ELECTROMAGNETIC IMMUNITY OF THE DIGITAL SERVO VALVES

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This paper presents a comparison between modern digital controlled servo valves and their advantages over analog controlled servo valves. Measurements were made on an original load simulation test bench to determine static and dynamic behavior of an integrated hydraulic axis, controlled by a digital servo valve connected with CANopen fieldbus. For comparison, the tests were performed with an analog controlled version of the same servo valve. Performance characteristics as well as the influences of electromagnetic interferences on the load simulation servomechanism was studied. The main conclusion of the paper is the high level of electromagnetic immunity of the digital control. This important feature will be widely used in power engineering and industrial environments.

Keywords: digital and analog servo valves dynamics, high electromagnetic immunity servo valves, and hydraulic load simulations

1. Introduction

Today's application developers of hydraulic control systems need to assimilate electro-hydraulic servo valves into the automation process. Thus, migrating from classic analog servo valves to the modern digital controlled version. This transition required the use of microcontrollers, signal discretization and discrete calculus instead of continuous analogue circuits and signals. Furthermore, the manufactures implemented widely established industrial communication protocols and application profiles for fluid power technology. By incorporating the configuration and parameterization process into the automation project management software, developers can optimize design through concurrent engineering.

The main qualities of the digital controlled servo valves are: flexibility, EMI susceptibility, distributed control and advanced diagnostics.

This paper tries to offer a complete image of the above performances in comparison with classic analog servo valves. For this purpose, a complete study was performed by the aid of a high quality equipment, promoting the high level applications in dynamic load simulators.

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2. Test bench structure and performance

The researches were performed on an original test bench (Fig. 1) built in the Fluid Power Laboratory of U.P.B. [1]. Its purpose is to control digital and analog servo valves and also to study hydraulic servomechanisms found in the speed governors of all the power plants, mobile and industrial applications. The servo valves can be control with digital commands over CANopen fieldbus and analog signals produced with a high performance signal generator. Feedback position and pressure transducers were installed to monitor the displacement and force produced by the servomechanism. The signals were acquired and analyzed with LabVIEW software.

