INTEGRATION OF RF COMMUNICATIONS FOR DISTRIBUTION AUTOMATION WITH DUAL REDUNDANCY

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Integration of RF Communications for Distribution Automation with Dual Redundancy

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Abstract:

Distribution Automation **(DA)** systems use Radio Frequency **(RF)** communications between Remote Terminal Units **(RTUs)** and the Distribution Control Center **(DCC)**. Motorola supplied a large RF based DA project to the Israel Electric Corporation **(IEC).** Serving hundreds of pole mounted Load Break Sectionalizers **(LBS)**, the IEC system has a capacity of expansion to thousands of sites and it utilizes multiple **MOSCAD** RTU configurations, suitable to interface with various types of Medium Voltage **(MV)** Air-Break and SF-6 type LBS. In future, similar RTUs will perform remote control of Internal Transformer Station switchgears **(ITS)**.

The system is controlled by five DCC computers located throughout the country, and each DCC will interface with a MOSCAD **TCP/IP Gateway,** and a Front-End Interface Unit **(FIU)** which manages the communication. The IEC system operates with mixed communications schemes supporting both Polling, Report by Exception and Contention modes. It efficiently handles an avalanche of messages which are common in DA systems. To increase the operating reliability, the system utilizes dual communication redundancy, the highlights of which are:

- Each RF link between the RTUs and the DCC, may operate on two pre-programmed frequencies. In case the default RF channel becomes unavailable, the site initiating the message automatically switches to the secondary channel.
- The DCC FIU and each of the main communication nodes utilize a redundant, dual channel RF Modem. In case the primary RF Modem fails, there is a secondary RF Modem which takes over.

MOSCAD RTUs can easily be modified for an alternative medium (fibre optic, wireline or other RF system), while still participating in the overall communication scheme. This arrangement creates an additional level of flexibility, redundancy and results in significant cost benefits.

The RF communications allows operator initiated Fault Isolation and System Restoration **(FISR).** The system can also perform automatic FISR based on a built-in algorithm as explained later in this paper. Availability of this capability helps improving overall system reliability, and allows shortening the outage duration in case a problem does occur.

The DCCs throughout the country are based on DEC computers with VGC software and IBM PC computers with Wizcon software. These will later be upgraded to a full scale Distribution Management System **(DMS)** software, which will run on modern powerful computers. With the MOSCAD TCP/IP Gateway and FIU, such a change will require only minor adaptations. Once the system is completed, the regional DMS control centers will be interconnected to the nationwide Energy Management System **(EMS)**.

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Overview

The Israel Electric Corporation **(IEC)** started integrating RTUs for upgrading the remote control capability of MV distribution power grids at the most critical sections, where problems were likely to occur. The system utilizes over 16,000 km of MV power grid (mostly based on overhead lines), operating in the 11 - 33 kV range. The nationwide power distribution network of the IEC comprises over 100 High Voltage to Medium Voltage **(HV/MV)** substations, over 25,000 disconnector and Load Break Sectionalizers (**LBS**) and thousands of Medium Voltage to Low Voltage **(MV/LV)** transformers.

When evaluating plans for improving the grade of service and increasing operating reliability, the IEC experts posed several important questions:

- Wireless versus wireline RTU communications?
- To what extent can a DA system reduce the duration of power outages?
- What is the optimal number of sites to be controlled in a DA system?
- Will the selected RTU technology be able to integrate with all types of existing and future Outdoor Air-Break and SF-6 type LBS and Internal Transformer Station (ITS) switchgears?
- How to evaluate the actual cost benefits resulting from installing a nationwide DA system?
- What is the most effective fault detection method for different types of MV lines?

Communications Network and Protocol Considerations

Since telephone lines or other physical communications media are not commonly available along the MV grid, RF remains the only choice. The IEC decided to utilize a set of conventional VHF frequencies, and re-use these channels as topographical conditions allowed (distances, hills, etc.).

Use of radio is convenient due to flexible connection and low installation cost, however RF channels are subject to interference which might affect system operation. Utilizing a high quality communication protocol helps to minimize such RF media limitations.

Protocol buzzwords such as UCA, DNP-3, IEC 870, MODBUS, TCP/IP, etc. are widely used by industry experts. However, a communications layman easily gets confused by not realizing the importance of specific features provided by each protocol, the importance of a specific protocol for a given communication media, and the differences offered by various vendors.

