To address this situation, live line construction has been carried out frequently. For improved live line work conditions and effective construction with safety maintained, we have developed two manipulator systems that have different remote control methods. We have evaluated their serviceability on real-scale model distribution lines.

System Concept

In the development, principal system requirements were established as follows.

(1) Remote manipulation by one operator
(2) Insulation performance for live line work up to 6.6 kV
(3) Installation of pneumatic or hydraulic actuated special tools on the top of the manipulator
(4) Mounting of power source, tools and materials for the construction on one vehicle.

System Design

On the basis of the system requirements, the following two manipulator systems were developed.

(On-boom Operation Type)

This system is controlled and manipulated by the operator seated in the cabin on the boom, for seeing perspective and identifying changes in surrounding conditions easily.

Two operation systems are adopted to perform various operations with high efficiency. One is the joystick system which is compact and easy to handle, and the other is the master-slave system which allows intuitive operation by position-position feedback.

Further, two systems are adopted for manipulator operation by the joystick, the speed command system and the position command system that provides the force feedback function.

(Ground Operation Type)

This system enables the operator to control it on the ground without approaching any live part in high places, thus improving the safety of manipulator operation and providing for future system upgrading.

A stereoscopic camera and support cameras are used to transmit all necessary visual information accurately to the operator. The master-slave operation system is adopted because of its excellent direct response performance and simplicity of operation. The operator can sense the force by the force feedback bilateral servo and his work load is reduced by gravity compensation.

Serviceability Verification Results

The serviceability of the "on-boom operation type" and "ground operation type" manipulator systems was tested using real-scale model distribution lines. The performance test mainly composed of insulator replacement work revealed that both systems can perform a series of work elements of the test operation, offering the prospect that the remote operation system can be introduced in the distribution line construction work.

The on-boom operation system needs TV cameras arranged to obtain the necessary visual information from behind the work place. However, it enables the operator to make a direct visual inspection of the work and offers the ease of having depth perception and shifting the observing point.

The ground operation system relieves the operator from direct visual observation of the work in progress. However, the verification test revealed that the system is fully capable of performing distribution line construction work using the stereoscopic and support TV system. The test also indicated that the system's bilateral function enables the operator to directly feel the external force through the master arm when the arm comes in touch with any part, to reinforce his visual grasp of the work and his working efficiency.

Field serviceability verification will be continued in the future for early development of a practical manipulator system and its extensive application in diverse operations required for constructing distribution lines.

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An Expert System for Load Allocation in Distribution Expansion Planning

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Summary

The load demand in Taiwan power system has been increasing during the past decade due to rapid economic growth on the island. To meet the ever-increasing demand, effective expansion plans for distribution systems are essential. The increasing load density can be met by either increasing the capacities of existing substations or planning a new substation. The load allocation problem arising from the latter approach will be addressed in the paper.

The purpose of a load allocation plan is to reallocate some loads in the study system to the new substation such that certain desirable features of the distribution system such as minimum loss, minimum investment cost, high reliability, satisfactory voltage regulation, etc., can be met.

Several approaches based on mathematical programming have been reported in the literature for the load allocation problem. However, these approaches require considerable computational effort and can not take many practical constraints into account.

After an intensive interview with system planners in Taiwan Power Company, it was found that current practice of load allocation is a combination of hand calculations on such items as losses, voltage regulation, investment cost, reliability, etc. and some heuristic rules, which has been established based on past experience. The use of these rules in the utility motivated the development of a rule-based expert system for the load allocation problem.

Considerable progress in the application of artificial intelligence (AI) technology to power system problems has been achieved during the past decade. However, the application of AI to distribution load allocation is rather limited.

The purpose of this paper is to develop a rule-based expert system for the load allocation in distribution expansion planning. In the development of the expert system, the AI language PROLOG, which stands for PROgramming in LOGic, is used because it is available for personal computers and it is an excellent language for building a rule-based expert system due to its capability of searching and backtracking. Since the whole system is developed on a personal computer, it is very cost-effective. To demonstrate the effectiveness of the proposed expert system, the expansion planning of a new substation on a distribution system in Taiwan Power Company which consists of three substations and twenty eight feeders is examined. The location of the new substation has been chosen by the system planners in the utility. The planning of the feeders for this substation and the reallocation of some loads in the present system to these new feeders are of major concern in this study. The philosophy underlying feeder planning and load allocation is to minimize system loss and investment cost while still maintaining high standard of service reliability. To this end, two algorithms aimed at minimizing power loss and minimizing investment cost, respectively, are presented. In addition, a software program

is written for the computation of distribution reliability. The computational procedure is shown in Fig. 1.

The main contributions of the paper are summarized as follows.

1. An expert system using the PROLOG language is presented for feeder planning and load allocation.
2. The proposed expert system has been applied to a distribution system in Taiwan.
3. The heuristic rules used by system planners are incorporated into the expert system.
4. An algorithm based on some heuristic rules is set forth for the minimum-loss design.
5. An algorithm based on minimal-path criterion is developed for minimum-cost design.
6. The reliability indices for various expansion plans are computed so that high reliability can be assured for the optimal expansion plan selected by the expert system.

Discusser: M. Etezadi-Amoli.

