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Multi-Sensors Systems using Semi-Active Control for Monitoring and Diagnoses of the Power Systems

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Abstract. The work presents the studies and research in order to implement new techniques concerning semi-active control of the magneto rheological dissipaters dynamic systems with applications to the antivibration isolating systems and the reducing of structural vibrations of the power systems. Starting with a new technique of active control with magneto rheological dissipaters of dynamic systems' vibrations is developed a real time control system in distributed and decentralized structure which allows the reducing of the vibration level, eliminating the resonance frequency, monitoring and diagnoses of power systems for smart microgrid.

Key words: smart microgrid, intelligent semi-active control techniques, magneto rheological damping, real time control systems

1. INTRODUCTION

Smart Microgrid (SMG) will represent the switch to a more flexible network topology that will allow two-way power flow between the grid and small-scale distributed energy resources. In this way cooperation will increase between consumers and utilities to reduce peak loads and optimize resource allocation and efficiency.

Implementing the Smart Microgrid will lead to an exponential increase in the amount of information coming from the grid and being fed to network operators, thus ensuring a more reliable, environmentally friendly and economically viable power grid. With the help of markets and real-time system information, utilities will be able to work in unison with consumers to produce the most cost-effective and efficient supply mix.

Smart Microgrid main components are: micro-turbines, solar photovoltaic cells, wind turbines, Plug-in Hybrid Electric Vehicles and grid energy storage units enable increased bi-directional power flow between power distributors and end-users.

This paper introduces a new component of a smart micro-grid system which leads to reducing of the vibration level, eliminating the resonance frequency, monitoring and diagnoses of power systems, while integrated into an open architecture system which fulfils the requirements of a SMG. In order to eliminate the resonance frequency we apply a semi-active control technique by using magneto-rheological dissipaters dynamic systems. For monitoring and diagnoses several intelligent control methods are used: plug and play process control, neutrosophic logic control and fuzzy control.

2. MAGNETO RHEOLOGICAL DAMPER SYSTEMS

The use of MR (magneto rheological) fluid dampers in semi-active vibration control have attracted large interest due to their simplicity, reliability and ability to describe the imposed control functions. They area of use is very large. General Motors, and Delphi Systems, for instance announced that vehicle suspension using MR dampers are available. Lord Co. presents the RD series, which consists of truck seat dampers. However the use of the MR Fluid dampers are not restricted to vehicle applications. There are many studies on the use of MR dampers for seismic protection of buildings during earthquakes or in the semi-active control of sagged cables [1, 2]. Recently the military has shown interest in using MR dampers to control gun recoil on field artillery. The MR fluids are materials that have the property to change their reological characteristic when a magnetic field is applied to them. The change usually consists of an monotonically increase of a yield stress, proportional to the magnetic field's level.

The formation of parallel columns type structure is induced when applying a magnetic field, through the interaction between magnetized dipoles (figure 1). The reduction of the liquid's moving speed is explained by the mechanical energy

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necessary for overcoming the formation of these parallel structures, resembling chains. With the increase of the magnetic field applied to the MR liquid, there is a considerable increase in both its viscoelastic behaviour and the mechanical energy, resulting in a field dependent yield stress [6,9].

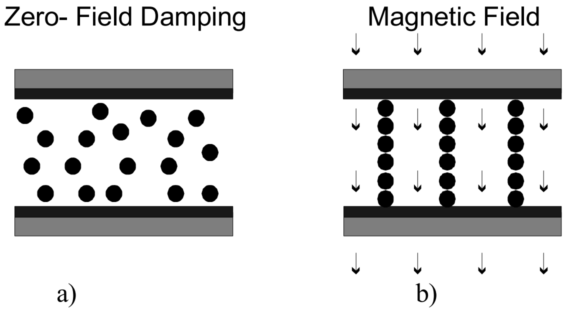

Fig.1The MR fluid at zero-field damping (a) and within a magnetic field (b)

