

should be zero except for areas that reach their generation limits. The interchange transactions among areas represent the transportation problem, embedded within the non-linear optimization process. The equivalent system concept has been adopted and the transmission losses are included in this study. Two study cases are presented to manifest the proposed method efficiency in solving the multi-area generation scheduling problem. All areas operate at system λ except those which have reached their generation limits or are restraint by interconnection capacities. The proposed approach can provide more economical schedule than other available methods which is coded in C language and requires 2 minutes of computation time on an IBM/PC 386.

Discussers: J.K. Delson, R.L. White, N. Deeb

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Special Considerations in Power System Restoration

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This paper is one of a series presented on behalf of the System Operations Subcommittee with the intent of focusing industry attention on power system restoration issues. This paper discusses five particular problems that require special attention in the development of system restoration plans.

Excessive Alarms: The problems encountered in defining an alarm as critical or non-critical, being able to dynamically change this base on a restorative state indicator, and preventing alarm backlog are described. The paper recommends implementation of an alarm system enhancement that initiates different alarm presentation and acknowledgement strategies based on the rate of alarms.

Assessment of Switching Status: This part of the paper describes two general switching strategies that may be used in restoration of the transmission system, "all open" and "controlled operation." Both strategies have certain advantages which must carefully be weighed against substation equipment characteristics, weather conditions and the local energy in developing restoration plan.

Optimal Sequencing of Generator Start-up: This part describes that in the early states of restoration there will likely be more units available than will be needed or than can be loaded. This would allow optimal sequencing of unit start-ups for minimizing the time required to restore service to 75%-90% of the system load. It observes that where systems have a mix of large and small generating units installed, returning some of the large units to service may be needed before the 75%-90% system restoration level can be reached. It recommends that the restoration program be coordinated around the restarting of large units, after restoring small generating units to secure off-site power to each of the plants.

Underground Transmission Systems: The primary concern with underground transmission systems restoration is the integrity of the oil (dielectric fluid) insulation system. This part describes that the concern is when all electrical power sources are lost to the pumping plants associated with high pressure oil filled systems, the pressure in this system drops rapidly as the cable system cools down from its previously loaded condition. The drop in pressure would cause the fluid pressures at high elevations to decay (to about 100 psi) liberating gases from the fluid and forming gas pockets. Re-energizing with existing gas pockets or vacuum voids could result in immediate electrical failure or a damage which could lead to failures in the future. It lists the requirements for rapidly restoring the underground transmission systems which include: a well thought out plan, a good hardware systems to provide flexibility, and well trained personnel who know the resources and can communicate/coordinate the utilization of such resources.

Telecommunication Capabilities and Limitations: Restoration plans are critically dependent on the ability to communicate.

It recommends that the utility contingency plans should include telecommunications systems such as the Public Switched Telephone Network (PSTN) and any available internal systems. Audits of these systems, including a complete back-up power check per location should be completed to note their capabilities and limitations. The paper also describes non-telecommunications requirements for effective communication such as the availability of adequate personnel and vehicles and the availability of fuel for generators and vehicles.

Discussor: R.F. Chu

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Overvoltage Control During Restoration

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This paper is one in a series prepared on behalf of the System Operation Subcommittee with the intent of focusing industry's attention on power system restoration issues. Restoration of bulk power supply system present the operator with unique challenges not normally encountered in daily operations. The initial, and even intermediate transmission system topologies are quite different from the well integrated system during normal operation. There are several problems that pertain to these non standard topologies which are of common concern to the operators, and need to be addressed. One of these, the problem of overvoltages, is the subject of this paper.

The paper identifies the following three kinds of overvoltages, discusses their causes and remedies, and illustrates an instance of each type of overvoltage on a small example system.

- Sustained power frequency overvoltages
- Switching transients
- Harmonic resonances.

The sustained power frequency overvoltages are caused by charging currents of lightly loaded transmission lines. If excessive these currents may cause generator underexcitation, or even self excitation and instability. The sustained overvoltage also overexcite transformers, generate harmonic distortions and cause transformer overheating.

The transient voltages or switching surges are caused by energizing large segments of transmission system or by switching capacitive elements. The switching transients which are usually highly damped and of short duration, in conjunction with sustained overvoltages may result in arrester failures.

Harmonic resonance voltages are oscillatory undamped or only weakly damped temporary overvoltages of long duration. They originate from switching operations and equipment nonlinearities, and are a result of several factors that are characteristic of the networks during restoration.

An example for each over voltage type is provided in the paper, together with the description of the tools used for the analysis. The intent was to illustrate problems, remedies, and tools that are of relevance while developing a restoration plan.

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New Approaches in Power System Restoration

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This paper is one of a series presented on behalf of the System Operation Subcommittee with the intent of focusing industry attention on power system restoration issues. This paper explores three of possibilities that are opening up for more power restoration strategies and practices.

Coordination and Overall Organization: The coordination and overall organization of the several aspects of the restoration

process will largely determine the effectiveness of the restoration and its speed of progress. The most basic determinants of this organization are the relative roles played by the operator and the computer. Increasing sophistication in analysis and computational programs, including those derived from artificial intelligence, raises the computer to a significance somewhat comparable to that of the operator. Thus there arises a choice between three basic organizing principles: automated restoration, computer dominated; computer aided restoration, operator dominated using interacting programs (possibly artificial intelligence type); and cooperative restoration, an operator-computer partnership with the leading role shifting between them.

