INTELLIGENT PROTECTION SYSTEM FOR SMART GRID

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ABSTRACT

The authors propose a concept for protection relay systems for operation within a Smart Grid and describe the results of a prototype development. This paper introduces each of the system characteristics that should be considered for protection operation within Smart Grid, and the evaluation methods that were applied under both normal and faulted conditions. The results of a field trial in the 66kV system operated by Shikoku Electric Power CO., INC indicate that the proposed system has the capability of evaluating power system characteristics in detail on a real-time basis and contributing toward supervision, coordination check and optimisation of setting values. Moreover, it has been proven that an agent system can be applied under practical conditions.

CONCEPTS OF PROTECTION RELAY SYSTEM FOR SMART GRID

In recent years, trends toward electricity liberalisation and the increased importance of environmental issues have led to diversification of power system configurations and characteristics, through the installation of distributed power sources based on photovoltaic and wind power generation technologies. Under these circumstances, there is concern regarding the effect on the reliability of power networks with respect to aspects such as overload, frequency variation, and harmonic content. Against this background, there has been increased focus on the concept of Smart Grid, which has the capability of collecting wide-area power system information on a real-time basis from intelligent power grids using Information and Communication Technology (ICT).

Although the setting values of protection relays in power systems are currently decided based on the power system conditions assumed in advance, instances of unnecessary or missed operations might occur in future due to unexpected power system phenomena or operations. In this paper, the concepts of protection relay systems for Smart Grid are suggested as follows:

(a) Protection relay operation suitable for actual power system characteristics

Evaluation of relay setting values can be performed by means of supervising the operating and non-operating margins of each relay characteristic quantitatively and detecting variations of power system characteristics precisely on a real-time basis utilising analogue input data under normal and faulted conditions. This approach leads to benefits such as modifications to the setting values suitable for actual power system characteristics, coordination check for each protection relay element based on wide-area data, and critical point detection for system operations.

(b) Intelligent collection of device data

Each protection relay device is provided with the aforementioned function and carries out first-stage evaluation, before transmitting only the data necessary for analysis. In addition, an agent system is applied, which has the capability of collecting protection relay data intelligently and evaluating data from wide-area protection relays without having any effect on protection functions. This approach can realise updating of applications executed in protection relays without needing to take equipment out of service.

EVALUATION OF POWER SYSTEM CHARACTERISTICS AND RELAY SETTING VALUES

Based on the concepts mentioned above, the authors have designed and developed a prototype protection relay system. Firstly, each of the system characteristics that should be considered under Smart Grid and their respective evaluation criteria will be described. Next, the evaluation methods for both normal and faulted conditions based on examples of system impedances will be introduced.

System characteristics and respective evaluation criteria

A key factor in the prototype system is the question of how to capture changes in system characteristics in terms of evaluating the margin and the coordination of relay settings relative to the change in system characteristics. Rather than detecting abnormal conditions directly from the change in system characteristics, the prototype system uses evaluation criteria related to each system characteristic within each protection relay unit, as shown in Table 1. On detection of abnormal conditions, the related disturbance record data can be sent to the information management servers, and a detailed evaluation can be executed with locus data on the characteristic plane being calculated in the server, and finally the results can be displayed on the client PC. The final confirmation of a change of system characteristics and modification of setting values would be made by operators of this system. In some cases the change in system characteristics can be captured based only on the power system quantities under normal conditions, and in other cases only under fault conditions. The power system quantities required for the evaluation differ for the various system characteristics, as shown in Table 1.