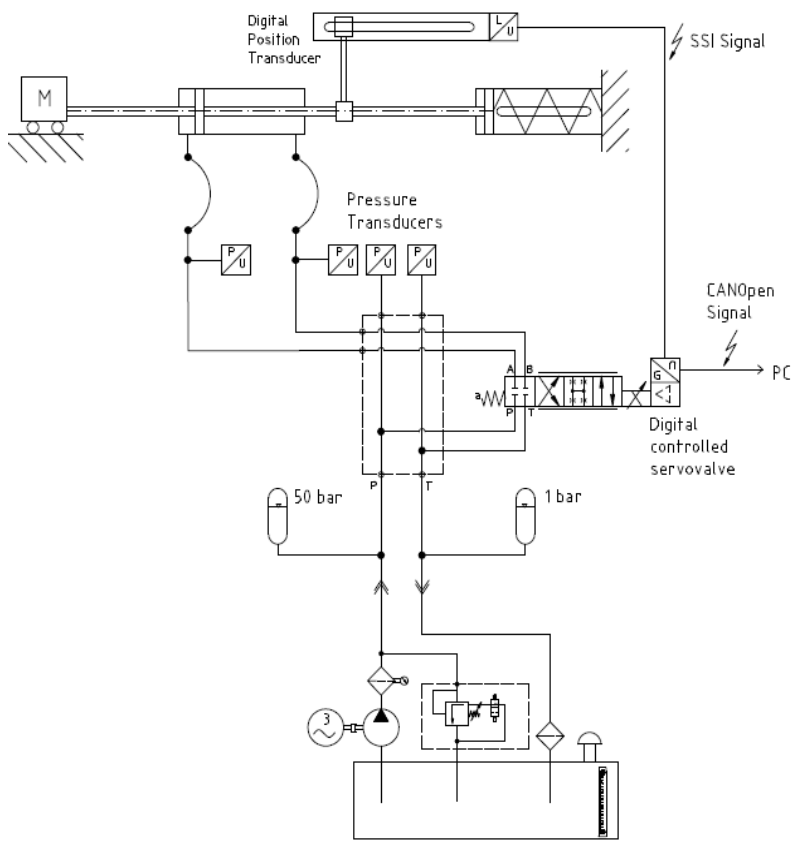

Fig. 1. Hydraulic diagram of the test bench

Basically, the test bench consists of an integrated hydraulic axis digital controlled over CANopen fieldbus with pressure and position feedback that counters friction, inertial and elastic forces (Fig. 2). An integrated hydraulic axis is a closed loop position and/or force electrohydraulic system composed of a linear actuator driven by a high response directional control valve with on board electronics capable of controlling the whole system. In our test bench for load simulations we have used a hydraulic power pack with 40L/min flow and up to 21MPa pressure supply. To reduce occasional oil hammer, two bladder accumulators were mounted on the pressure lines. As an actuating device we used a 200mm stroke double acting cylinder with □40mm rod and □63mm bore. The control was done by a high response digital proportional valve with CANopen interface, SSI digital position feedback interface and analogue pressure feedback interfaces. The position feedback is a magnetostrictive position transducer with SSI digital communication and 2μm resolution; the force/pressure feedback is composed of two analogue pressure transducers with unified signals of 0...10V for 0…20MPa; the actuated mass is a 50kg load sustained by a low friction moving platform; the elastic force is generated with a stiffness of 87,500N/m preloaded springs. As digital reference signals we used absolute position points sent though a USB to CANopen interface. With this setup we were able to perform a series of experiments in close loop with the spring-mass load, typical for a machine-tool driving axle. As an electro-magnetic interference generator we have used a three-phase electric motor placed in close proximity of the servomechanism.

Fig. 2. Image of the final test bench including all the control and driving components

3. Interconnectivity of digital controlled servo valves

The highest level of network connection, regarding speed relative to servo valve response times, seems to be EtherCAT fieldbus. This is an open, high performance Ethernet-based communication system. In comparison to other fieldbuses, EtherCAT has a very short cycle time due to communication support function handled by the slave controller instead of the main microcontroller. The slave controller uses deterministic hardware architecture like ASIC or FPGA technology to control process data operations on the fly. In our test bench we used CANOpen (Fig. 3) fieldbus due to its simplicity and reliability in mobile applications.

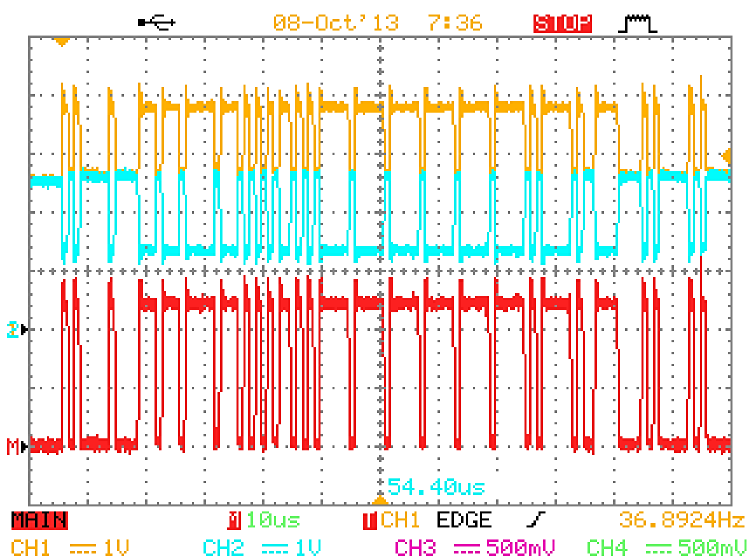

Fig. 3. Tipical CANopen message recorded during the test: logic signal (red), CAN high signal (yellow), and CAN low (blue)

Extensive studies have been published [3...5] regarding the potential impact of CAN bus faults dependent on the bus physical characteristics and the amount of Electro-Magnetic Interference (EMI) that is expected in the surrounding environment. In [2] the author presents a study on mobile machinery in which the amount of error caused by EMI is qualitatively estimated based on the number of messages retransmitted and the corresponding message delays. According to the author's conclusions, CAN bus is a robust communication protocol that can be used in harsh environments with significant EMI perturbations. A research system developed and described in [4] concluded tests in a normal laboratory environment and in close proximity of a welding process (aggressive environment) to measure the errors in CAN bus communication. Parts of the results are shown in Table 1.

