Realization of a "Band-Stop" Device to Damp Inter-Area Oscillations with Intervention into the Turbine Governor

Dr. Lajos Kiss and József Zerényi

Abstract – **We can observe in all electrical systems in the world, cc. 0.2,…,0.35 Hz oscillations in state variables in steady state operation. The amplitude of these – so called inter-area oscillations – is growing going away from the centre of a large electrical power system. In the UCTE (European) system in the centre (near the German - French border) the amplitude of oscillations in frequency deviation time function is less then 2 mHz and near the borders (at present: Greece, Poland, Portugal, Romania, etc.) greater than 6 mHz, in steady state operation. Our ten years' experience has shown that PSSs, realized with "conventional" stages are not efficient in inter-area frequency domain. In addition, these instruments have a disadvantage: there are frequency intervals in the operating range of PSSs in which the PSSs increase the amplitude of active power oscillations and reactive, too; which are exported into the network. In our former activity we presented the model investigation to solve the problem by intervention into the turbine governor [1], [2]. In this paper the realization of the method is shown.**

Index Terms **– Turbine primary governors, Inter-area oscillations, Large electric systems cooperation, Damping of active power and frequency oscillations, Constructing and tuning of PSS, Time-frequency analysis, Power system dynamics, FFT analysis.**

I. NOMENCLATURE

s: Laplace operator [sec^{-1}], f_0=50 Hz,

f_N: network frequency, Δf_N: network frequency deviation [Hz],

$\Omega_1 = 2\cdot\pi\cdot f_{t1}$, $\Omega_2 = 2\cdot\pi\cdot f_{t2}$ [sec^{-1}] where: f_{t1}, f_{t2}: the tuning frequency of he "Band-Stop" filter number (1) or (2) respectively,

D_1, D_2: damping coefficient [sec^{-1}],

Δf_N: network frequency deviation time function [sec^{-1}],

Δf_{m1}, Δf_{m2}: modified network frequency deviation time function (modified by "Band-Stop" operation) [sec^{-1}],

F{ΔP}, F{ΔU}: Fourier transformed function of the active power and terminal voltage deviation time function [MW], [p.u.],

SF{ΔP}, SF{ΔU}: Summarized Fourier transformed function of the active power and terminal voltage deviation time function, based on [5] [MW] [p.u.].

II. INTRODUCTION

The electromechanical oscillations can be classified into four categories:

- Local oscillations between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 2.0 Hz. (In the Hungarian case: local mode cc. 1.2 Hz).
- Inter-plant oscillations between two electrically close generation plants. Frequencies may vary from 1 to 2 Hz. (In the Hungarian case: Hungarian groups of units swing against the neighboring system; cc 0.5 Hz).
- Inter-area oscillations between two major groups of generation plants. Frequencies are in a typical range of 0.2 to 0.8 Hz. (In Hungarian case: the former CENTREL systems swing against the rest of UCTE system 0.2,…,0.33 Hz).
- Global oscillation characterized by a common in-phase oscillation of all generators as found on an isolated system. The frequency of such a global mode is typically under 0.2 Hz. (In our case: in the UCTE system cc. 0.025 and/or cc. 0,0125 Hz).

With the "conventional" PSS structure containing low-pass and high-pass filters and two lead-lags we can't reach a satisfactory damping effect in all operating frequency ranges of PSSs. But employing this type of ***p*** or ***f*** input PSS can easily damp the natural frequency of (cc. 1.2 Hz) active power oscillations of generators.

We can reach a better damping effect accepting the IEEE proposals namely: IEEE PSS 2A/2B and 4B structures. The manufacturers offer their own similarly sophisticated solution, too. But in consequence of the principle of operation: by damping the amplitude of active power deviations the amplitude of reactive power deviation will be increased in the case of all PSSs mentioned above. Despite this PSS + exciter devices the inter area oscillations exist and we can observe them in steady state and during transients, too; and not only in the UCTE system [**3**]. But by employing our simple method these disadvantages of PSSs + exciters can be eliminated in the circumstances of the tuning frequency.

