OVERSEAS DISTRIBUTION AUTOMATION SYSTEM BASED ON JAPANESE EXPERIENCE

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Abstract—Outage time in Japan is the shortest in the world because Japanese power utilities have applied Distribution Automation System (DAS) in whole area. Toshiba developed and supplied DAS using computer from 20 years ago and have been supplying DAS in Japan and in oversea countries. Therefore, we introduce DAS for oversea country based on our long-term experience. Major points are as follows.

1. DAS using only local equipment (Vacuum Switch (VS)/ Fault Detecting Relay (FDR))
   (1) Comparison between recloser and VS/FDR
   (2) Recommendation system combined recloser and VS/FDR
2. DAS using computer
   (1) Display of distribution network with mapping system
   (2) Automatic power supply
   (3) Underground DAS using automatic Ring Main Unit
3. Communication system for DAS
   (1) Comparison among radio, twisted pair cable and optical fiber
   (2) Optical fiber communication system

We also introduce DAS in future with new technology such as TCP/IP network.

Index Terms—DAS, VS, FDR, Mapping system, Ring Main Unit, Communication system, Computer.

1. Introduction

Japanese power utilities adopted Distribution Automation System (DAS) from 30 years ago and have been widely used in whole area in Japan.

The 1st stage of DAS consists of local equipment which are pole-mounted Vacuum Switch and Fault Detecting Relay, because DAS is simple system, low price, accurate fault detection and free maintenance.

Toshiba developed 2nd stage of DAS using telecommunication and computer system about 20 years ago. The DAS using computer is first system in Japan and probably first system in the world. The 2nd stage of DAS was also applied for whole areas of Japanese power utilities, the number of which is more than 200 systems. Outage time in Japan is the shortest in the world as shown in Fig.1. This is the result of the Japanese power utilities that have been applying DAS. Toshiba introduced and supplied DAS for oversea countries in accordance with a lot of Japanese experience.

In this paper, we introduce the technical point in order to apply for DAS.

2. System Configuration of DAS

DAS consists of the following two (2) stages as shown in Fig.2.

(a) 1st stage

DAS of 1st stage can automatically isolate the faulty section only by local equipment which consists of Pole-mounted Vacuum Switch (PVS), Fault Detecting Relay (FDR) and Switch Power Supply (SPS). Japanese power utilities have adopted 1st stage DAS about 30 years ago and have much successful experience during operation of 30 years.

(b) 2nd stage

DAS of 2nd stage is remote control system using computer and communication facilities. Distribution network data, which are status of PVS / voltage / current, are transmitted to Tele-Control Receiver (TCR) through Remote Terminal Unit (RTU) and communication line such as optical fiber or twisted pair cable. Datas integrated from the distribution network and substation are transmitted to computer system in central office through Tele-Control Master unit (TCM). DAS using computer had developed about 20 years ago and applied for Japanese power utilities. After the successful experience, Japanese power utilities expanded DAS of 2nd stage for all area.

FIG.1 OUTAGE TIME (1997)
3. 1st stage of DAS

A. Fault detecting procedure

Typical fault detecting procedure in radial network is described as Fig.3. 1st stage of DAS can also be applied for looped network.

![Fault Detecting Procedure by Local Equipment](image)

When a fault occurs on section “C”, CB “A” in substation trips and PVS opens automatically because the power is lost. CB “A” will be re-closed after a certain interval and power supplies to section “a”, so that FDR of “B” detects the voltage and counts the closing time (so called X-time / example 7s). After X-time, PVS “B” closes and power is supplied up to “C” and “D”. FDRs of “C” and “D” detect the voltage and start counting the closing time, which are intentionally differred (example 7s for “D” / 14s for “C”), starts.

Therefor, PVS “D” close after 7s and PVS “C” closes after 14s. If the fault remains at section “C”, CB “A” will trip again after the closing of PVS “C”. The FDR of “C” judges that the voltage has dropped within the fault confirmation time (so called Y-time / example 5s) after PVS “C” closing, so that the FDR of “C” is locked. After CB “A” re-closes again for the second trial, PVS “B”/”D”/”E” are closed after the closing time (X-time) but PVS “C” is locked by FDR in the state of opening. Therefor, the faulty section is automatically isolated.

