

# Feasibility of a Bilateral Market for Load Following

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**Abstract**—In the ongoing process to create a competitive electricity market, the problem of Ancillary Services is assuming a fundamental role. Ancillary Services are those services performed by generators, transmission and control equipment, which are necessary to support basic services and to maintain reliable operations and system security. In this paper, we focus our attention on one of these services, load following, and propose a competitive way to provide this service through bilateral contracts between supplier and customer. In general, we assume that there will be both a competitive market for the provision of load following and an authority responsible for the amount of load following not met by bilateral contracts.

## I. INTRODUCTION

IN THE deregulated scenario, one of the issues related to the Ancillary Services (AS) is the possibility to provide them (at least some of them) competitively. Regulation and load following are services classically provided by, and under the jurisdiction of, a control area to balance the measured mismatch between generation and load. Deviations in load from the scheduled value are normally supplied by some generating units under AGC or participating in manual frequency control [1]–[3]. They are substantially the same service except for the time frame. While regulation should follow minute-to-minute load variations, load following addresses variations that occur over a longer time horizon [4]. In some cases there is no real possibility of distinguishing between the two services. For this reason, we will refer sometimes to both with just the term load following.

In the last few years, there have been several proposals for creating competitive markets for AS [5]–[8]. The main idea is to let a certain number of generators bid in the market, while the system operator acquires an amount of each AS on behalf of the customers. Providing them competitively is becoming a reality. Still many issues related to AS, and in particular to the provision of load following, remain unresolved.

A major problem is the proper role of the Independent System Operator (ISO), or an equivalent authority, in the competitive market. In some cases, the ISO is the institution ultimately responsible for the procurements of AS. If each competitive market for ancillary services is treated individually and sequentially, the ISO has the fundamental task of redispatching generating units once a market is closed [5]. In other cases, the role is primarily a supervisory one because the competitive market can be decentralized [6].

Other examples of unsolved issues linked to the competitive provision of load following are: who will have the ultimate responsibility for performance, how to increase the number of suppliers involved, and how to allocate payments specifically to customers. The last item, in particular, has become an extremely important issue; we, together with many researchers, believe that the FERC pro forma tariffs should be changed to reflect the impact of each user on the AS market.

In this paper, we propose a model which addresses some of these problems. The main difference with other works on the subject is in our attempt to decentralize the market for load following [9]. In accordance to NERCs definition of Self-Provision [4], we allow the procurement of load following through bilateral contracts between generating units and customers. In addition, there may also be either a competitive market or an authority responsible for the remaining power balance not involved in bilateral contracts. The implementation of such a bilateral market is neither trivial nor costless; nevertheless, once some conditions are guaranteed, this could be a way to overcome many of the problems related to the load following provision.

## II. THE BILATERAL MARKET FOR LOAD FOLLOWING

The aim of this section is to describe and explain in detail the proposed model structure and the conditions under which it works. We also offer some considerations to improve the performance of the model under issue and give examples to show its effectiveness.

### A. Model for a Generator With a Load Following Bilateral Contract

This section shows that a market with bilateral contracts is possible. The main point is one of considering a type of “local supplementary control” on each generator involved in the bilateral market. If the required technical conditions, which we will emphasize later, are satisfied, each of the generators will have a closed loop load following controller.

Consider a generator in a control area with a bilateral contract. As shown in Fig. 1, a demand signal  $\Delta P_{gt}$ , that arrives directly from the load, is compared to the power output of the generator  $\Delta P_G$  to yield a mismatch that we call Generator Control Error (GCE). One can consider GCE as a type of local area control error (ACE). GCE is given as an input to a reset controller that will force the mismatch to zero so that the generator follows the load.

It is necessary to emphasize that such variation in the classic AGC model [10] does not compromise the frequency control. Such a generator contributes, because of its speed droop feedback loop, to the primary frequency regulation. It also can be

Manuscript received February 11, 2000; revised February 26, 2001. This work was supported by a scholarship awarded to E. Nobile from Politecnico di Bari and the European Community.

