Impact of non Coordinated MVAr Scheduling Strategies in Multi Area Power Systems

Y. Phulpin, M. Begovic and M. Petit

Abstract— **Interregional reactive power flows are rarely a decisive issue for transmission system utilities operating on interconnected systems. However, economic constraints and increasing stress on interconnection lines may lead to recurrent conflicts, which could be avoided with a better inter-utility coordination. This paper exposes a method for evaluating the impact of multi-utility MVAr scheduling. This method is illustrated with an IEEE 118 bus system with 2 separately controlled regions, whose MVAr scheduling objective is different. The regional scheduling process is described and the state of the interconnected power system is compared with a global optimization. Differences from global optimal solution are highlighted for active power losses and reactive power reserves.**

Index Terms— **Interconnected Power Systems, Power Systems Planning, Reactive Power Control**

I. Introduction

ONE mission of a Transmission System Operator (TSO) is the continuous compensation of active and reactive power demands and losses in its own region. The natural uncertainty among consumption, generation and transmission systems has thus required TSOs to introduce strategies for real time control of both frequency and voltage [1].

Strategies for voltage control are most often hierarchical, with a clear distinction between dynamic control, which is basically distributed among all control units, and a longer term regulation, which may be partially scheduled in a regional frame. Following some major black-outs, MVAr scheduling has become a key issue [2] and many strategies have been proposed in the literature [3]-[6] in order to achieve regional objectives such as minimization of active power losses or maximization of the voltage stability [7]. In this frame, many TSOs schedule the settings of transportation systems (tap or phase transformers, capacitor banks, FACTS) and of generators' output voltage according to its own optimization function and with a local forecast of the interconnected power system state. In previous work [8], we explored the need for a data exchange between agents involved in a multi area control scheme, which is a decisive topic in modern large scale power systems. The goal of this paper is to go further with the analysis of the impact of non-coordination between regional strategies.

In a first section, a framework for global optimization of MVAr management is exposed. Then, strategies for local MVAr scheduling and for interconnection representation are developed. Finally, regional strategies are compared with a global optimization in the case of the IEEE 118 Bus test system with two regions, defined in [9], where each region has a different MVAr scheduling strategy.

II. Optimization of MVAr Scheduling

A. Strategies

The increase of physical and economic constraints stresses the need for an efficient regulation in electric power systems. Therefore, the voltage regulation has been widely automated with an objective of maintaining the system stability and minimizing the operating costs. In all large scale power systems, TSOs have developed strategies to set parameters of existing voltage control units such as generators' output voltage, capacitor banks or FACTS reactive power injection, tap or phase transformer settings, etc.

In most of the existing systems, some of these parameters are subject to automatic voltage regulation (AVR), which maintains the reference voltage by adapting the reactive power injection. This kind of regulation relates to the dynamic voltage control and will not be discussed in this paper.

Considering a static demand and a redistribution of the active power injections (decentralized slack bus), the MVAr scheduling is the optimization of the control parameters, which are listed below as a function of a selected optimization objective. It is indeed a variety of optimal power flow (OPF). There are at least five main criteria which can be used to define methods for MVAr scheduling, which are listed below.

1) State Variables:

Centralized techniques [10] may set all control units parameters according to a general optimization function. This approach requires important computation capabilities and may be difficult to apply in large power systems.

Consequently, many TSOs have decided to use a hierarchical voltage control [11]. In this context, the regional power system is divided into sub regions, in which all voltage control units are supposed to maintain the reference voltage of the pilot node [12]. The Tertiary Voltage Control is scheduled

Y. Phulpin and M. Petit are with the Department of Power and Energy Systems, Ecole Superieure d'Electricite, France (0033-16985-1516; e-mail: yannick.phulpin@supelec.fr, marc.petit@supelec.fr).

M. Begovic is with the Department of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250 USA, (e-mail: miroslav.begovic@ece.gatech.edu).

by the TSO as the reference voltage of all pilot nodes [4]. It could be compared with a centralized voltage control in a simplified power system. In this paper, we focus on centralized techniques.

