NEW METHOD FOR COMPLICATED AUTOMATION SYSTEMS SIMULATION TEST

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Abstract – This paper describes a new method for complicated automation systems testing, particularly, power systems protective relays hardware and real-time software. Test platform is based on Monte-Carlo method utilization. A simulator produces voltage and current samples and protection device settings. A control program performs test case generation, waveform production, event identification, and result comparison. This paper will discuss the advantages of stochastic approach and determination of test case number necessary to achieve the desirable level of confidence.

Key words - Microprocessor-based devices, protective device, real-time software testing.

INTRODUCTION

Recent advances in digital technology encourage utilization of microprocessors in automation devices, particularly in power system protection as shown by Lundqvist et al [1], and Odmansson and Ohlen [2]. Compared with conventional hardware, the embedded controllers are capable of providing the enriched functionality. Santoso and Avins [3], and Redfern and Walker [4] point up that combined functions offer great advantages and on the other hand complicate the process of proving the design. The digital technologies and instruments provide new opportunities for error occurrences in software programs, algorithms, and hardware design as noted by Bernard et al [5], and Kezunovic [6]. Higher level of confidence is obtained if the digital devices are tested for conformance to the specification and for withstand of the operation environment possible in field application. For this purpose, digital simulation systems have been used since the early 80's. The simplified test system configuration is shown in Fig. 1; computer runs the test procedure that obtains input currents and voltages waveforms and control settings, examines the test case and event identification procedure, and performs comparison of the results. Here, the digital samples of current and voltage are fed to the tested device by the D/A converters and power amplifiers. Computer software that carries out these functions is available [3]. The fundamental features of this scheme are:

- Computer is used both to simulate the power system and to control the conformance of test device response to the specification.
- The power amplifiers are involved being cause of high costs and large dimensions of the testing system. In fact, typically current signals range up to about 300A in peak, while the voltage signals up to 200V in peak. The energy required to generate the signals may range up to several kVA. Frequently, modern digital relays are connected to high number of current and voltage channels. For instance, transformer protection relay could control up to 9 voltages and 9 currents, while the relay of two-terminal-based line protection controls 8 voltages and 6 currents, as minimum. High number of channels produces two types of difficulties for testing arrangement:
  - Each channel requires costly and massive power amplifier;
  - In conventional arrangement, the number of cases to test is strongly dependent on the channels and settings number.

Henville and Mooney [7] describe the system structure that does not contain amplifiers. The devices should have special low energy input channels to be tested by the system [7]. The channels are used for signal input,

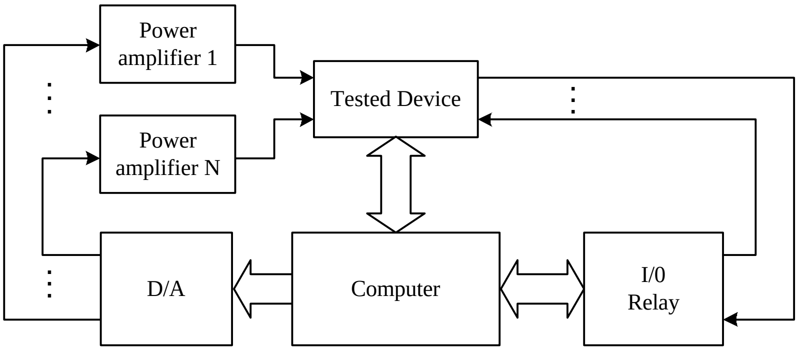

Fig. 1. Testing system configuration

which are converted to analogue form. This paper proposes new test method that, generally, utilizes simply digital signals. Subsequently, that makes it possible and rational to take the stochastic approach to the task, and employ Monte-Carlo method based procedure for test-case generation.

THE NEW TEST METHOD

New test system scheme that takes the advantages of digital technology utilization is shown in Fig. 2. The fundamental feature of this structure is the ability of the tested device to communicate with the external computer, as well as the possibility to hold in internal memory waveform data of the input signals.

Thus, for real time software and device hardware testing it becomes necessary and sufficient:

- to hold in memory waveform data of the input signals;
- to ignore input signals in testing mode, instead using the stored in memory data;
- to compare the responses of the “ideal” and the tested device, using computer simulation of device performance as “ideal” characteristic.

Let us note the requirement for storage of the waveform data could be satisfied not involving additional memory capacity, as the modern devices usually perform functions of the disturbance recording and, therefore, are provided with significant capacity of memory. That capacity is fully sufficient for holding the testing sequences.

If the digital testing signals are the only used, the isolation transformer, analogue low-pass (antialiasing) filters and A/D converter are bypassed. Each of these elements (or the whole chain) can be verified by highly simplified conventional procedure and equipment. Furthermore, the operation of input circuit elements can be tested on the basis of power system current and voltage utilization.

