

DEPOS: Design Environment for Power System Automation

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Abstract- This paper introduces new concept of a design environment to be used to carry out development, engineering, testing and maintenance of the power system automation equipment. This environment is based on a digital computer simulator implemented using several computers connected by a Local Area Network (LAN). The simulator is utilized in the design activities for power system control, protection and monitoring equipment.

DEPOS environment enables generation of power system signals such as voltages and currents using two methods. One is to replay actual waveforms recorded in the field by devices such as digital fault recorders. The other is to simulate power system signals using one of the known simulation packages such as Electromagnetic Transient Program (EMTP). Signals from either source are generated in the sampled form and may directly be used in this form if an evaluation of the automation equipment models is to be performed. Analog signals could also be generated if design activities are related to evaluation of the actual equipment. This is performed using D/A converters and power amplifiers.

The paper gives discussion of the DEPOS functional requirements, implementation characteristics and design methodology.

Keywords: Design, Simulation, Power System, Automation, Testing

INTRODUCTION

The problem of design environments for development of power system automation equipment is not properly valued and well defined today. The conventional practice in this area is to use different design tools for different types of equipment. As an example, one approach is used for protective relaying equipment, while a different one is used for revenue metering equipment. In the first case analog models of a power system are used to simulate fault conditions, while in the second case some high precision laboratory signal sources are used to generate calibration signals. Further more, different levels of complexity of the design environments are made available to different type of users. Research and development laboratories and manufacturing facilities are equipped with much more sophisticated design environments than what is available to the engineering firms and the utility companies. Finally, the whole design process that includes development of equipment models, prototypes and final products, as well as different evaluation levels of each of the design steps, has been considered as a set of mutually independent steps. This has led to development of different design tools and methodologies that are quite unique to each of the design steps.

Introduction of the microprocessor based technology to the field of power system automation has resulted in this technology being utilized for implementation of variety of protective relaying, control and monitoring devices [1]. Since the common basis for all of the microprocessor-based designs are digital algorithms [2], it has been suggested that the new technology can also be utilized to improve the design environments needed to develop and evaluate such designs [3].

The main topic of this paper is a new concept of the Design Environment for Power System Automation (DEPOS). This environment relates to number of activities needed to design automation equipment such as protective relays, logic controllers, Supervisory Control and Data Acquisition (SCADA) Remote Terminal Units (RTUs), revenue meters, and recording devices. The design activities include development of device models, analysis of the models using simulation techniques, development of actual device prototypes, evaluation of the prototypes using different tests, analysis of the engineering design problems by simulating different application environments, and equipment maintenance supported by trouble-shooting methodology and tools. The new concept discussed in this paper proposes that all of the mentioned design activities for all of the mentioned type of automation equipment may be supported by one DEPOS solution.

This paper provides an example of the DEPOS concept implementation. This development is used so far in evaluating digital algorithms for protective relaying and revenue metering [4,5]. Present activities are related to utilization of such a design environment in testing protection relay devices and systems [3,6].

The first section of the paper gives discussion of the DEPOS functional requirements. Implementation characteristics are presented in the following section. Next, design methodology is illustrated using examples from protective relaying and revenue metering developments. Conclusions are given at the end.

DEPOS FUNCTIONAL REQUIREMENTS

Design Environment

Typical design activities in the power system automation industry and their allocation is given in Table I.

Table I. Design Activities and their Allocation

DESIGN ACTIVITY	DESIGN STAGE	ALLOCATION
Development	Algorithm Simulation	Manufactures
	Sensitivity Study	Utility R&D
	Prototype Evaluation	
Testing	Acceptance Tests	Manufacturers
	Commissioning Tests	Utilities
	Type Tests	
Engineering	Engr. Design	Engr. Dept
	Performance Evaluation	(Manufact., Utilities)
	Trouble-shooting	Consultants
Maintenance	On-site Tests (Regular)	Utilities
	Laboratory Tests	Other Users
	(Repairing)	

Development activities usually require extensive simulation facilities where different models of algorithms, devices and systems can be analyzed. Due to the lack of the appropriate facilities to carry out this type of development work for the power automation equipment, this design stage is quite often reduced to a minimum. For the same reasons of the lack of the facilities, only the manufacturers may have this type of environment implemented and used.

Extensive testing activities are needed at both the manufacturer and the utility sites. The most common situation in the power industry is that the manufacturers have much more extensive test facilities than the users. This causes a lot of concern on the user side when some new devices and systems have to be evaluated for the first time. Another case of concern is the lack of the appropriate facilities when the user has to verify performance of a substantially repaired device.

Engineering design of the power system automation devices is heavily dependent on the simulation as well as the actual device test capabilities. In general, this activity is not very well supported by the advanced hardware and software tools, and it is usually carried out based on the rule-of-thumb experiences. In particular, equipment malfunction trouble-shooting is quite difficult to carry out with the limited design environment options.

Finally, maintenance tests are usually done by the utilities. As mentioned earlier, facilities needed to do this kind of design evaluation are limited to very simple, portable equipment. Even though this equipment is quite appropriate for routine maintenance tasks, it is difficult to use the conventional test equipment to carry out complex maintenance procedures needed for extensive repairs.

