IMPROVEMENTS IN SMART GRID MANAGEMENT THROUGH ADVANCED DISTRIBUTION MANAGEMENT SYSTEMS

Dr. Roland EICHLER
Siemens AG – Germany
roland.eichler@siemens.com

Benjamin RIEGEL
Siemens AG – Germany
benjamin.riegel@siemens.com

ABSTRACT

This paper describes the components of an innovative concept for an Advanced Distribution Management System (ADMS), the technologies applied to tie them together and how the ADMS masters today's challenges. It furthermore outlines concepts and technologies for a user interface meeting control room requirements for both performance and workflow-orientation.

INTRODUCTION

Energy distribution systems become increasingly complex due to the integration of distributed energy resources and storage, smart metering and demand response. In combination with increased grid automation, this leads to inundating utilities' systems with data that needs to be intelligently managed. At the same time, utilities are under growing regulatory and customer pressure to maximize grid utilization and provide reliability at all times.

Traditionally, utilities have approached distribution grid management from different perspectives: some were applying Distribution SCADA systems with focus on real-time monitoring and control while others were applying Outage Management (OM) Systems with focus on managing large amounts of planned work and unplanned outage activities with less focus on activities in real-time. Application packages for grid analysis and optimization were somehow available but more or less only loosely coupled. Such approaches are inadequate to sufficiently respond to today's challenges that require common addressing of formerly separated concepts such as grid loss minimization, congestion management, outage management and automated service restoration.

An innovative concept is needed to combine SCADA, outage management and fault and network analysis functions on a software platform under a common user interface and thus overcome these deficiencies. Furthermore, the concept has to consider that in today's distribution utilities, everything concerning managing the grid must be integrated into the utility's IT.

This paper first introduces the ADMS in general with its platform features given in detail. Since SCADA is widespread, the functional description focuses on the remaining two main subsystems, namely OM and Distribution Network Analysis (DNA), followed by the presentation of a sample workflow. Case studies and some outlooks conclude the paper.

ADMS OVERVIEW

Catering to the next era of distribution control systems, the ADMS integrates three core components (refer to Fig. 1) Distribution SCADA, OM, and Advanced Fault and Network Analysis operated under a Common User Environment. It enables the user to

- monitor, control and optimise the secure operation of the distribution network, and
- efficiently manage day-to-day maintenance efforts while guiding operators during critical periods such as storms and outage related restoration activities.

ADMS integrates the intelligent use of Smart Meter information and distributed resources regulating capabilities at the same time, thus providing a solid foundation for the management of the emerging Smart Grid.

Fig. 1 Three-in-one solution

ADMS PLATFORM

In order to meet the above mentioned requirements, the ADMS has to meet manifold requirements in the areas of reliability and availability (24/7 control centre operation), user interface (business process integration), application performance (grid analysis and optimization) and openness (integration with corporate IT). This leads to the following platform features of an ADMS:

A wide-spread and open operating system such as LINUX lays the basis together with Oracle databases, the latter being used for all purposes except the handling of real-time data. High-availability features such as server hot-standby for front-end and SCADA servers are a given. Cyber security features follow international standards such as NERC CIP, ISO/IEC and BDEW. A Multi-Site feature enables multiple control centres to co-operatively manage a power system in main/back-up or main/regional configurations, thus reducing efforts for data maintenance and minimising costs in temporarily shifting grid control responsibilities according to workload and available staff.

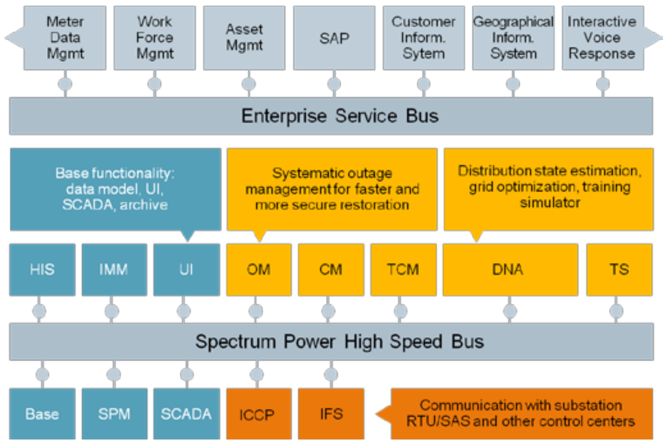

Fig. 2: ADMS modules as part of the overall control centre environment applying SOA and ESB concepts