Table 1

Bit error rates on a CAN bus measured in different environments

	Normal environment	Aggressive environment
Bits transmitted	1.98×10^{11}	9.79×10^{10}
Bits errors	609	25,239
Bits error rate	3.1×10^{-9}	2.6×10^{-7}

4. Digital servo valve time response

Different types of experiments were made with the digital controlled servo valve: in open loop and close loop. The open loop tests helped us to identify the time for an end-to-end and center-to-end spool movement at 5MPa supply pressure (Fig. 4). The sampled data was downloaded from the digital control valve through the CANOpen fieldbus with the aid of the manufacture's acquisition software.

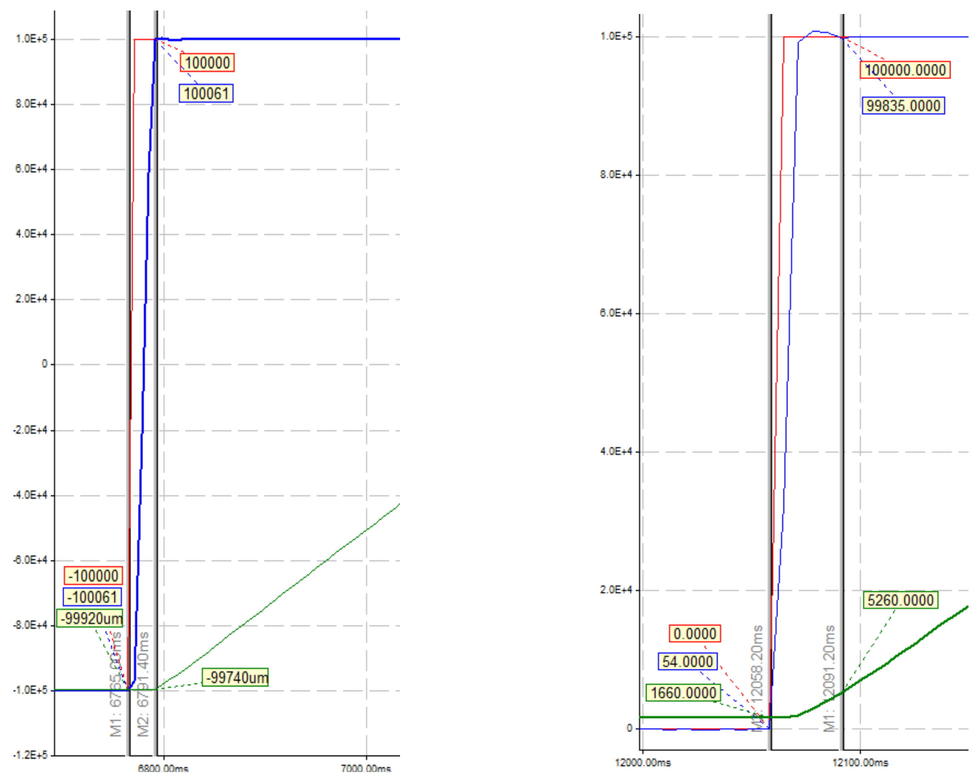

Fig. 4. Normalised end-to-end and center-to-end spool stroke evolution

If we consider the time constant τ (tau) the time it takes the spool to reach $1-\frac{1}{e}$ (approx. 63.2%) of its final position from a step input then we can say that $\tau_{\pm 100} \approx 12.6ms$ and $\tau_{0-100} \approx 4.41ms$.

5. Differences in hydraulic analog and digital controller

Another set of tests were done in close loop position with different parameters of the position controller at various pressure setting. The chosen controller type was PT_1 due to the nature of the elastic forces and mostly for comparison reasons with the analog counter valve which only has this type of controller. The digital valve controller (Fig. 5) has a more complex controller than the analogue version (Fig. 6). It has a feed forward velocity control; position, velocity and acceleration feedback; PDT_1 controller with integrator summation possibility; output adaptation specific to the servo system.