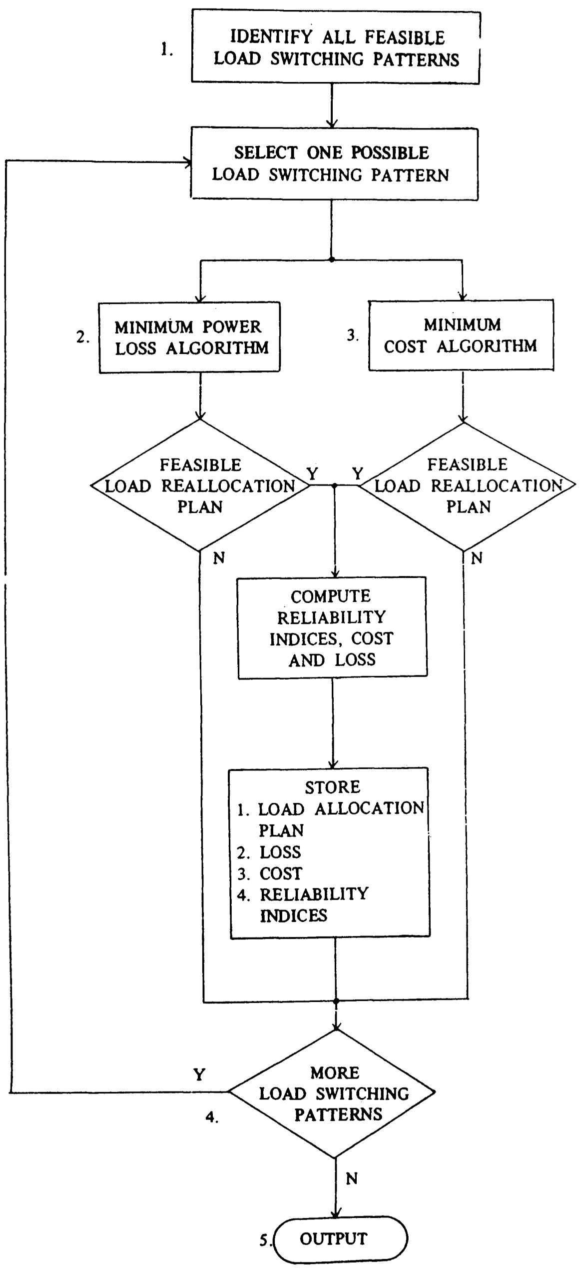

Fig. 1. The overall computation procedure for load reallocation

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Harmonic Interactions in Thyristor Controlled Reactor Circuits

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As switching circuits in power systems proliferate there is an increasing need to accurately model the harmonics that they introduce and to understand the resonance problems they can cause. Different methods have evolved to study these problems. In this paper two of these methods are described and they are applied to thyristor controlled reactors (TCRs).

The first method develops a Fourier matrix model for the TCR. A harmonic admittance matrix is found, satisfying $I_R = [Y_{TCR}]V_T$, where I_R is the current and V_T is the terminal voltage of the TCR. The matrix $[Y_{TCR}]$ is the product of the admittance of the reactor and a matrix made up of the Fourier components of the switching function shown in figure 1.

The function has a value of one whenever a thyristor is conducting and it is zero otherwise. The equation can be rewritten as:

$$\begin{bmatrix} \vdots \\ I_{R-3} \\ I_{R-2} \\ I_{R-1} \\ \vdots \end{bmatrix} = \begin{bmatrix} \cdot & & & \\ & Y_{R-3} & & \\ & & Y_{R-2} & \\ & & & Y_{R-1} \\ & & & & \cdot \end{bmatrix} \cdot \begin{bmatrix} \cdot & \vdots & \vdots & \vdots & \cdot \\ \cdots & h_0 & h_{-1} & h_{-2} & \cdots \\ \cdots & h_1 & h_0 & h_{-1} & \cdots \\ \cdots & h_2 & h_1 & h_0 & \cdots \\ \cdot & \vdots & \vdots & \vdots & \cdot \end{bmatrix} \begin{bmatrix} \vdots \\ V_{T-3} \\ V_{T-2} \\ V_{T-1} \\ \vdots \end{bmatrix}$$

It is a full matrix and it is the off diagonal elements that model the interaction between the different harmonics.

In thyristor circuits the switching function is dependent on the voltage. The thyristors can be turned on at any time but they need to wait for the current to go to zero to turn off. The commutation process is dependent on the voltage. As a consequence, $[Y_{TCR}]$ is also dependent on the voltage V_T. In order to use the TCR admittance matrix equations for the dependency need to be found. They come from the frequency domain equations for the current zeros.

The elements in the switching function, which defines $[Y_{TCR}]$, fall off as $1/n$. The harmonics in power systems will generally do the same. This allows the higher harmonics to be ignored and the admittance matrix to be truncated at a harmonic number above the harmonics of interest.

The TCR admittance matrix can be incorporated into the system equations. This method can be a powerful tool for studying the harmonics that arise from the interaction of a TCR and the power system to which it is connected. One example is the study of the effects of an ambient harmonic voltage on the harmonic current in the TCR. This is shown in figure 2.

The second method uses state variable analysis to write the system equations for a circuit containing a TCR. The coefficients of the state variables will contain a time varying term, the switching function shown in figure 1. This results in a set of linear time varying equations which are, in fact, periodic.

Although finding a closed form solution is cumbersome and is generally not done, a lot can be learned from this formulation. For example, linear system theory gives the resonance condition for a set of period equations. This is applied to a simple circuit containing a TCR. It was found that this method was able to predict a resonant point by simple