HIGH PRECISION LEVEL MEASUREMENT SYSTEM

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Abstract: The main purpose for this work was to measure with high accuracy an analog value from one process where this value is critical. This value has an wide range of variation, has a slowly variance in time and is critical for process. At this moment there are no transducers at an acceptable cost that can cover the whole domain with required precision.
The system is based on controlling multiple transducers with an PLC-based filtering and conversion algorithm. The program was implemented already and is in testing phase to the beneficiary.
This system offers also the possibility of long time drift correction with or without human operator – based on statistical data (values obtained in real time acquisition can be stored for further statistical analysis into data base files on PC).

Key words: transducers, analog to digital conversion, PLC.

1. INTRODUCTION

This work is designated to design a high precision system for acquisition of one process variable, on witch is based the main decision algorithm. This algorithm takes many decisions for a minimum variance of inputs – that's the reason for demanded accuracy of measurement.

This system is part of one major system witch controls the hydro electric power station. For command and monitoring the hydro station processes it must provide a high safety in use, a good endurance and an improved response to the systems events. All those are realized using intelligent command units like personal computers and programmable logic controller (PLC).

The safeties in use are provided not only by proper command (based on specific algorithm for each system) but also by the concept of "self-monitoring system" that means that all sub-systems are tested periodically and any malfunction is signaled into the surveillance room (visual and acoustic messages).

Thus, numeric systems will provide real-time acquisition and backup of all information about controlled systems (this backup is putted into files and can be used for statistical analysis about each subsystem); visual and acoustic alerts of any malfunction into controlled system or into itself; visual and acoustic alerts for over-passing any of the prescribed limits; online guide for human operator and, most important, real-time displaying of the current state of the process.

2. SYSTEM CONFIGURATION

2.1. General description

The control and monitoring system consist of following blocks: transducers for analogical parameters, programmable logic controller for numerical processing and, optionally – a personal computer. We have structured this system on two main levels:

- *the higher level subsystem* - placed into the surveillance room. It is a personal computer on that is installed an application software for communication, acquisition, data analysis and saving.
- *the lower level sub-system* - placed to the nearest possible point to controlled process. This level consists of: PLC (Siemens S7 200 - for basic data analysis, decision and command), supplementary extension modules (from the same Siemens family), transducers (placed into the controlled processes).

2.2. The configuration of higher level sub-system

The higher level of this system is based on PC (IBM) that has an extension card for supplementary serial ports. This computer can be used as an interface between the human operator and the process, using the application software for monitoring and statistical data analysis.

Communication with the lower level of the control and monitoring system this computer is provided by a modem on dedicated line.

Note that this upper level is required only for further development of the system or for integrate the lower level into a bigger surveillance system.

2.3. Lower level system configuration

Lower level of this system consists in an automation cabinet, placed into the control room nearest to the controlled process – in this case at 8km distance from hydro power station. This level consists on following modules:

a) **Command unit**:

- ♦ **PLC S7-226 AC / 24 V DC / Relay,** with the following characteristics:
  - user program memory: 4 KW/EEPROM
  - data memory: 2.5 KW/RAM
  - power supply 100 - 230 V ca
  - communications ports (RS485 only): 2
  - digital inputs: 24, with optocouplers
  - digital outputs: 16, with optocouplers
- ♦ **Analog to digital converter - EM231** module:
  - Number of channels: 4
  - Inputs: unipolar/bipolar current/voltage
  - Resolution: 12 bits (recommended by manufacturer – all 15 used)

b) Analogic acquisition block - based on relative pressure transducers and intelligent measurement units for level.
- measurement range according to de value of input variable;
- accuracy: 0.1 – 0.2 % of full scale range (FS) ;
- long term drift : 0.1 – 0.2 % FS ;
- power supply : 12 – 30 Vcc
- output: 4 – 20 mA (1 – 5 Vcc).

c) Communication block:
- ♦ Adapter block RS 232 / RS 485
- ♦ Modem

In this particular application we had to measure with high accuracy the level of water into the main reservoir of hydro-electric power station. This value is further processed in order to determine the particular operational conditions of the hydro-electric power generators, in order to obtain maximum power at lower costs.

On the other hand, the same value is used by the others systems that controls the stability and the safety in use of the whole hydro station; this can prevent any possible malfunction on each level (main reservoir, secondary basins, tunnels) and provide real time information and alarms to prevent human operators.