No	System characteristics	Evaluation criteria	Nor-mal	Fault
1	Three-phase unbalance	Zero-sequence currents	巣	
2	Unbalance between 1L and 2L	Segregated transverse diff. current	巣	巣
3	Zero sequence circulating current	Zero-sequence transverse diff. current	巣	巣
4	Load conditions	Load / Fault impedance	巣	巣
5	Charging current	Diff. current	巣	巣
6	The effect of branch load or source	Diff. current	巣	巣
7	Transient overreach	Fault impedance		巣
8	Overreach of lead phase	Fault impedance		巣
9	CT saturation	Diff. current		巣

Table 1: System characteristics and evaluation criteria

Evaluation method for normal conditions

Under normal conditions, the evaluation is executed periodically utilising power system quantities, which are routinely measured within each protection relay unit. As an example, an evaluation method based on the system impedance will be introduced here. Under normal conditions, an evaluation focused on the load impedance would be executed so as to confirm the margin to non-operation between load impedance and the mho characteristic (or quadrilateral characteristic) of a distance relay element. Hence, as shown in Figure 1, an abnormal condition could be detected by means of whether or not the load impedance locus enters the indicated region, which has a judgement threshold K_D * Z∠θ, providing sufficient margin to the setting of the mho characteristic. Storage of a disturbance record would be triggered by this evaluation result, and this recorded data would be sent to the information management servers simultaneously.

Evaluation method for fault conditions

Under fault conditions, each protection relay unit stores voltage and current input data as disturbance records triggered by the operations of UV/OC relay elements, and the evaluation is executed utilising these data. As an example, an evaluation method based on the fault impedance will be introduced here. Under fault conditions, the evaluation focused on impedance would be executed so as to confirm: (1) the margin to operation or non-operation between fault impedance and the mho characteristic (or a quadrilateral characteristic) of a distance relay element; (2) the risk of transient overreach, and; (3) the risk of overreach of the leading phase. Therefore, as shown in Figure 1, judgment would be made by means of whether or not the fault impedance locus enters the region consisting of the mho and reactance characteristics, which have threshold values K_D' * Z∠θ and K_X1' * X1, so as to detect forward fault cases which occur just inside or outside of zone 1. Since disturbance records triggered by the operations of the UV/OC relay elements are utilised, this evaluation could also cover external fault cases for the same protection relay unit. Hence, for example, the non-operation margin to the load blinder element of a distance relay under external fault cases could be evaluated properly.

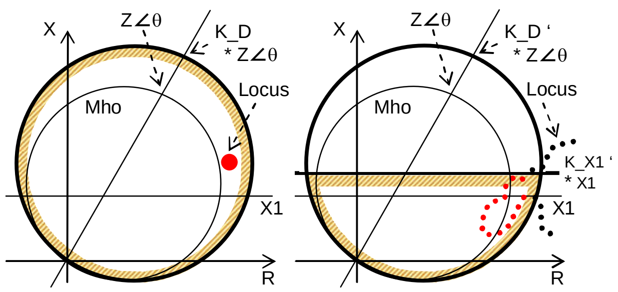

Figure 1: Evaluation characteristics under normal conditions (left) and fault conditions (right)

SYSTEM CONFIGURATIONS

The prototype system is composed of information management servers, clients and protection relays using agent technology. All devices are connected to each other via a dedicated network for maintenance over which they can send and receive relevant data. Although there are no physical constraints on the information management servers for practical operation, we recommend that servers should be located in each engineering office of a power utility in view of distributing the processing load and maintenance activities.

Information management server

The information management server has both data server functions and application server functions as follows:

(a) Data server functions

These functions collect and store disturbance record data from each protection relay, calculate locus coordinate data and detect changes in system characteristics precisely based on each evaluation method by utilising disturbance record data collected from each protection relay.

(b) Application server functions

The application software executed in each protection relay is stored in the information management servers. The servers can dispatch this application to each protection relay for execution depending on the situation.

Protection relay

The protection relays implement an agent platform, which is a mechanism for executing applications stored in the information management servers and processing assigned functions. A network processing module in each protection relay has functions which provide the capability of detecting changes in system characteristics under both normal and fault conditions. If this module detects a change, the related disturbance record data is sent to the server. Since system characteristics are evaluated within each protection relay, the system avoids the unnecessary transmission of data from each protection relay to the information management servers, and as a result, an intelligent system is realized.

Client

The client in this system provides HMI functions and implements functions for displaying current and voltage waveforms and evaluation results of system characteristics as well as maintenance management functions on evaluation parameter settings. A screen example of a client is shown in Figure 2.

