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Interactions analysis of UPFC multifunction controller

S. Robak, and D.D.Rasolomampionona, *Member, IEEE*

Abstract – **Internal interactions between control paths are a pivotal issue in multifunction FACTS controller design. One of the main stages of controller synthesis is an appropriate interaction analysis. This paper presents an analysis of interactions of Unified Power Flow Controller (UPFC). It is shown that multifunction operation of UPFC controller could be a source of interactions. The test system analysis has been performed on the basis of linear system control theory.**

Index Terms-- **FACTS devices, inter-area oscillations, relative gain array, stability.**

I. Introduction

In order to meet demanded electric energy quality as well as to ensure stable operation of power system different types of controllers are applied. One category is associated with network controllable elements among other FACTS devices, which generally are installed in order to make power transmission more flexible.

For the sake of FACTS numerous control advantages, their application in power system control is expected to be much wider than today. Because of wide control capability the research centers paid a particular attention on magnitude and phase regulated device Unified Power Flow Controller (UPFC). The main advantage of UPFC is that it offers a simultaneous control of line reactive and active power as well as node voltage magnitude. Therefore, in the general case UPFC is equipped with a multifunction controller, which realizes steady state control. Additionally UPFC has supplementary control loops, which can be used to gain an efficient damping of power system oscillations. The above mentioned advantages of UPFC resulted in publication of many papers concerning UPFC appropriate control algorithm development [1-3], but only a few of them include investigations of control interaction effect [3,4].

Nowadays awareness of control limitations due to controllers' interactions is much common. On the other hand the number of controllable elements installed in power system arises rapidly. Therefore the problem of interaction analysis becomes more complex.

Interactions caused by UPFC controller have been preliminary studied and reported in [3,4]. Published conclusions are the results of inadequate tuning of the UPFC multifunction controller or specific conditions of UPFC interactions. Investigations presented in this paper enter in the framework of earlier researches and show that there are also other reasons of interactions among different control paths of UPFC multifunction controller.

The structure of this paper is as follows. First, a general approach to the analysis of UPFC multifunction is shortly presented. Then a simple functional UPFC model is described. The next step is a short description of multi-machine power system model including UPFC devices and chosen test system. In the case of different multifunction UPFC controller input signals interactions are investigated using relative gain array (RGA). For more precision about interaction analysis the generalised dynamic relative gain (GDRG) is used. Finally an eigenvalues analysis is performed to confirm earlier obtained results.

II. Multifunction control of UPFC device

A. Unified power flow controller

A general scheme of the different UPFC elements is given in Fig. 1 [5,6].

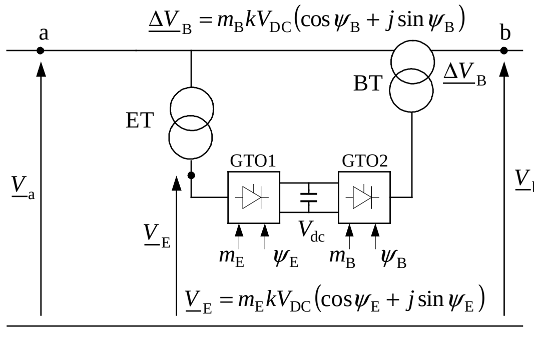

Fig. 1. Schematic diagram of UPFC.

Considering the above-presented scheme, it is well known that input signals m_E, m_B and ψ_E, ψ_B control magnitude and phase modulation of converters GTO1 and GTO2, respectively. A full control performance of the UPFC can be obtained using all of four control signals m_E, m_B and ψ_E, ψ_B, of which the UPFC controller is used. The UPFC series part controls active and reactive power flow of the transmission line whereas shunt part influences only reactive power by controlling the node voltage $\underline{V}_E$. Detailed description of

S. Robak is with Institute of Power Engineering, Warsaw University of Technology, (e-mail: sylwester.robak@ien.pw.edu.pl).

D.D Rasolomampionona is with Institute of Power Engineering, Warsaw University of Technology, (e-mail: desire.rasolomampionona@ien.pw.edu.pl)

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UPFC device can be found in [5].