Modern communications systems are based on the *Seven Layer* protocol concept that was designed according to guidelines provided by the International Standards Organization **(ISO)** for Open Systems Interconnection **(OSI)**. The advantage of the ISO/OSI type protocol structure is in separating communications and application functionalities.

By using the seven layer protocol approach, the programmer does not have to deal with management functions such as remote diagnostics, networking, error handling, confirmation of message integrity, etc. The benefit is, that all the above functions are automatically taken care of by the protocol structure, and the system programmer has to worry only about his application. In this DA system the IEC utilizes the Motorola Data Link Communications **(MDLC)** seven layer protocol. The MDLC supports the connection of multiple media (RF, Wireline, Fibre-optics, etc.) into an integrated communications scheme. The MOSCAD based system is ready for migration to future analog RF bands and/or digital RF channels, which are likely to become available.

Dual Channel RF Modem

Motorola addressed the RF interference concerns of the IEC, and implemented a redundant system. The Front-End Interface Unit (FIU), Store & Forward repeater **(S&F)** and field RTUs are all operating on two RF channels. The FIU and the S&F repeater are equipped with two separate radios and modems and the RTU sites include a single radio that can be switched to operate on either channel. Using the dual channel approach, the DCC is served by two separate RF Modems (primary and secondary), which provide another level of redundancy. See Figure 1.

In case the primary RF channel is not available for any reason, the system switches to an alternative channel. Selection of the channel among the two available frequencies and the networking communication scheme via S&F repeaters is controlled by the application program. The MOSCAD S&F repeater receives and re-transmits the message over the same (simplex) RF channel. Programming of the logic functions is performed using ladder diagram.

An RTU site switches to the alternative RF channel if it detects an unreasonably long “channel busy” condition or, when a transmitted message is not acknowledged. Once an RTU switches to that channel, it will stay there for a predefined / programmable time, and then switch back to the default channel. In locations where a direct RF link between an RTU and the DCC is not possible, the messages are received by a S&F repeater, checked, corrected using the retry mechanism, and re-transmitted to the designated RTU.