The MR liquids are less known than the electro rheological liquids (ER). Both consist of polarized particle suspensions, non-colloidal, with micrometer scale measurements. Jacob Rabinow is considered to be the researcher who discovered the MR liquids, due to his activity after 1940. In parallel and in competition to him, Winslow researched ER liquids. This research led to more patents and published papers up to 1950, without generating any notable applications. After almost 40 years, interest in these MR liquids has been once again raised through the works of Starkman (1991), Kordonsky (1993), Weis and Carlson (1994), which led to increased performance and the emerging of new applications such as controllable MR shock-absorbers used for the suspension of auto-seats, shock-absorbing systems for automobiles, etc.

2.1. Stand for Real Time Measuring and Control

The trial stand for real time measuring and control of the vertical vibration induced by the centrifugal force is presented in fig.2. The driving system consist of a 3kW m_1 engine which drives an eccentrically disk D_{ex} of m_3 mass. In order to obtain oscillations of the entire mechanical system by controlling of the electrical engine m1 an elimination of material from the D_{ex} disk was obtained in the form of a circle sector of approximately 18^0. The mechanical system subject to vibrations that is suspended from the base frame by two elastic lamellas L_e consists of a rigid metallic frame - C_M on which there is also suspended an m_2 mass. For the damping of the entire system an MR liquid shock damper is used. The control of the m_1 engine is achieved through an ACS frequency convertor controlled by an PLC [5].

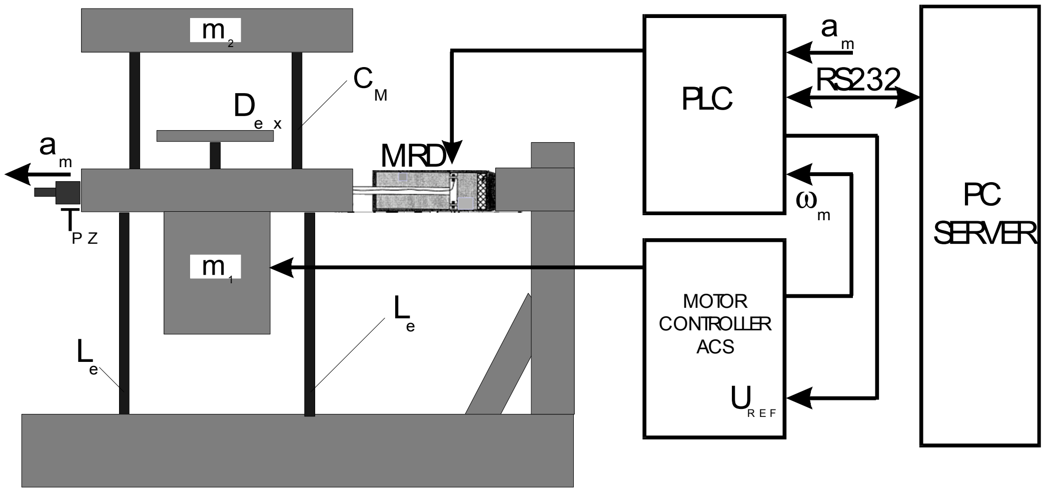

Fig. 2. Stand for Real Time Measuring and Control of machinery rotating with magneto rheological damping at high speed

A computer with great processing power determines the mathematical model of the mechanical system dynamic behavior. The computer sends back to the PLC, off-line, a reference signal made on the basis of the mathematical model. In the active control phase the magneto rheological system behaves as an actuator with the role of energy dissipater in a PID loop. The reference signal is generated by the PLC on the basis of the data received from the computer. The gain, integration and derivation variables of the feedback loop are tuned through a PLC real time control system.

