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ALTERNATE STRUCTURES FOR PUBLIC POWER SYSTEMS

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The basic structure of interacting public utility systems is addressed in the paper. Several alternative structures dealing with networking and shared resources recently have been proposed. These structures are considered by using a system dynamics model to explore system behavior under various options. Various types of utilities, demand sources, and power types may be addressed using the model.

INTRODUCTION

The objective of the study outlined in this paper was to develop a system dynamics simulation model of an investor-owned-utility (IOU). Although the model is conceptually based on previous studies of the Tallahassee City Utilities organization, it has been broadened to make it more generally applicable to investor owned utilities [1,2]. The paper primarily is directed toward investigating the effect of "interchanging" or "networking" in which separate firms can purchase from and sell to other firms in order to more efficiently meet the energy needs of both the local communities and the regional network (grid) [3]. Intuitively, it appears that the ability to sell unplanned (or even planned) excess capacity to those firms experiencing excess demand or dependent on expensive sources of energy should result in a flattening of the short run cost curve for the entire industry and therefore, a lowering of utility rates for the economic region as a whole. This should be accomplished without sacrificing corporate profits. Intuition, however, can be misleading and the dynamics of such a network system (including the financial negotiations involved) may yield counter-intuitive results [4]. Another objective, therefore, is to provide a vehicle of investigation that removes the burden of reliance on intuition. Given these objectives, the dynamics of a two-utility network are investigated in this study.

Each utility is assumed to be identical in current generator capacity, customer demand, and financial condition. Such an assumption is made to allow experimentation with the effects of interchanging energy when each utility is faced with differing constraints, such as varying patterns of demand growth, fuel cost growth, and financial options. The basis for each utility was framed from data in the public records of Florida Power & Light (FPL) Corporation and referenced to the period from 1970-1983. FPL services approximately 40-45% of the customers in Florida and using twelve generating facilities. By aggregating the multiple generating facilities, a smoothing effect for time-related data is created. This is in contrast to the discrete growth patterns exhibited by companies with one or two generating facilities. The geographical diversity also tends to "wash out" any extreme variations at a particular facility. These features of the system were the key factors in choosing a system dynamics continuous world-view modeling strategy.

SYSTEM AND MODEL STRUCTURE

The utility firm is viewed as five interacting subsystems or sectors. The variables are organized in terms of the Demand, Capacity Expansion, Production and Interchange, Rate and Financial subsystems. A representation of the structure is shown in the causal diagram of Figure 1. Such structural models portray the interaction among two systemic elements considered one at a time. A hypothesis of behavioral result for each interaction is indicated by the plus (+) or minus (-) signs at the head of each arrow. These are formed by asking the question: If variable A increases, what is the direction of movement in variable B?

At the systemic level several positive and negative feedback relationships may be described. These feedback relationships or loops create goal seeking or stabilizing behavior in the case of negative loops or reinforcing behavior in the case of positive loops. For example, a negative loop or stabilizing structure exists in the relationship between Generating Capacity Required and Generating Capacity. As capacity required increases, capacity would tend to increase. As capacity increases, capacity required would decrease. The expected behavior over time would be stable, with capacity oscillating about some level.

The various relationships shown were translated into a parametric model, the structure of which is shown in Figure 2. The various sectors will be discussed in the following sections.

DEMAND SECTOR

The demand sector contains those elements of the model that determine energy demand from all customers (residential, commercial, and industrial). Potential demand is the maximum demand that is expected to be placed on the system and is measured in Giga-watt-hours per quarter. The growth in potential demand is an average growth over the period modified by factors that account for utility rate changes and the price elasticity of electricity. Florida Power and Light estimates the price elasticity at -.03 [5]. Actual demand is a fluctuating percentage of potential demand that changes with season and random effects. It also is affected by the various reasons that consumers are willing to conserve electricity. These structures are smoothed to prevent the system from reacting to transient, short-term changes.

CAPACITY EXPANSION SECTOR

The capacity expansion sector contains those elements that create growth pressure on the level of generating capacity. There are four basic pressures that determine the expansion rate: short run, long run, interchange (purchased energy), and current construction.