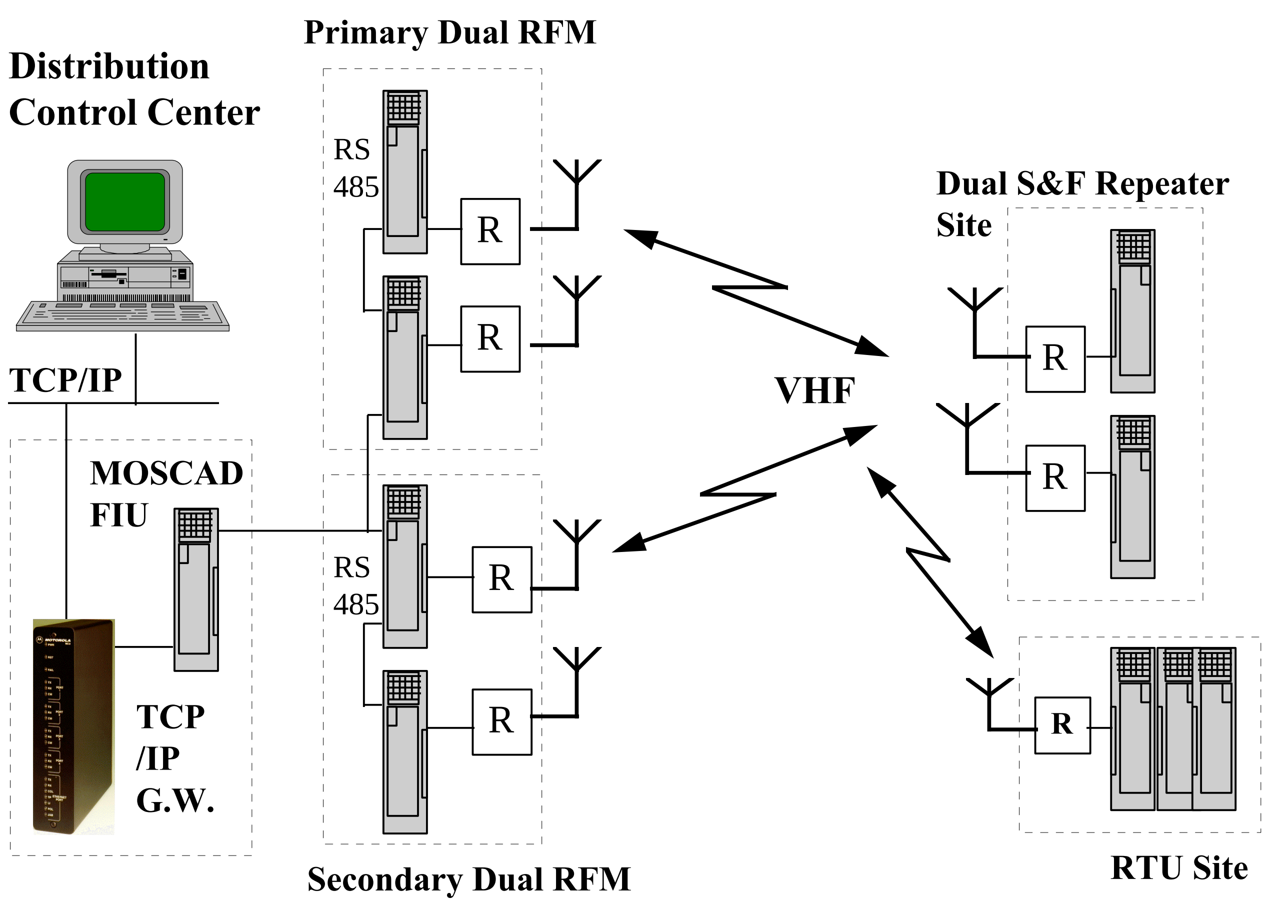

Figure 1. Illustration of Communication Links

IEC System Components

Once completed, the DMS will include thousands of RTUs of various types. All these RTUs and the five DCCs will integrate into a nationwide communications scheme**.** As shown in simplified form in Figure 2, the IEC project includes the following **MOSCAD** type units:

1) Front-End Interface Unit **(FIU)** (“A”)

The MOSCAD based TCP/IP Gateway directly interfaces with a Wizcon/5 DCC from PC Soft International. The Gateway interfaces to a MOSCAD CPU, which manages the communications with the field RTUs. The combination of these two units acts as the FIU.

2) RF Modem Interface (“B1/B2”)

As shown above the FIU comprises two RF modems. Switching between the two RF modems (B1, B2) is done by the application software in the FIU. Each RF Modem includes two VHF radio units, allowing field RTUs to reach the DCC on either channel.

3) Store & Forward **(S&F)** Repeater (“C”)

The MOSCAD based S&F repeater also includes two RF Modems. It communicates upwards with the DCC (via the RF Modem and FIU) and downwards with the RTUs using either of the two designated RF channels. The unit is normally installed at a topographically elevated location to allow communication with a maximum number of RTUs in the region.