2) Time Scale

The MVAr scheduling is based on a forecast of active and reactive power demand, which may be forecasted an hour ahead [4]. Some TSOs may however optimize their voltage level in real time [6]. In this paper, it is considered that all regions use an "hour ahead" forecast.

3) Control Variables

An issue is also to determine what is regulated by the TSO. As their reactive power injection capabilities are greater than those of capacitor banks or FACTS, generators' reactive reserves may be preserved for emergency cases [7]. Further, tap or phase shifting transformers may be used only for active power management. In this paper, generators' and compensators' output voltage, tap and phase transformers settings are considered as controls.

4) Constraints

TSOs have a large knowledge base of historical constraint violations and they integrate N-1 security constraints in an optimal power flow [13]. This restriction is more difficult when no history of constraint violations is known. That is why only N level security constraints (the cases without contingencies) are considered in this paper.

5) Objectives

A decisive characteristic of MVAr scheduling is a choice of the objective function. As for the other parameters, there are several possibilities. Most of the TSOs apply a multi-objective function, based on the two following objectives.

Traditionally, a trend is to minimize the active power losses, which are defined by:

$$P_{Loss} = \sum_{i=1}^{N_G} P_{Gi} - \sum_{k=1}^{N_D} P_{Dk} \qquad (1)$$

Where P_{Loss} are the active power losses, P_{Gi} the active power injection of generator i, P_{Dk}, the active power demand of demand k, N_G the number of generators, N_D the number of demands.

Practically, TSO maximizes the voltage profile across their region in order to reduce the line currents and therefore minimize losses. This kind of regulation also increases the transfer capacities of existing lines, which are mainly dependent on maximum currents.

Recent focus on voltage stability has lead TSOs to maximize the reactive power reserves [5]. As for active power losses, this objective is global. The same objective is achieved when TSO minimize reactive power support, defined as:

$$Q_{TOT} = \sum_{i=1}^{N_G} \left| Q_{Gi} \right| \qquad (2)$$

Where Q_{TOT} is the reactive power support and Q_{Gi} is the reactive power injection of generator i.

B. Results

1) Benchmark System

An illustration of MVAr scheduling is presented in the case of the modified IEEE 118 Bus test system, originally defined in [14]. In this section, it is considered that only one TSO controls the entire power system. Originally allocated tap changing transformers are operating in the voltage band between maximum (1.05pu) and minimum (0.95pu). Further, 2 phase shifting transformers have been introduced at the interconnections:

- between buses 30 and 38, driven by TSO A
- between buses 15 and 33, driven by TSO B

Maximum (28,64°) and minimum (-28,64°) angle deviations have been chosen for those 2 transformers. At all buses, the voltages are set to stay within the limits [0.94pu, 1.06pu]. The new power system is represented in Figure 1.

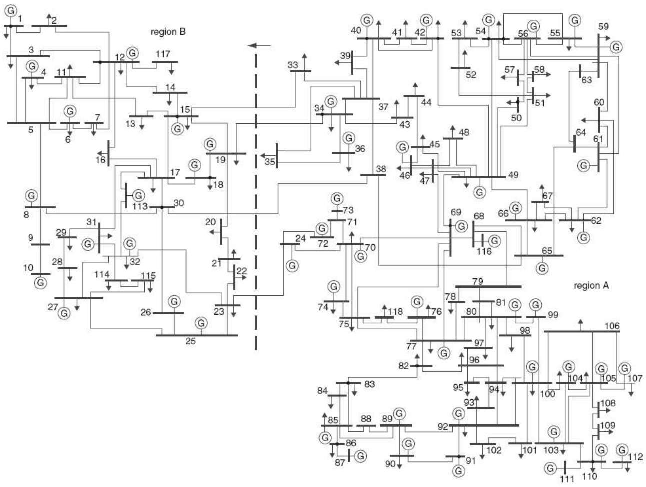

Figure 1: IEEE 118 Bus System with two areas

In an optimal power flow, active and reactive power demands are considered fixed. Capacitor banks, or FACTS, are considered as PV buses and a decentralized slack bus is chosen in order to compensate for active power losses.