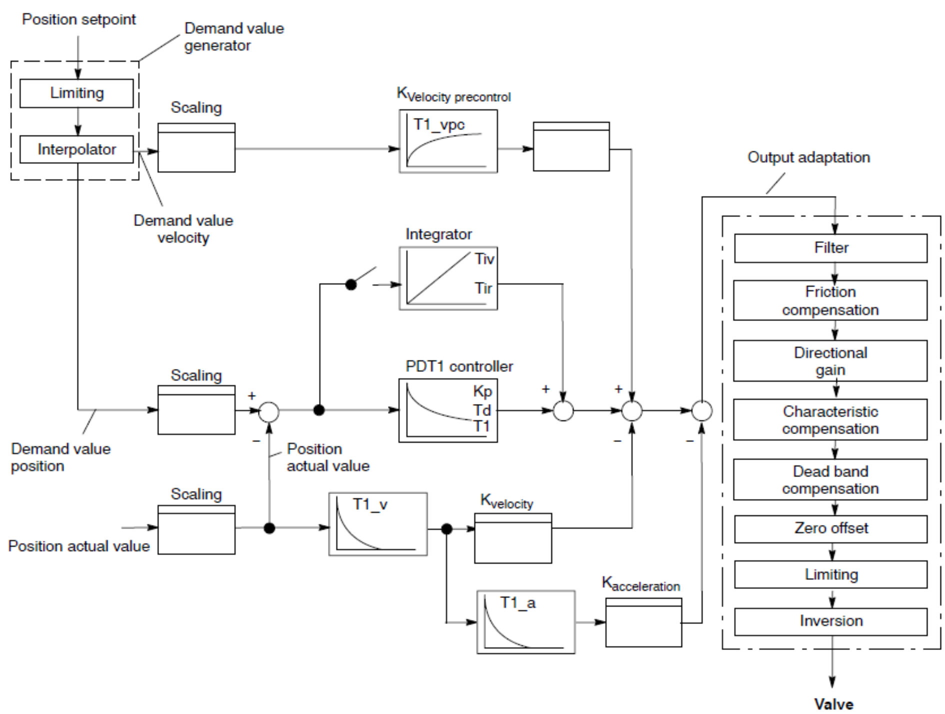

Fig. 5. Digital hydraulic servo controller structure (Bosch-Rexroth) [11]

The controller structure of the digital servo valve is designed as PDT_1 controller, in which every component can be activated or deactivated individually by varying the K_p, T_d and T_1 parameter. In this way, you can obtain a P, PT_1 and PDT_1 controller.

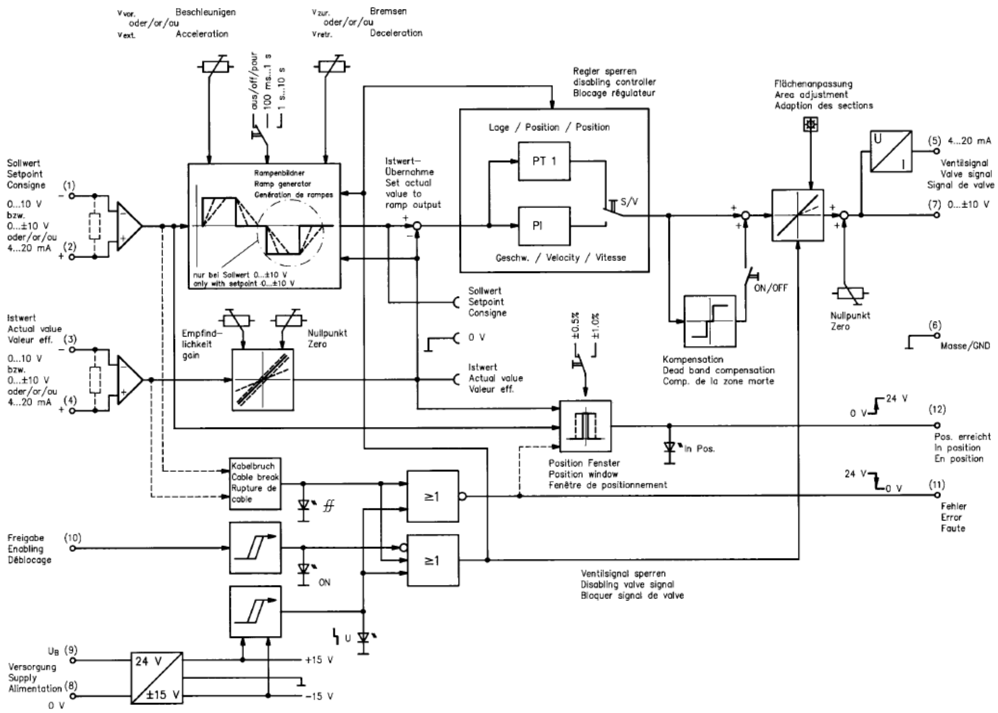

Fig. 6. Analog hydraulic servo controller structure (Bosch-Rexroth) [10]