For enterprise integration with external systems such as Customer Information System (CIS), Interactive Voice Response (IVR), Advanced Metering, Workforce Management and Asset Management systems, a CIM-based SOA integration framework as an integral part of the ADMS provides minimum risk and a long-life cycle.
Modern User Interfaces are always a compromise between comfortable simple browser based technology and performance/feature-rich customized and specialized applications; in order to meet the ADMS' needs, these applications visualize geospatial grid worldmaps with thousands of variables. A suitable approach consists of web-browser clients for lists, tabular displays and other "office like applications", as well as a powerful rich-client application in server-client architecture for working with large single-line worldmap-type network representations. Provided features include drag & drop, panning & zooming and opening additional frames on different monitors out of an existing frame. A library for rendering 3D scenes paves the way for upcoming requirements. Automatically loading the rich client application during run-up (if actualization is necessary) yields UI deployment with no need for "Control Center Software" installation effort.
Nowadays in most utilities, a GIS not only contains geographic maps but also large parts – if not all - of the grid-related data. A GIS Data Import tool transforms and imports maps and engineering data into the ADMS' Database Management Tool thus reducing engineering efforts and eliminating inconsistencies that may arise from duplicate data entry. Imported data – like other data entered via the Database Management Tool -can be activated into the operational databases online i.e. without operation interruption. This yields automatic and - if necessary - cyclically creation of fully operational displays (worldmaps) for the control system that have the same appearance as the geographic maps in the GIS environment. An Auto Display Builder (ADB) feature - based on thus imported geospatial information - eliminates the effort of drawing schematic displays (feeders, MV switching stations, secondary substations etc); instead they are built / constructed automatically and displayed based on the current database content when selected.

DISTRIBUTION NETWORK APPLICATIONS

The major modules of a Distribution Network Applications (DNA) suite have been outlined to some detail in [1]. Therefore only a brief summary follows here: Fault Location (FLOC) of permanent faults evaluates real-time data received from the feeder breakers, reclosers, etc, as well as leveraging impedance values returned from feeder IEDs. Fault Isolation & Service Restoration (FISR) determines a set of switching operations to isolate specified sections of the network and to restore service to de-energised areas of the network thus making sure there is no violation of substation transformer capacities and other constraints like line overloads or voltage deviations. Distribution System State Estimation (DSSE) is a robust tool for the estimation of the real-time state of the distribution network using all available measurements and load data profiles [2]. As a post-processing to DSSE, the Short-Term Load Scheduler (STLS) maintains a database of load schedules, the latter being updated with the results of each DSSE run and, if available, with data from Meter Data Management. STLS load schedules are used by any DNA module which requires load data. Distribution System Power Flow (DSPF) is an efficient tool for the evaluation of alternatives and strategies for the real-time network situation, as well as for studying planned configurations under different load and injection conditions [3]. A Distribution Contingency Analysis (DCA) determines the impact of faults and planned outages on the security of the distribution network. DCA determines the ranking of outages by means of severity indices. DCA simulation includes the effects of restoration / reconfiguration measures after an outage. Distribution Short-Circuit Calculation (DSCC) calculates fault currents in the distribution network to determine potential operating conditions and network configurations that may exceed circuit breaker ratings. Optimal Voltage / VAr Control (VVC) provides recommendations for the control of transformer tap changers, switchable shunt reactive devices and energy storages. Optimization by VVC consists of minimizing an objective function that is

user-selectable: minimize power losses, minimize active / reactive power demand, or maximize power revenue. Optimal Feeder Reconfiguration (OFR) determines switching plans and options for feeder reconfiguration accounting for equipment loading.
Thus the DNA package comprises four functional areas (Fig. 3): security analysis (YELLOW), optimization (RED), state determination (BLUE) and fault management (GREEN).

