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INTEGRATION OF DISTRIBUTION NETWORK SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM WITH BASIC DMS APPLICATIONS

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INTRODUCTION

Electric power utilities worldwide are confronted by two major challenges nowadays, namely deregulation and the rapid development in information technology (IT). While deregulation and restructuring has brought on structural and operational changes to utilities, causing increased challenges regarding power system operation and control, the IT development has provided advanced technical possibilities for utilities to cope with these new challenges. As a result of deregulation and restructuring more cost-effective operation of overall utilities and thus operation of power systems closer to their limits is required. Implementation of modern IT based tools and applications on all hierarchical levels of power system operation and control is of a major importance in satisfying these both technical and business requirements. Therefore, powerful application tools, namely Energy Management System (EMS) and Distribution Management System (DMS) have been developed and implemented in majority of utilities worldwide in order to improve operation and control of transmission and distribution power networks. With a help of EMS/DMS application tools utilities are able to operate the system in a more efficient way and thus supply customers with good-quality electrical energy at lower prices. According to these requirements, basic EMS/DMS platform has been developed and coupled with a Supervisory Control and Data Acquisition System (SCADA) into integrated SCADA/EMS/DMS system for supervisory and control of transmission and distribution networks.

This paper presents the way of integration distribution network SCADA system with basic DMS applications, which has been developed out of the project on network applications of flexible supervisory and control SCADA/EMS/DMS system for transmission and distribution power networks. Specific features of designed architecture of SCADA/EMS/DMS are described first. Detailed architecture and overview of major functional modules of basic SCADA/DMS system are discussed further. Main functions of applicable DMS software application tools are also included in the paper. Full description of algorithm solution and software implementation of basic DMS applications for network topology (NT) and dispatcher distribution load flow (DDLF) is also described. Finally, implemented NT/DDLF software package is integrated with the SCADA system into basic SCADA/DMS system.

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SCADA/EMS/DMS ARCHITECTURE

Architecture of proposed SCADA/EMS/DMS system for supervisory and control of transmission and distribution networks which is more detailed described in (Cukalevski, Stojic, Trhulj and Jakupovic (1)), is presented in a figure 1. This modular architecture enables control system to be easily configured either as an SCADA/EMS or as an SCADA/DMS system in accordance with specific requirements of particular control centre.