For the teach-in phase implementation, there is generated a m1 engine rotation speed with a linear slope and slowly variable, so that one may process and determine in real time, in a cvasi-simultaneous fashion, both the amplitude of the oscillation of the mechanical system with the $\mathbf{T_{PZ}}$ vibration transducer with piezoceramic elements and the m1 motor's rotation speed **(ω_m).** The two signals, measured in real time, are stored by the PLC to form the system's transmissibility function, and sent by serial cable, off-line, to a PC server. After the numerical processing in the PC, the data is resent by serial cable to the PLC and stored in the EPROM.

In the control phase, the PLC receives the rotation **(ω_m)** from the frequency convertor and generates, on the basis of the transmissibility function stored in the EPROM, the control current $\mathbf{i_{MRD}}$ of the dampening to the magneto rheological liquid damper- MRD.

2.2. The MR damper Modeling

The equation of motion, modeling the vertical vibration induced by the centrifugal forces of the unbalance as the machine is running down with linearly decreasing rotational speed (corresponding to constant friction torque) is [7,8]:

$$M\ddot{x} + f\{x, \dot{x}, i[\omega(t)]\} + kx = me\omega_0{}^2\left(1 - {}^{t}\!/_{t_s}\right)^2 \sin \omega_0 t\left(1 - {}^{t}\!/_{2t_s}\right)$$

where:

- M-sprung mass (machine and foundation);
- m-unbalanced mass; e- excentricity;
- ω_0 -nominal rotational speed;
- t_s -time interval to attain full stop;
- $\omega(t) = \omega_0 t\left(1 - {}^{t}\!/_{2t_s}\right)$ -variation of rotational speed from nominal value to full stop;
- $f\{x, \dot{x}, i[\omega(t)]\}$- damping force developed by magnetorheological device for supplied current $i[\omega(t)]$
- k -stiffness coefficient of vibration isolation system;

According to the representations of Philips(1996), the MR liquid controlled through a magnetic field behaves like a plastic deformable material of Bingham's equations. In this way, considering a stress τ on the field yield stress τ_y , the debit is determined through the Bingham equation [4]:

$$\tau = \tau_y(H) + \eta\ \dot{\gamma},\ \text{cu}\ \tau \geq \tau_y, \qquad (1)$$

At a yield stress having a 10^{-3} order strain the material becomes viscoelastic, characterized by the relation:

$$\tau = G\gamma,\ \text{cu}\ \tau \leq \tau_y, \qquad (2)$$

where G is the complex module of the material, which is dependent upon the applied magnetic field (Weiss, Carlson, 1994; Nakano, Yamamoto and Jolly 1997). When there is no magnetic field present, the MR liquid has a Newtonian characteristic. The model generated by the relations (1) and (2) was the basis for the researches regarding design for the real time control system.

3. PLC SYSTEM FOR REAL TIME CONTROL

The PLC system structure (Programmable Logical Control) is presented in figure 3 and is composed of three main modules:

- The analogical signal acquisition and logical control module
- Teach-in control module in phase 1
- Active control module in phase 2

The control commands are generated by the operator: start-stop, disc rotation and work mode choosing, instructing, active or PC server communication.