B. Comparison between voltage and current sensing method

There are two fault detecting method which are voltage and current sensing system. Table 1 is described the comparison between voltage and current sensing method.

Voltage sensing system have been used during long period (more than 30 years) with more than 200,000 units, so that the technology to isolate a fault section was established and the outage time was decreased. The voltage sensing system has the problem that the faulty current flows two times in order to detect the faulty section. However, there are a small difference between two times and one time for current sensing system. In case of OCB or oil cable, it is problem to flow the faulty current two times, but OCBs have been replaced by exchanged VCB or GCB recently and oil cables are not used either.

Current sensing system is influenced by the faulty current, especially grounding faulty current I₀. It is important to set I₀ that is not mis-operated with the unbalance of load current.

Current sensing system should be equipped with battery in order to operate LBS or RMU without AC power. The battery is required for the periodical maintenance, which is generally replaced for each 5 years. The labor for maintenance will be very large when many batteries will be installed widely and will be used long time.

<table>
<thead>
<tr>
<th>Fault Detecting</th>
<th>Voltage sensing</th>
<th>Current sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounding network</td>
<td>○</td>
<td>⨋ (Influenced by faulty current)</td>
</tr>
<tr>
<td>No-grounding network</td>
<td>×</td>
<td>⨌ (Difficult for earthing fault)</td>
</tr>
<tr>
<td>Operation time of CB</td>
<td>○ (2 times)</td>
<td>(1 time)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>(Battery periodical replacement is required.)</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>(Communication and computer system are required.)</td>
<td></td>
</tr>
</tbody>
</table>

C. Pole-mounted Vacuum Switch (PVS)

Switch mounted on pole is used under severe condition which are dust, salt, animals and so on, so that switch of sealing type as shown in Fig.4 is suitable for pole-mounted condition in accordance with a lot of experience. There are three arc extinguishing types of switch which are vacuum, SF₆ gas and air.

![The Appearance of PVS](image)
Therefor, the usage of SF6 gas had better been decreased as small as possible.

Regarding switchgear of more than 80kV, there are no useful products instead of SF6 gas, so that GCB/GIS should be designed to use SF6 gas as little as possible. The SF6 gas should be requested to collect after the repair or the life.

In case of middle voltage class, there is an excellent switch so called VS, which can be used instead of SF6 Gas Switch (GS).

The switching time of automatic operation should be less than 1s because of shortening the outage time. In case of maintenance work or overload work, DAS should remotely control to operate auto PVS/RMU as shown in Fig.5.

Therefor, we recommend to adopt the coil operation type which can be realized less than 1s for switching operation time.

D. Fault Detecting Relay (FDR)

There are two types of FDR which are for normal closed point and normal open point.

The closing time and starting condition between the normal closed type and the normal open type are different as shown in Table 2. The change of setting, which are closing time / fault detecting time / type (normal close / normal open), can be easily performed on the bottom of FDR.

E. Lightning Surge countermeasure

When the equipment of 1st stage had been installed about 30 years ago, the trouble by lightning surge had occurred. The reason was the connection of earthing cable that was not considered the surge voltage occurred by the surge current of arrester operation. After the suitable earthing connection among arrester, outer case of PVS / FDR / SPS and one phase earth of SPS secondary voltage was performed as the countermeasure, the trouble by lightning surge except direct lightning have not occurred during 30 years. It is necessary to install arresters on both side of PVS, and it is important to connect the earthing line considered to avoid inductance by arrester current and the voltage rise by arrester operation.

F. Application of recloser

Japanese power utilities had used reclosers in the past but they have changed their policies to adopt DAS instead of recloser more than 30 years ago, because the reliability and expansion of DAS is for more better and serial installation of recloser is very difficult as shown in Fig.6.