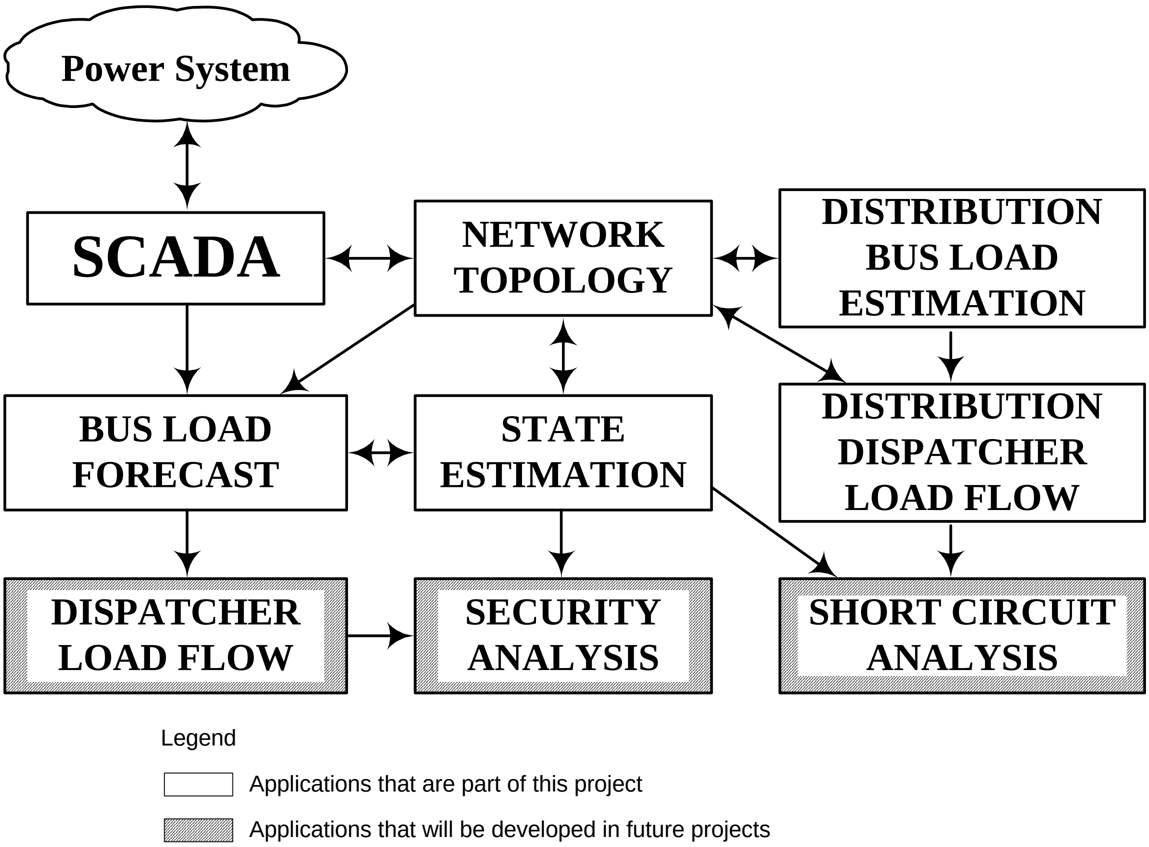

Figure 1 **-** Architecture of proposed SCADA/EMS/DMS system

This flexible system consists of following software packages:

Supervisory Control and Data Acquisition System (SCADA) is a distributed computer system that periodically acquires and processes real-time measurement and indication data obtained from remote terminal units located throughout power system and allows users to perform remote control of network devices from their consoles.

Network Topology (NT) is a function that determines configuration and energized parts of the transmission or distribution network based on the static network connectivity model and dynamic switch statuses.

State Estimation (SE) is a function which, based on redundant telemetered measurements, calculates voltage magnitudes and phase angles at all buses, real and reactive power flows, injection and currents on all branches in the observable part of the power network and thus produces more accurate, consistent and reliable data on network operating state.

Bus Load Forecast (BLF) is a function that estimates active and reactive power consumptions in transmission network buses according to their distribution factors and forecasted system load. These distribution factors are dynamically estimated according to SE output data.

Distribution Bus Load Estimation (DBLE) is a function that estimates active and reactive power consumptions in distribution network busses. Because of a very low measurement redundancy in distribution networks, this estimation is based both on available telemetric and historical data.

Dispatcher Load Flow (DLF) is a function that calculates voltages, real and reactive power injections at all buses as well as real and reactive power flows, currents and losses on all transmission lines of the network model under pre-specified system conditions.

Distribution Dispatcher Load Flow (DDLF) is a function that computes voltages, currents, real and reactive power flows on each node and branch of radial and weakly meshed distribution networks based on actual loading conditions, or based on planned system loading conditions.

Short Circuit Analysis (SCA) is a function that computes short circuit currents and voltages that could arise due to possible faults at various buses in the system or at various points along transmission lines. Short circuit calculation could be done for both transmission and distribution network.

Security Analysis (SA) is a function that determines accurate system state solution of transmission or distribution system in a situation when single or multiple contingencies occur. For pre-selected possible contingencies load flow calculations are done in order to identify potential critical contingencies and determine preventive and corrective control actions.

DMS FUNCTIONS

Network Topology is a function that determines configuration and energized parts of the distribution network based on the static network connectivity model and dynamic switch statuses. NT is a basic DMS function whose output data are used as input data for other analytical functions such as DDLE and DDLF. Main function of this software application is to determine dynamic topology of distribution network based on the network static topology and dynamic switch and breaker statuses obtained from real-time acquisition by SCADA system. This function is performed by the following subfunctions:

Determination of distribution substation configuration.
Based on a static connectivity models and dynamic statuses of switches and breakers, topology of distribution substations is determined. Topology tracing is determined by the depth-first or breadth-first search method. Number of electric nodes and substations divided in several electric nodes are also identified.