III. REALIZATION OF SUPPLEMENTARY TURBINE GOVERNOR STAGES

In the first step we had to choose an old unit where the turbine governor is realized with analog stages. We can't install a new element into a modern microprocessor based governor at the moment as an experiment. But after the field tests and trial operation have been executed successfully we will begin this activity. The principal scheme of the analog scheme of the "Band-Stop" filter is given in Fig. 1 [**4**].

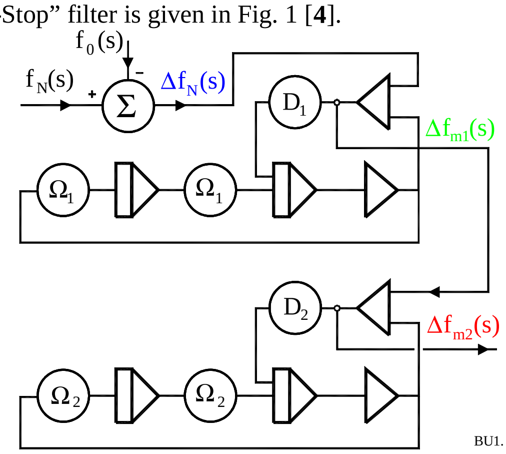

Fig. 1 *Principal analog scheme of the "Band-Stop" filter equipped into the speed controller circuit of the unit*

For the easy connection to the existing turbine governor our realized “Band-Stop” filter stage contains the frequency deviation measuring element, too. As we can see in Fig. 1 for the better damping result the “Band-Stop” filter tuned 0.25 Hz is realized with two series connected filters. The first stage of these is tuned to 0.2 and the second one is tuned to 0.3 Hz. Its transfer function is pictured in Fig. 2

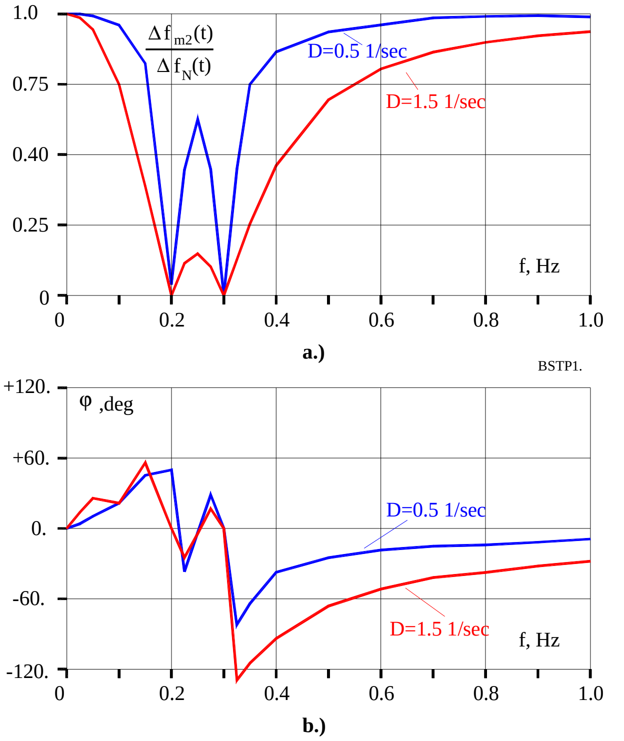

Fig. 2 *Transfer function of the “Band-Stop” filter stage.* ***a.)*** *transfer function for amplitude of the filter stage,* ***b.)*** *phase shift of the filter stage*

In accordance with Fig 2 the operation of the “Band-Stop” filter meets our requirements in steady state. In our solution D = 1.5 1/sec is chosen. The performance of the filter stage isn’t influenced by the great change of the phase shift of the filter.

IV. The Impact of “Band-Stop” Filters on Network Frequency Oscillations

The frequency deviation time function, measured in a field test in steady state operation, on the investigated 62.5 MVA generator terminal is given in Fig. 3. The $\{\Delta f_N(t)\}$ time functions are results of a 1200 sec continuous measuring action, but time functions are divided into 12 parts. It is visible to the naked eye that the inter-area oscillations in frequency deviation time function with cc. 0.25 Hz frequency are there.