B. Simplified representation of UPFC

Fig. 2 shows a simplified illustration of UPFC configuration given in Fig. 1, where shunt and series part of the UPFC is represented by the shunt voltage source $\overline{V}_{\mathrm{E}}$ and the series voltage source $\overline{V}_{\mathrm{B}}$.

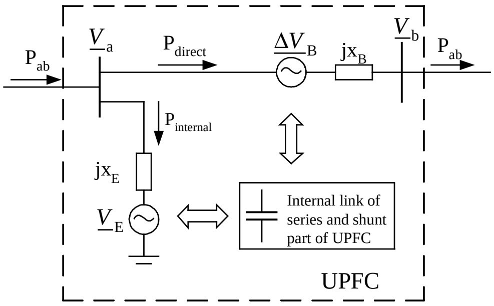

Fig. 2. Simplified representation of UPFC configuration.

In the general case active power input to UPFC flows by two channels direct and internal, i.e. $P_{\mathrm{ab}} = P_{\mathrm{direct}} + P_{\mathrm{internal}}$. The converter GTO1 absorbs (or supplies) active power P_{internal}, then also the GTO2 converter absorbs (or supplies) through DC link provided by a storage capacitor. The case for which $P_{\mathrm{internal}} \cong 0$ is considered as a particular one. The UPFC action is then considered as a combined action of two elements: shunt element, which can either supply or absorb reactive energy and series element, which is characterized by voltage magnitude and phase flexibility for quite a large scale. However, having regard to the fact that $P_{\mathrm{internal}} \cong 0$, there is no direct electric connection between UPFC series and shunt part [4].

If the condition given by the formulae $P_{\mathrm{internal}} \cong 0$ is fulfilled, control interaction between UPFC series and shunt part resulting from active power flow through internal link of shunt and series part disappears [4]. According to author's observations that situation does not result automatically in disappearing of interaction with any other system device. Interactions could arise as a result of the action of UPFC multifunction controller on different control paths. Control interaction in case of $P_{\mathrm{internal}} \cong 0$, are presented and discussed in the following sections.

Basing on the above presented considerations the following simplified model of UPFC [1] shown in Fig. 3 can be used for the analysis of this particular case where $P_{\mathrm{internal}} \cong 0$.

The ratio component β is in phase with the voltage transmission line, in which the UPFC device is installed. Its value corresponds to the voltage magnitude at the UPFC location, hence it influences the reactive power flow. The γ component is perpendicular to the voltage transmission line then it influences the active power flow. The combination of the action of both components corresponds to reaction of UPFC device series part. The component B_{B} influences reactive power generation or absorption, then its role is to control the voltage $\overline{V}_{\mathrm{a}}$. The above presented model is close to the simple UPFC functional model depicted in Fig. 3, however from the point the of view of interaction analysis is accurate enough.

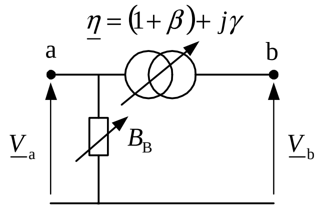

Fig. 3. Simplified model of UPFC.

C. UPFC multifunction controller

In order to design the controller as well as carry out interaction analysis the variables $\beta, \gamma, B_{\mathrm{B}}$ are considered as control signals. Therefore UPFC should be equipped with three control elements which allow controlling $\beta, \gamma, B_{\mathrm{B}}$ simultaneously. In general, each of the three outputs $\beta, \gamma, B_{\mathrm{B}}$ of the above-mentioned multifunction controller consists of two paths [1]: (i) the main path executing the required steady-state control strategy (typically it is a PI controller with a time constant equals or greater than 10 seconds); and (ii) a supplementary control loop executing the stabilising control. Basing on results published in [4] the influence of PI main controller on UPFC control interactions can be ignored. Hence only the influence of UPFC stabilising path has been considered in this paper.