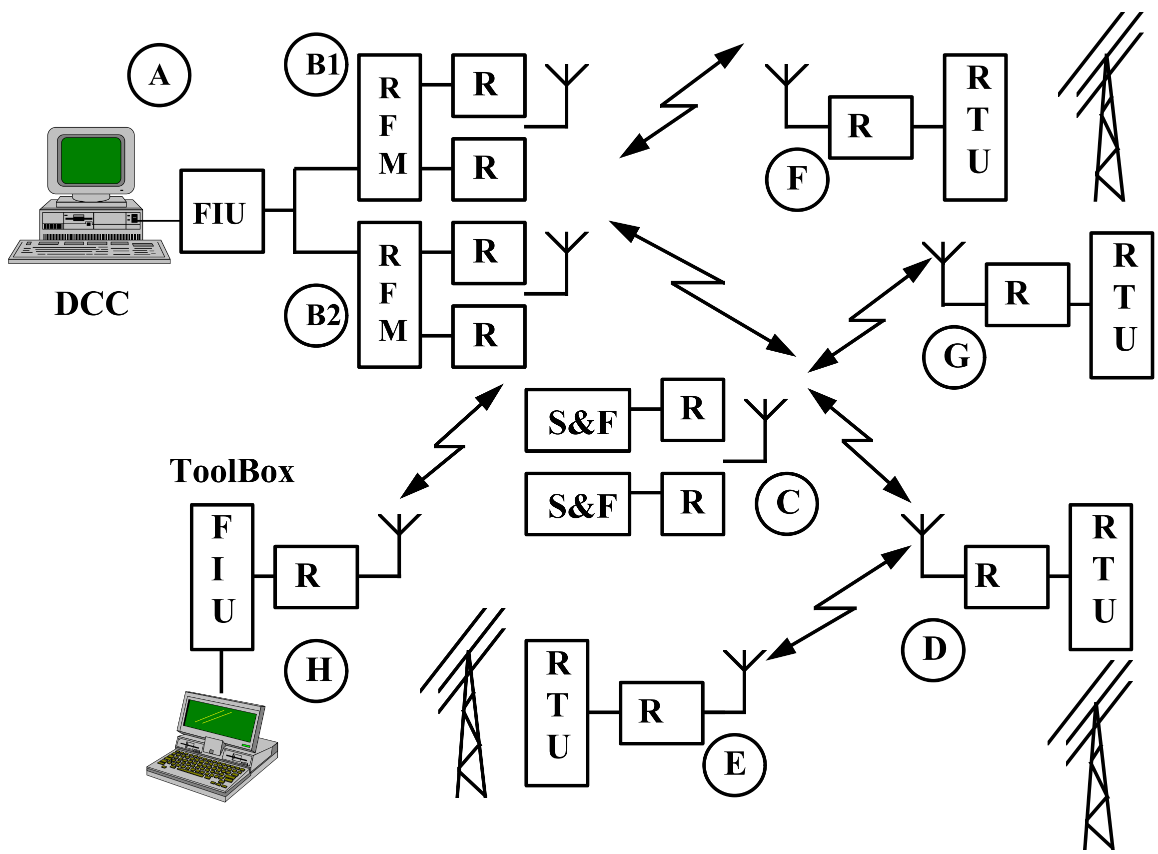

Figure 2. IEC System concept for a single region

4) Communication Links

The RTU "F" site communicates directly with the FIU (via the RF Modems). On the other hand RTUs "D" and "G" communicate via the S&F repeater ("C"). In some locations, there are RTUs such as type "E" which due to topographical conditions can not be reached directly by the FIU or the S&F repeater. These RTUs will communicate via RTUs such as "D", which in addition to their main function as a switchgear controller operate as a S&F repeater.

5) ToolBox Connectivity ("H")

One of the strongest features of the MOSCAD is provided by the ToolBox connectivity. In traditional SCADA systems, the programming tool is either built into the Master Control Center or is connected to the system only at designated locations. The MOSCAD ToolBox is an advanced, Windows based stand-alone unit, which communicates with any of the MOSCAD RTUs, from ***any*** remote site included in the communication scheme. The ToolBox can also utilize a dedicated RF modem (see above), and it communicates with ***any*** of the MOSCAD RTUs in the coverage range. In case the maintenance person wishes to communicate with a site which is out of range, it is possible to reach that RTU via one or more MOSCAD site(s) that serve as S&F repeater(s). The Programming TolBox can perform reconfiguration of the communications scheme, or updating of the application program. Using the Toolbox, a new software application can be downloaded to the RTU locally at the site, or remotely via the communications network.

Communication between the ToolBox and any RTU is protected by a unique System Password. In addition to the System Password, operators are assigned specific priority level of access. Some operators can perform monitoring, others are allowed to change certain parameters and so on, up to seven priority levels. Obviously, the user has to know the correct System Address and the Site ID in order to communicate with the RTU.

6) RTU unit acting as a Switchgear Controller ("D", "E", "F", "G").

The IEC system utilizes a range of RTU configurations adapted to various Air Break or SF-6 type LBSs. The basic RTUs used in this project are the RCU and the ICU:

- The Remote Control Unit **(RCU)** interfaces to an external Local Control Unit (**LCU**), which includes a built-in controller, power supply, and a local control panel. The RCU controls one or two LBSs, depending on the I/O configuration.
- The Integrated Control Unit **(ICU)** includes a built-in motor drive serving specific types of Air-Break LBSs and SF-6 switches, which do not have an integrated motor drive.
- In future the IEC system will utilize additional RTU configurations, intended to provide remote control of Internal Transformer Station (ITS) switchgears. The MOSCAD is suited to fill this role.

ICU Design Details

The ICU was originally designed for motorized control of specific "manually operated" Air-Break LBSs, and later it was adapted to control various SF-6 type switches. It integrates the following components: MOSCAD CPU, I/O modules, Power Supply, Backup Battery, AC Power fail sensor, spring load motor drive and local control panel.

The spring-loaded mechanism gives the Air Break load switch a "making capacity". For SF-6 type switches which include that spring mechanism, to load that spring, the motor drive performs a slow motion action. For further details of the ICU design refer to Figure 3.