Determination of distribution network configuration.
Based on a determined substations' topology and their connectivity, topology of whole distribution network is determined. Network islands are identified. Network parts, which are energized or grounded, are determined also.

Measurement allocation.
Based on measurements' topology characteristics, allocation of measurements to appropriate distribution network element is performed. Network model variables are calculated (power injections, voltages and power flows) based on these allocations.

Error identification.
In order to detect obvious errors in topology and measurement simple tests are performed.

Network model generation.
Network model is generated using determined dynamic topology and parameters of equivalent circuit for network elements - lines, cables and transformers. Finally, node admittance matrix is generated.
NT software package has been developed using C++ programming language. It is a 32-bit application that can be run on PC LAN under OS Linux, or Windows 95/98/2000/XP operating systems.

Distribution Dispatcher Load Flow is a function that computes voltages, currents, real and reactive power flows on each node and branch of radial or weakly meshed distribution network. DDLF is one of the most important DMS software applications since its calculation results are used as input data for other applications such as Short Circuit Analysis. DDLF is based on a distribution network topology data obtained from the NT, measurement data collected by the SCADA system and estimated load values calculated by DBLE application. The algorithm used for the distribution load flow calculation is known as a compensation-based power flow method for radial and weakly meshed distribution networks described in details in (Shirmohammadi, Semlyen, Hong (2)). This algorithmic solution is capable of handling radial structure, high R/X ratios and other specifics of distribution networks. Solving of distribution load flow is based on the branch-oriented approach and direct application of Kirchhoff's voltage and current laws on nodes and branches of the network. Optimal branch numbering scheme is implemented also in order to enhance efficiency of algorithm. In order to apply this algorithm on weakly meshed networks their transformation into radial network is required first. Conversion into radial network is done by breaking of all loops in selected points called breakpoints. To compensate for the breaking, appropriate current injections are assigned to both sides of a breakpoint. These breakpoint currents are proper if the voltages at both sides of breakpoints are equal both in magnitude and phase. That is used as a convergence criterion. Initial values are assigned to breakpoint currents. In each iteration they are corrected until they converge to their final values. Each iteration is done in two steps: breakpoint voltage mismatch calculation and breakpoint current correction. Breakpoint voltage mismatches are calculated in the inner iterative procedure by the direct application of the Kirchhoff's voltage and current laws. In the backward sweep, branch currents are calculated using Kirchhof's current law. In the forward sweep, nodal voltages are calculated using Kirchhof's voltage law. Backward-forward procedure is repeated until convergence is reached. Maximum real and reactive power mismatches at the network nodes are used as a convergence criterion. Breakpoint current corrections are calculated using sensitivity matrix and breakpoint voltage mismatches calculated in the previous step. Breakpoint impedance matrix is used as a sensitivity matrix. Actually, breakpoint impedance matrix is Thevenin equivalent impedance matrix, which is determined using multi-port compensation method. Ports of the circuit are formed from the opening of the breakpoints. Breakpoint impedance matrix is a square non-sparse matrix with a number of rows and columns equal to the total number of breakpoints. Each column of this matrix is generated using open circuit breakpoint voltages and currents calculated by a backward-forward sweep.

DDLF software application has been developed using C++ programming language and object oriented technology.

Distribution Bus Load Estimation is a function that estimates active and reactive power consumptions in distribution network busses Because of very low measurement redundancy in distribution networks, a special program for load assessment is being developed. Mathematical model is linear based on correspondence between load curve of particular node in time and normalized load curves of typical consumers. Load on every node is calculated as a linear combination of values from time diagram of all typical consumers. These diagrams are determined using Bayesian estimation analysis of historic data (Handchen and Dornemann (4), Villalba and Bel (5)).