III. Power System Model with UPFC

The linearised power system model including UPFC can be shortly described as follows [7]:

$$\Delta\dot{\mathbf{x}} = \mathbf{A}\Delta\mathbf{x} + \mathbf{B}\Delta\mathbf{u}\,, \tag{1}$$

$$\Delta\mathbf{y} = \mathbf{C}\Delta\mathbf{x} + \mathbf{D}\Delta\mathbf{u}\,, \tag{2}$$

where: (i) $\Delta\mathbf{x} = \left[\Delta\mathbf{E}'_{\mathbf{q}} \quad \Delta\mathbf{E}'_{\mathbf{q}} \quad \Delta\boldsymbol{\delta} \quad \Delta\boldsymbol{\omega} \quad \Delta\mathbf{z}\right]^{\mathrm{T}}$ - state vector in case when generators are represented by means fourth order model, and AVR systems are represented by means second order model $\Delta\mathbf{z} = \left[\Delta\mathbf{z_1} \quad \Delta\mathbf{z_2}\right]^{\mathrm{T}}$; (ii) $\Delta\mathbf{y}$ - output vector; (iii) $\Delta\mathbf{u} = \left[\Delta\beta \quad \Delta\gamma \quad \Delta B_{\mathrm{B}}\right]^{\mathrm{T}}$ - input (control) vector; (iv) $\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}$ - state matrix of size $n \times n$, input matrix of size $n \times r$, output matrix of size $m \times n$, feedforward matrix of size $m \times r$; (v) n, m, r - number of state variables, number of output variables, number of input variables, respectively.

IV. Test System

A three machine test system shown in Fig. 4 has been chosen for analysis purpose. An example of UPFC location on the transmission line L4 is indicated in Fig. 4. Detailed parameters of the test system are given in [1]. Two types of electromechanical oscillations occur in the above presented system. The nature of these oscillations is different. Frequency oscillation 1.2 Hz results from local mode between generators G1 and G2, whereas 0.8 Hz are inter-area mode oscillations between Area 1 and Area 2.

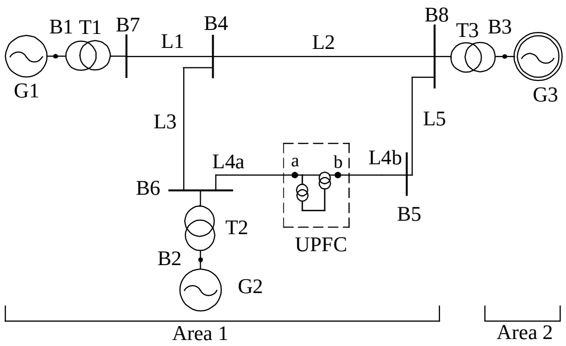

Fig. 4. Three-machine test system.

V. Relative Gain Array

A. Background

Several approaches to the analysis of controllers interaction have been proposed in different papers [8,9]. Because of its simplicity and practicability the relative gain array (RGA) has been extensively used as a measure of static interaction. In this approach, the relative gain between the input u_j and the output y_i is defined as follows [9,10]

$$RGA_{ij} = \left[\frac{\partial y_i}{\partial u_j}\bigg|_{u_l=0, l\neq j} \right] \left[\frac{\partial y_i}{\partial u_j}\bigg|_{y_l=0, l\neq j} \right]^{-1} \quad (3)$$

Basing on the above presented definition, the matrix of relative gain can be expressed as

$$\mathbf{RGA}[G(0)] = [\mathbf{G}(0)] \otimes [\mathbf{G}^{-1}(0)]^{\mathrm{T}} \quad (4)$$

where $\otimes$ denotes the element-by-element product of the two matrices and $\mathbf{G}(s)$ means open loop transfer function matrix of the system without controller. Main properties of the $\mathbf{RGA}[G(0)]$ have been widely published in many papers [9,10]. Same of them can be shortly described as follows:

- $RGA_{ij} = 1$, there is no interaction with other control;
- $RGA_{ij} = 0$, manipulated input i, does not affect the output j;
- $RGA_{ij} = 0.5$, there is a high degree of interaction;
- $0.5 < RGA_{ij} < 1$, there is an interaction between the control loops. However, this would be the preferable paring as it would minimise interactions;
- $RGA_{ij} > 1$, the interaction reduces the effect gain of the control loop. Higher controller gains are required;
- $RGA_{ij} < 0$, care must be taken with negative RGA elements. Negative off-diagonal elements indicates that closing the loop will change the sign of effective gain. More importantly, negative diagonal elements can indicate "integral instability" i.e. the control loop is unstable for any feedback controller.

