively. For the same reason mentioned above, we add \( \Theta^-(h) \), \( \Theta^+(h) \) and \( \zeta(h) \) to the constraints. In addition, we impose penalties \( \mathbb{E}(C^-\Theta^-h + C^+\Theta^+(h) + C_\zeta h(h)) \) to the objective function, where \( C^- \), \( C^+ \) and \( C_\zeta \) are the unit costs of \( \Theta^-(h) \), \( \Theta^+(h) \) and \( \zeta(h) \), respectively. In addition, we assume that \( s(h) \), \( E(h) \) and \( \Theta(h) \) have finite sample spaces, then the smart house scheduling problem can be formulated as a mixed integer programming problem.

We compare the proposed method and a conventional method which is based on the assumption that \( s(h) \), \( E(h) \) and \( \Theta(h) \) are deterministically given. We compute the running costs by using 15 week real data on soler power and demands for electricity and heat. As shown in Fig. 2, the proposed method gives lower total operation costs for all the values of the unit profit of electricity sale \( C_6 \). The cost reduction rate of the proposed method is 33.1% at the current \( C_6 = 0.049 \) [yen/Wh].

![Fig. 1. Mathematical model of smart house](image1)

![Fig. 2. Comparison of the proposed method and the conventional method](image2)
A Voltage Control Method of Static Var Compensator for the Remote System Interconnected by Long Distance AC Cables

Yuji Tamura Member (Toshiba Corporation)
Shinji Takasaki Member (Kyusyu Electric Power Co., Inc.)
Yasuyuki Miyazaki Member (Toshiba Corporation)
Hideo Takeda Member (Toshiba Corporation)
Shoichi Irokawa Senior Member (Toshiba Corporation)
Kikuo Takagi Member (Toshiba Corporation)
Naoto Nagaoka Member (Doshisha University)

Keywords: long distance AC cable transmission, remote island AC interconnection, voltage control, SVC

1. Introduction

The voltage variation in the remote system is large when the system is connected by long distance AC cables due to the cable capacitance. In Japan, the longest 54 km 66 kV AC submarine cable interconnection between Kyushyu mainland and Goto-islands was commissioned in 2005. It is requested to mitigate voltage variation caused by switching off and on of one circuit of AC cables out of two circuits when a fault occurs. Since the conventional voltage control methods such as transformer tap changer or shunt capacitor and reactor banks are not sufficient because of their slow response time, therefore an SVC (Static Var Compensator) was installed in Goto-islands.

2. Voltage Control Method of SVC

In such application, SVC automatic voltage regulator control method should be developed not to override the existing voltage control system. Furthermore the SVC standby capacity should be preserved as much as possible in preparation for sudden voltage variations due to the AC cable switching following by a fault. To meet such requirements the SVC V-I characteristics with dead band and two stage inclinations as summarized in Fig. 1 was proposed. Reference voltage is controlled by following the system voltage with time constant delay of several hundreds seconds thus the SVC output returns to a preset stable standby SVC output of $I_{ref}$ after the fault.

3. Verification of the Voltage Control Method

The proposed control method was verified by using effective-value-based simulation model. Figure 2(a) and (b) are simulation results when one of the two AC cables is switched off and on. The SVC with the proposed control method mitigates the voltage variations from $-5.47\%$ to $+4.62\%$ by SVC while the variation is $-19.65\%$ to $+7.98\%$ if there is no SVC as summarized in Fig. 2(c). SVC output returned to zero after mitigating voltage increase in around several hundreds seconds to preserve SVC standby capability with enhancing operation of the existing voltage control facilities.

The same AC cable switching operation was implemented at the field test with SVC before commissioning of the SVC in 2007. The results were consistent with the simulation results thus the validity of the simulation model was verified.

4. Conclusion

SVC with the proposed control method is effective to control voltage in the remote system interconnected by long AC cables.

Fig. 1. V-I characteristics of SVC

(a) Without SVC
(b) With SVC

(c) Summary of voltage variations

Fig. 2. Calculation results of voltage variations in Goto-islands when AC cable switched off and on
Identification of Insulation Defect by Sequential Measurement of Partial Discharge in GIS

Masanobu Yoshida Member (Nagoya University, Chubu Electric Power Co.)
Keisuke Suzuki Student Member (Nagoya University)
Hiroki Kojima Member (Nagoya University)
Naoki Hayakawa Member (Nagoya University)
Masahiro Hanai Member (Nagoya University)
Hitoshi Okubo Member (Nagoya University)

Keywords: GIS, partial discharge, space charge, surface charge

1. Introduction
Metallic particles contaminated in gas insulated switchgears (GIS) can be a cause to induce partial discharge (PD) and decrease dielectric strength. To maintain the insulation reliability of GIS, PD monitoring techniques have been utilized. The risk of metallic particles depends on its adhesion location, and the metallic particle fixed on solid insulator such as epoxy spacer is regarded as one of the most serious defects. Therefore, it is strongly required to diagnose the insulation condition of GIS in service under ac high voltage application.

The authors studied the identification technique for the particle location based on PD measurement, because it is one of the important elements for the risk assessment.