Short run pressure is a function of the load factor which is the ratio of average demand to potential demand. The higher the ratio, the less the variation and thus the less the pressure for expansion to meet possible peak demand. The lower the ratio, the greater the variation and thus the pressure to expand to meet peak demand. The values are smoothed to prevent over-reaction to transient movements and to represent the delay between the actual movement in demand and observation of the actual movement. Thus delay stems from the ability to sense change, create information about it, and transmit it to the decision structures that react to it.

The long-term expansion pressure is a function of the ratio between potential demand and the level of capacity to meet the demand. Industry standards recommend a 20% margin [6]. As the ratio rises above the 20% margin, expansion pressure increases very rapidly. There is a lessening of expansion pressure as new construction proceeds. This is acommplished by creating a ratio between the capacity under construction and generating capacity. The larger the ratio, the greater the pressure reducing effect.

The last component of expansion pressure derives from the amount of energy sold to or purchased from another company (interchanging or networking). First a weighted proportion of energy that has been bought or sold to total sales is formed. Selling energy indicates an excess of capacity over demand resulting in a negative pressure. Purchasing indicates a dependence on other sources so the pressure is reversed although not totally.

These pressures are balanced by the financial situation of the firm. There is a constraining effect produced by the considerable capital requirements for expansion. If pressure rises high enough and adequate funds are projected to support expansion, it proceeds. Otherwise, it does not.

PRODUCTION AND INTERCHANGE SECTOR

The production and interchange sector contains those elements of the model that determine the generation of electricity and the purchase and selling of electricity to meet customer demand determined in the demand sector. The level of generating capacity under construction necessary to maintain a level of production sufficient to meet demand and maintain a reasonable safety level is included in this sector. It results from the pressure decision-structure noted in the last section and from several functions that represent the corporation executives' willingness to undertake expansion.

Generator capacity, measured in Giga-watt-hours per quarter, is the amount of electricity that can be generated in that period. It is a function of the amount of capacity added and the amount that is removed (or wears out) in a period. The amount of capacity used is determined (up to its maximum value) by demand. Information about excess capacity is gathered and transmitted to sales and interchange decision structures.

The set of equations that represents the complex interchange agreements between utilities also is contained in this sector. Energy is exchanged in a process where bids to buy and sell energy are brokered. The price of these bids is based on the marginal costs involved in producing the electricity. This model is based on production and fuel costs representing an estimate of variable costs plus a markup to give a normal rate of profit on the exchange. Purchasers will utilize a markdown in order to make the exchange cost efficient. The decision to interchange is based solely on a comparison of relative variable costs and the existence of excess capacity for at least one company. Utility rates have no effect on the interchange. Since a purchase by one company constitutes a sell by another, the equation set in the sector is duplicated for each firm.

RATE SECTOR

The rate sector contains those elements that determine the level of utility rates for the company. There are four primary components that contribute to the pressure to increase or decrease utility rates. These pressures generally are related to fixed and variable costs and must be relieved if the company is to maintain the financial integrity necessary to attract the funds required to expand the facilities enough to continue servicing the level of consumer demand.

The first component determining rate growth concerns the negative presure associated with the ability to interchange capacity. Since the purchase of energy actually reduces variable costs, there is a downward pressure on rates. Selling also provides downward pressure because additional funds are generated which improves the overall long-term financial position of the firm.

There is an upward pressure on rates when new construction is required and when fuel and variable (operation and maintenance) costs increase. A series of equations develop costs for these components and create pressure on rates through a series of transfer functions. This process represents the position of the firm in rate increase requests to a Public Service Commission or other rate regulation authority. In rate cases, there is a bargaining process that is represented in the model but not used in this study. Simple historical rate information is duplicated in the model.

FINANCIAL SECTOR

The equation set of the financial sector contains elements that establish the internal financial policy and replicate various external financial market conditions. The collection of revenues is established in the receivables level. The rate at which receivables are collected determines the utility's operating funds. The level of these funds, in turn, influences the ability of the firm to meet operating expenses, support long-term debt and expand. They also are the basis for rate changes. The sector is structured to mimic the current reported financial structure of Florida Power and Light [7].