B. Analysis

RGA method does not require knowledge of control structure. Therefore in the presented paper RGA has been used for determinating the possibility of interaction arising in case of applying different input signals to supplementary stabilising controllers of UPFC multifunctional controller. This approach could be treated as a preliminary study of UPFC interactions.

The following local available quantities at UPFC switching nodes a, b have been chosen as input signals for UPFC stabilizing controllers: active power P, reactive power Q, line current magnitude I, squared line current magnitude I^2,active line current Ia, reactive line current Ir, node voltage magnitude V, squared node voltage magnitude V^2, local frequency f. Table I shows some example results of RGA analysis. Except the full control of UPFC executed by simultaneous control of three control variables $\Delta\beta, \Delta\gamma, \Delta B_{\mathrm{B}}$, other possible UPFC control actions using only two control signals have been analysed. .

TABLE I

RGA matrices in case of different input signals and different of UPFC control actions

Cases	Input signals	UPFC control actions			
		$\Delta\beta - \Delta\gamma - \Delta B_{\mathrm{B}}$	$\Delta\beta - \Delta\gamma$	$\Delta\gamma - \Delta B_{\mathrm{B}}$	$\Delta\beta - \Delta B_{\mathrm{B}}$
Case I	$\Delta q_{\beta} = \Delta Q_{\mathrm{ab}}$ $\Delta q_{\gamma} = \Delta P_{\mathrm{ab}}$ $\Delta q_{\mathrm{B}} = \Delta f_{\mathrm{a}}$	$\begin{pmatrix} 0.792 & 0.002 & 0.205 \\ -0.07 & 1.002 & 0.068 \\ 0.278 & -0.005 & 0.727 \end{pmatrix}$	$\begin{pmatrix} 0.998 & 0.002 \\ 0.002 & 0.998 \end{pmatrix}$	$\begin{pmatrix} 0.915 & 0.085 \\ 0.085 & 0.915 \end{pmatrix}$	$\begin{pmatrix} 0.723 & 0.277 \\ 0.277 & 0.723 \end{pmatrix}$
Case II	$\Delta q_{\beta} = \Delta Ir_{\mathrm{ab}}$ $\Delta q_{\gamma} = \Delta Ia_{\mathrm{ab}}$ $\Delta q_{\mathrm{B}} = \Delta \lvert I_{\mathrm{ba}} \rvert^2$	$\begin{pmatrix} 0.46 & -0.002 & 0.542 \\ 0.11 & 1.013 & -0.123 \\ 0.429 & -0.011 & 0.581 \end{pmatrix}$	$\begin{pmatrix} 1.002 & -0.002 \\ -0.002 & 1.002 \end{pmatrix}$	$\begin{pmatrix} 1.265 & -0.265 \\ -0.265 & 1.265 \end{pmatrix}$	$\begin{pmatrix} 0.575 & 0.425 \\ 0.425 & 0.575 \end{pmatrix}$
Case III	$\Delta q_{\beta} = \Delta Q_{\mathrm{ba}}$ $\Delta q_{\gamma} = \Delta P_{\mathrm{ab}}$ $\Delta q_{\mathrm{B}} = \Delta Q_{\mathrm{ab}}$	$\begin{pmatrix} 0.317 & 0 & 0.683 \\ 0 & 0.998 & 0.002 \\ 0.683 & 0.002 & 0.315 \end{pmatrix}$	$\begin{pmatrix} 1.005 & -0.005 \\ -0.005 & 1.005 \end{pmatrix}$	$\begin{pmatrix} 0.998 & 0.002 \\ 0.002 & 0.998 \end{pmatrix}$	$\begin{pmatrix} 0.317 & 0.683 \\ 0.683 & 0.317 \end{pmatrix}$