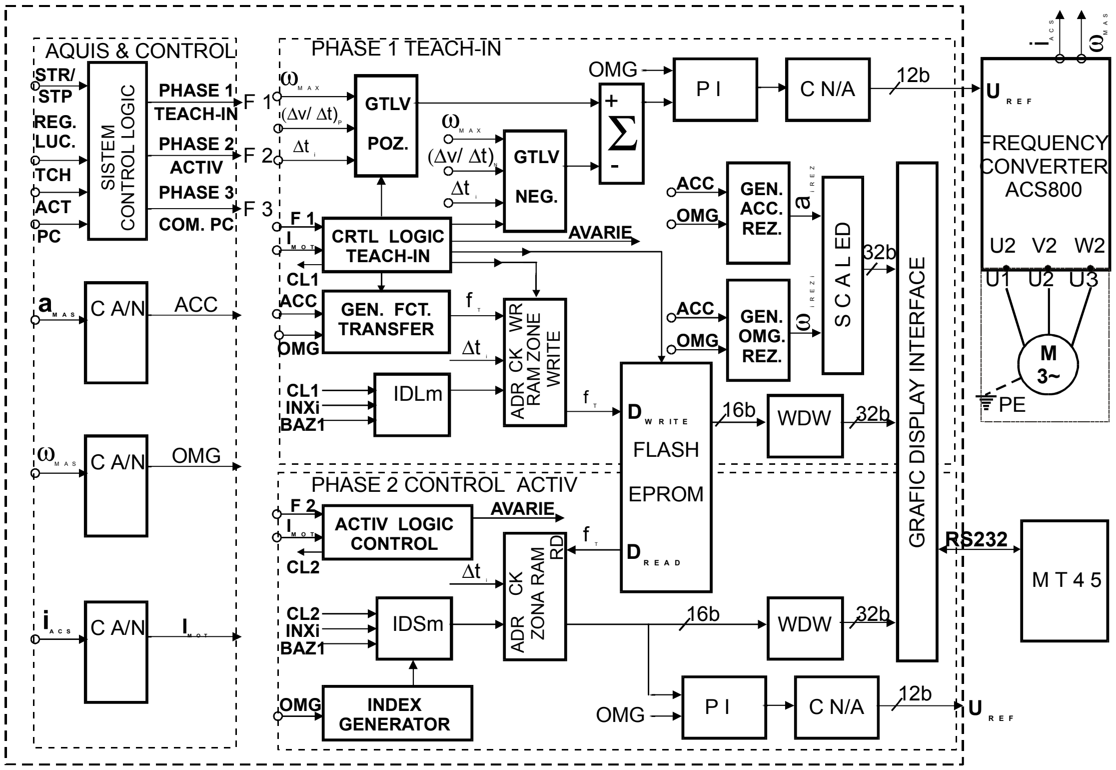

Fig.3.Real Time Control Systems for the Active Control with the Magneto rheological Damping

From the input signals a_{mas} and ω_{mas} through analogical-numerical conversion with a 12 bits resolution, the numerical values ACC and OMG are obtained.

In the teach-in phase 1, references for the control of the D_{ex} disk rotation speed are generated, through GTLV POZ and GTLV NEG. The maximum rotation speed ω_{max} , the slope of the rotation speed variation ($\Delta v/\Delta t$) and the sampling period Δt_i are taken into account. These parameters are stored by the operator from the MT45 graphical terminal or are transmitted by serial cable from the PC server.

Transfer functions generated are realized through (IDLm) indexed addressing where INXi index is processed as report between ω_{max} and Δt_I sample period thus the memorized value to fit to measured speed. Because the obtained speed value from traducer is a sinusoidal signal it was necessary to obtain the cover signal for it. More than that, the PLC allows to view maxim speed and sound frequency through numerical memory of this values, there scale and MT45 transmission.

In active control phase is generating in real time command i_{MR} current of magnetically field of magneto rheological liquid damper - MRD. In this case, it is realized an index reading from EPROM memory of ACC speed value report to OMG rotation speed. The resulted value is input for SCL scale module and analogical converted with 12b resolution to generate i_{MR}. Also, by 32b conversion and serial transmission to MT45 numerical value of command current of i_{MR} magnetic field could be read on graphic terminal.

4. MULTI-SENSORS DECENTRALIZED AND DISTRIBUTED SYSTEM STRUCTURE

This control method also addresses to applications with a greater number of rotating machines placed over a large space. In this case, there was developed an open architecture system with decentralized and distributed structure which allows the real time control of rotating machines (figure 4). The open architecture system [3;5] executes in the teach-in phase a test cycle with (a_n, ω_m, i_{MR}) date vector acquisitions in condition of zero field damping for magneto rheological liquid damper- MRD. The received data are serial sent to a PC server which, through numerical processing, generate transfer functions between i_{MR} command current of the liquid MR magnetic field and the rotation speed of the machine.