The transfer function of the PDT1 controller in frequency domain is:

$$G_{PDT_1}(s) = K_p \frac{T_d s+1}{1+T_1 s} .$$

By setting T_d to zero, we obtain the PT_1 controller

$G_{PT_1}(s) = \frac{K_p}{1+T_1 s}$ in the frequency domain or

$H(t) = K_p \left(1 - e^{-\frac{t}{T_1}}\right)$ in time domain.

6. Electromagnetic influences on the servo valves

Further test were made by inducing an electro-magnetic noise of an electric motor running at 400VAC at 50Hz as found everywhere in an industrial environment. In fig. 7 (blue curve) is represented the spool position of the analog servo valve with noticeable fluctuations. After a close analysis of the influences, we were able to detect the noise frequency of 50Hz induced in the command value by the electric motor (fig. 8).

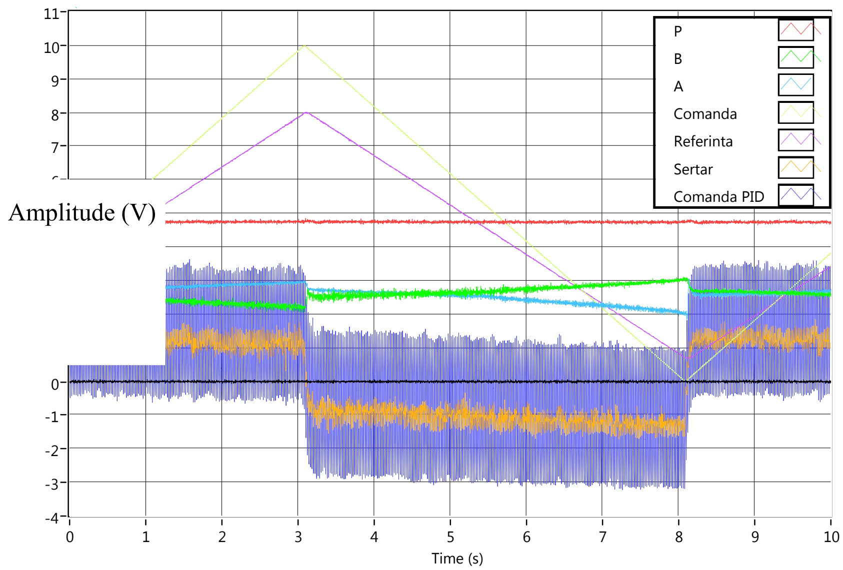

Fig. 7. Unstable spool position influenced by EMI in analog servo valves

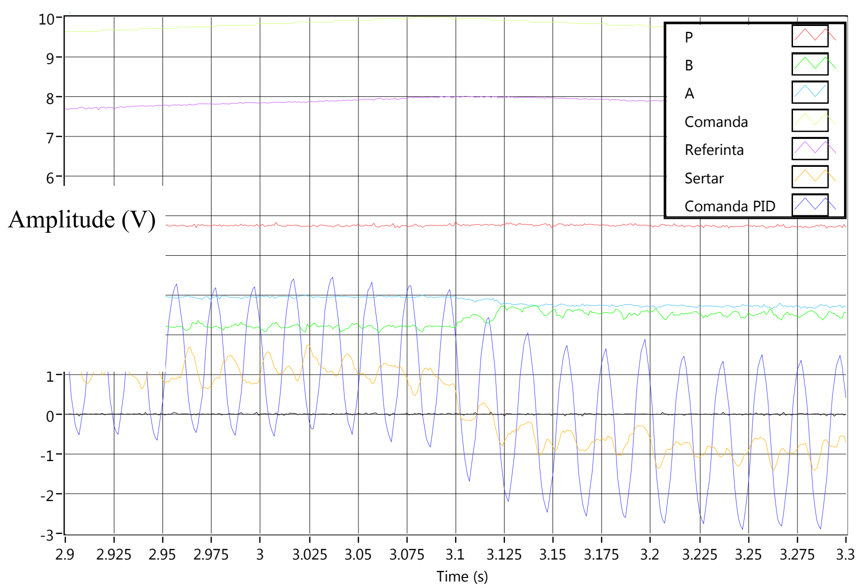

Fig. 8. Close analysis of the analog servo valve's spool instability.