Comparison of UPFC input signals different variants show that from the point of view of control interaction the best results have been obtained when the following input signals have been used: $\Delta q_{\beta} = \Delta Q_{ab}$, $\Delta q_{\gamma} = \Delta P_{ab}$, $\Delta q_{B} = \Delta f_{a}$ (case I). In that case, selected input signals allow to avoid interactions between the following pairs of control signals: $\Delta\beta - \Delta\gamma$ and $\Delta\gamma - \Delta B_{B}$. For these variants of UPFC action the value of off-diagonal elements of **RGA** matrix are very close to zero. The operation of UPFC series part only (i.e. $\Delta\beta - \Delta\gamma$) results in absence of any interaction. Contrary to the action of pair $\Delta\beta - \Delta\gamma$, the control action of $\Delta\beta - \Delta B_{B}$ results in interaction arising. For this case the off diagonal element of **RGA** is equal to 0.277, which means that interactions occurred. This case reflects general features of the system because it was impossible to select adequate input signals, which would ensure the fading of all possible interaction for any UPFC control action, especially in case of $\Delta\beta - \Delta B_{B}$ action. The remaining cases, which are presented in Table 1 (Case II and Case III) confirm this conclusion.

To conclude this part of investigation It can be said that there are conditions for which interactions between control loops of UPFC device can appear.

VI. GENERALISED DYNAMIC RELATIVE GAIN

A. Definition of GDRG

As it was mentioned, the RGA approach is very simple but does not take into consideration the control structure, therefore it is useful only for preliminary tests. In order to carry out more detailed analysis, a method which involves the controller structure and parameters is required. Then a generalised dynamic relative gain approach which takes into account both the dynamics of the controller and the dynamics of the process has been utilized. [9]. According to this approach dynamic interactions can be assessed using the following formulae:

$$GDRG_{ii} = \frac{g_{ii}(s)}{h_{ii}^{i}(s)} \quad (5)$$

where g_{ii} is the (i,i) element of matrix $\mathbf{G}(s)$ whereas h_{ii}^{i} is the (i,i) element of matrix $\mathbf{H}^{i}(s)$ defined as follows

$$\mathbf{H}^{i}(s) = [\mathbf{I} - \mathbf{G}(s)\mathbf{G}_{C}^{i}(s)]^{-1}\mathbf{G}(s) = [h_{ij}^{i}] \quad (6)$$

where $\mathbf{G}_{C}^{i}(s)$ is the diagonal matrix of system controllers with $g_{c_i} = 0$. In the considered case of UPFC controller, the matrix $\mathbf{G}_{C}(s)$ includes individual controller for each control signal $\Delta\beta, \Delta\gamma, \Delta B_{B}$ respectively. $\mathbf{H}^{i}(s)$ is a matrix describing the closed–loop transfer function matrix of the system with $u_i - y_i$ loop open.

A practical measure of dynamic loop interactions of multifunction controller can be obtained from GDRG number [9]

$$N_{GDRG}(j\omega) = \sum_{i=1}^{k} \left| GDRG_{ii}(j\omega) - 1 \right| \quad (7)$$

where k is the number of individual controllers in the multifunction control system.

From Equation (5), it can be concluded that a zero GDRG number indicates the absence of interaction between control loops at a frequency $\omega = 2\pi f$. Hence it is desirable to have $N_{GDRG}(j\omega)$ close to zero for frequency range of interests.

B. Case study

An adequate selection of UPFC multifunction controller is necessary for utilizing the GDRG approach described in section VI.B. Obviously there are several types of UPFC controllers. The main reason for which the selection is to be performed is the limitation of the paper length. The selection has been conducted after taking into consideration the following criteria, which should be fulfilled by the controller:

- the controller should be designed basing on nonlinear power system model,
- the controller is characterised by high effectiveness of power system oscillations damping,
- local available quantities can be used as input signals the at UPFC switch nodes,
- the controller should be easy to implement and its structure should be as simple as possible.