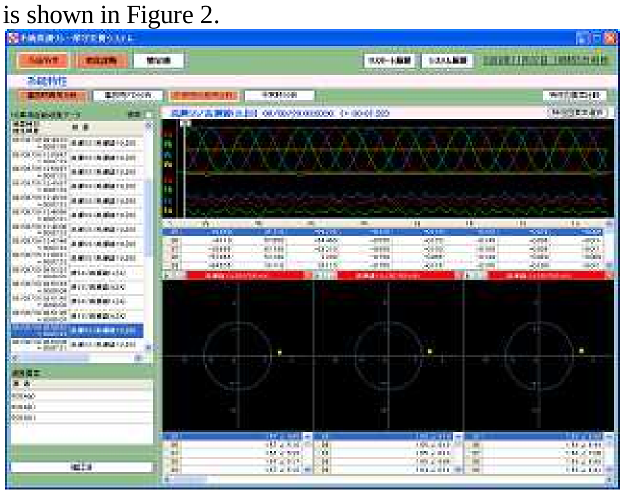

Figure 2: Example of Client Display

FIELD TRIAL AND EVALUATION

In order to demonstrate the capability of this system, a field trial was established in the 66kV system operated by Shikoku Electric Power CO., INC from June 2008 to February 2009. The system configuration for the field trial is shown in Figure 3. An information management server and a client system were located within the head office, three protection relays (RY1, RY2 and RY3) were situated within two substations, and a dedicated network was provided for maintenance. Although no internal faults occurred during the operation of the trial system, the results of the evaluation of power transient fluctuations utilising wide-area data during system operations, e.g. disconnecting one circuit, 1L shown in Figure 3, of a double-circuit parallel line will be introduced below.

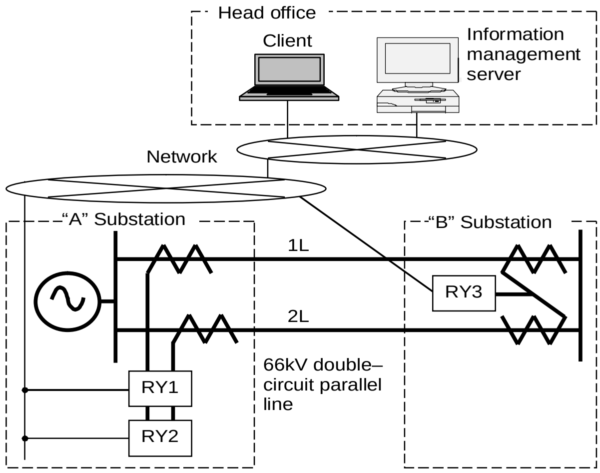

Figure 3: System configuration for the field trial

In this field trial, zero-sequence and segregated transverse differential current as well as impedance as shown in Table 1 were applied as the evaluation criteria under normal and fault conditions. The evaluation equations for zero-sequence and segregated transverse current are shown by the following expressions (1) and (2) respectively, and the evaluation characteristics for impedance are shown in Figures 1.

$$|\,Ia(1L) - Ia(2L)\,| > K\_ID * ID \quad (1)$$

$$|\,I0(1L) - I0(2L)\,| > K\_I0D * I0D \quad (2)$$

Key:

ID Setting value for segregated transverse differential current relay element [A]

I0D Setting value for zero-sequence transverse differential current relay element [A]

K_ID Evaluation threshold for segregated transverse differential current relay element [%]

K_I0D Evaluation threshold for zero-sequence transverse differential current relay element [%]

The field trial was established with high sensitivity evaluation thresholds compared with the usual relay settings, as shown in Table 2.