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Publisher Item Identifier S 0885-8950(01)09435-4.

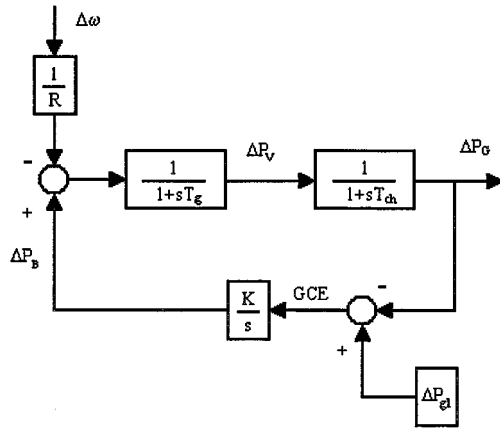


Fig. 1. Local supplementary control.

under AGC and join the classic supplementary control while satisfying the bilateral contract; in this case, the governor will receive another power demand signal from the AGC. One problem that can arise in such a situation is the interference between the two inputs. In general, a generator which is supplying bilateral load following is expected to have less power to offer to the supplementary control. Sometime the generator may be receiving an input to increase the power output from the load and, at the same time, an input to decrease the power output from the AGC. This kind of conflict can be easily overcome by fine tuning, among generators, the distribution factors of the AGC demand signal. It is expected that generators with bilateral contracts have to respond to a smaller sharing factor.

In the next section, we show that our closed loop load following controller actually acts as a local supplementary control to bring back to zero the deviation in frequency due to the variation in load when there is no centralized AGC. This is true only if all the load variations in the system are supplied through bilateral contracts. Of course, it is unlikely that the power system can perform adequately without classical supplementary control. Still, even considering a scenario in which all the load variations are supplied through contracts, the system will require centralized control to address such concerns as losses, that cannot be completely included in a bilateral contract.

As shown in Fig. 1, the generator control error is defined as:

$$GCE = \Delta P_{gt} - \Delta P_G. \quad (1)$$

If another speed droop feedback loop provides input into the local control on the generator, one can define GCE similarly to the definition of ACE as:

$$GCE = -\beta \Delta \omega + \Delta P_{gt} - \Delta P_G \quad (2)$$

with  $\beta$  as the local bias.  $\beta$  can be set simply as  $1/R$ , where  $R$  is the slope of the speed-droop characteristic of the generator under analysis, or it can be set differently to improve system performance. In fact, nonzero  $\beta$  changes only the speed, not the overall quality of performance, since if  $\beta \neq 0$  the local controller is sensitive to both the frequency and the load variations.

$\Delta P_{gt}$  is the demand signal received by the generating unit with local supplementary control. Note that  $\Delta P_{gt}$  is not necessarily just one load following contract that a generator has with

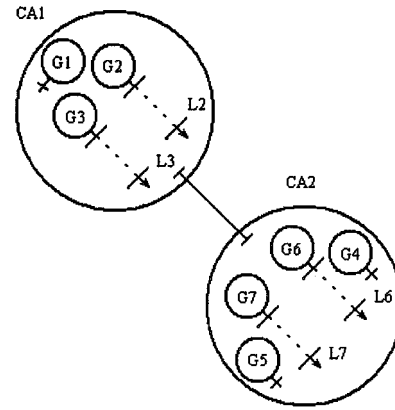


Fig. 2. Two-area system.

a particular customer. The generating unit can also have, concurrently, several bilateral contracts. In this case, the demand signal from each customer,  $\Delta P_{li}$ , is added to give the total demand signal,  $\Delta P_{gt}$ , for the specific generator and:

$$\Delta P_{gt} = \sum_i \Delta P_{li}. \quad (3)$$

It is also possible, with this structure, to provide load following with bilateral contracts across control areas.