Among other possible choices one rather new published decentralized controller has been selected [1]. It is worth underlining that the presented analysis concerning GDRG approach can be carried out the same way for another type of UPFC controller.

The following input signals have been used as input signals of the above-presented controller: line reactive power for $\Delta\beta$ control, line active power for $\Delta\gamma$ control, line reactive power for ΔB_{B} control, respectively. A block diagram of controller regarding $\Delta\beta$ is shown in Fig. 5. Similar block diagrams can be used for signals $\Delta\gamma, \Delta B_{B}$.

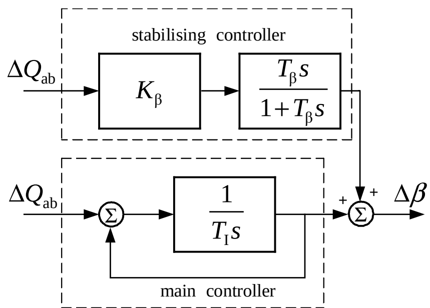

Fig. 5. Block diagram of controller [1].

The time constant of the main steady-state control path is larger enough to avoid the appearing of strong signal during power swings [1], therefore the signal of main control loop can be ignored during the analysis of control interaction affecting the electromechanical power swings damping. The supplementary stabilising controller is a practical differentiator with a small time constant. Detailed data of UPFC controller are from [11]: $K_\beta = 0.25$, $T_\beta = 0.4$, $K_\gamma = 0.25$, $T_\gamma = 0.2$, $K_B = 2$, $T_B = 0.2$.

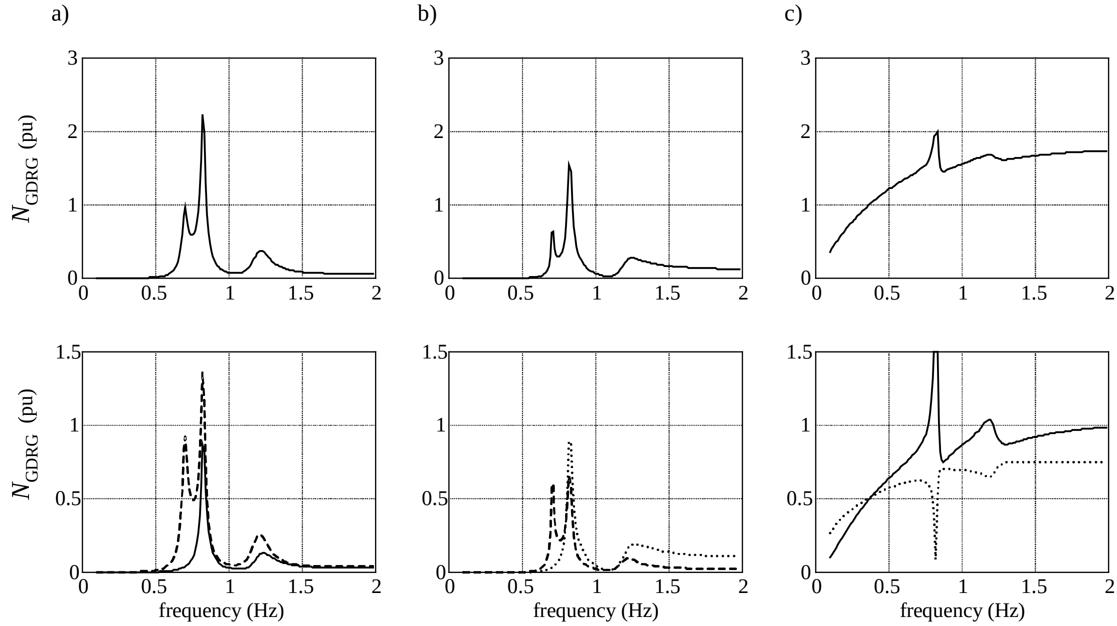

Fig.6. Magnitudes of GDRG in case of different partial control action of UPFC device: a) $\Delta\beta - \Delta\gamma$ action, b) $\Delta\gamma - \Delta B_B$ action, bottom plots: ——— $\Delta\beta$, ------- $\Delta\gamma$, ············ ΔB_B.