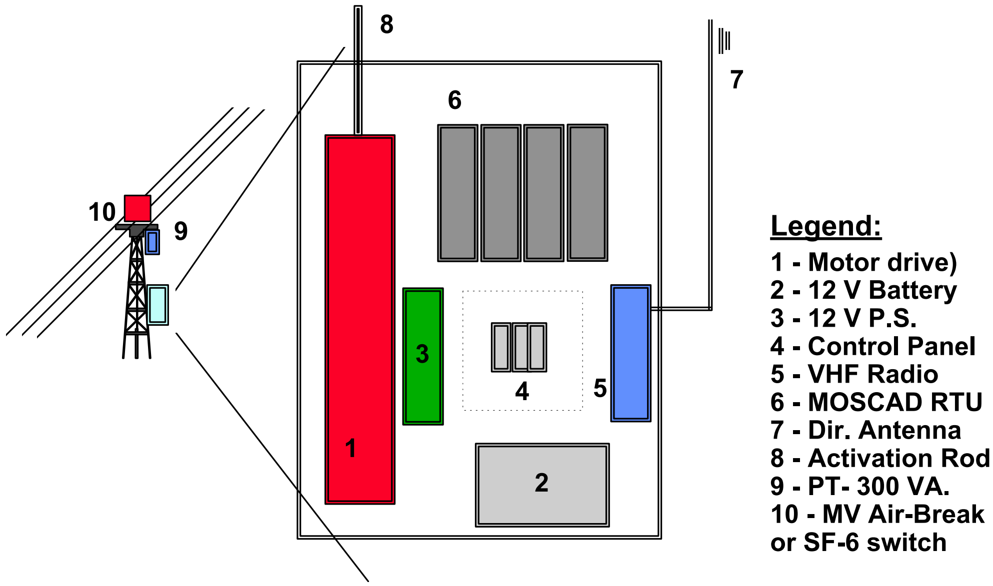

Figure 3. Illustration of the ICU

AC power for operating the RTU, whether ICU, RCU or LCU is supplied from an auxiliary MV/LV Potential Transformer **(PT).** This PT supplies 110V AC to the MOSCAD Power Supply, which also acts as an integrated battery charger. The back-up battery is able to power the site for tens of hours, including multiple "open/close" operations of the switch.

A unique characteristics of the ICU is provided by its "True Power Supply" capability, a feature specifically requested by the IEC. Both power sources, the AC power supply and the back-up battery, have the required "Peak Current" capability to start the motor (>15A/1 sec). This feature allows operating the switchgear immediately after the AC power is restored (when the battery is fully discharged). Without this capability, a delay would have been required for partial recharging of the battery after the AC power is restored.

Note: The internal serial impedance of a discharged battery is high, not allowing delivery of the peak current (>15 A) required to start operation of the motor drive.

Fault Isolation System Restoration

Thanks to the reliable communications of the ICU and the RCU, the system operated by IEC performs operator initiated Fault Isolation System Restoration **(FISR)**. Alternatively the system can operate in an automatic FISR mode, a process performing power restoration to all the unaffected sections of the MV network. The operator can monitor the process via the communications network. This process is based on; preprogrammed time delays, line voltage monitoring, automatic re-closing of the CBR at the substation, and RTUs controlling the LBS along the line. See Figure 4.

The automatic FISR process is demonstrated via the following steps:

1. Before a fault occurs, substation "A" feeds four sections (via SW1 - SW3) and the other substation "B" feeds only one section of the MV grid.
2. Once a fault occurs (for example, at the 3rd section), that fault will immediately trip the Circuit Breaker/Recloser **(CBR)** at substation "A".

3. CBR "A" will immediately try to "re-close".
4. If this reclose attempt fails, the CBR remains "Open". As a result of this event, all RTUs "feel" that the power disappeared, and each one opens the LBS (via the motor drive).
5. Within a preprogrammed time period, the CBR recloses again, an action which is gradually followed by all RTUs along the defined power grid section. This will happen subject to presence of line voltage and in preprogrammed time steps each from the preceding RTU.
6. Once the re-closing process (in this example involving SW1 - SW2) reaches the faulty section (#3), the CBR at substation "A" trips again.
7. The RTU adjacent to the- faulty section (#3 which caused the second tripping of the CBR) will now lock to "Open" state.
8. Within a preprogrammed time delay the CBR will close again, and the power will be restored to all sections (between CBR "A" and SW2).
9. Following completion of the automatic FISR process, electric power to the remaining unaffected section (between SW3 to SW4) can be supplied from substation "B", by closing SW4.
10. After repairing the faulty section, the power grid can be re-configured to its original scheme, as it was prior to the event (see step 1)

Note: To avoid overloading of substation B , step #9 is always operator-initiated. The re-configured network supplies power to a maximum number of customers who receive power from the unaffected sections: 1,2,4,5.