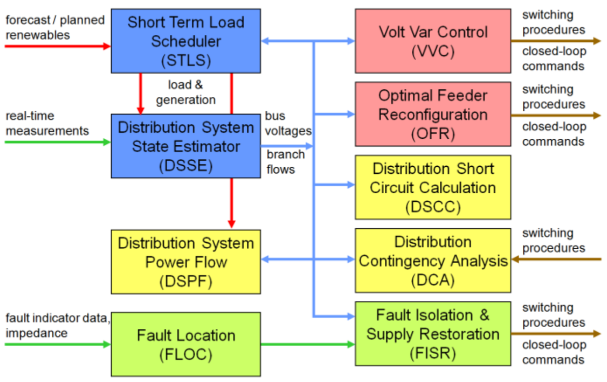

Fig. 3: Distribution Network Applications (DNA)

While some modules – such as DSPF, FLOC, FISR-open-loop, VVC-open-loop and OFR - have been in practical use for quite some years, there are new modules necessitated by the increasingly more dynamic loading scenarios of modern distribution networks, the latter caused, for instance, by increasing amounts of non-dispatchable renewable generation or demand response schemes. DSSE and STLS together provide a complete, consistent and reliable basis for any monitoring, analysis or optimization process; the closed-loop version of VVC continuously maintains distribution feeder equipment loading and voltages within defined limits and thus strongly supports the integration of renewable generation. FISR running in closed-loop, is decisive to reduce outage duration in the presence of remotely controllable switches. These functionalities make the DNA package a necessary component of an ADMS – provided this package really contains all modules.

OUTAGE MANAGEMENT

Outage Management (OM) serves to reduce service down time and covers outages, planned as well as unplanned. OM comprises processes and functions to support operators at all stages of the outage life cycle right up until power is restored.
When **unexpected events** such as ground faults or short circuits occur, any one of several indications such as a trouble call, smart meter service interruption or telemetered status change etc. causes the automatic generation of an outage record. If a switch changes state - whether manual or telemetered - a topology analysis is executed, comparing current energisation state of transformers with their previous states. If any transformer has changed state, an outage is concluded to have occurred and information of all affected switches and transformers is made available. This, in turn, is matched with existing outage records to determine whether or not a new outage record needs to be created. The FLOC and FISR applications are used to identify the fault location and define isolating and restorative switching actions.
Planned work comprises an action plan to isolate, repair or change a part of the network. The work is initiated internally or externally (for example Asset Management system) and causes the OM to create a planned work record. This type of outage record essentially consists of the identification of the respective equipment, affected customers, crew assignment, switching operations that caused the de-energisation / re-energisation, switching procedures and grid impact. Nowadays, many utilities are obliged to report supply reliability indices. OM stores the relevant source data (duration of supply interruption, number of customers affected) in the archived outage records.
Whether planned or unplanned, in both cases the user workflow includes OM sub-functions such as Crew Management (CM) and Switching Procedure Management (SPM).
A further beneficial feature is the Prediction Engine. It evaluates trouble information from all available sources, e.g. generated manually or by external applications such as CIS, IVR or by corporate websites and is able to relate those calls to a service point and associated transformer. While doing this, trouble calls are grouped and associated to a predicted outage event based on configurable rules and heuristics. OM provides the operator with customer-related information about the outage; the customer's data and outage information is always logged. The user has the opportunity to manually push a grouped outage upstream or downstream forcing it to group respectively to a common device or disperse into multiple predicted outages.
During certain peak conditions (e.g. extreme weather conditions), the OM must provide the capability to handle the large number of trouble calls from customers or via smart meters and guide and support the operator to focus on most important events. By activating the storm mode, the Prediction Engine changes the rule settings appropriately; for example:
- suppress those MDM messages and deactivate them from the Prediction Engine calculations that are related to already known outages
- filtering for more severe outages by increasing the threshold for notified trouble calls or AMI

signals that are required to move a predicted outage location upstream
- suppress local service outages from appearing on the geospatial worldmaps
- queue up trouble calls for a defined period of time before using them for prediction