Fig. 6 shows $N_{GDRG}(j\omega)$ index corresponding to three different partial control actions of UPFC i.e. $\Delta\beta - \Delta\gamma$, $\Delta\gamma - \Delta B_B$ and $\Delta\beta - \Delta B_B$. Upper plots show the total number of $N_{GDRG}(j\omega)$, whereas bottom plots show different contributions of control signals in $N_{GDRG}(j\omega)$. It is easy to observe that in the first two cases ($\Delta\beta - \Delta\gamma$ and $\Delta\gamma - \Delta B_B$), the properties of considered system are quite similar. For the considered cases $N_{GDRG}(j\omega)$ is equal to zero except for the neighbouring frequencies corresponding to electromechanical swings (i.e. 0.8 Hz and 1.2 Hz). This feature is especially important from the point of view of additional control interaction between UPFC controller and Automatic Voltage Regulator systems located in each synchronous generator. After having performing the comparison of the above-mentioned cases, a slightly better control has been obtained using $\Delta\gamma - \Delta B_B$ as a control action. In this case the amplitude of total $N_{GDRG}(j\omega)$ is the smallest.

In the third case of UPFC control action $\Delta\beta - \Delta B_B$ the properties of the considered system are quite different. Firstly it could be seen that the index $N_{GDRG}(j\omega)$ associated with $\Delta\beta$ and ΔB_B control signals has non-zero values for the whole considered frequency range. Moreover $N_{GDRG}(j\omega)$ associated with $\Delta\beta$ has a high-value visible maximum for frequency corresponding to one of two electromechanical swings. Fortunately for this frequency the $N_{GDRG}(j\omega)$ associated with ΔB_B has deep minimum. Hence the total magnitude of $N_{GDRG}(j\omega)$ is not so high. It can then be said that for this particular oscillation frequency the action of ΔB_B control signal alleviates that of $\Delta\beta$ control signal.

A more general view of properties of the considered system is shown in Fig. 7, which depicts the index $N_{GDRG}(j\omega)$ in case of full control of UPFC device i.e. $\Delta\beta - \Delta\gamma - \Delta B_B$.

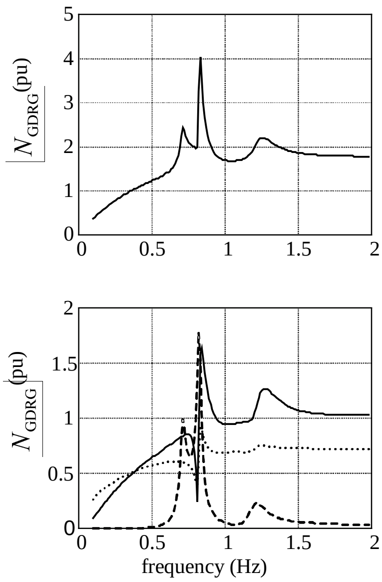

Fig. 7. Magnitude of GDRG in case of full control of UPFC device, bottom plots: ——— $\Delta\beta$, ------ $\Delta\gamma$, ············ ΔB_B.

As it was mentioned above the upper plot shows the total number of $N_{\text{GDRG}}(j\omega)$, whereas bottom plot shows the contribution of individual control signals in $N_{\text{GDRG}}(j\omega)$. In this case the maximum value of the total amplitude of $N_{\text{GDRG}}(j\omega)$ is higher comparing to cases, in which the UPFC action was partial. Additionally it can be seen that the total amplitude of $N_{\text{GDRG}}(j\omega)$ is more similar to the one corresponding to the case of partial action $\Delta\beta - \Delta B_{\text{B}}$ than other cases of UPFC partial action. Hence we can say that control interaction between $\Delta\beta$ and ΔB_{B} has an important influence on properties of the UPFC control in case of UPFC full action.