The dynamic model for the system in Fig. 1 is given by:

$$\begin{aligned} T_{ch} \Delta \dot{P}_G &= -\Delta P_G + \Delta P_V \\ T_g \Delta \dot{P}_V &= -\frac{\Delta \omega}{R} - \Delta P_V + \Delta P_B + x \\ \Delta \dot{P}_B &= K \cdot GCE \end{aligned} \quad (4)$$

where

$x$ in the second equation	is the additional input that the generator may receive from the AGC;
$T_g$	time constant of the governor;
$T_{ch}$	is the time constant of the prime-mover;
$K$	is a constant gain.

## B. Simulation Results

In the following, we demonstrate the model for the various situations. Consider a system of two Control Areas, with three and four generators, respectively (see Fig. 2).

In CA1, all three generators are under AGC. In CA2, only three of the four generators, G4, G6 and G7 are under AGC. The model combines the classical control of generation [10] together with our local control shown in Fig. 1. Both the AGC and the local control are discrete with a four-second sampling period.

Suppose that G2, G3, G6, G7 have local supplementary control so they are able to have bilateral contracts for load following. Then consider the following cases:

- Case a)** all four generators have bilateral contracts and there is no other system variation in load. The summations of all the bilateral contracts for each of the above generators are considered as a step variation in load with:  $\Delta P_{gt2} = 0.1$ ,  $\Delta P_{gt3} = 0.1$ ,  $\Delta P_{gt6} = 0.1$ ,  $\Delta P_{gt7} = 0.2$ .

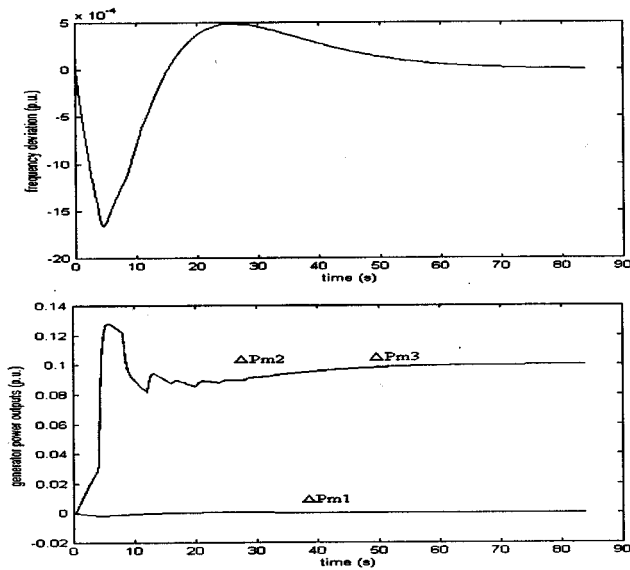


Fig. 3. System behavior: case a).

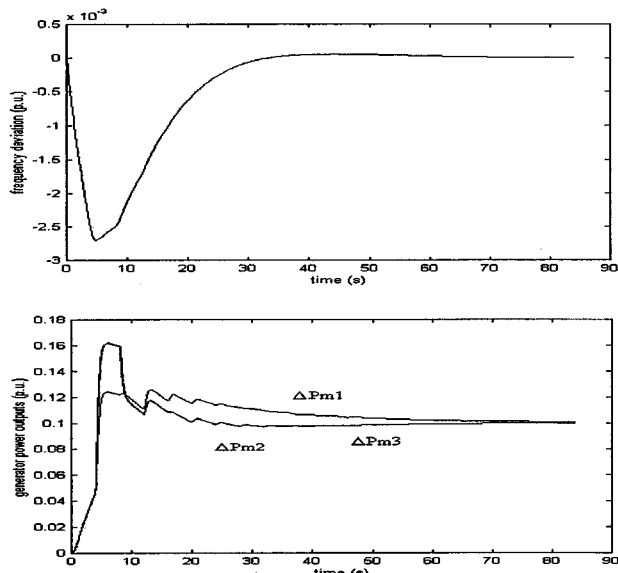


Fig. 4. System behavior: case b).