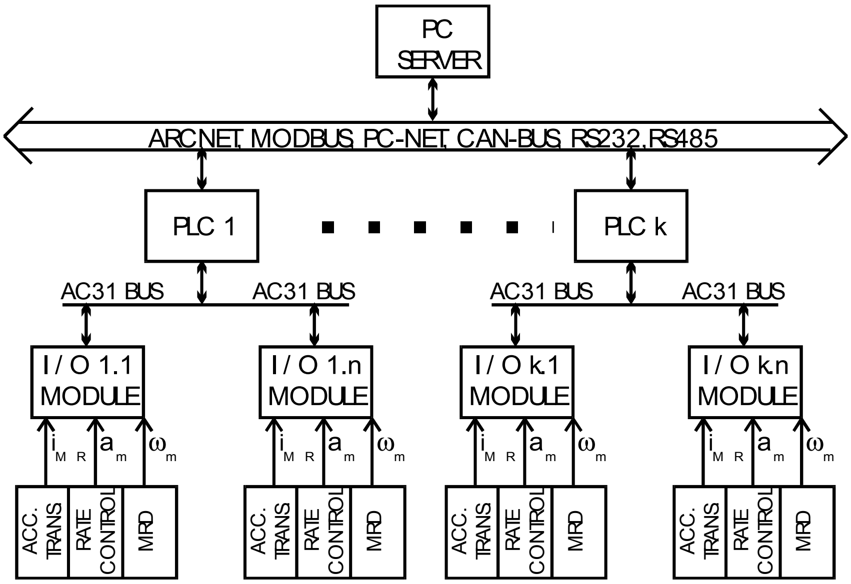

Fig.4. Real Time Control of Rotating Machines using Multi-Sensors Open Architecture System

These numerical values are serial resent in off-line mode to PLC which are memorized in EPROM memory and are used in the adjusting loop as reference for real time control of the level of damping.

Another possibility is for phase 1 control method to be auto teaching. Thus, the teach-in function would acquire in each cycle or pre-established time periods, with on-line transmission of numerical values to the PC server. *The data received by the PLC* after being processed by the PC server will enter into the i_{MR} current adjusting loop for the MRD real time control damper to which there will be applied the fuzzy adjusting method. Of course, this approach will impose the use of PLCs with much lowered time cycle and a high-speed communication bus (ARCNET, PC-NET,CAN-BUS, fiber optic, etc.).

4.1. Open Architecture System for Smart Microgrid

Designing a mathematical model that is complete enough for smart micro-grid study is of interest both from the point of view of achieving a high quality system for intelligent control, as well as with the aim of verifying the underlying principles and simplification hypotheses which are the basis of algorithms used in real time control programs. With the aid of such a model of the control system, a considerable part of the algorithm hypotheses can be evidenced and eliminated from the design phase, which leads to less time and effort during computer simulations.

The control system is distributive with many process areas, sensors and periphery equipment such as: LAN network for offline communication, CAN fast network for online control, digital and analogue interface modules, etc. By using distributive open architecture control, the informational load on the main controller is diminished. For this we developed a slave control system and communication lines to the main (master) control system. The system was conceived as open architecture (OAH), in distributed and decentralized structure, to easily allow for the development of new applications or adding new hardware or software modules for new control functions. Figure 5 shows the general configuration of an open architecture system for the smart micro-grid using magneto rheological dissipaters dynamic systems and intelligent control.