EXPERIMENTATION

The primary objective of the experimentation was to determine the effects interchanging or networking have on the two interacting utilities. The basis of comparison is their condition had the networking option not been available. A pilot model run was made given the assumptions discussed in the sector descriptions. These assumptions were based on the historical growth patterns for PFL over the last fourteen years. The simple comparison of model output to system behavior was made for a single independent utility. Although this test does not fully validate the model, output behavior does not indicate any unreasonable results over the period. The structure requires more extensive validation and consideration, although for current purposes it is adequate.

The results of a basic run are plotted in Figures 3 through 7. In Figure 3, generating capacity, potential demand, and modified (actual) demand maintain very stable growth patterns and relative positions. In Figure 4, the utility rate rises in a slightly exponential, yet stable fashion, whic again is to be expected. The slight difference in rates between firm 1 and firm 2 during years 20 through 40 is due to random variation in modified demand resulting in slightly different pressures on the rate. Figure 5 indicates that operating funds and receivables are also growing at stable yet slightly exponential rates. This is not unreasonable given utility rate increases. Again, slight differences temporarily occur due to random variations in modified demand. In Figure 6, it can be seen that the ratio of potential demand to generator capacity (RPDTGC) decreases gradually to about 68% If the period of operation is extended the ratio risers, indicating a response to the pressure to expand. This is indicative of the extremely long-term operating behavior of such systems. The load factor moves randomly around the expected 51% to 55% range. Finally, Figure 7 plots the ratio of capacity under construction to current generating capacity. The ratio rises smoothly peaking in the 15% to 17% range. In summary, it appears that the model does not create any unreasonable results given its structure. Again, more extensive validation would be required for specific study applications.

Given the results of the base run, two scenarios are proposed to demonstrate the effect interchanging has on the utility organization under various conditions. The first scenario is structured as follows:

	Utility #1	Utility #2
Demand Growth	8%/yr	4%/yr
Productive Costs Δ	0.2%/yr	1%/yr
Fuel Costs Δ	11%/yr	1%/yr

This structure compares on utility to another when the first firm is experiencing higher demand and cost growth. The second scenario is structured as follows:

	Utility #1	Utility #2
Demand Growth	8%/yr	8%/yr
Market Factors	0.75%/yr	1.25%/yr
Production Costs Δ	2%/yr	1%/yr
Fuel Costs Δ	2%/yr	1%/yr

The effect of adjusting market factors in the second scenario is to reduce the rate of growth in utility #1 and accelerate the growth of utility #2 given the same cost structure as developed in scenario 1. Each scenario is operated with and without networking.

SCENARIO 1

The results of the model runs (with and without networking) are displayed in Figures 8 through 12. In Figure 8, the level of generating capacity for both utilities is lower with interchanging, eventhough the potential demand is greater because of the lower utility rates brought on by the decrease in capital expenses. The level of actual demand also is slightly higher because of the greater level in potential demand. These results are consistent with those hypothesized at the beginning of the paper.

Figure 9 illustrates the relationship between the levels of operating funds and receivables. For the purchaser (firm 1), operating funds and receivables maintained a stable growth pattern before interchanging. With interchanging, there is a sharp disruption of this pattern at about ten years, with receivables increasing and operating funds dropping. Receivables stabilize in a short time at about $6,000,000. Operating funds increase quickly after about a three-year slump, surpassing the performance of the firm without interchanging. The seller (firm 2), on the other hand, does not experience these temporary oscillations, as it benefits from an increase in operating funds while maintaining a steady level of receivables. While the dynamics of the adjustment period for firm 1 are not immediately apparent and warrent further study, the overall state of the system indicates an improvement in the financial condition of both firms given the opportunity to interchange.

Figure 10 displays the utility rates over time. Again, at about the ten-year point a clear reduction in rates occur for both firms with firm 2, the seller, appearing to receive the greatest benefit. This is consistent with the fact that lower levels of capital are needed to meet the collective needs of all consumers, with the savings being distributed to both firms.

The key demand and capacity ratios are plotted in Figure 11. For both firms, the ratio of potential demand to generator capacity recovers to a relatively normal level (80%) under conditions of networking, with firm 1 actually reaching a relatively risky position (90%) at the end of the period. As with the basic run, the structure of this portion of the model requires additional development to further analyze the interactions inducing the behavior of this ratio. The load factor (RATOPD) shows no significant changes, which is to be expected.