Due to the mechanical nature of the test bench the noise is not picked up in the feedback circuit because of the large bandwidth differences in natural resonance frequency the low cutting frequency of the mechanical structure.

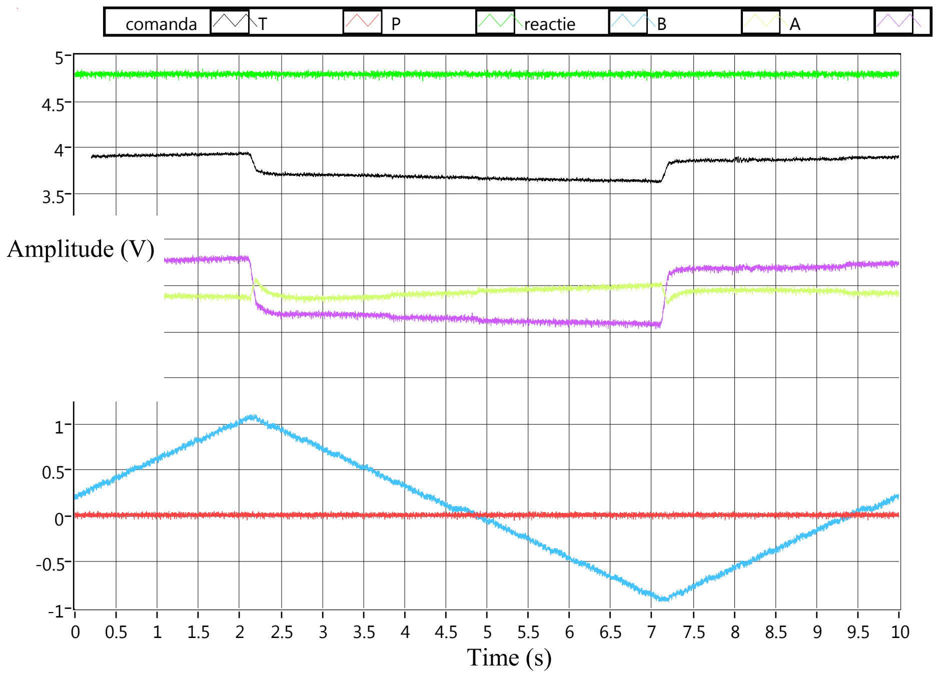

Fig. 9. Stable spool motion of the digital servo valve in EMI environment.

Same EMI experiment was performed with the digital control servo valve to compare results with the analog version. As seen in fig. 9 (blue curve), the digital controlled version is not affected by the presence of electromagnetic noise.

7. Conclusions

Most important gain of digital servo valves is the presence of fieldbus connection and device profiles protocols. Fieldbus integration was developed to replace analog unified signals (±10V, 4…20mA) transmission. This transmission has a high susceptibility to electro-magnetic interferences and signal attenuation due to long cabling and parasitic capacitance in parallel conductors. Fieldbus systems have error correction functions implemented in the communication protocol in order to significantly increase immunity to interferences. The device profiles standardization offers interoperability between same types of devices, independent of the manufacturer. While digital fieldbus communication appears to be more complex in comparison to analog systems, this method is more userfriendly, offers decentralization, enhances flexibility to upgrade and expansion, provides less wiring because of serial interconnection and improves safety, diagnostics and maintenance. Another important feature of the digital controlled servo valve is the built-in feature of a servo axis controller inside the On Board Electronics. This way, the complex tasks of the position/force controller are assigned to local devices, reducing the complexity and the processing power required by the main Programmable Logic Controller or Industrial PC.

There is also a drawback to fieldbus communication in hydraulic servo systems due to the high dynamics of servo valves. This demands high speed data transmission and high processing power, which is difficult to realize without expensive DSP microcontrollers or FPGA. A good quality of the electric power supply network [12], continuously monitored in SMART GRIDS, is an important way for protecting both analog and digital servo valves operation.

The author's research will be applied to some important industrial projects from the hydropower engineering field [13].

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