These $\{\Delta f_N(t)\}$ time functions are modified by the “Band-Stop” filter stage which is installed into the turbine governor (see Fig. 4). The impact of “Band-Stop” filter stage on frequency deviation time function is demonstrated in Fig. 5 in two chosen cases. The very effective damping effect of the filter stage is visible. An additional result is that we can read the value of the amplitude of the frequency deviation time function of the border of the Hungarian system in 2009. Its greatest value may be 5 mHz, which is demonstrated in Fig. 5 a.), and may be observed between a cc. 26 – 32 sec time interval. Its value is cc. 5 mHz.

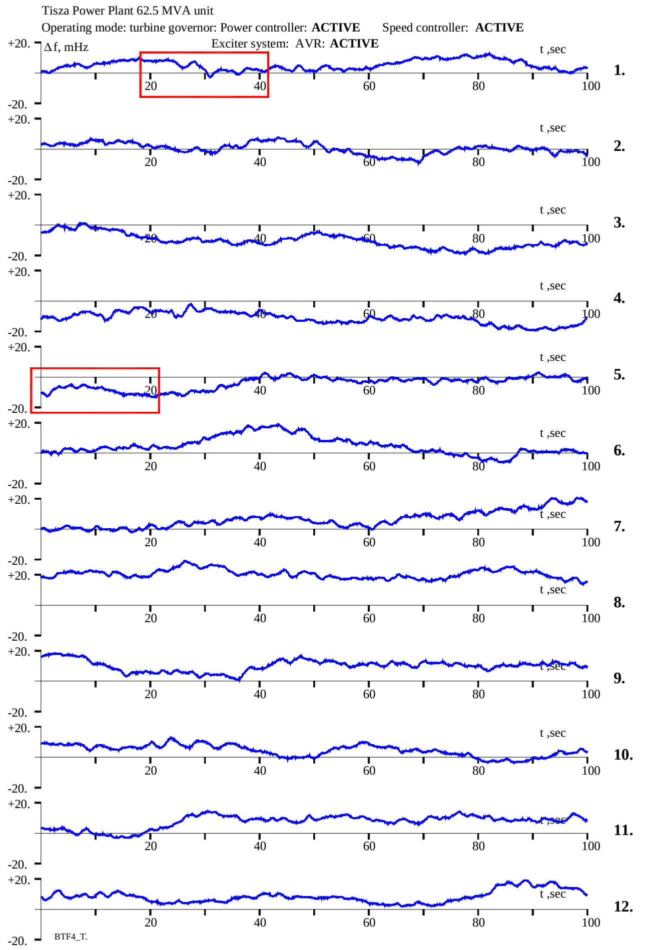

Fig. 3 *Field test results of frequency deviation time functions on Tisza Thermal Power 120 kV bus in steady state operation;* $\{\Delta f_N(t)\}$ *measured in mHz.*

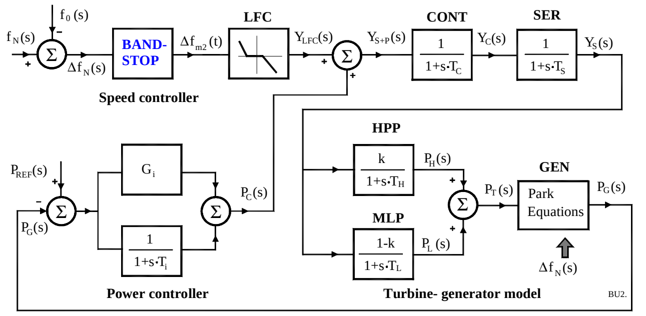

Fig. 4 *Thermal turbine model with “Band-Stop” filter (simplified structure). In figure:* ***LFC****: Static Load Frequency Characteristic stage,* ***CONT****: Controller stage,* ***SER****: Servo motor unit,* ***HPP****: High Pressure Part of turbine,* ***MLP****: Middle and Low Pressure Part of turbine. (The model given in this Figure is a general scheme. In our case the 62.5 MVA unit contains only one turbine part.)*