Figure 12 contains plots of the behavior of capacity under construction. At about the ten year mark, construction decreases quickly with the seller (firm 2) terminating construction by year 17 with interchange and by year 34 without interchange. Firm 1 increases construction gradually when independent, leveling off at about 15% of current capacity. When purchasing from firm 2, however, construction begins decreasing at year 10 to about 3% of the former value, then increasing exponentially beginning in year 27. The basic behavior of the system (a decrease in need for capacity expansion when networking) is expected although the degree warrants further investigation to validate the scale of the movements.

In summary, scenario 1 models a situation in which the purchaser experiences twice as fast a rate of growth in both potential demand and variable costs (fuel and production) as does the seller. The results indicate that the hypothesized behavior was essentially supported, but that additional analysis of the structure of the system is needed to clarify and validate all of the dynamics involved.

SCENARIO 2

The results of the model runs with and without networking for scenario 2 are shown in Figures 13 through 17. In Figure 13, the relative levels of generating capacity, potential demand, and modified (actual) demand are plotted. The relationships and levels appear basically stable with a slight decrease in generating capacity and potential demand when interchanging is allowed. Firm 2 levels are greater than for firm 1 because of the increase in the growth rate of potential demand. In Figure 14, the results are very similar to those shown in Figure 19. Receivables and operating funds are slightly lower than before for firm 1 due to the decrease in demand. Firm 2 maintained a very similar path as before in spite of the increase in demand. There was a slight increase in receivables and decrease in operating funds towards the end of the period. In Figure 15, a pattern is shown that is similar to that of Figure 10 with the differences attributed to the change in growth rates for potential demand.

Figure 16 plots demonstrates that the ratio of potential demand to generating capacity is very sensitive to changes in the growth rate of potential demand. Without networking, the ratio for firm 1 decreases constantly reaching 50% at the end of the period. With networking, this ratio stabilizes at about 70%. For firm 2, the ratio remained fairly stable due to the continued increase in the growth rate of demand (in scenario 1, it decreased steadily), but increases under networking to a value greater than 1.0. Both of these results indicate that considerable attention must be paid to the long-time pressures for growth. The system must be structured to maintain a relatively stable ratio given changing demand growth rates especially given the option of networking. Further analysis and exploration of executive decision functions are necessary in this area.

Figure 17 demonstrates the effect of the structure on capacity under construction. The results were similar to the previous scenario without networking, with the ratio for firm 1 decreasing slightly more rapidly and the ratio for firm 2 increasing more rapidly because of changes in demand growth rates. With networking, the results are slightly more dramatic, with both firms terminating construction at an exponential rate at year 27 reaching a 25% rate before the model ends at year 41. This indicates an instability created by networking and is evidence that apparently excellent short-term decisions may produce undesirable future results. It underlines the need for the some type of dynamic model to assess system behavior overtime.

SUMMARY AND CONCLUSION

The model presented in the paper is an initial step toward a multi-dimensional model of utility power grids. It addresses the interaction among two utilities that are buying and selling power to each other. Given the results it appears that the model offers promise in investigating the phenomenon of networking or interchanging energy between utility companies. It is clear that additional research and development of the model is necessary to include all of the complexities involved and to expand the scope of the model to the interaction among more than two utilities. The essential intuitive hypotheses mentioned at the beginning of the paper are supported by the results obtained thus far. Networking is very beneficial if long-term consequences are considered in the decision. Several scenarios other than the ones presented have been tested and are consistent with the results given here. This gives credibility to the basic structure for the model and is the basis for motivating further research towards its development.