For the new technology application, the relay should be designed to accept the digital format of testing waveform data and to support the ability to ignore the A/D conversion results in testing mode. For this purpose special software should be developed and installed both to computer and to micro-controller of the tested device.

TESTING PROCEDURE AND NUMBER OF TEST-CASES

Protective relay tests could be divided into three categories, i.e.: acceptance, commissioning, and maintenance [5],[6]. Moreover, several types of tests are usually applied to ensure operability: steady state, dynamic, and transient [7]. For each of these test categories and types realization either deterministic or stochastic approach could be utilized.

Let us formulate the testing problem in terms of theory of multidimensional integral calculation as is shown in “Modern Mathematics for the Engineer” [8] to compare the rationality of these two fundamental approaches. For this purpose, we introduce the g -dimensional response function R and “ideal” relay definition. Supposing that function R describes the signal state at the output of tested device:

$$R = R(x_1,....,x_n,\ l_1,....,l_k,\ s_1,....,s_e) \qquad (1)$$

where $g = n+k+e$, n – is the number of controlled analog signals parameters $\underline{X}$ (equals to number of magnitudes and angles in simplest case), k – is number of controlled input logical signals $\underline{L}$, e – is number of relay settings $\underline{S}$.

Suppose then g -dimensional set of parameters $\underline{X}, \underline{L}, \underline{S}$ and settings $\underline{s}$ can be divided into two disjoint subsets (Fig. 3.):

1. Subset R_1, which accords to relay operation (triggering) requirements.

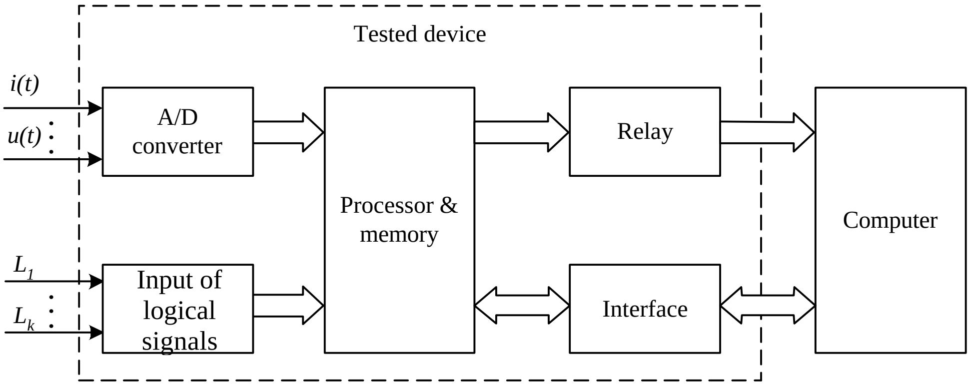

Fig. 2. Microprocessor-based automation device structure

2. Subset R_2, which accords to relay non-operation (non-triggering) requirements.

Let us assume also, that distribution functions F_1 and F_2 of parameters $\underline{x}$, $\underline{l}$ and settings $\underline{s}$ are known for each R_1 and R_2 set.

The ideal relay is defined, as follows:

$$\begin{aligned} &R = 1,\ \text{ if and only } if\, [\underline{x}, \underline{l}, \underline{s}] \in R_1 \ \text{ and} \\ &R = 0,\ if\, [\underline{x}, \underline{l}, \underline{s}] \in R_2 . \end{aligned} \tag{2}$$

Taking into account (1) and (2), we can define the probabilities:

$$\begin{aligned} P_1 &= \overbrace{\int\ldots\int}^{g}_{R_1} dF_1(\underline{x}, \underline{l}, \underline{s}) = 1 \\ P_2 &= \overbrace{\int\ldots\int}^{g}_{R_2} dF_2(\underline{x}, \underline{l}, \underline{s}) = 0, \end{aligned} \tag{3}$$

where, P_1 – is the probability of the device operation when it should operate (the inversed probability of lack of operation), P_2 – is the probability of the device operation when it should not operate (the inversed probability of the false operation).

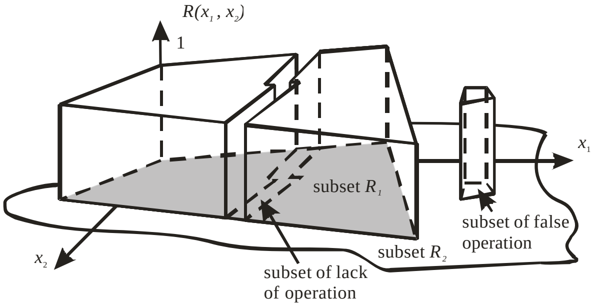

Fig. 3. Example of two-dimensional response function

For real tested devices, if the operating software or hardware contains errors or irregularities, the response function deviates from the ideal one $R_{RE} \neq R$. Thus, for tested relay one can declare: $P_1 \leq 1$, $P_2 \geq 0$.