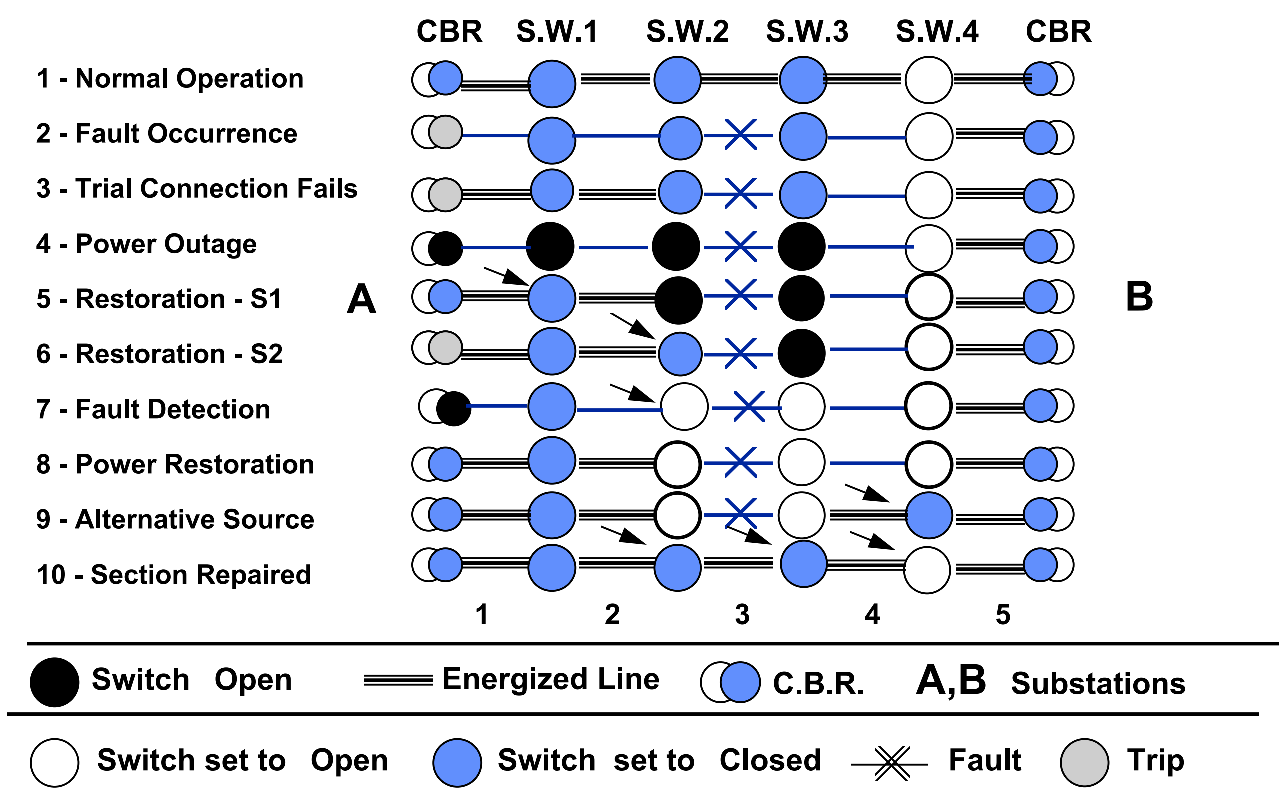

Figure 4. Automatic FISR Sequence

Communications and System Upgrade Options

The IEC plans to integrate thousands of additional DA sites serving pole mounted LBSs and MV/LV Internal Transformer Station **(ITS)** switchgears. This will obviously require additional RF communication channels and more repeaters.

The important advantage of MOSCAD for the IEC project is, that adaptation to different communications media is simple, and does not require changing of system parts or the application software. Use of the MDLC protocol provides even more advantages, since DA systems, comprising thousands of RF network based sites, must operate in a contention mode, i.e. use a special Channel Access Mechanism to contend for transmission on an often busy channel. As mentioned, the MDLC protocol was especially designed for such an operating environment.