WORKFLOW 'UNPLANNED OUTAGE'

The ADMS architecture supports the **seamless interplay** of applications such as geographic, schematic, tabular, list references, OM, SCADA, DNA etc. to provide a common user experience. With the seamless workflow support throughout an ADMS, comprehensive outage views and improved situational awareness, the operator can reduce outage times, prevent errors and ensure a high operational efficiency. He/she stays in control and manages the ongoing changes within the distribution grid.
As mentioned earlier, an outage can be identified by various sources. Once **trouble call information** is received in the OM or TCM, an alarm is generated and an outage icon is displayed at the predicted location in the worldmap.
From the geospatial worldmaps, the operator can gain a **fast overview** about outage locations, affected customers or available crews in the area (refer to figure below).

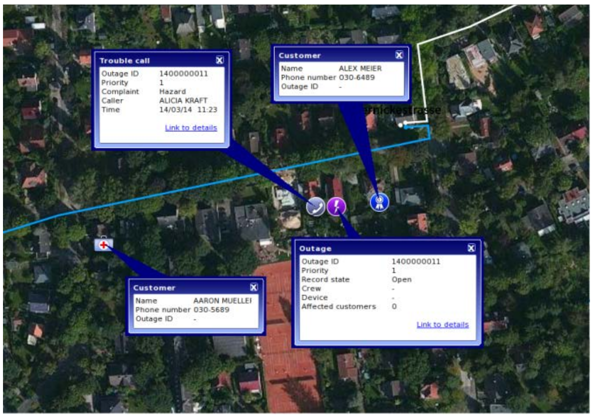

Fig. 4: Icons in geospatial worldmaps

In order to **review the outage details**, the DMS operator needs a comprehensive overview of the outage situation. For that purpose, the information of various applications are integrated thus minimizing navigation efforts, affording an interplay of SCADA/AMI/MDM system, OM, CM, TCM and the schematic and geospatial diagram viewer. These applications are typically available by clicking symbols or info-boxes on the geographic display. The OM provides the central access in order to review a summary of outages, customers, trouble calls, crews and non-premise outages. It gives detailed information on, for example, estimated restoration times, outage duration, affected equipment as well as customers, work state and grid impact.
If a new outage occurs, the DMS operator will **assess the fault**. Typically the DMS operator needs to send out a crew for investigating the fault cause and location. The operator needs to select the most appropriate crew (based on availability, skill set, equipment, and current location) and communicate with the crew. The ADMS provides means to easily handle the crew assignment: either the operator can select the icon of a crew located nearby the predicted outage location in the worldmap and assign it per drag and drop functionality to the outage record, or the operator can navigate per dynamic link displayed on the outage info-box (Fig. 4) to the outage record and gets displayed a list of crews for reviewing more detailed information on their current location, status and job assignment. The selected crew will receive the job assignment and task description, for example, per mobile device connection and can directly send the investigation outcome back to the control center.
Based on the fault cause, the DMS operator will continue with actions for **fault isolation and restoration**. This involves planning of switching procedures for one or multiple crews (depending on complexity of fault) and executing various switching actions together with the field crew. The operator can select in a schematic or geospatial worldmap the related equipment or line segment and via the context menu, directly initiate the FISR (Fault Isolation and Service Restoration) function (refer to figure below).

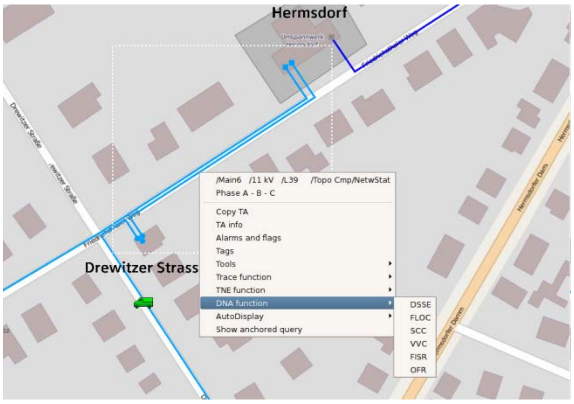

Fig. 5: Dynamic navigation to DNA modules via context menu

FISR ensures there is no violation of substation transformer capacities and other constraints such as line overloads or voltage deviations. The user can evaluate the proposed switching operations in a study context with visualization of the switching results in the worldmaps, before executing them in real-time mode. Service restoration is performed in three steps as follows:

- Power is restored to as many customers as possible (immediate restoration) with the network still in a disturbed or abnormal state.