Finally, considering that MVAr scheduling must respect the economic constraints, active power flow from area A to area B is kept constant and equal (in the base case) to 74 MW.

2) Maximization of Reactive Power Reserves

Figure 2 represents the voltage magnitude in the IEEE 118 Bus test system, when reactive power reserves are maximized. Active power losses and reactive power injections in this case are summarized in the final section.

3) Minimization of Active Power Losses

Figure 3 represents the voltage profile in the IEEE 118 Bus system, when active power losses are minimized. Active power losses and reactive power injections in this case are summarized in the final section.

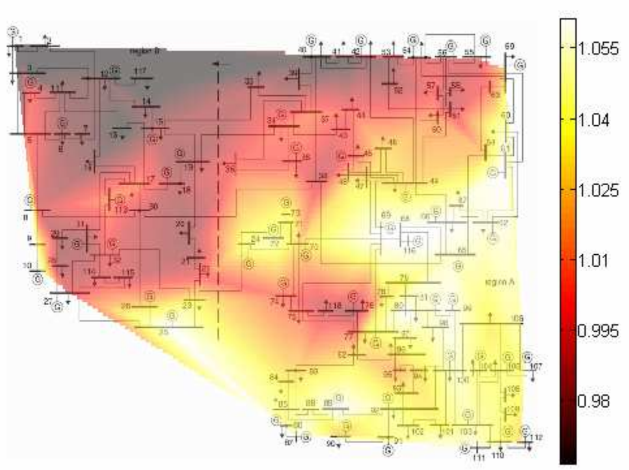

Figure 2: Interpolated voltage level across the IEEE 118 Bus System where the global amount of reactive power reserves has been maximized. Voltage is in p.u.

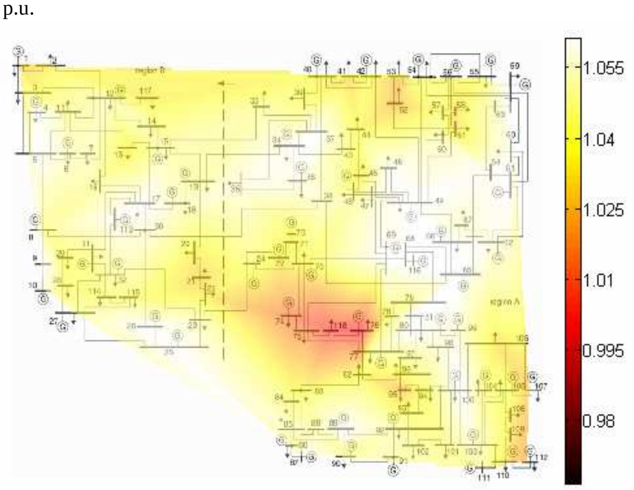

Figure 3: Interpolated voltage level across the IEEE 118 Bus System where the global amount of active power losses has been minimized. Voltage is in p.u.

III. Local Strategy For Tertiary Voltage Control

A. Problem

In a large scale power system, it is common that different TSOs control different parts of the system. Those regions are often interconnected with multiple tie lines in order to enable a common electricity market and to ensure a greater security. However, voltage control remains a prerogative of the local TSO.

1) Local Optimization Function

A main issue is the choice of the optimization function. TSOs do not always agree on their objectives due to the fact that they do not possess the same reactive power injection capabilities and of the same network topology.

This may lead to controversial situations at the interconnections, when one TSO maximizes the voltage in its region and the other one minimizes it. In order to illustrate this problem, we assume that each TSO chooses a different optimization function among those presented in the previous section.

2) Partial Knowledge of the External Power System

Another problem is the TSO's partial knowledge of the external part of the power system. In this paper, it is assumed that each TSO possesses a perfect forecast of the demand and of the generation configuration in its own region, but no knowledge about the network architecture in other regions nor voltages and power flows at interconnections. An external network model (ENM) thus needs to be used. A probabilistic method is chosen to determine the parameters of such models at interconnections. These two steps are presented in the following subsections.