Power System Automation Equipment

Power system automation equipment performs different control, protection, data acquisition and monitoring functions in various power system operational states including normal and fault situations. This broad application area requires a number of different power system conditions to be simulated in order to carry out the design process. Some of the most typical power system signal generation requirements needed to evaluate various types of the automation equipment are given in Table II.

Table II. Requirements for Equipment Evaluation

FUNCTION	TYPICAL EQUIPMENT	EVALUATION CONDITIONS
Protection	Distance Relays	fault transients, out-of-step c.t. saturation, fault resistance
	Transformer Protection	inrush, through faults, harmonic restraint, over excitation
Control	Switching Sequences	breaker status, blocking functions
	SCADA RTU	contacts, analog signals
Monitoring	Revenue Metering	harmonics, non-linear loads
	Frequency Measurements Transient Recorders	rate of change, deviation from normal signal disturbances, triggers

The most complex requirements come from the relaying functions. Design activities are based on availability of analog power system signals corresponding to fault transients. In general, fault transients include signal components such as DC offset, harmonics, subharmonic and noise. Protection equipment evaluation also requires simulation of some "normal" disturbances such as out-of-step conditions on the lines and inrush conditions on the transformers. These conditions are needed to verify that the equipment will not operate in these conditions.

Design activities for the control equipment usually require extensive capabilities for simulating changes in the contacts corresponding to alarms and indications obtained from the switching equipment. These conditions are easily produced by a digital computer. However, some simulation of the analog signal changes, corresponding to the normal conditions of the power system operation are also needed to carry out design activities related to the V/Var and SCADA controllers.

Monitoring equipment is designed to cover various functions in normal and abnormal power system conditions. Also, some of the monitoring equipment requires only analog signals, some only contact data, and some require both. Revenue metering is a function that requires simulation of analog signals that correspond to various conditions that may affect meter accuracy such as signal harmonic content. Disturbance recorders such as DFR and SOE recorders do require simulation of wide range of power system disturbances. Included are both fault and normal conditions for analog signals and contact information reflecting switching equipment operation and malfunction.

DEPOS IMPLEMENTATION CHARACTERISTICS

Hardware

Hardware configuration is given in Figure 1. This configuration contains several computers connected via ETHERNET Local Area Network (LAN). All of the computers can be divided in two groups. One group is acting as an interface to the outside devices, and one is devoted to signal simulation. The role of the specific computer in testing different power automation equipment is discussed in the next section.

The computers that are interfacing the outside devices are used either to obtain recorded signals (HP Vectra) or to generate analog signals (MASSCOMP). Recorded signals may be obtained from the field using various analog or digital recording devices. Analog signals can be reproduced from the recorded signals using D/A converters and power amplifiers.

The simulation computers (Sun Workstation, VAX) are used to run various power system simulation programs. They are also used to simulate models of different automation equipment. Simulated signals may also be replayed to the outside devices by transferring data files to the interface computer.

Software

Functional block diagram of the software is shown in Figure 2. This simplified representation indicates that two basic design situations are supported. One is related to evaluation of device models, and the other one to evaluation of actual devices.

Design environment for device model evaluation may be used for both development and engineering activities. The early stages of device development may need extensive device model evaluation using thousands of cases of the simulated signals. Elaborate engineering activities may need evaluation of different models using specific input signals obtained by recording the most representative cases of the field signals.

Evaluation of actual devices may again be performed using either recorded or simulated waveforms. Typical application where the simulated signals may be used is the acceptance test stage where specific device design is evaluated against given application environment. The recorded waveforms may be used to perform trouble-shooting test activity. In this case the test condition needs to be replayed several times in order to analyze the wrong operation of the device.