As shown in Fig. 3, the frequency initially decreases because of the increasing in load, then returns to zero. The overshoot is due to the fact that G1, G4 and G5 are all contributing to bring the deviation in frequency back to zero by increasing their power output. Each of them joins the primary control and, since G1 and G4 are under AGC, they also contribute to supplementary control. The second plot of Fig. 3 shows the power outputs in CA1 (in CA2 the situation is similar). The power outputs of generators G2 and G3, after the transient, are exactly equal to their bilateral load variations while G1 varies only a little initially and then quickly reaches zero.

**Case b)** in addition to the four bilateral contracts, there is a system load variation,  $\Delta P_L$ , in both the CA's. Suppose  $\Delta P_{L1} = 0.1$  and  $\Delta P_{L2} = 0.2$ . As shown in Fig. 4, the frequency deviation reaches zero at the

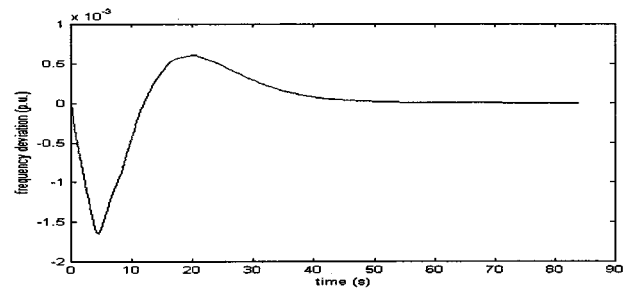


Fig. 5. Frequency behavior: case c).

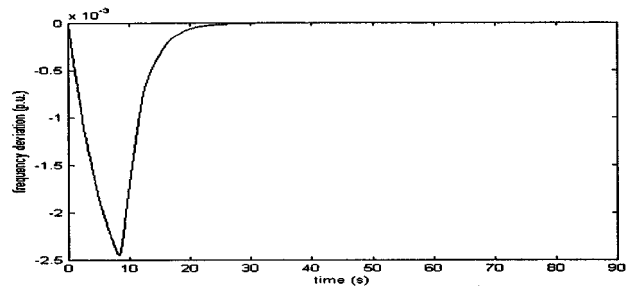


Fig. 6. Frequency behavior: case d).

steady state. The overshoot in this case is very small since the generators without bilateral contracts are following the system load variations, not just the frequency. This time, in the second plot, G2 and G3 continue to follow their bilateral contracts while G1 follows the system load variation. In CA2, while G6 and G7 follow bilateral contracts, only G4 follows the system load since G5 is not under AGC and contributes only to the primary regulation.

**Case c)** a speed droop feedback loop is included into the local supplementary control model in Fig. 1 so that  $\beta = 1/R$  and GCE is defined as (2). There is no system load variation. Fig. 5 shows the frequency behavior.

The only difference with case a) is that the variation in frequency reaches zero slightly faster. Tuning  $\beta$  in different ways can improve the speed response but performance does not substantially change. The local supplementary control is, in this case, sensitive to frequency variation and so it can help the AGCs secondary control to return the frequency to the nominal value.

**Case d)** no centralized supplementary control is available and no single generator is under AGC either in CA1 or in CA2. G2, G3, G6 and G7 have bilateral contracts and there is no other load variation in the system. The local supplementary control on the generators with bilateral contracts is modeled as in case c). Fig. 6 shows the frequency behavior.

Even without centralized supplementary control, the frequency variation returns to zero at the steady state. There is no overshoot since all the generators without bilateral contracts respond naturally, because of the governors, to frequency regulation, but they do not follow frequency deviations. It is