B. Representation of Interconnected Areas

There are many ways for representing an external network model (ENM) with little knowledge about it. A complete review is available in [15]. Different ENM have been experienced, such as REI equivalent [16], Thevenin Equivalent [17], PQ buses [8] or PV buses. Choosing one representation over another impacts of course the results, but not decisively. Therefore, for the sake of simplicity, a PV representation has been chosen. It means that all interconnection lines are replaced by PV buses, whose parameters P and V remain constant throughout regional optimization. This also ensures that the sum of active power flows through the interconnection remains constant, in accordance with economic constraints.

C. Probabilistic Method to Determine the Parameters

In order to determine the values of ENM parameters, each TSO is supposed to have access to a historical record of voltages and power flows at the interconnections. Depending on the generation, transmission and distribution forecast, TSO chooses a set of data which is supposed to be realistic at the interconnections. A regional optimization is performed for the situations similar to the data set at hand and the expected value of the control variables is selected as the optimal choice.

In the base case example, no historical data had been known for the interconnection. This process has thus been simulated. Parameters were measured by global active power loss minimization and by global reactive power reserve maximization with a load factor varying from 0.8 through 1.2 in steps of 0.1pu.

D. Results

1) Region A

The results of MVAr scheduling in region A are presented in Figure 4. The left figure shows the voltages in region A when reactive power reserves are maximized by TSO A, while the right one shows the voltages in region A when active power losses are minimized. In both case, parameters are set to their active power loss minimization value by a load factor of 1.0.

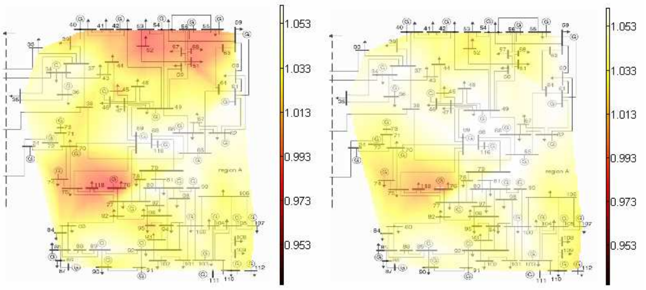

Figure 4: Interpolated voltage level across the Region A of the IEEE 118 Bus System. On the left, reactive power reserves are maximized. On the right, active power losses are minimized. Voltage is in p.u.

2) *Region B*

The results of MVAr scheduling in region B are presented in Figure 5. The left figure shows the voltages in region B when reactive power reserves are maximized by TSO B, while the right one shows the voltages in region B when active power losses are minimized. In both cases, parameters are set to their active power loss minimization value by a load factor of 1.0.

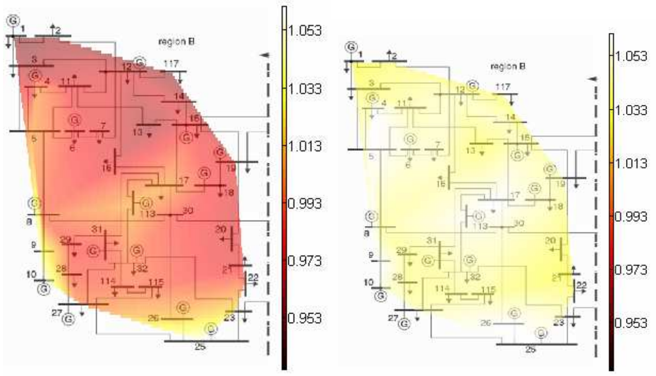

Figure 5: interpolated voltage level across the Region B of the IEEE 118 Bus System. On the left, reactive power reserves are maximized. On the right, active power losses are minimized. Voltage is in p.u.

IV. Aggregation of Local Optimization

A. *Aggregation*

1) *New Power Flow*

All regional MVAr scheduling is confronted in real time. At this time, all generators' and compensators' output voltage and tap and phase transformers' settings are defined. A new load flow is run with a distributed slack bus and constant active power flow at the interconnection.

