Power Flow (SCORPF) procedure should be recommended for the solution of the problem. Besides the constraint settlement, the choice of the objective function is a point of needed discussion.

The maximization of the loadability margin [4] to maintain adequate reactive reserves for additional transactions but also the traditional minimization of real power losses to reduce the transmission service rates are still now proposed [5]. The SCORPF solution gives important indications, by means of the Lagrange multipliers of the active constraints, on the possible pricing of the reactive support at operation level and on an efficient allocation of new reactive resources at planning level. Combining technical and economical requirements, SCORPF seems to be able to give information also on the nondominant component of the variable cost. The discussers would like to know the opinions of the authors about the suitability of the use of the OPF tools for the definition of reactive power support costs (paying attention also to the nondominant terms).

REFERENCES

[1] G. Gross, S. Tao, E. Bompard, and G. Chicco, "Unbundled reactive support service: Key characteristics and dominant cost component," *IEEE Trans. Power Syst.*, vol. 17, pp. 283–289, May 2002.

[2] W. Xu, Y. Zhang, C. P. da Silva, P. Kundur, and A. Warrack, "Valuation of dynamic reactive power support services for transmission access," *IEEE Trans. Power Syst.*, vol. 16, pp. 719–728, Nov. 2001.

[3] S. Corsi, P. Marannino, N. Losignore, G. Moreschini, and G. Piccini, "Coordination between the reactive power scheduling and the hierarchical voltage control of the EHV enel system," *IEEE Trans. Power Syst.*, vol. 10, pp. 602–608, May 1995.

[4] P. Marannino, F. Zanellini, M. Merlo, S. Corsi, M. Pozzi, and G. Dell'Olio, "Evaluation of load margins with respect to voltage collapse in presence of secondary and tertiary voltage regulation," in Bulk Power System Dynamics and Control—V, Onomichi City, Japan, Aug. 26–31, 2001.

[5] K. Bhattacharya and J. Zhong, "Reactive power as an ancillary service," *IEEE Trans. Power Syst.*, vol. 16, pp. 294–300, May 2001.

Closure on "Unbundled Reactive Support Service: Key Characteristics and Dominant Cost Component"

George Gross, Shu Tao, Ettore Bompard, and Gianfranco Chicco

We thank Prof. Marannino and Mr. Zanellini for their interest in and discussion of, our paper [1]. We appreciate their complimentary and insightful comments on the paper and are most pleased that they share our views on the key physical characteristics and the dominant cost component of the generator-based reactive support as an unbundled ancillary service in the restructured electricity industry.

The discussion raises issues concerning the role of the Independent Grid Operator (IGO) in voltage support and reactive power control and the computational tools deployable for the acquisition and pricing of the reactive support service. The discussers refer to a Security Constrained Optimal Reactive Power Flow (SCORPF) procedure as a possible tool for this purpose. They state that such a tool will be useful in "the definition of reactive power support costs (paying attention also to the nondominant terms)." Unfortunately, we do not share the view expressed in this statement since the SCORPF tool has, in reality, no capability to provide cost information. The OPF may provide appropriate pricing signals when the economics of the situation are properly represented. But, the discussion on OPF application requires that a few aspects of OPF be clarified.

The OPF is a powerful centralized decision-making tool developed for the vertically integrated utility (VIU) structure. Its effective application in the competitive environment requires the appropriate representation of market economics and the introduction of meaningful metrics [2], [3]. A key complication in the OPF formulation lies in the arbitrariness of the optimum due to the wide discretionary powers of the IGO in the formulation of the constraint set and the definition of the set point values of certain control variables [2]. These considerations make the choice of an appropriate objective very challenging since the economics of the situation must be appropriately reflected.

The OPF framework provides the setting for the evaluation of dual variables that have the economic interpretation of prices. For example, the relatively simple model for the reactive loads used in [4] can provide effective price signals for congestion relief. The OPF framework permits the incorporation of contingencies; however, in the presence of contingencies, the *value*—not the cost—of reserves must be explicitly represented. This value is linked to the *effective* limit of a reactive power source, which depends on the amount of reactive power that can be actually provided under specified system conditions [5]. This *effective* reactive limit is different than the generator reactive power limit since the system conditions under one of the specified contingencies may prevent the generator from reaching its reactive power limit.

This brief discussion leads to the conclusion that the deployment of an OPF tool for the reactive power support service acquisition and pricing requires the careful consideration and addressing of some very challenging issues. Two issues are particularly critical. These are detailed below.