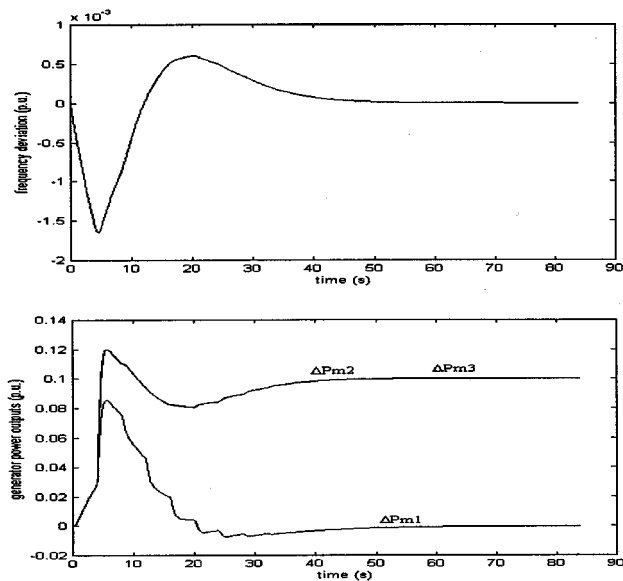


Fig. 7. System behavior: case e).

TABLE I

	Local bias $\beta \neq 0$	Bilateral contracts Inside CAs	Bilateral contracts across CAs	System load variations	Centralized AGC
Case a)	No	Yes	No	No	Yes
Case b)	No	Yes	No	Yes	Yes
Case c)	Yes	Yes	No	No	Yes
Case d)	Yes	Yes	No	No	No
Case e)	Yes	Yes	Yes	No	Yes

the summation of the effects of each local supplementary control that allows the frequency to return to the nominal value. This is true as long as the variation of load in the system is completely supplied by bilateral contracts. If any other variation in load, besides the contracts, occurs, the frequency will reach a nonzero, typically small, steady state value. In this case, the system requires other control actions, such as AGC, to return the frequency to the nominal value.

**Case e)** G3 in CA1 has a bilateral contract  $\Delta P_{g13} = 0.1$  with a customer that belongs to CA2. G2, G6, G7 have the usual contracts with customers in the CA they belong to and there is no other system variation in load. A centralized AGC is available. Fig. 7 shows the behavior of the frequency and the power output in CA1. Comparing with case c), the system behaves exactly as if G3 had the bilateral contract inside the boundary of CA1.

Together these cases show how the changes in the classical model structure, to allow a bilateral market for load following, do not compromise the normal system behavior. Table I summarizes the five examples presented.

### C. Performance Considerations

The proposed model is in line with the new NERCs requirements. In the latest version of NERCs Policy 10, a new

definition of Self-Provision is introduced, [4]. Self-Provision allows a customer to purchase an Interconnected Operation Service (IOS)<sup>1</sup> directly from a third party IOS supplier. It also attempts to split the responsibility of the provision of IOSs between the operating authority and the IOS suppliers. To this purpose, NERC is willing to introduce new performance criteria, besides the traditional measures applied to ACE [11], that the supplier is required to comply. The new performance criteria are expected to include those applied to a Supplier Control Error (SCE) defined as [4]:

$$SCE = P_a - P_s \quad (5)$$

where  $P_a$  is the supplier actual metered power while  $P_s$  is the sum of all schedules at each sampling period for this supplier. Our GCE in equation (1) is very similar to the NERCs definition of SCE in [4]. New performance criteria regarding load following and frequency control could be easily applied to each generator with bilateral contracts through this GCE.

The advantages of such a bilateral market are many. The possibility of setting the price in the contract directly between customer and supplier solves the problem of the allocation of payment specifically to each customer in an equitable way. Moreover, it allows increasing competition in the ancillary services market and, as a consequence, avoids the problem of shortfalls in supply of load following. The generator with a bilateral contract is compensated in a fair way for the service that it is offering and this could be good reason for generators to join the load following market. An increase in competition also arises because of the possibility that generators may be able to enter into bilateral contracts outside their CA, as shown in the previous section. This requires a communication network across Control Areas.

The other important point is that it relieves the ISO, or an equivalent authority, from the burden of responsibility. With this structure, it is easier to impart liability, for deviations from the scheduled amount of load following, directly to the customer and supplier. The ISO may still need to monitor performance.