2) *Constraints Violations*

Due to loop flows and approximations in the ENM, flows change and constraints may be violated. Generator reactive power injection limits can not be exceeded, while their voltages are adjusted to maintain operation at their injection limit, if the limit is reached.

Demand buses, however, may reach voltage levels over the limits. However, in practice this violation remains relatively small and inferior to 0.0001p.u.

B. *Results*

Four different cases are simulated, where both TSOs have different strategies. Voltage profiles for each case are presented in each subsection, whereas active power losses and reactive power support are summarized in a final comparison.

1) *Case 1*

Here, both regional TSOs maximize their own reactive power reserves. The voltage across the interconnected network is quite similar to the case of global maximization of MVAr reserves. It is represented in Figure 6.

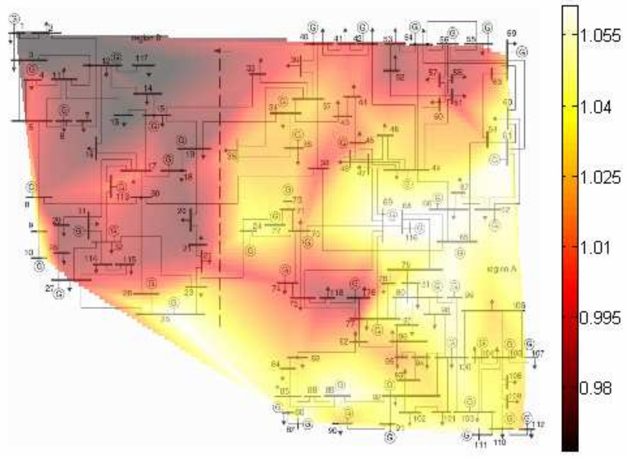

Figure 6: Interpolated voltage level across the IEEE 118 Bus System by Case #1. Voltage is in p.u.

2) *Case 2*

Here, region A TSO maximizes its own reactive power reserves while region B TSO minimizes its own active power losses. It is to be noted that the TSO that is concerned about active power losses maximizes the average voltage in its region. Voltages are lower close to the TSO A, leading to higher active power losses. Region B is exporting an important amount of reactive power toward region A despite the low reactive power flows that have been considered as external network parameters.

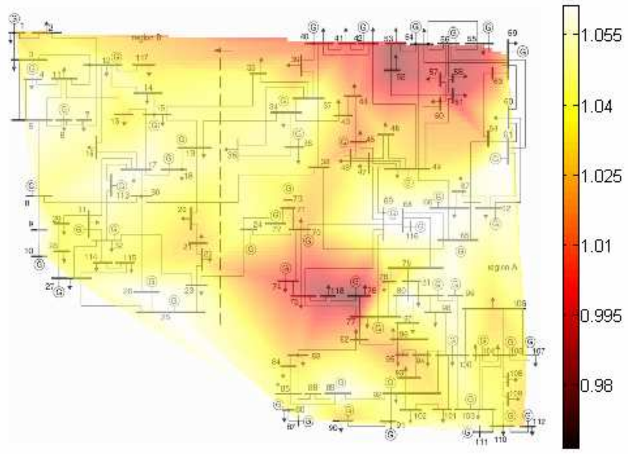

Figure 7: Interpolated voltage level across the IEEE 118 Bus System by Case #2. Voltage is in p.u.

3) *Case 3:*

Here, region A TSO minimizes its own active power losses while region B TSO maximizes its own reactive power reserves. Region A voltages are maximized while Region B voltages reach a lower level as power lines. No reactive power injection is needed in this region due to the intrinsic reactive support (capacitance) of the EHV power lines. As a consequence, voltages near interconnection are rather low and region A's TSO is not only exporting an important amount of reactive power but also getting higher active power losses. Nevertheless, Region B TSO would probably choose another strategy, due to its higher active losses and, consequently, higher cost.