The current communications medium is in the VHF band, but due to availability limitations the IEC is constantly reviewing other options. Defining communications alternatives for the expanded system, takes into consideration the currently available channels (UHF, Trunked radio, etc.) and other media which are likely to become available in future. Among these options are:

- Telephone line connectivity to ground mounted MV/LV Transformer Stations.
- Expansion of the existing Fibre Optic network along the MV grid.
- Digital and analog cellular radio infrastructures.

FIU Redundancy

The Distribution Control Center can be upgraded by adding another level of redundancy. Instead of using a single TCP/IP Gateway and a single FIU, the DCC can be expanded with a Hot-Standby configuration, utilizing two MOSCAD TCP/ IP Gateways and two FIUs. The benefit of this concept is, that any single RF channel related problem will not cause failure of the entire system. Similarly to the earlier shown redundancy options, each FIU is linked to two RF Modems. See Figure 5.

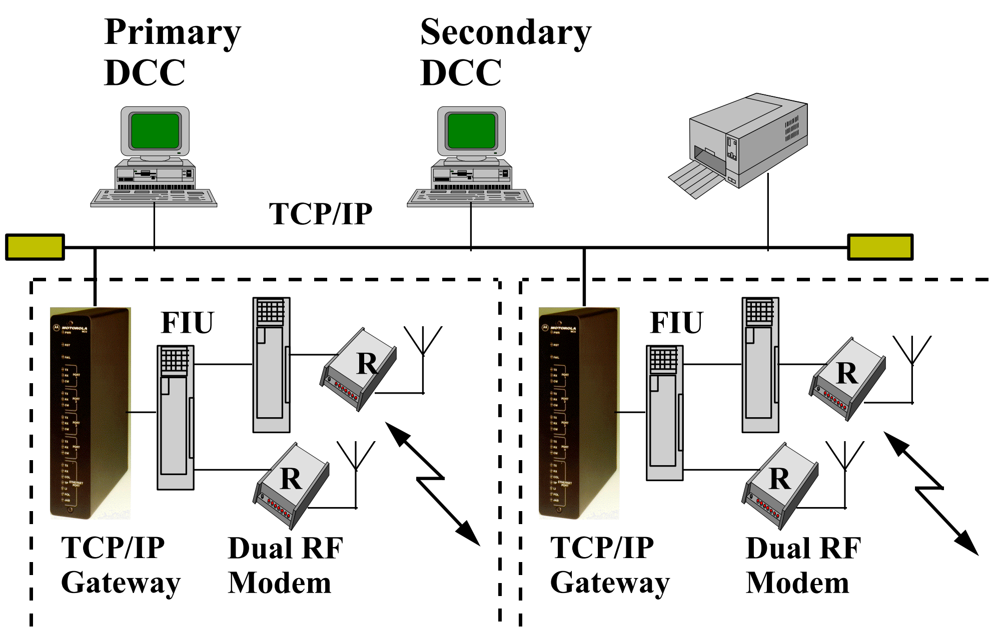

Figure 5. Full Redundant DCC Interface

Summary

The system integration and implementation process as envisaged by the IEC proceeds, and by the end of 1997 about 1000 various RTUs, ICUs and RCUs will be installed. In future, the IEC plans to add thousands of remotely controlled devices: Pole mounted LBSs, Internal Transformer Stations, Capacitor Banks, Fault Detection devices, etc., all reporting to five regional Distribution Control Centers across the country.

The IEC is also using MOSCAD RTUs to monitor their HV/MV substations. The I/O capacity of these RTUs varies between hundreds of points for RTUs serving mobile substations, to very large substations with more than 3000 points. Connection of these RTUs to the nationwide EMS control center will be done via the MOSCAD TCP/IP Gateway.

Evaluating the cost benefits provided by a DA system is a complex task. The main reason is, that over a long time period, several measures were taken to improve the reliability and service level of the entire system. However, from the feedback provided by the operators and maintenance teams, the IEC could learn that they have benefited from this system. Among the achieved goals are:

- Reduction of the time required to restore the power following an outage.
- Operator has real-time picture that helps him make critical decisions.
- Ability to perform faulty section isolation faster and more safely.

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Related Reading:

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7. *Integration of Automatic Meter Reading System with Fresh Water and Wastewater SCADA Systems*, Jacob Cohen, Rick Keith, AWWA 1996 conference
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