2.4. Command and monitoring system functions

The command and monitoring system functions are:
- ♦ analogical signal acquisition from level transducers;
- ♦ real-time digital filtering of primary data;
- ♦ determination of current displayed value, based on previous values and current measured value;
- ♦ display new calculated value;
- ♦ buffers temporary lasts values in order to determine time evolution of displayed value;
- ♦ self monitoring of all modules and signaling acoustically and visually of any malfunction or issues that can occur;
- ♦ long distance transmission of new calculated value;
- ♦ local display and storage in specific and/or data-base files of the received data at the higher level – meaning PC;
- ♦ specific statistical analysis in order to determine the best way of corrections that can be made (by human operator) on local level of the subsystem.
- ♦ corrections or adjustments to the main algorithm for displayed value calculation.

4. DESCRIPTION OF THE ALGORITHM

The whole domain of physical parameter is divided into multiple sub-domains based on measurement range of the transducers. For example: if measurement range is 10m, and the range of physical parameter (level) is 50m, then this domain is divided in at least 5 sub-domains. This ensures the precision of 1mm for the entire range, even if it is used normally precision transducer. The precision of measurement is even higher if it used multiple domains, increasing the costs. Also it can be obtained an higher precision (regarding temperature span and long term drift of transducers) by using *[2*n-1]* transducers instead of *[n]*, where *[n]* is the number of sub-domains. Each sub-domain is covered by 2 transducers, as shown in Fig.1.

For each sub-domain was designated minimum 2 standard points in order to establish the corrections to numerical value that has to be considered by the algorithm when calculates the displayed value.

Also, for each sub-domain are defined – in setting operating mode – two limits (upper and lower). These limits are recalculated whit an acceptable tolerance in the main algorithm.

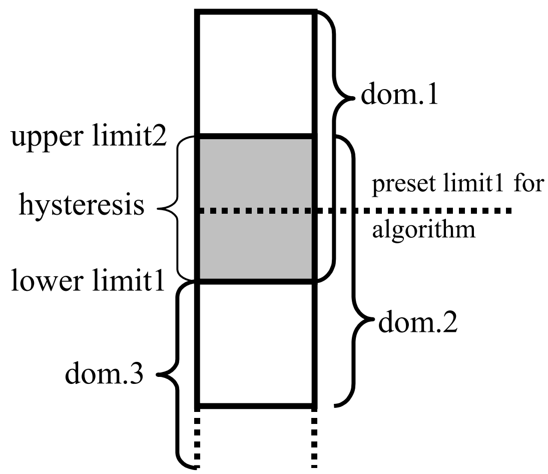

Figure 1: Subdivision of the main domain

The programs takes numerical values from EM231 module periodically, values that is proportional to the physical parameter from process. The acquisition rate is must be set in order to eliminate the perturbations of power network.

These numerical values are stored into LILO stack (defined in data memory block) and are used for digital filter implemented in program. This digital filtering – combined with acquisition cycle time – gives a good protection against electrical perturbations and also eliminates the effects of wind. It is a first degree digital filter adapted to the specific conditions of physical value (wind, waves, tide).

Upon the digital filtering, the displayed value is calculated using the following formula:

$$DysplVal = N * x1 + x2 \qquad (1)$$

where:

- N –represents the numerical value obtained previously;
- x1 and x2 – are coefficients calculated based on standard points. These two coefficients are adjusted by internal algorithm and also by human operator in the setting operating mode.

This "Displayed Value" is used into one specific algorithm in order to eliminate the errors of transducers (due to internal conversion or – worst case – malfunction).

Basically, the algorithm follows next steps:

1. on first run establish a probability rate for each domain – witch one is "current";
2. based on first step, recalculate the probability for "current" and the two additional domains.
3. the most two probable values are taken and are used to determinate the predominance of the main value over the secondary value. This is a coefficient calculated according to presets limits (lower and higher) for each domain, and takes also the next probable domain. For current proposed domain are calculated the predominance of the value over the next upper domain and the predominance over the next lower domain:

$$p_{\min} = \frac{\min[v2, v3] - L2_{low}}{hist} \qquad (2)$$

and:

$$p_{\max} = \frac{\max[v1, v2] - L2_{up}}{hist} \qquad (3)$$

where:

- L_{low} and L_{up} are the two presets limits for current domain;
- hist – are an predefined interval, set according to specific application – if is smaller then the algorithm has an lower influence over displayed value and the accuracy decrease;
- V1, V2 and V3 - are the corresponding values, calculated for each domain (for each transducer witch cover that domain);
- 2 represent the current domain, and 1 is considered the next upper domain;

4. based on each predominance is now established the right domain (witch transducer has the most accuracy value). The predominance is now adjusted in order to fit into [0 ÷ 1] range. In case of erroneous value it is an indication of malfunction of transducers or analog-to-digital converter.
5. determination of displayed value, basing on following formula:

$$Value = p * v1 + (p-1) * v2 \qquad (4)$$

where:

- v1 – the most probable value
- v2 – the next value (witch have the next probability after the main value v1)
- p – coefficient of predominance of main value v1 over the secondary value v2
- Value – the value that has to be displayed.

6. display the calculated value and store this one for the next iteration of algorithm.
7. verify the lower and upper limits of current transducer according to displayed value (an inconclusive value is signaled as an possible fault in system).

On first tests the algorithm had demonstrate a very good protection against malfunctions of one transducer. In any fault situation it is more susceptible to signaling the right transducer that has generated that malfunction. In the diagrams presented in Fig.2 there are shown some values taken from the transducers and the response of the algorithm to the simulated malfunction.

The algorithm was implemented in the PLC – it is applicable only on slow – varying systems. The response time of the system depends mainly of the window of digital filtering, a large windows offers a better result but a slow response time.

5. CONCLUSIONS

This algorithm was implemented on PLC S7-family – Siemens; that ensures not only a good endurance due to its quality of this but also enough resources to perform all tasks: reading transducers, digital filtering and algorithm iterations. The overall costs are increased using this family of PLC's but it is compensated by the lower costs of transducers. Using this algorithm there are no need for high-precision transducer.

Also it offers the possibility to perform other long-time statistical analysis in order to be used to calculate the inflow and outflow on the main reservoir.

Comparing with other similar products, this one offers following features:

- installing and maintenance low costs;

- easy configuration according to process;
- no need for scholarship for the technical personal;
- slightly auto-correction against long-time drift of transducers.

In the Figure 2 are two cases of correction, using real data series, using two transducers in labs conditions.

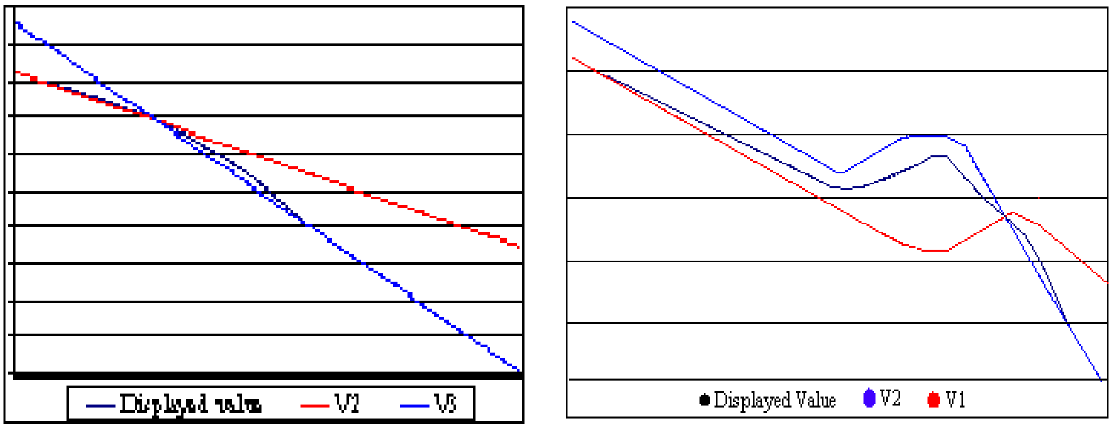

Figure 2: Algorithm results on passing to the next domain:

a. correction of linearity for the first value (v2) and reconsidered probability in order to translate to the second value (v3)
b. correction of the second value (v1), by primary value (v1), before to reconsider current domain

The next step is to implement this method on other safety/critical systems where the redundancy is needed in order to prevent disasters, like: pressure measurement in pressured tanks, level measurement on water reservoirs in hydro systems, positioning a movement detection etc.

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