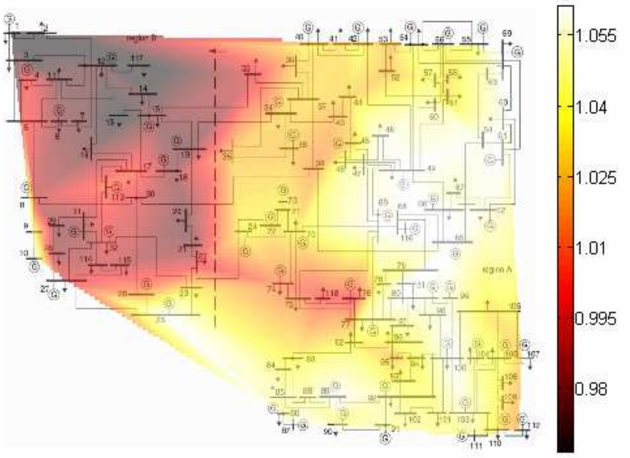

Figure 8: Interpolated voltage level across the IEEE 118 Bus System by Case #3. Voltage is in p.u.

4) *Case 4*

Here, both regional TSOs minimize their own active power losses. As a consequence, they both tend to maximize the average voltage across the interconnected network. As in case 1, results after aggregation are quite similar to those obtained with the corresponding global optimization.

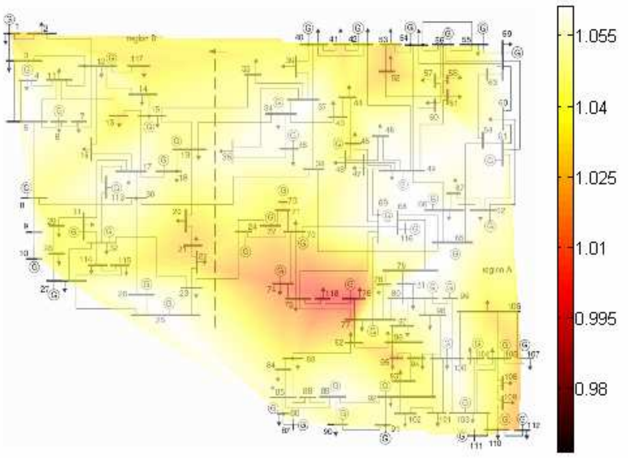

Figure 9: Interpolated voltage level across the IEEE 118 Bus System by Case #4. Voltage is in p.u.

5) *Comparison with a Global OPF*

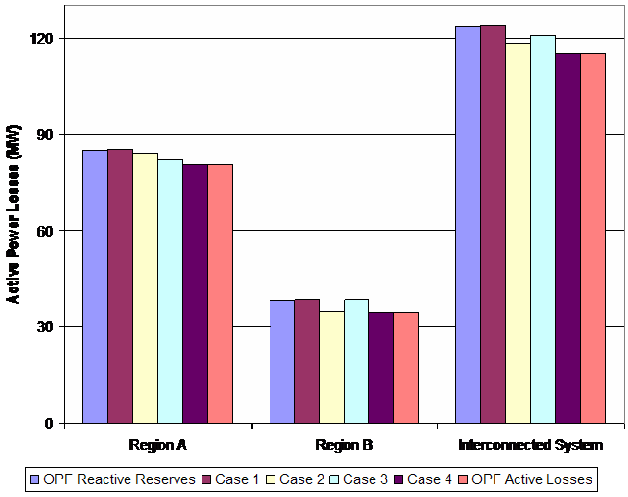

Figure 10: Active power losses in Region A, Region B and in the interconnected power system