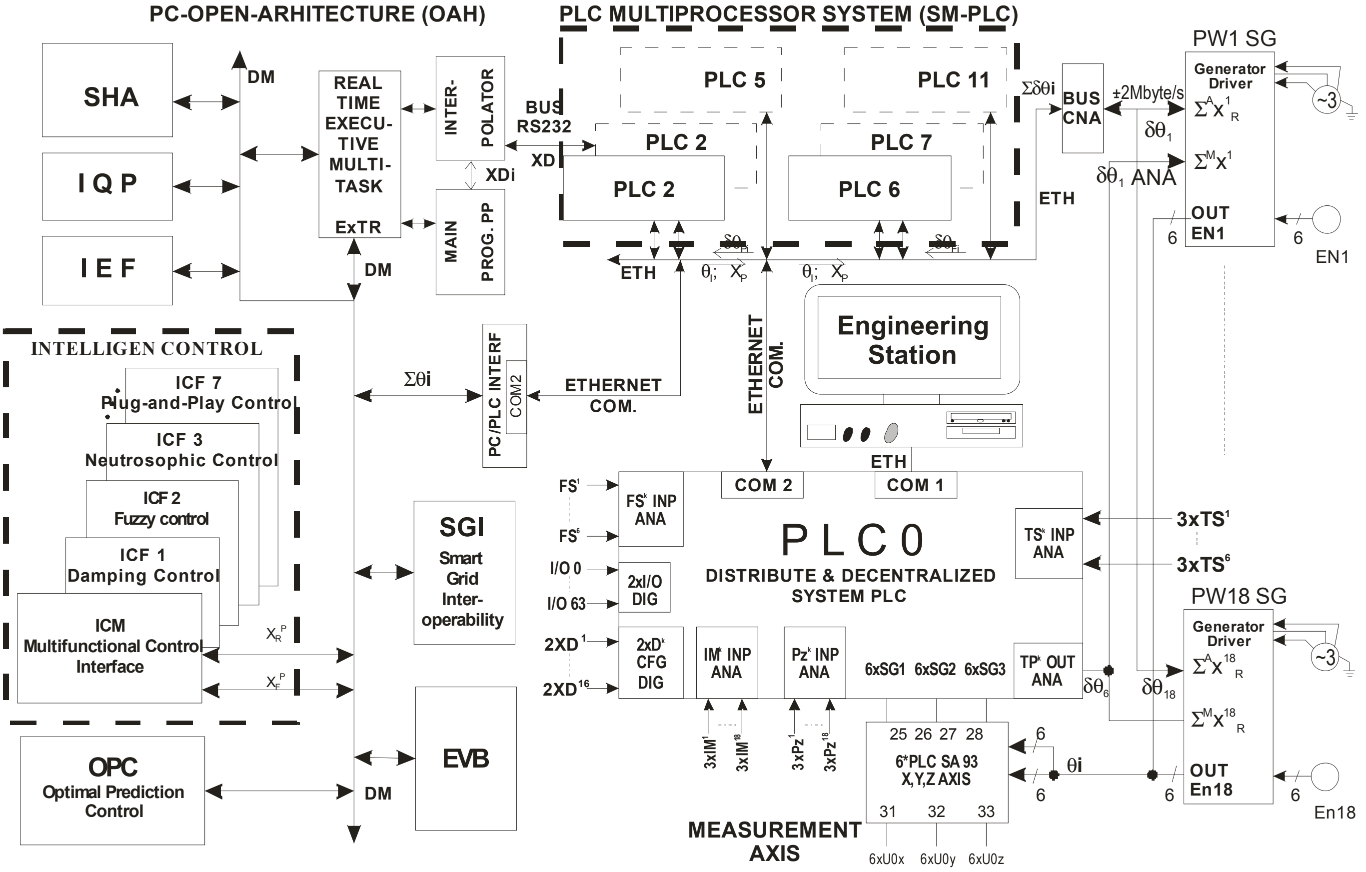

Fig. 5. Open architecture system for smart microgrid using magneto rheological dissipaters dynamic systems and intelligent control

The following outlines succinctly the new control modules. The open architecture system provide the following characteristics for the Smart Micrgrid:

- **Self Healing and Adaptive (SHA)**, which will consist of continuous self assessments to monitor and analyze its operational status.
- **Improved Quality of Power (IQP).**
- **Integration of a Wide Variety of renewable energy sources.**
- **Improved System Reliability.** The Smart Microgrid will provide dynamic, real-time monitoring, control and optimization of grid operations and resources, by implementing advanced network visualization, a more efficient balance between demand and supply, cyber security, significant reductions in residential peak demand energy consumption,
- **Increased Efficiency (IEF).** Advanced power electronics will improve the quality of the power supply by allowing for variable-speed operation of electric generators and motors, controlling reactive power.
- **Environmental Benefits (EVB).** Improved integration of smaller generators in the distribution system will increase the role **of renewable energy supplies in meeting regional demand**.

Smart grid interoperability is the basis for the system implementation, which ensure the capability of different systems and devices to communicate and operate effectively with one another in a “plug-and-play” fashion.

Intelligent control methods is used for implementing a smart microgrid with plug and play operability are: fuzzy control, neutrosophic logic control and plug and play process control. The **Plug-and-Play Process Control** (ICF7 Interfece Control) is the main part of an adaptive system that can be upgraded with new sensors/actuators in a easy to use way. The system detects new signals, and determines their usefulness and exploits it in an optimal way over time. The two main ways to reconfigure the control system after the detection of other signals are to recreate the entire design or network which is controlled, or by adding new nodes and features on the existing design or network. The modeling and update is done using a closed loop. To redesign the control system one can use **the fuzzy** (ICF2 Interface Control) or **the neutrosophic logic** (ICF3 Interface Control). By using these two approaches the control system can be upgraded to meet the new requirements based on the updated list of sensors and actuators.

The programmable logical controller in decentralized and distributed structure (PLC0) ensures the control of power from the PC-OPEN to the PLC and continuously transmits data referring to process. The PLC0 is processing 60 analogue inputs, 16 digital output, 18 analogue outputs, and other 64 digital inputs/outputs configurable for auxiliary functions. The PLC Multiprocessor system (SM-PLC) ensures the real time control of power systems PW1-PW11 using a network of microprocessors PLC1-PLC11 which implement the intelligent control algorithms.

5. CONCLUSIONS AND RESULTS

In this paper is modelled and studied the semi-active control of power systems integrated into a smart micro-grid system using magneto rheological dissipaters dynamic systems and intelligent control.

The research issues are about maximisation of the efficiency, plug-and-play operation with respect to the grid, robustness to environment fluctuations, environmental impact, reliability of the system, etc.

The real time control methods presented herein for improvement the performances of power systems allow a better approach to larger applications with a high level of vibration isolation of rotating machines.

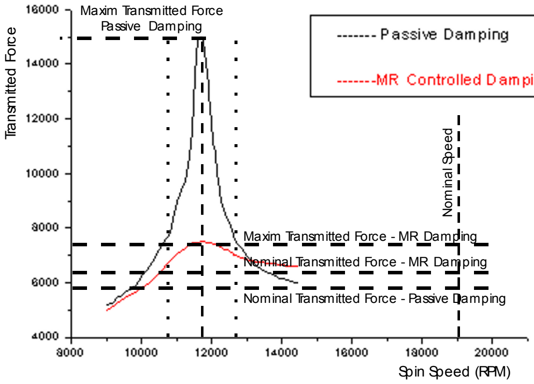

Fig.6. Overload of vibration resonance level

There is obtained a reduction of the amplitude of oscillations to the resonance frequency of the mechanical system, with a transmissibility function slightly superior to the oscillations' amplitude at nominal speed, with positive effects on the wear and performances of the machine. The experimental results lead to the reducing about 90% of overload of vibration resonance level (fig.6) through semi-active control of the mechanical systems subjected to excitations with linear variable speed.

By using intelligent control methods such as plug and play process control, neutrosophic logic control and fuzzy control integrated into an open architecture system allows for the monitoring and diagnosis of power generators, while leading to improved performance on the part of the smart grid power systems.

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