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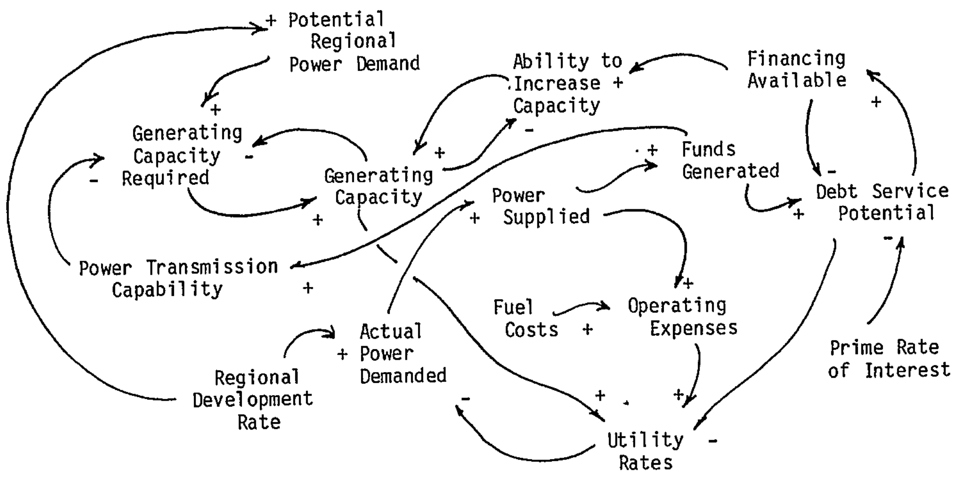

Figure 1: Regional Power System Causal Structure

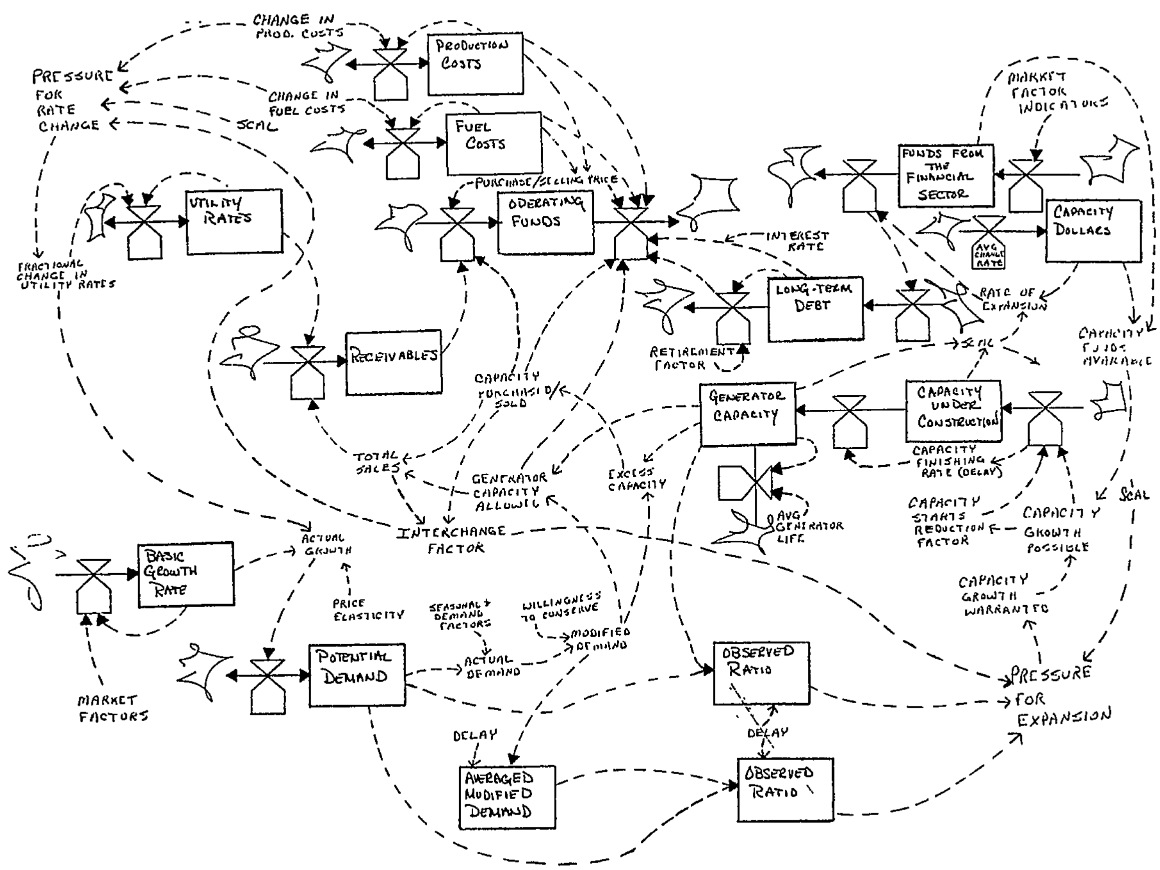

Figure 2: System Dynamics Model Structure.