Recently, DAS in Japan have been applied for the looped network instead of the radial network. However, a lot of foreign countries apply the radial network for the rural area. Although DAS can be applied for the radial network also, the reclosers are useful for branch point combined with DAS of 1st stage as shown in Fig.7.
The time setting; t₁ is long, so that the distribution line and equipment are damaged by long flowing of faulty current.

**FIG.6. I-T CURVE OF RECLOSER SYSTEM**

**FIG.7. RECLOSER SYSTEM COMBINED WITH DAS OF 1ST STAGE**

### 4. 2nd stage of DAS

**A. System configuration**

DAS of 2nd stage consists of communication and computer system as shown in Fig.2.

There are two kinds of computer systems that are simple skeleton display system for rural area and full graphic display system with geographic map for city area.

**B. Communication system for DAS**

DAS has been used four (4) types of major communication media which are radio wave, telephone line (Twisted pair cable), PLC (Power Line Carrier) and optical fiber.

The comparison among three communication systems is described as shown in Table 4.

PLC has widely used for DAS in Tokyo area since 1991. Japanese power utilities have adopted no-grounding system in distribution network and the reliability is no problem because there are no transformers between phase and ground. However, a lot of foreign countries have adopted grounding distribution network, so that the reliability is not so good with the signal decay by transformers. Therefore, we recommend the following communication system for each area.

**City area**

Telephone line or optical fiber are suitable for DAS of city area because

- Reliability is excellent in comparison with radio wave, the signal of which is influenced by building, weather and so on.
- Length of communication line in city area is shorter than rural area, so that the cost for the installation is acceptable.

**Rural area**

Radio wave or 1st stage are suitable for DAS at rural area, considering cost efficiency.

In recently, a lot of power utilities have adopted optical fiber system for DAS and remain cores will be used for communication business.

**TABLE.4 COMPARISON OF CHARACTERISTICS BY TRANSMISSION MEDIA**

<table>
<thead>
<tr>
<th>Transmission media</th>
<th>Communication cable (Twisted pair cable)</th>
<th>Communication cable (Optical cable)</th>
<th>PLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission rate</td>
<td>1Mb s⁻¹</td>
<td>Several Gb s⁻¹</td>
<td>Several Gb s⁻¹</td>
</tr>
<tr>
<td>Transmission loss</td>
<td>Several dB/km</td>
<td>About 0.5dB/km</td>
<td></td>
</tr>
<tr>
<td>Transmission reliability</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Influence of Noise</td>
<td>Little</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Influence of weather</td>
<td>A little</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Experience</td>
<td>Cheap</td>
<td>A little expensive</td>
<td>A little</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Suitable in urban area</td>
<td>Suitable in urban area</td>
<td>Suitable in rural area</td>
</tr>
<tr>
<td></td>
<td>Suitable in urban area</td>
<td>Suitable in rural area</td>
<td>Suitable in non-grounding network</td>
</tr>
</tbody>
</table>

**C. Optical fiber system**

Passive multi-drop system has been used for the optical communication between TCR of substation and RTU in Japan.

The feature is as follows.

- Batteries are not used because of passive system. (no maintenance)
- Cheaper cost
- Length and branch number for communication capability are limited with less than 10 km and up to 10 branches.

Recently, the optical communication system using TCP/IP will be developed and the concept is as follows.

- Layer 2 switch (Bridge) or router can be realized without any delay for communication.
- A lot of nodes can be connected and the communication with long distance of 15 km or over can be available because of active method.

**D. Computer system**

There are two types of computer system which are simple display of distribution network and geographical display of distribution network.

The cost of the single line diagram display type as shown in Fig.8 is cheaper, so that the type was used for rural area.
The functions of the geographical display type for city area are as follows.

- Geographical display of network on CRT
  - Distribution network diagram linked in map as shown in Fig.9.
  - Real-time display by changing network colors when a fault occurs.
  - Zoom in and out function (1/200,000 to 1/100)
  - Smooth scrolling of display
  - Display of detail equipment diagram on window

- Real-time monitoring and on-line control on CRT.
  - Control: PVS, Auto RMU, CB in substation
  - Monitoring: Status of PVS/RMU/CB/Ry, voltage and current

- Automatic restoration
  When the distribution fault occurs, the fault is detected by the status change of CB in substation. Regarding the source side of faulty section, power is automatically supplied by FDR function of stage 1.
  Sections on load side of the faulty section are automatically supplied from the connected feeders in accordance with switching procedure by computer calculation, which consider
  - to unify the spare power of connected feeders and bank
  - to avoid the drop of voltage.