SCADA/DMS IMPLEMENTATION

Architecture of designed SCADA/DMS system, whose software implementation is in progress, is presented in the figure below

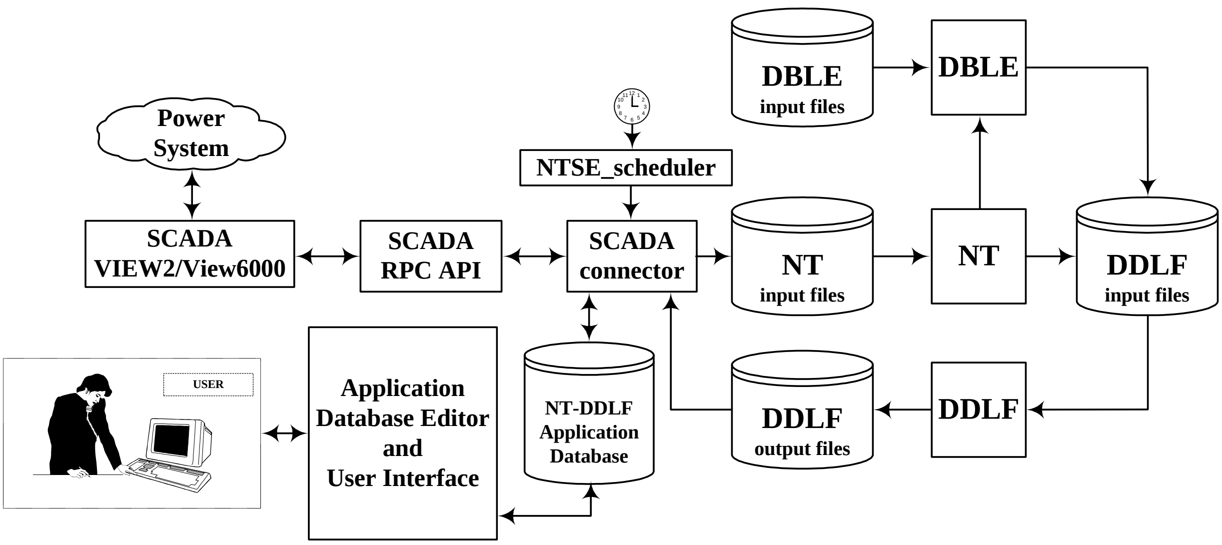

Figure 2 - Detailed architecture of integrated SCADA/DMS software package

Supervisory Control and Data Acquisition System (SCADA) is distributed system that gathers real-time measurement data of a selected set of measurement points and the status changes of network switches via remote terminal units (RTUs), programmable logical controllers (PLCs) and other data acquisition and communication devices and saves them in SCADA database. SCADA system performs analysis of collected real-time measurement values, such as checking on data limits, reasonability and communication failures. Generating alarms for abnormal data conditions and providing users with capability of remote control are also some of the major SCADA functions. Visualization of the relevant data and current operating state of the power system via one-line diagrams and graphs is performed through the SCADA Graphical User Interface (GUI). SCADA system with all its functions and acquired measurement data presents informational foundation of SCADA/DMS system and provides the basic framework for operation of Network Topology processor and other DMS applications. In most Distribution Companies in Serbia VIEW6000 and VIEW2 SCADA systems are implemented. These SCADA systems are run on Intel based PC under Linux operating system.

Application Programming Interface (API) has been developed in order to enable DMS applications to access measurement data and network switches statuses needed from SCADA system without direct communication with SCADA system real-time database. Although VIEW6000 and VIEW2 SCADA systems are run under Linux operating system, first version of DMS applications is developed under MS Windows NT/2000/XP operating system. Introduction of additional SCADA API layer between DMS applications and SCADA system based on Open Network Computing Remote Procedure Call (ONC/RPC) allows DMS applications to be run on the application server and at the same time to communicate via TCP/IP protocol with the SCADA server within the same LAN. This architecture, presented in the figure 3, allows DMS applications to be fully independent of implemented SCADA systems within a distribution control centre and thus easy to incorporate into the SCADA/DMS applications suite. API has been written in C++ programming language using object oriented technology and supports VIEW6000 and VIEW2 SCADA systems.