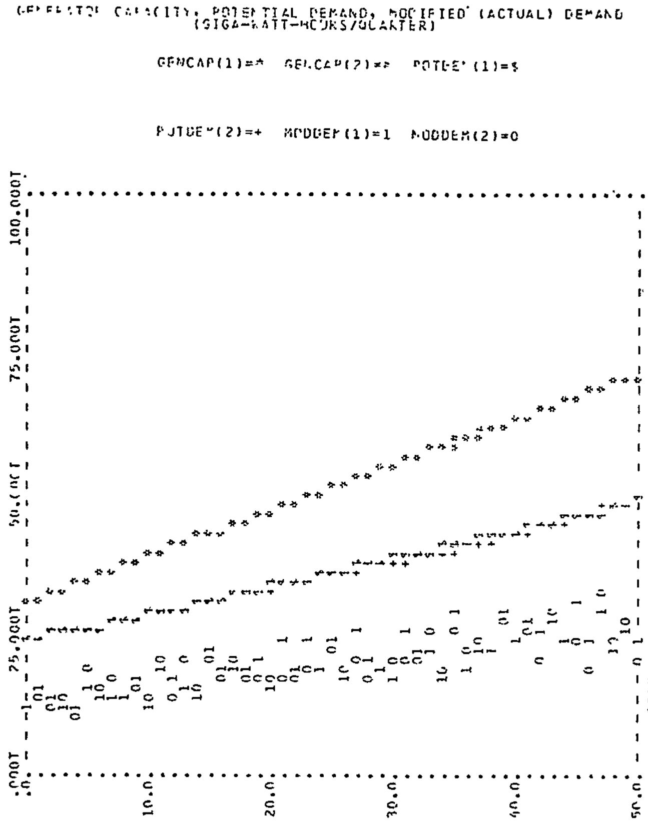

Figure 3: Base Case Output

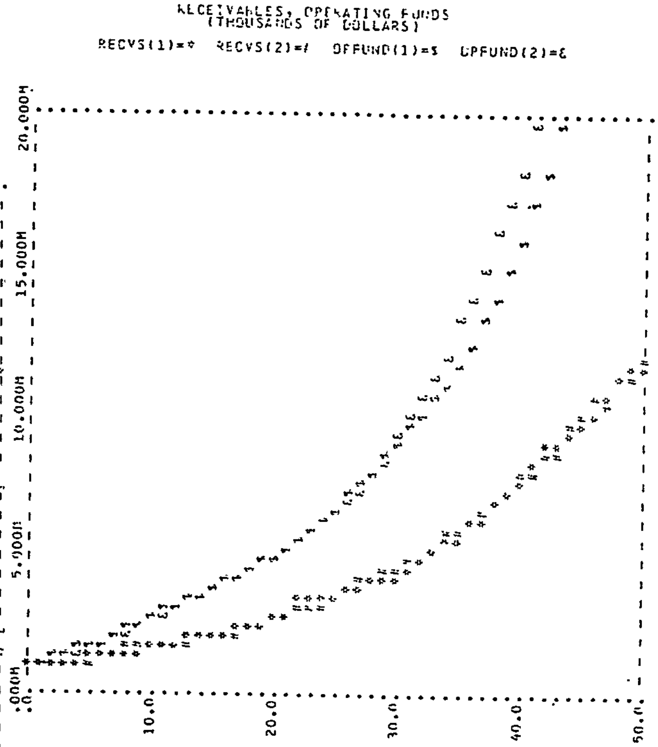

Figure 5: Financial Status

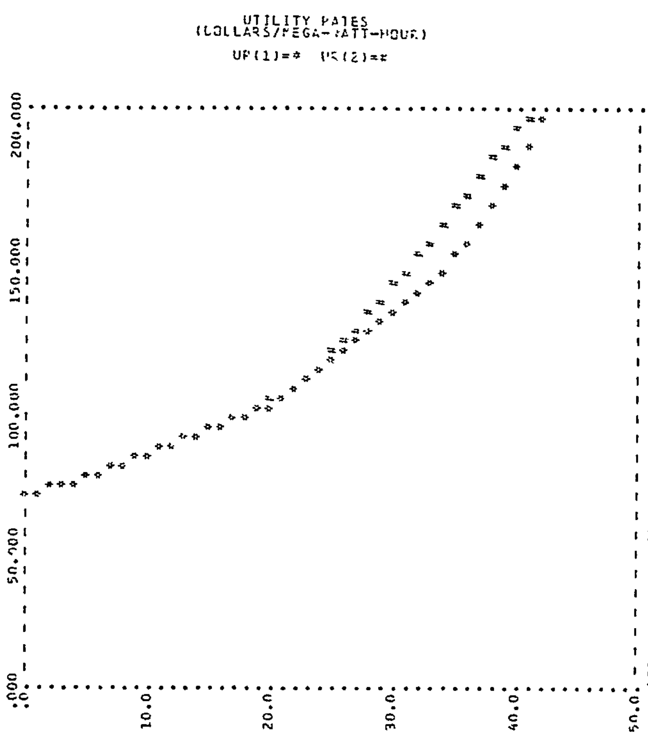