Expert System: The major steps in the development of an expert system are the compilation of the knowledge required to solve a specific problem, the identification of the process that a human expert undergoes to determine appropriate control actions, the derivation of governing rules for the operation and control of that process, and the implementation and testing of these rule on practical situations. The quality of these rule-based approaches depends, to a great extent, on the flexibility of the model used to represent the actual power system and the closeness with which the rules mimic the problems solving techniques of an expert operator. However, the phenomenal advances to hardware and software which have taken place in recent years have made it possible for expert systems to analyze a much wider range of possibilities in a much shorter time and with much more attention to details than even an experienced operator could ever hope to achieve. Expert systems thus have the potential to identify on-line the restoration strategy best suited to the situation at hand, to quickly develop plans showing how this strategy can be implemented and hence to minimize the time required for system restoration.

Operator Training Simulator: Operator training simulators provide an invaluable off-line environment for practicing system restoration. Since restoration situations occur infrequently in real life, and because during restoration there is extreme pressure to quickly and safely restore service, the OTS training will prepare operators to deal with the situation in a much more prompt and competent manner.

The potential of expert systems and full graphics to assist in restoration provides a great deal of promise. At each stage of the restoration. The operator could potentially be presented with the recommended "next action." This action could be the result of using the formal restoration procedure, in conjunction with an expert system network function, to quickly analyze the possible options and to suggest one that is "best." The graphical user interface could be used to highlight and clearly depict system conditions if the "next action" were implemented — possibly by visually highlighting the recommended next action on a display and showing the flows and voltages that would result from implementing the action.

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Electricity Tariffs Under Imperfect Knowledge of Participant Benefits

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We consider the problem of establishing tariffs for electrical energy under uncertainty about the value of the energy to the participants. A tariff update is proposed that achieves welfare maximization asymptotically through successive approximations to the ideal tariff. The successive update of the tariff avoids the need for accurate *a priori* knowledge of electricity system demand and generation as a function of price. Our key results are a tariff update algorithm and a proof of local convergence, two necessary steps for implementation of practical responsive pricing.

In many parts of the world, electric power systems are undergoing structural changes including reduced utility control and ownership of generation. Concurrently, there is a desire to reduce regulatory oversight by enlisting market forces; however, the operational characteristics of the electricity system limit the application of market forces. For example, in a classical competitive market [1, §2.2], it is usual to posit an endogenous market adjustment process where bilateral trades between buyers and sellers occur as sellers adjust prices in response to demand. In such a market it is possible to show, under relatively weak conditions, that prices converge to equilibrium values [1, §6.9 and §6.10] [2, §5.7] that are 'welfare optimal' [1, §5.5 and §7.7].

Unfortunately, convergence relies on the existence of stockpiles, through the notion of the 'excess demand function' [1, §5.4] [2, §5.7]. Electrical energy can be stored, for example, as mechanical or chemical energy in hydroelectric systems or batteries, respectively. However, electrical energy *itself* cannot be economically stockpiled, so that supply must meet demand essentially continuously. An *endogenous* market adjustment mechanism could only function if at least some of the prices were also adjusted essentially continuously. Such a market would be unprecedented in its need for fast multi-lateral communications.

Furthermore, all electricity production and consumption in an electricity system is coupled through the load flow equations. The flow of electricity does not respect the contractual provisions of the participants. Instead, sellers inject energy into the grid while buyers extract it: to avoid system collapse, total demand must be met by supply, irrespective of agreed prices and contracts. This over-riding need to match supply and demand limits the applicability of market discipline.

In place of an endogenous market mechanism, this paper assumes the existence of an exogenous rate maker whose goal is to guide the system to welfare optimality. This rate maker, however, has only partial knowledge of the value placed on electricity by participants. We propose an iterative tariff update scheme that obtains information about participants from their responses to previous prices and thus asymptotically optimizes 'welfare,' subject to operating constraints.

Schweppe et al. [3, §5.2], Vogelsang and Finsinger [4], and Cox and Isaac [5] have also proposed frameworks with exogenous rate makers and schemes for iterative tariff updates. Our model generalizes previous work by simultaneously:

- Incorporating system operating constraints such as line flow limits as well as energy balance constraints
- Treating temporal aspects of generation and consumption using ideas based on the work of Schweppe et al. [3] and Kaye and Outhred [6].

We consider tariffs that:

- Are set in advance of participation
- Are updated on a periodic, for example weekly, basis that matches a natural periodicity of participant behavior
- Consist of a time sequence of prices to follow anticipated changes in production costs of generation
- Are long-lived relative to power systems time constants.

We could think of these tariffs as time-of-use; however, the periodic update makes them unlike most existing time-of-use tariffs. On the other hand, the proposed tariff is not, precisely speaking a real-time or spot tariff, since it is long-lived.

We assume that telemetered participant demand and generation information is available to the rate maker from 'smart' meters. The rate maker uses this information to iteratively update the tariff, however, we minimize the use of information that is not revealed directly by participation in the electricity system. Our goal is to set a tariff in advance of participation that achieves the potential efficiency advantages of time-of-use prices, but which also tracks changes in the system over successive periods. Our rate maker is both a 'market coordinator' and an 'information consultant' [3, Figure 5.1.1].

It is envisaged that most participants would respond to the tariff. However, because of the absence of stockpiles, it is assumed that the rate maker can dispatch some of the participants so that supply meets demand in the system. Dispatchable resources can be either demand or supply side. The goal of the rate maker is to choose tariffs to induce welfare optimal behavior: dispatch makes up for the difference between estimated and actual behavior; it compensates for any error between the rate maker's model of the tariffed participants and reality.