- Easy data maintenance
  Distribution network will be usually changed, so that easy data maintenance with man-machine interface is required.

- Simulation for operator’s training
  Computer based system should be installed for each branch office because
  - Distribution network will be daily changed and a lot of remote control will be performed every day, so that operator should be limited to control the distribution network within district office.
  - Operator sends the command to maintenance crew who is under the district office, so that operator should know and be able to control the maintenance crew in detail.

TEPCO, who is the biggest power utility in Japan, had installed the computer based system of DAS for every district office, the number of which is more than 100 systems.

5. DAS for underground network
Fault detecting procedure is generally applied for the current sensing system using auto Ring Main Unit (RMU). The system configuration is shown in Fig.10.
The faulty section can be judged by the information of faulty current which are transmitted from each RTU.

(a) Application for existing manual RMU

There are following two applications.
  - Existing RMUs of manual operation are modified to automatic type by addition of motor in site.
  - Automatic RMUs or automatic PVSs are installed among existing RMUs of manual type.

Item is not recommended because the reliability of modification and adjustment in site is not so good and the switching speed of motor operation is Fig.11.

Automatic RMUs are installed on road or in room of building, but the investment including installation work is expensive. Therefore, we can recommend to install PVS with the same function as auto-RMU.

![Fig.8 Sample picture of single line diagram](image)

![Fig.9 Sample picture of distribution network diagram](image)

![Fig.10 Underground system configuration](image)

![Fig.11 Underground network combined with automatic and manual operation switch of existing RMU](image)
Japanese power utilities adopt the voltage sensing system for underground network because OCBs and OF cables are not used for distribution underground network.

Recently, other countries such as China consider to adopt for the underground DAS using voltage sensing system instead of current sensing system.

Features of the latest auto RMU are as follows.

- Vacuum interrupter molded with epoxy resin → No SF6 gas
- Branch circuit for customer is assembled VCB instead of fuse.
- High speed operation by coil → No motor operation

6. Economical evaluation of DAS

DAS has four economical benefits as follows.

(a) Improvement of loss income by outage

DAS can decrease outage time, so that the income can increase as shown in Fig. 13.

(b) DAS can realize the effective operation of distribution feeder, so that new construction of distribution substation can be decreased.

(c) DAS can reduce the personnel expense who operates manually switches and detect the faulty section.

(d) Improvement for the lack of power

DAS can control outage sections, so that the planned outage for non-severe customer loads can be performed before the lack of power occurs.

The cost of DAS is much cheaper than the construction of generator.

7. Conclusion

DAS will be used for overseas countries because the society will strongly request to decrease outage time year after year.

Communication network (especially optical fiber) using DAS will be useful for the future Information Society which can realize

- to connect distributed generators such as fuel cell, micro gas turbine, wind generator and so on.
- to transmit movies such as maintenance works in site, surveillance of facilities against terrorism and so on.
- to promote customer automation such as DSM, auto metering and so on.

8. Biography

Atsushi Fujisawa was born in Mie Prefecture, Japan on July 1, 1950. He received his B. S. Degree from Nagoya Institute of Technology in 1974 in electrical engineering.

In 1974 he joined Toshiba Corporation. From 1974 to 2001, he was in head office where he has been engaged in distribution system engineering. In 2002 he joined TM T&D (Toshiba Mitsubishi Transmission and Distribution) Corporation, he is chief engineer in head office where he has been engaged in T&D System Engineering Dept.

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In 1993 he joined Toshiba Corporation. From 1993 to 2001, he was in head office where he has been engaged in distribution system engineering. In 2002 he joined TM T&D Corporation, he is in head office where he has been engaged in distribution system engineering.

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