Evaluation criteria		Evaluation threshold [%]		
		Name	Normal cases	Fault cases
Zero-sequence transverse diff. current		K_I0D	60	80
Segregated transverse diff. current		K_ID	60	80
Impedance	Mho	K_D	140	120
	Reactance	K_X1		120

Table 2: Evaluation thresholds in the field trial

The 1L and 2L current waveforms of RY1, which were collected in the information management server on disconnection of 1L of the double-circuit parallel line, are shown in Figures 4 and 5. These waveforms conform to the system phenomenon because the 1L currents became "0" and the 2L currents doubled just after this system operation. The locus of the zero-sequence transverse differential currents based on the disturbance record data and compared with the relay characteristics are shown in Figures 6. In accordance with the evaluation algorithm, the change in system characteristics can be detected correctly in Figure 6 by means of evaluating the zero-sequence transverse currents, which are generated for a short time just after the 1L disconnection.

Through the field trial, it was demonstrated that this intelligent system has the capability of monitoring system phenomena appropriately and evaluating the validity of relay setting values based on the system phenomena which would be faced under Smart Grids. A total of 31 notifications of changes in system characteristics were issued during the field trial, and all necessary data were correctly collected at the information management server.

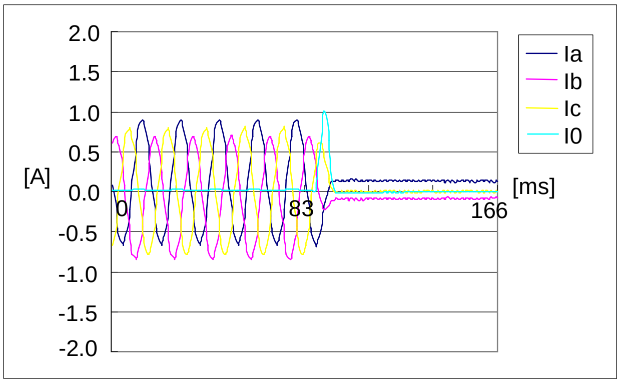

Figure 4: Waveforms of currents (1L) on disconnection of 1L of the double-circuit parallel line

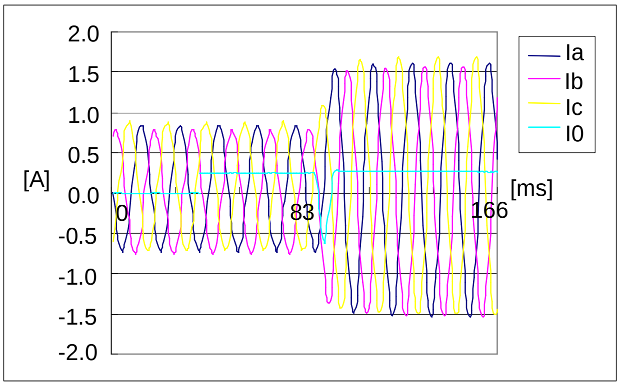

Figure 5: Waveforms of currents (2L) on disconnection of 1L of the double-circuit parallel line

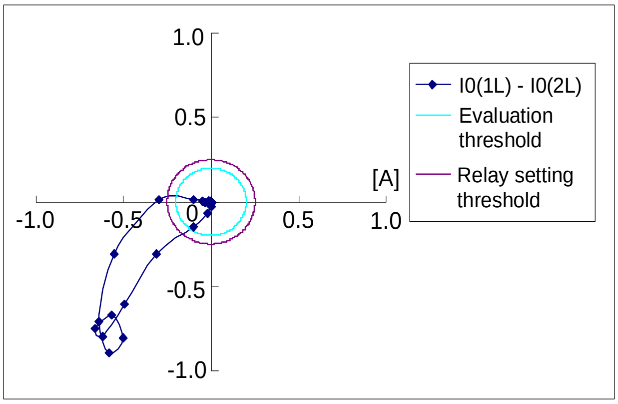

Figure 6: Locus of zero-sequence transverse differential current on disconnection of 1L of the double-circuit parallel line

CONCLUSION

The authors have proposed the concepts of intelligent protection relay systems for Smart Grid and have proceeded with a prototype development based on these concepts. The results of the field trial of this system demonstrate that the proposed system has the capability of evaluating power system characteristics in detail on a real-time basis and contributing toward supervision, coordination check and optimisation of setting values. Moreover, it has been proven that an agent system can be applied under practical conditions. Further developments aimed at commercial operation are being considered.

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