Discussion

Art Hughes (ESCA Corp., Bellevue, WA): The paper is innovative in its approach to emergency operation of the power system. It very nicely bridges the gap between the automatic control of one variable by one controller on the one hand and full OPF optimization on the other. There are some underlying issues that must be addressed, however, prior to practical implementation of such a scheme including:

1. It assumes that the overloaded variable is measured directly which may not be the case.
2. While the time for performing the state estimator and OPF solutions is effectively eliminated, the time for control variable moves is not. The relative magnitude of these times should be discussed in the paper.
3. Reference [NYPP] has used a technique resembing reference 3, in conjunction with an AGC, to provide rescheduling action similar to that described in the paper. Thus, there are other approaches from that described here. Since the IRCC method uses a simplified model of the system to calculate the La Grange multipliers, it has all the accuracy limitations of reference [NYPP].
4. A major weakness of the IRCC method as compared to apriori analysis is that if the system is not correctable after the contingency has occurred, then the opportunity has been lost for performing preventative action.

   The relative stability of the approach of the paper and referene [NYPP] is hard to assess from the information at hand; however, it is importan.t

In summary, it is very good to see new approaches to the problem of secure and economic operation of the power system being described and tested.

Atteri Kuppurajulu and **Paul Ossowski:** I thank Dr. Art Hughes for raising some interesting points. While agreeing with him in general I would like to clarify the following points.

1. How the overloaded variables are measured is not addressed to in the paper. Like the tieline flows, they may either be directly measured or obtained through SCADA.
2. The time required to evaluate the control signal is very small as the required computations to be done on the on-line basis are not significant. However the time taken for the control action itself is a function of various time-constants is the turbine-governor loops.
3. As explained in the paper, the use of the D-C model in the control loop can affect the speed of reasons of the controller but cannot affect the accuracy. The accuracy is determined by the measurements. In anology with a single variable integral feedback contraol system, the gain value can only affect the speed of response and not the final accuracy. Instead of the feedback gains fixed in an arbitrar manner, the d.c. model is used for this purpose. Thus the relative strength and the direction of the various signals is determined by the d.c. model.
4. The IRCC is to be seen not as a replacement but as a major supplementary control action. Viewed in this manner, the value of the Lagrange multiplier directly reflects both the severit and duration of overload and hence can be used for other more drastic emergency procedures like load shedding etc.
5. I agree with the discusser that stability of control is an important consideration. However, as the following brief discussion shows the control path is determined by the gradient of the objective function and should not lead to any instability problems if a sufficient delay is provided in the closed loop. This delay is already inherent in view of the large time constants of the governor-turbine blocks.

The Kuhn-Tucker conditions [1] for minimizing the objective function (1) can be expressed in terms of the modified objective function (6) as follows: [2] (considering only inequality constraints)

$$F(\chi,\lambda) \leq F(\chi,\lambda) \leq F(\chi,\lambda) \qquad \text{-(D1)}$$

$$\chi \geq o \quad \lambda \geq o$$

where χ, λ is the optimum point.

Expressed in a different way the objective is to

$$\min_{\chi} \; \max_{\lambda} F(\chi,\lambda) \qquad \text{-(D2)}$$

Solving (D2) by the gradient method requires

$$\frac{d\chi}{dt} = -k_\chi \frac{dF}{d\chi}$$

and

$$\frac{d\lambda}{dt} = +k_\lambda \frac{dF}{dt} \qquad \text{-(D3)}$$

where k_χ and k_λ are constants.

It can be seen that the Controller Simulates these equations (D3) in a discrete manner as the measurements are obtained at discrete intervals of time. Because of the fact that the gradient (or negative gradient direction as the case may be) is always so as to minimize the objective function the integral control should finally lead the system to the optimum value. If the signals are properly attenuated and delayed it is reasonable to expect that there will not be any stability problems. This is a general requirement of all Integral closed loop controls. In particular even AGC has to satisfy this requirement.

Finally in equation (11) of the paper:

$$\dot{\nu} = -Ka^{dF}/_{d\nu} = Kah$$

and not as given.

REFERENCES

[1] H. W. Kuhn, A. W. Tucker, "Nonlinear Programing", in Second Berkeley Symposium on Mathematical Programing Statistics and Probability 1950, University of California Press, Berkeley, 1951.

[2] D. A. Wismer, "Optimization Methods for Large-Scale Systems with Applications" (Book) McGraw-Hill, New York, 1971.