- Problem on the network is repaired.
- Grid is restored to the pre-fault situation (full restoration).

After the outage has been restored, the relevant data is updated in the outage record. The record state is set to 'closed'. The **closed records** are moved to the Outage Management archive database. Transferred outage records are archived together with all supporting data including any switching procedure associated with them.

CASE STUDIES

The ADMS concept did not appear from nowhere but evolved over a number of years. Recent breakthroughs include web based UI technology as well as the consequential use of CIM standards. User benefits were achieved also with partial ADMS solutions in the past. One of the first implementations of a distribution management system applying numerous components of an ADMS such DNA, OM and fully operational geographic displays, was with a regional distribution company in Austria (today: KNG Kärnten Netz GmbH). Ordered in 2005, the system enabled fast and secure user orientation in geographic worldmaps which were regularly and incrementally updated from GIS. During import, a schematic worldmap was automatically generated from the geographic data. A particular benefit was a smooth workflow for outage planning and execution by integrating SCADA/OM with back office applications associated with external systems GIS and SAP – the latter for retrieving customer and customer-related equipment data. IT integration at that time was achieved using point-to-point file transfers.
A regional distribution company in Slovakia (VSE) did a further step two years later. The effort for display maintenance was significantly reduced by introducing the ADB concept. The number of integrated external systems increased to over ten. Almost 80% of the interfaces were realized by means of web services (point-to-point, no ESB). With the necessity to communicate with increasing number of partners, the user clearly benefits from the flexibility of this technology.
In the same year, an additional project was started for a large metropolitan and rural distribution provider in USA (ONCOR, Texas). Here, the user gained benefits from more accurate and more reliable load flow calculation as well as Volt/Var optimization since such analytics could be based on the results of the newly introduced DSSE application. As a particular characteristic, this implementation comprised an external OM communicating with the DNA package over an ESB. Also ESB-based, was the integration of further IT systems which – for the first time – included a Meter Data Management (MDM) system. Thus smart meter data could be used for significantly improving the load models applied in DNA.
As a final example of early ADMS implementations, a regional distribution provider in Spain (Iberdrola) is worth mentioning. Ordered in 2010, the system today comprises many features of the previously mentioned case studies. In addition, a fully automated application for fault isolation and system restoration was added.
In order to increase system availability the multi-site concept for backup control centre was applied in the Dubai/UAE (DEWA) system which went into operation in 2013.

OUTLOOK

The ADMS will continue to develop in several dimensions e.g.: the further integration of OM and DNA will allow fully automated service restoration with each intermediate step checked by load flow calculation; operator displays will be augmented by 3D-features e.g. advanced visualisation of voltage or thermal violations; the implementation of integration web services will grow with the ongoing growth of the IEC 61968 standard.
In a few years, the information contained in social media such as Twitter will be made available for outage detection in the ADMS since people tend to chat about their 'out-of-power' experience more readily than using the telephone function of their mobile device for issuing a traditional trouble call.

REFERENCES

[1] R. Eichler, 2013, "Next generation network analysis applications for secure and economic integration of distributed renewable generation in distribution grids", *Proceedings 22nd International Conference on Electricity Distribution (CIRED),* Stockholm, 10-13 June 2013, Paper 0652.

[2] I. Dzafic, S. Henselmeyer, H.-T. Neisius, 2010, "Real-time Distribution System State Estimation", *9th International Power and Energy Conference (IPEC),* Singapore.

[3] I. Dzafic, H.-T. Neisius, M. Gilles, S. Henselmeyer, V. Landenberger, 2012, "Three-Phase Power Flow in Distribution Networks Using Fortescue Transformation", IEEE Transaction on Power Systems, Vol. 99.