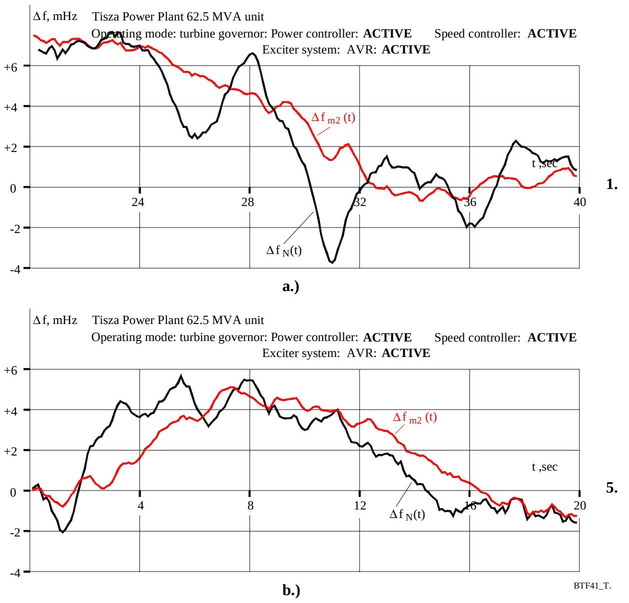

Fig. 5 *The impact of "Band-Stop" filter stage on network frequency deviation time function; measured in field test;* ***a.)*** *the framed interval of No 1. and* ***b.)*** *the framed interval of No 5. In this case D = 1.5 1/sec*

V. ASSESSMENT OF THE IMPACT OF "BAND-STOP" FILTER'S OPERATION IN ACTIVE POWER AND TERMINAL VOLTAGE DEVIATION OF THE UNIT

In field tests the main aim of our activity was to determine the effect of the "Band-Stop" filter stage on the inter-area oscillations. With our methods elaborated [**5**], we can determine the effect of the "Band-Stop" filter stage, without disturbing the normal steady state operation of power plants. In our field test procedure the turbine governor power controller and speed controller circuit was **active** in all cases. A power controller out of operation mode in the Hungarian system is not allowed. It would be very important to measure it in cases of out of operation of AVR, but it is not permitted in the Hungarian system, either. So AVR was active during in the whole field test procedure. PSSs are not installed into this old generating unit. In order to separate the effect of the main parameters which influence the inter area oscillations and especially the role of the "Band-Stop" stage the following two field test cases were performed:

- "Band-Stop" stage **out** of operation (**OFF**),
- "Band-Stop" stage **in** operation (**ACTIVE**).

The results are pictured in Fig. 6 and Fig. 7, where the Fourier transformed function of the active power deviation time function and voltage deviation time function are given. We can adjudicate the impact of the "Band-Stop" filter stage on the amplitude of active power and voltage deviation with naked eye in the frequency domain 0.15,…,0.35 Hz.

To determine the effect numerically we compose the summarized Fourier transformed function of the active power deviation and terminal voltage deviation.

The impact on active power deviation of the generator is:

$$100 \cdot \frac{0.03 - 0.027}{0.027} = 11.1\,\%$$

and the impact on terminal voltage deviation of the generator is:

$$100 \cdot \frac{2.25 - 2.03}{2.03} = 10.8\,\%$$

The numerical value of the impact of the "Band-Stop" filter depends on the frequency coefficient of the static load frequency characteristic. During the field test its value was 0.1 MW/mHz.