2. Experimental Setup
Two kinds of defect (particle in gas or particle on epoxy spacer) were simulated in a model GIS. PDs were generated at the particle tip by applying ac high voltage in SF₆ gas. PD current pulses were measured by the ultra high speed PD measurement system named “Partial Discharge Current Pulse Waveform Analysis (PD-CPWA)”. PD-CPWA is able to obtain precise waveforms of PD current pulses in nano-second time resolution and series of pulses from PD initiation to breakdown. In addition, the surface potential of epoxy spacer and the PD light emission image were observed.

3. Experimental Results and Discussions
The temporal transition of the PD pulse number, PRPD pattern and PL/DA pattern were analyzed by using PD-CPWA data as shown in Figs. 1 and 2. In the case of particle on spacer, temporal change of PD characteristics (pulse number and so on) were observed. In addition, steady PD occurrence was also observed in the case of particle in gas. We concluded that these changes of PD characteristics were based on the accumulation of the surface charge on epoxy spacer in the case of particle on spacer. Then, the temporal change of PD characteristics is important information of the charge accumulation on epoxy spacer around the particles. In other words, we can discriminate the particle condition whether it exists on the epoxy spacer or not by analyzing the temporal change of PD characteristics. We proposed the continuous PD monitoring to analyze the temporal change of PD characteristics for the reliable PD diagnosis.
Forecast Method of Solar Irradiance with Just-In-Time Modeling

Takanobu Suzuki Member (Waseda University, st.road-up77@toki.waseda.jp)
Yusuke Goto Student Member (Waseda University, y-gotou.1988@ruri.waseda.jp)
Takahiro Terazono Student Member (Waseda University, 20011101terazono@akane.waseda.jp)
Shinji Wakao Member (Waseda University, wakao@waseda.jp)
Takashi Oozeki Member (National Institute of Advanced Industrial Science and Technology, takashi.oozeki@aist.go.jp)

Keywords: solar irradiance forecast, black-box modeling, Just-In-Time modeling, GPV data, solar irradiance over wide area

1. Introduction
PV power output mainly depends on the solar irradiance which is affected by various meteorological factors. So, it is required to predict solar irradiance in the future for the efficient operation of PV systems. In this paper, we develop a novel approach for solar irradiance forecast, in which we introduce the combination of black-box model (JIT Modeling) with the physical model (GPV data). We investigate the predictive accuracy of solar irradiance over wide controlled-area of each electric power company by utilizing the measured data on the 44 observation points throughout Japan offered by JMA and the 64 points around Kanto area. Finally, we propose the application forecast method of solar irradiance to electric power company, re-ratio can be reduced to 0.3–0.4. On the other hands, focusing on the point which is diverse, we can estimate the smoothing effect in the controlled-area corresponds to the half of prediction error compared with the case of single point prediction.

2. Algorithm of Solar Irradiance Forecast
Prediction method mainly depends on JIT Modeling. JIT Modeling is one of the black-box modeling based on the database. First, in the method, we prepare the database of the input-output relationship obtained from objective system. Second, we select the past data in the database whose parameters are similar to the targeted conditions to be predicted. Then, we estimate the system output by means of the selected data. In this paper, the input is MSM-GPV (default time=0) and the output is solar irradiance. MSM-GPV is numerical weather forecasting based on the thermodynamics and hydrodynamics calculation, such as atmosphere, temperature and cloudiness at every 5 kilometer grid point. As the one of the advantage of JIT Modeling, it is possible to treat multidimensional input data. However, if there are irrelevant inputs which have a low correlation with solar irradiance, they have negative effects on estimate accuracy of JIT Modeling. So, we extract correlative inputs by employing round-robin based on AIC statistics value and input-weighted of input by partial regression coefficient.

3. Main Result
(1) Solar irradiance prediction at single point Figure 1 shows the hourly prediction result in Tokyo. The prediction error RMSE is 0.176 [kWh/m²] at 12. It is revealed that cloudiness have high correlation with solar irradiance among MSM-GPV.

(2) Solar irradiance prediction over wide area We carry out the hourly solar irradiance forecast over wide area by summing up the predictive value of each point. The investigate area is 44 points throughout Japan and 64 points around Kanto area. We research the relationships among number of points (nop) and size of area (a_dist) as in expression (1), and prediction accuracy (re_ratio) as in expression (2). Nop is the number of randomly selected points in the investigated area, a_dist is average distance between 2 points out of the randomly selected points, and re_ratio is the relative error of prediction over wide area versus that on single point, respectively. Figure 2 shows the relationships among nop, a_dist and re_ratio in the case of hourly prediction over wide area. From the result, re_ratio can be reduced to 0.3–0.4. On the other hands, focusing on the case of a_dist range of 70–250 [km], i.e., the controlled-area of electric power company, re_ratio is saturated around 0.4–0.6. So, we can estimate the smoothing effect in the controlled-area corresponds to the half of prediction error compared with the case of single point prediction.

\[
a_{\text{dist}} = \frac{1}{A} \sum_{i=1}^{A} \sum_{j=1}^{i} d_{ij} \quad [\text{km}] \quad (1)
\]

\[
\text{re}_{\text{ratio}} = \frac{PE_{\text{total}}}{\frac{1}{A} \sum_{i=1}^{A} PE_{i}} \quad (2)
\]

Where: \( A \) is the number of points, \( d_{ij} \) is the distance between \( i^{th} \) point and \( j^{th} \) point, \( PE_{\text{total}} \) is prediction error over wide area, \( PE_{i} \) is prediction error at \( i^{th} \) point, respectively.