As shown for case d), if all the load variations are supplied through bilateral contracts there is no need for centralized AGC. Unfortunately, it is not reasonable to suppose such an ideal scenario. Still, if the load variation of the system can be covered primarily by bilateral contracts, the amount of real power that the controlling authority must manage will be small. As a consequence, it might be possible to simplify and improve the AGC and to redefine roles and responsibilities.

## III. ECONOMIC CONSIDERATIONS

### A. Condition for Creating Bilateral Market for Load Following

As explained above, the implementation of the bilateral market for load following, from a technical point of view, is rather straightforward. For such a market to be economically feasible, more considerations are necessary. To begin the demand signal  $\Delta P_{gt}$  must arrive directly from the load. This means that, to create a bilateral market, a necessary condition

<sup>1</sup>In NERCs definition Ancillary Service is referred to as an IOS.

is that of having a very well developed communication system with the possibility of monitoring customers.

In NERC's Policy 10, among the general requirements for the provision of IOS, the supplier is asked to provide and maintain real-time voice and data communications with the operating authority [4]. The reason is two-fold: one, so the supplier is able to respond to the authority's instructions or controls and two, so the authority can monitor the performance. In the case of self-provision, the authority should be able to ensure, on and off line, that the self-procurement of ancillary services satisfies all the requirements. For this reason, a customer wishing to self-provide ancillary services should have a real-time communication connection with the center.

For our model, each customer with a bilateral contract shall have a communication channel with the provider. The provider must be connected to the center so that the authority can check and monitor the self-provision of load following. Clearly, this communication requirement means further cost for the customer.

It is important, at this point, to consider some economic issues related to the customer's point of view in our bilateral market. Besides the previously underlined advantages of our model, choosing to purchase load following through bilateral contracts guarantee the great advantage of having the generation strictly match all the load variations. This is an important point especially for those loads, which create large or fast real time power imbalance. At the present, on the contrary, there is good reason for the customer not to be interested in such a market. The charges applied for services such as load following are still flat and there is no real differentiation between users. Prices for load following are incorporated into tariffs which do not take into account the different burden imposed by each user on the system and do not compensate adequately the generation provider. As long as a new pricing scheme for AS is not developed, it is difficult for any kind of competitive market to be feasible.

### B. After-the-Fact Accounting

The last consideration here concerns after-the-fact accounting; this is an issue that still requires further investigation. The Self-Provision of an ancillary service has to be previously approved by the authority, and, as stated in Policy 10, the authority will have the possibility to monitor on line the actual delivery of the load following service. It might be convenient, for these purposes, that the supplier and the customer, in their bilateral contract, stipulate clearly a scheduled amount of load following service the customer needs and the supplier is able to provide over the period of time their agreement takes place. In this way it is easier, for the authority, to check deficiencies, on and off line, and to impart responsibility to either supplier or customer. The advantage of the model we propose is in the full automatic closed loop, which has input directly from the load: if the generator meets all the requirements needed to supply the specific amount of load following, and the customer's load deviations match closely enough the schedule in the contract, the power output from the generator automatically

matches the input from the load. Failure to provide the service can only be a matter of unforeseen events (which may also be related to deficiency in the communication system). For such unpredictable contingencies, there will be the need to set penalties and payments that either the two parts has to pay to compensate for the failure. There will also be the necessity to understand who must be compensated and how to adjust the payment for a contract that has not been met.

## IV. CONCLUSION

In this paper, we demonstrate the feasibility of providing load following competitively. Compared to other recent works on the subject, we attempt to decentralize the market for this AS, suggesting the procurement of load following through bilateral contracts. In our opinion, with a bilateral market for load following, it is possible to solve some of the urgent problems related to the provision of this service and, at the same time, it is possible to release the ISO or an equivalent authority from this burden, moving the ultimate responsibility to the supplier. We believe this is critical and needs an urgent review of the pricing methodology for this service. FERC pro forma tariffs do not appropriately identify the impact of each user on the market and make difficult a fair development of any kind of competitive market for AS.

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