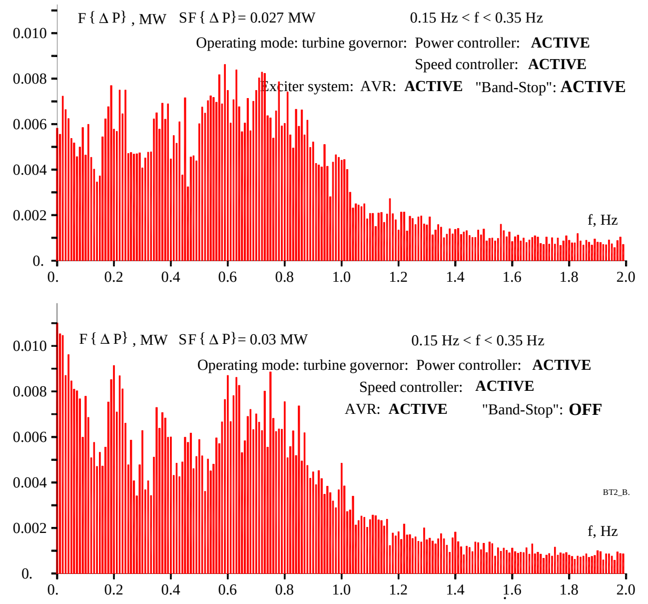

Fig. 6 *Fourier transformed function of the active power deviation time function of Tisza Thermal Power Plant 62.5 MW unit. (spectrum lines derived from field test results)*

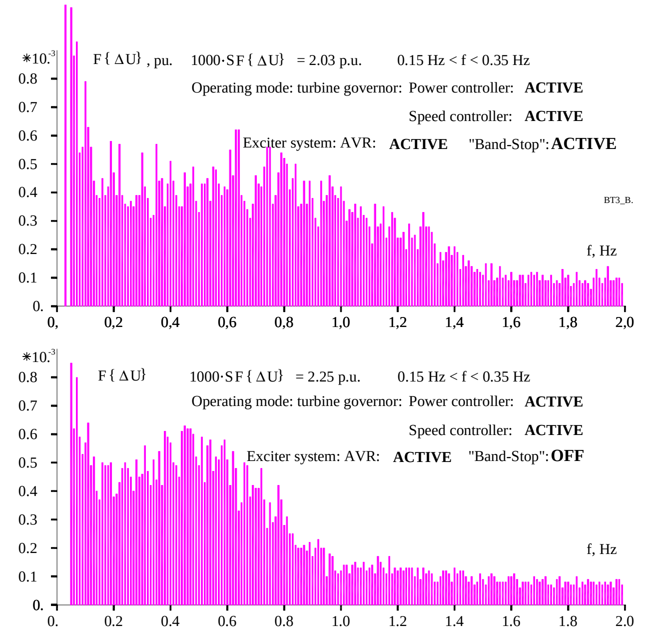

Fig. 7 *Fourier transformed function of the frequency deviation time function of 220 MW Tisza Thermal Power Plant 62.5 MW unit. (spectrum lines derived from field test results)*

We have to see clearly that the impact of the "Band-Stop" stage will be greater than the value which was pointed out in this chapter of the paper. Because the operation of PSSs makes voltage deviations on the high voltage side of the set up transformers of units. These oscillations spread on the network change the terminal voltage of the busbars. This phenomenon will be the source of an additional active power deviation on the transmission lines and as a consequence of this deviations will arise in the network frequency (Δf_N). In this manner we will be given a positive feedback for (ΔP_N). and (Δf_N); making interference on the state variables of the system, which we can observe e.g. in frequency deviation time function (Δf_N) in steady state and in transient operation, too. We can observe this phenomenon in Fig. 3 where the frequency deviation time function is pictured. The gain of the controlling loop mentioned above can be decreased with our method. These facts underline the importance of our method, on damping the amplitude of inter area oscillations by turbine governor interventions.

VI. CONCLUSIONS

Despite the sophisticated PSS + exciter devices the inter-area oscillations exist and we can observe them in steady state and during transients, too; and not only in the UCTE system (See Fig. 3).

It is reinforced by our field tests that there are frequency intervals in the operating range of PSSs, in which the PSSs increase the amplitude of active power oscillations and reactive, too, which are exported into the network.

By employing our simple method the disadvantage of PSSs mentioned above may be avoided. We can decrease the amplitude of active power oscillations and terminal voltage (consequently reactive power oscillations) simultaneously.

We have to see that this “Band-Stop” filter stage doesn’t replace the operation of PSS functions, because this stage is tuned only for one of the inter-area modes. But it is very useful and effective on the border of a large electric system where the amplitude of frequency deviation is greater then cc. 5 mHz.

VII. REFERENCES

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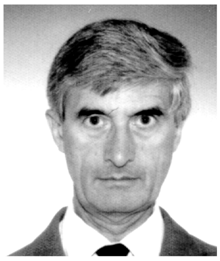

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