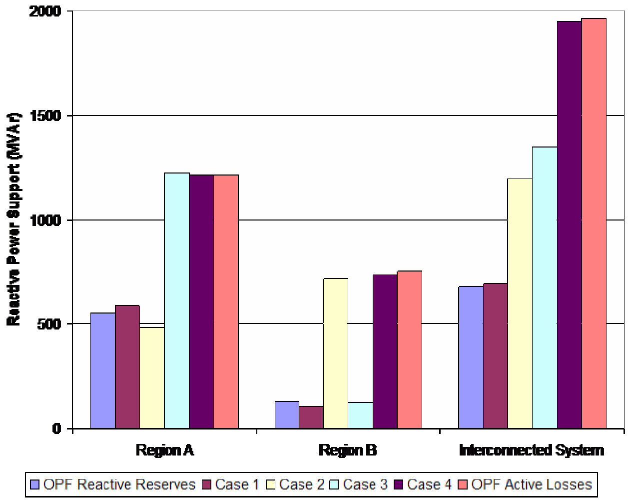

Figure 11: Reactive power support in Region A, Region B and in the interconnected power system

Active power losses are evaluated for each case. They are compared with their values obtained by global optimization and summarized in Figure 10 The similarity between case 4 and a global minimization of active power losses is noticeable. We can also deduce from the comparison of cases 2 and 3 that the choice of the interconnected regional TSO for a different strategy increases the active losses in the area where they are supposed to be minimized by respectively 1,88% and 0,55%. The amount of losses in the interconnected system is respectively 3,01% and 4,98% higher than the results achieved by global optimization

Reactive power support is computed for each case, and presented in Figure 11. It is observed that the regional maximization of reactive power reserves is quite similar to the results obtained by global optimization. Further, a different strategy of the interconnected TSO allows one to maximize even more of its own reserves, leading to a regional decrease of the reactive power support of 12,56% (case 2) and 3,60%

(case 3). This gain is however only local. Indeed, the global reactive support is increased by 76,97% (case 2) and 99,04% (case 3), leading to a lower global voltage stability.

V. CONCLUSION

This paper shows that coordination of the regional MVAr strategies is critical in a multi utility environment. Choosing a minimization of reactive power support may be more efficient for one TSO, but it may increase the costs of the interconnected utilities, if they are trying to minimize active power losses. Further, the final objective, which is to increase the voltage stability margin, is not reached, because of the higher reactive support that is provided by the other TSO. Interconnection lines are also facing greater reactive power flows, limiting the transmission capacities and stressing the entire interconnected power system.

Better coordination between TSOs is one promising strategy toward a more efficient MVAr scheduling. This could be achieved not only through exchange of system measurements close to the interconnections, but also through coordination of objective functions for MVAr scheduling in the interconnected regions.

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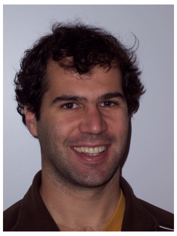

Yannick Phulpin (S'05) received both degrees in electrical engineering from Supelec in Paris, France, and from the Technical University of Darmstadt, Germany, in 2004. He is currently assistant professor at Supelec and he is pursuing a Ph.D. in voltage stability and reactive power management at interconnections at Supelec and the Georgia Institute of Technology in Atlanta, Georgia.

Miroslav M. Begovic (S'87, M'89, SM'92, F'04) is Professor with School of Electrical and Computer Engineering, Georgia Institute of Technology in Atlanta, Georgia. His research interests are in the general area of computer applications in power system monitoring, protection and control, and design and analysis of renewable energy sources. Dr. Begovic was a Chair of the Working Group "Wide Area Protection and Emergency Control" and Vice-Chair of the Working Group "Voltage Collapse Mitigation" of the IEEE PES Power System Relaying Committee. He authored a section "System Protection" for the monograph "The Electric Power Engineering Handbook", CRC Press LLC, 2000. Dr. Begovic was a contributing member of the IEEE PES PSRC Working Group "Protective Aids to Voltage Stability", which received the IEEE Working Group Recognition Award in 1997. He is currently serving as Chair of the Emerging Technologies Coordinating Committee of the IEEE PES. Dr. Begovic is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi.

Marc Petit is a former student of the Ecole Normale Supérieure de Cachan in Paris, France. He received the Ph-D degree from the University of Orsay, France, in 2002. Currently, he is assistant professor in the power systems group of the Department of Power and Energy Systems of Supelec in Paris, France.