VII. Eigenvalues analysis

The confirmation of the above presented interaction analysis has been conducted by means of eigenvalues analysis. Table 2 shows some results for different values of stabilizing gains of UPFC control actions. Selected gains of UPFC controller presented in section VI.B assure a good damping of both electromechanical eigenvalues. However increasing control path gain corresponding to $\Delta\beta$ control signal makes the system unstable (see case 3 when $K_{\beta} = 0.35$). Instability is caused by hunting phenomena, which explanation can be found in literature [12]. The considered system can be brought back to stable work by common operation of $\Delta\beta - \Delta B_{\text{B}}$ control signals. It can be seen very clearly that the action of ΔB_{B} control signal alleviates the effect of $\Delta\beta$ control signal. Then the interaction between $\Delta\beta$ and ΔB_{B} is positive. Additional results presented in Table II show, that there is no positive interaction between $\Delta\gamma$ and ΔB_{B} or $\Delta\beta$ control signals. The instability caused by hunting phenomena in case of $K_{\gamma} = 0.35$, could not be alleviated by running other control signals.

TABLE II. Closed loop eigenvalues

Case	multifunction controller gains			eigenvalues		
	K_{β}	K_{γ}	K_{B}	local	inter-area	unstable
1	0	0	0	-0.363±j7.597	-0.077±j5.175	-
2	0.25	0.25	2	-1.156±j7.702	-0.677±j5.357	-
3	0.35	0	0	-0.435±j7.439	-0.137±j5.000	2.820±j15.845
4	0.35	0	2	-0.469±j7.707	-0.272±j5.248	-
5	0.35	0.25	0	-0.918±j7.521	-0.583±j5.147	1.112±j15.526
6	0	0.35	0	-1.042±j 7.269	-0.787±j5.136	3.181±j22.761
7	0	0.35	2	-1.057±j 7.216	-0.862±j5.157	3.949±j22.891
8	0.25	0.35	0	-1.086±j7.173	-0.892±j5.104	3.913±j27247

VIII. Conclusions

The need for interaction analysis of controllers used in power system is real. Negative interactions may be the source of abnormal states and disturbances, even black-outs.

In this paper two approaches have been applied to determine the properties of UPFC interactions. The first approach was based on Relative Gain Array method. The RGA has been used in exploratory analysis in order to determine the influence of different input signals on interaction between UPFC control paths of multifunction controller. The control of two signals $\Delta\beta$ and ΔB_{B}, on line reactive flow and bus voltage magnitude respectively was described. It has been outlined that a common action of both signals can result in interaction. The performed analysis has shown that it is impossible to select such local available input signals, whose the use could prevent system from UPFC interactions.

The second more detailed approach was based on Generalised Dynamic Relative Gain method, which takes into account both system model and a particular controller model. For this approach the study results obtained by means of frequency characteristics confirmed previously made observations using RGA method. Moreover it was observed that the action of ΔB_{B} control signal can alleviate that of $\Delta\beta$ control signal. Therefore the revealed interaction has a positive character.

Additionally eigenvalues test results performed for different gains of UPFC multifunction controller have confirmed the righteousness of the conducted analysis based on RGA and DGRG methods.

Although the above-presented analysis has been carried out on a functional model of UPFC, it can be easily adopted and confirmed for a more detailed one. The described approach may be used for the analysis of complex interactions between multifunction controller UPFC and other than FACTS power system controllers.

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X. BIOGRAPHIES

Sylwester Robak was born in 1971 in Poland. He received his M.Sc. (1996), Ph.D. (1999) and DSc (2008) degrees in Electrical Engineering from Warsaw University of Technology (Poland). Since 1999 he has been with Warsaw University of Technology. His research interests are in the power system stability and in the automatic control.

Desire Dauphin Rasolomampionona was born in 1963 in Madagascar. He received his MSc (1988), PhD (1994) and DSc (2008) in Electrical Engineering from Warsaw University of Technology. He joined the Warsaw University of Technology faculty in 1994 at the Power System Protection Division, Institute of Power Engineering. His research interests include protection and control of power system and computer networking