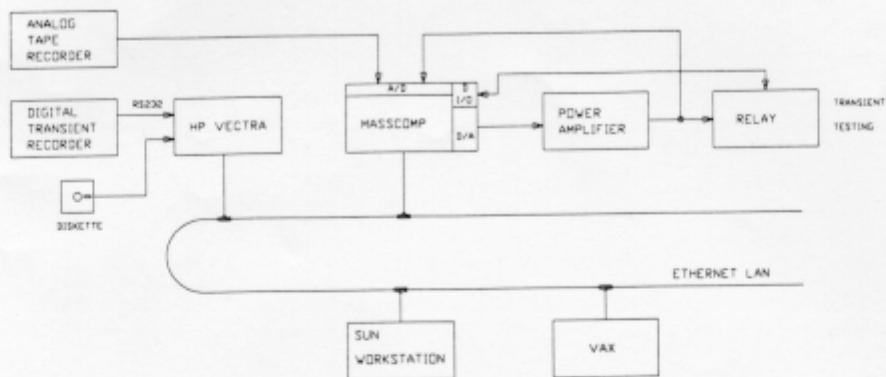


Figure 1. Hardware Configuration

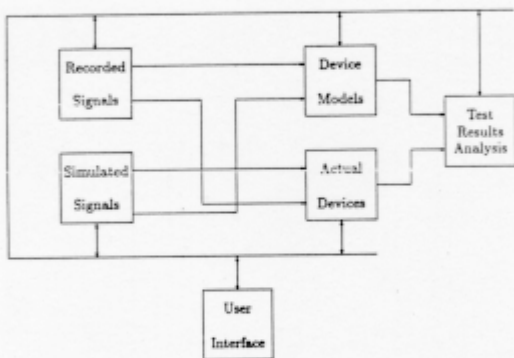


Figure 2. Software block diagram

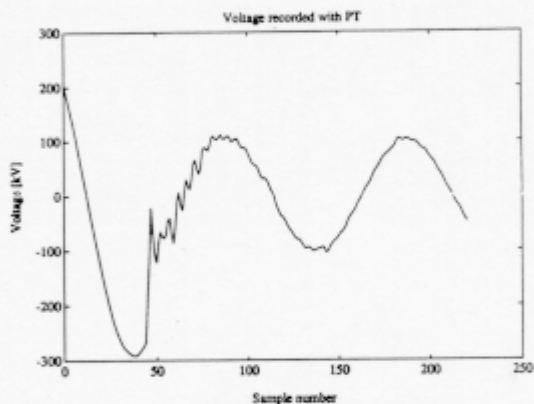


Figure 3. Fault signals recorded by DFR

DEPOS METHODOLOGY EXAMPLES

Example 1: Protective Relaying

Protective relaying equipment requires fault signals as an input. The most common approach to obtain these signals is to either record them in the substations, or to simulate them using Electromagnetic Transient Program. Typical fault signals recorded using Digital Fault Recorder (DFR) are given in Figure 3. Equivalent simulated signals obtained using the EMPT simulation are shown in Figure 4. It can be observed that the simulated signals are quite close to the recorded signals, which indicates accuracy of the EMTP simulations.

In any case, the signals are represented in a sampled form. They could be used in this form to evaluate digital algorithms for relaying [3,4]. These signals can also be used to evaluate actual devices by converting the sampled form into analog signals. Before the D/A conversion is done, filtering and decimation of the signals have to be performed in order to obtain the required output sampling rate and signal bandwidth. The analog signals are amplified so that the required output power is achieved.

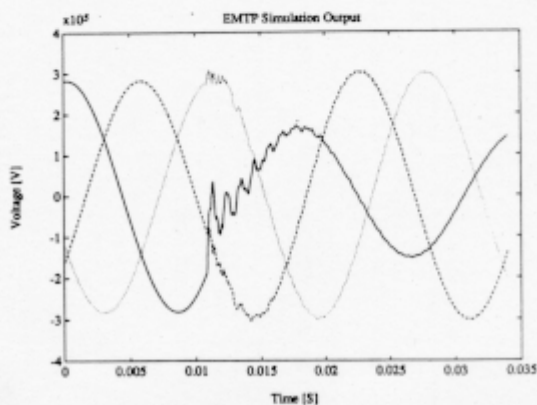


Figure 4. Fault signals simulated by EMTP

Example 2: Revenue Metering

Revenue metering tests may require distorted signals that contain different harmonics generated by nonlinear loads and other disturbances. Typical application is reactive power measurement under different level of harmonic distortion [7]. In this case the required signals may be produced either by synthesizing the desired waveform or by recording disturbances in the field. Typical representation of a recorded signal with a high harmonic content is given in Figure 5.

The revenue metering application is quite different from the relaying application since disturbances in the normal power system operational state are of interest. It is also important to determine what are exact measurements for each type of disturbance, so that precise device errors can be determined. In this case quite often a frequency representation of the signal is required [7]. Due to the fact that the signals are available in the discrete form, an extensive digital signal processing can be performed to represent the signal in different forms and to analyze it in various ways. Again, the signals can be used for evaluation of both the device models and the actual equipment.

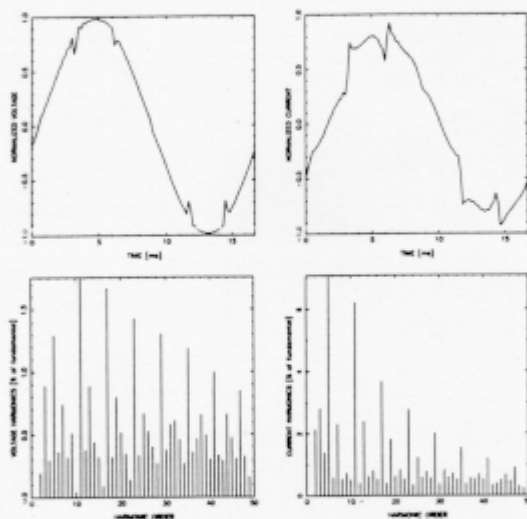


Fig. 5. Harmonic content of a recorded signal

CONCLUSIONS

This paper describes a new concept of Design Environment for Power System Automation (DEPOS). This concept has been implemented in the Power System Automation Laboratory at Texas A&M University. The DEPOS design tools have been fully developed for protective relaying and revenue metering design activities. For both classes of the automation equipment, the following activities are supported: Device model evaluation, actual device testing, engineering design analysis. Future developments will be related to extension of the DEPOS facilities to include design tools for other classes of the power system automation equipment.

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