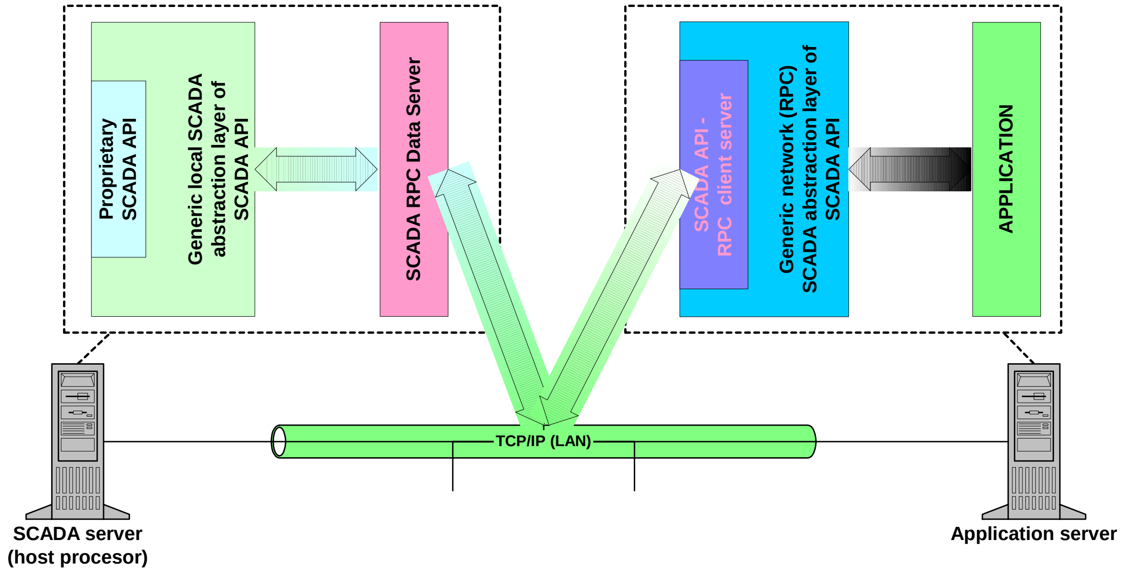

Figure 3 - API architecture for access to SCADA via LAN

SCADA connector is a software module designed and implemented for the purposes of coupling DMS applications with SCADA system and Application Database. This module provides simple shift of applications from real-time regime to study mode and reverse. SCADA connector communicate with the SCADA system via specific SCADA RPC API and with the application database via specific ODBC drivers. Main functions of SCADA connector are:

- Retrieval of network static topology from the application database via ODBC interface
- Retrieval of measurement data from the SCADA system via SCADA RPC API
- Feeding data from the SCADA system into the application database via ODBC interface
- Generating dynamic topology in a Network Topology input files' format
- Triggering of Network Topology and Distribution Load Flow applications
- Reading data from DLF output files and writing them into SCADA system for the purpose of presentation on the SCADA MMI
- Storing data from DLF output files into the application database for the purpose of their later retrieval

This architecture allows efficient adaptation of DMS applications to different SCADA systems and Application Databases.

NTDLF Scheduler is a software module developed for the purpose of automatic triggering of SCADA connector in a predefined time period. This function provides cyclical execution of NT and DLF program packages.

Application Database contains the static topology description of the network, technical characteristics of network components and other software control parameters. Application database has been implemented as relational database using MySQL RDBMS. Since the access to the data stored in database is provided via ODBC interface, any other RDBMS that has appropriate ODBC driver such as ORACLE, Microsoft SQL Server etc. could be used too.

Application Database Editor and User Interface has been developed using Microsoft Visual Basic version 6.0. Main functions of user interface are:

- Writing and modifying network static topology and parameter data in application database
- Display of output files of NT program
- Display of reports of DDLF program
- Triggering and aborting applications
- Writing and modifying software parameters

CONCLUSION

This paper presents design and software implementation of basic DMS function as well as the way of their integration with distribution networks SCADA system into modern SCADA/DMS in order to develop basic platform for flexible supervisory and control SCADA/EMS/DMS system for transmission and distribution power networks.

Implementation of SCADA/EMS/DMS system, described in the paper, would provide benefits relating to transmission and distribution system operation and control of vertically integrated electric power utilities as well as utilities operating in a new deregulated environment. With a help of EMS/DMS application tools utilities would be able to operate the system in a more efficient way and thus supply customers with good-quality electrical energy at lower prices.

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