Therefore, the conformance of the tested device to the specification could be proved by sufficiently accurate estimation of the probabilities P_1 and P_2.

In accordance with (3), the probabilities P_1 and P_2 could be calculated by use of the Stieltjes-Lebesgue integral as shown by Korn and Korn [9]. There are basically two approaches to calculation of the integrals of type (3):

- classical or regular method of numerical integration [8] that is based on partition of the integration space to high number of equal cubes. Here, the error of the calculation results strongly depends on the cubes number;
- Monte-Carlo method. In this case, the error of approximation is determined by number of trials.

Let us discuss both these approaches from the point of view of necessary calculations for the testing problem solution. For simplification, we assume the parameters $\underline{x}$, $\underline{s}$ are uniformly distributed on the interval from 0 to 1. The effect of the logical parameters $\underline{L}$ is neglected.

As it is known [8], the order of error introduced by regular approach:

$$\Delta_1 \approx N^{-2/g} \tag{4}$$

while for the Monte-Carlo method [8], the order of error is:

$$\Delta_2 \approx 1/\sqrt{N} \tag{5}$$

where N - is the number of integration mesh points for classical method or number of trials for Monte-Carlo method, $g = n + e$ considering that the impact of logical signals is neglected $k = 0$.

One can suppose that at random combination of the input parameters $\underline{x}$ and $\underline{s}$ the probability of tested device failure equals to q for arbitrary test. Thus, for sufficiently reliable detection of the failure it is necessary to calculate the integrals (3) with appropriate accuracy:

$$\begin{aligned} \Delta_1 &\leq q \\ \Delta_2 &\leq q \end{aligned} \tag{6}$$

Fig. 4 shows the dependence of necessary number of points or tests N on desired accuracy q.

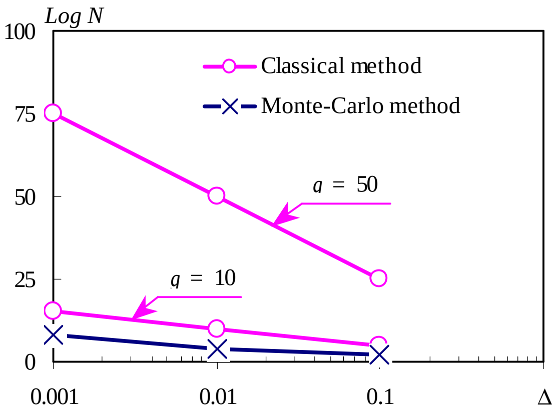

Fig. 4. Number of tests related to required accuracy and number of parameters

For approximate estimation of q, we will request the probability of the device maloperation due to unrecognized software errors or defects that lead to software errors to be not higher than probability P_A of device failure due to hardware faults for one year period of operation.

For determination of P_A, it is sufficient to know the average lifetime T_{aver} of the modern microprocessor device: this varies form 25 to 50 years [6]. Assuming, $T_{aver} = 25$ and applying the exponential reliability law, one could determine the probability of device failure during one year period of exploitation:

$$P_A = 1 - \exp\left(-t/T_{aver}\right) = 0.04 \qquad (7)$$

Under the hypothesis of $q \le P_A$, the required number of tests can be easily determined from Fig. 4.

It can be concluded from data analysis in Fig. 4 that Monte-Carlo method application is more advantageous even at space dimension $g = 4$.

Therefore, for modern devices controlling dozens of currents and voltages and holding hundreds of settings, the advantages of the method become evident and dominating. Moreover, it can be asserted that the classical approach utilization could not guarantee checkout sufficiency for modern device.

RESULTS OF TESTS AND IMPLEMENTATION

The described methodology is utilized for testing of developed protection and automation system for 110-330 kV power transmission lines. The system controls 5 voltage channels and 4 current channels, 15 logical signals and contains more than 200 settings. At statistical testing of the device, which was already checked with standard routine, two more software errors were discovered that could take an effect at relatively rare combination of settings and signal values.

CONCLUSIONS

1. The test procedure should be divided into following two parts:
    - Simplified testing of input circuits (input transformers, antialiasing filters and A/D converters). The simplified conventional equipment (including power amplifiers) can be used to run tests of this kind;
    - Testing of the correct operation performing sophisticated functions of digital signals processing.
2. The new technology provides means and tools for acquisition of primary system quantities, which used to test protection relays performance on computer simulation base. The test equipment is less costly than conventional one that contains high number of power amplifiers.
3. For new technology realization protective relays must be designed to accept and hold in memory the digital input signals, at the same time, the computer software can be based on available power system simulation tools.
4. The stochastic approach to test case generation ensures cost saving and increases the level of confidence.

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