1) As correctly pointed out by the discussers, the selection of the objective function for an OPF tool is not a straightforward issue. Due to the local nature of reactive power, the optimization to minimize the total costs of reactive power support services based on the price bids submitted by the generators is unfortunately not appropriate. Moreover, the local monopoly power of certain generators makes a centralized IGO-operated structure for reactive support both impractical and unsuitable for competition. This has been clearly illustrated and strongly emphasized in the paper. The discussers refer to the maximization of the loadability margin to maintain adequate reactive reserves for additional transactions and the traditional minimization of real power losses as two possible candidates for the objective function. While the loadability margin maximization and the loss minimization can be thought of as a common *good* enjoyed by all the market participants, i.e., all the transmission network customers, such objective functions may conflict with each individual generator's self interest. Moreover, since these objective functions do not involve either the costs incurred by the individual generators or the values to the transmission customers in providing/acquiring the reactive support requirements, they are unable to provide a direct and clear price signal for reactive support services to individual generators. The lack of such a price signal results in no appropriate incentive to the generators to supply the necessary reactive support services. Thus, while these objective functions may be appropriate choices in the VIU

Manuscript received May 28, 2002.

G. Gross is with the Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA (e-mail: gross@uiuc.edu).

S. Tao is with the ABB Energy Information Systems, Santa Clara, CA 95050 USA (e-mail: shu.tao@us.abb.com).

E. Bompard and G. Chicco are with the Dipartimento di Ingegneria Elettrica Industriale, Politecnico di Torino, corso Duca degli Abruzzi 24, 10129 Torino, Italy (e-mail: bompard@polito.it; chicco@polito.it).

Digital Object Identifier 10.1109/TPWRS.2002.804966

structure, where all the generators are owned and controlled by one single entity, they may not necessarily be suitable in the restructured regime. In the latter structure, the IGO does not own the VAr-producing generators and must issue appropriate price signals to the generators to acquire the reactive support services from them.

2) The equity issue is a key consideration in the OPF formulation. In a centralized optimization, the IGO has to specify the acceptable voltage profile for the transmission network as an input to formulate the constraint set. As clearly shown in the paper, however, the bus voltage profiles have significant impacts on the reactive power outputs of the various generators in the system. In other words, under two different voltage profiles, both of which are judged to be acceptable with respect to the operational requirements, the reactive support contribution made by a particular generator may vary considerably. Similar statements hold for generator setting points. While two different specifications for the generator setting points, may produce nearly indistinguishable objective function values, the reactive power outputs of a particular generator may vary considerably. This, in turn, implies that the costs incurred by the generator to satisfy the system reactive support requirements are different. This has been illustrated by the reactive support "*leaning*" example in our paper. Therefore, in such a centralized decision framework, the reactive support service acquisition and costing are under the total discretion of the IGO. Such a consideration is important in the selection of a tool that would further enlarge the IGO authority.

We believe that the consideration of these issues must be carefully addressed before an OPF tool may be deployed to set up a competitive and system-wide market for reactive support services.

We thank again the discussers for the opportunity to provide more details on the concepts explored in our paper.

REFERENCES

[1] G. Gross, S. Tao, E. Bompard, and G. Chicco, "Unbundled reactive support service: Key characteristics and dominant cost component," *IEEE Trans. Power Syst.*, vol. 17, pp. 283–289, May 2002.

[2] G. Gross, E. Bompard, P. Marannino, and G. Demartini, "The Uses and Misuses of Optimal Power Flow in Unbundled Electricity Markets," in Memoria 14, 23° Corso di Aggiornamento Apparecchi Macchine e Impianti Elettrici: Il Nuovo Assetto Dell'Energia Elettrica in Italia a Seguito Dell'Attuazione Della Direttiva Comunitaria 92/1996 per la Liberalizzazione del Mercato Elettrico, Pavia, Italy, Oct. 19–21, 1999.

[3] P. Correia, G. Gross, E. Bompard, E. Carpaneto, and G. Chicco, "Application of Microeconomics Metrics in Competitive Electricity Markets," in *Proc. Electric Power Engineering at the Beginning of the Third Millenium*, vol. 2, Naples-Capri, Italy, May 12–18, 2000, pp. 101–131.

[4] E. Bompard, E. Carpaneto, R. Napoli, and G. Gross, "Modeling of Load Participation in Competitive Electricity Markets," in *Proc. Bulk Power Systems Dynamics and Control Conf. V*, Onomichi, Japan, Aug. 26–31, 2001, pp. 144–152.

[5] F. Capitanescu and T. van Cutsem, "Evaluation of Reactive Power Reserves with Respect to Contingencies," in *Proc. Bulk Power Systems Dynamics and Control V—Security and Reliability in a Changing Environment*, Onomichi, Japan, Aug. 26–31, 2001, pp. 377–385.