Figure 4: Utility Rates Movement

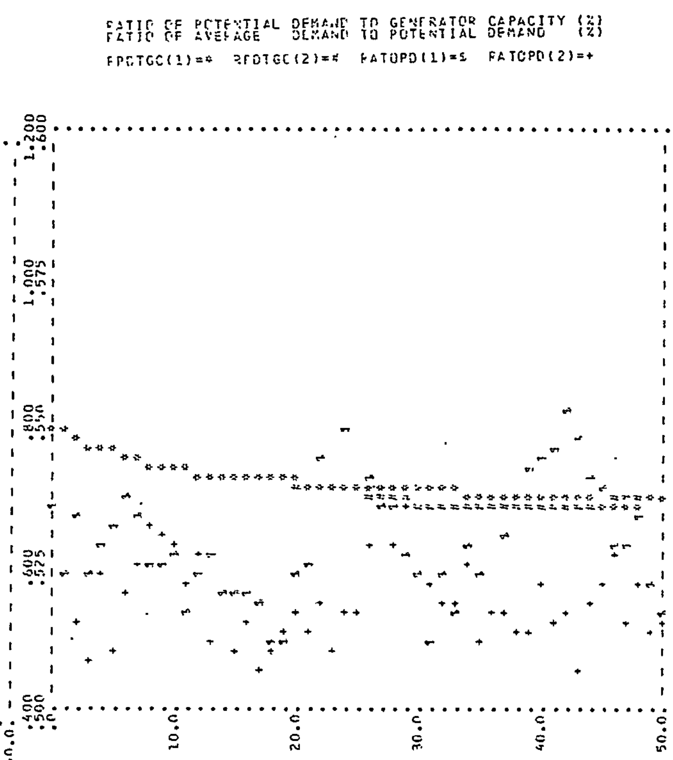

Figure 6: Load Factors

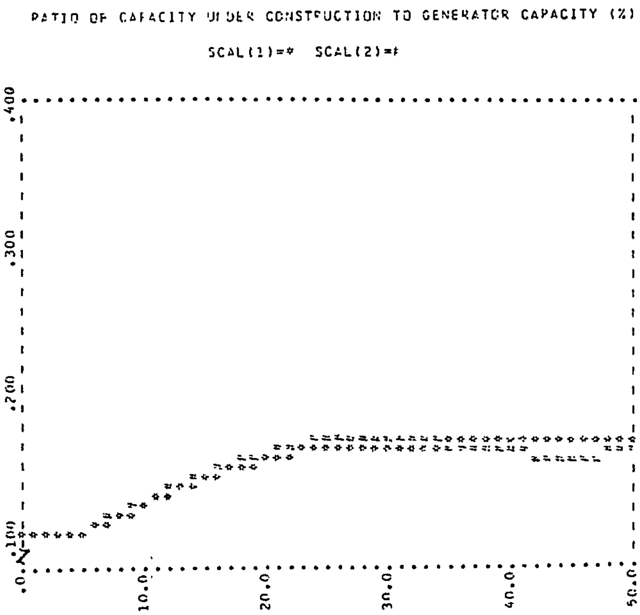

Figure 7: Construction Movement

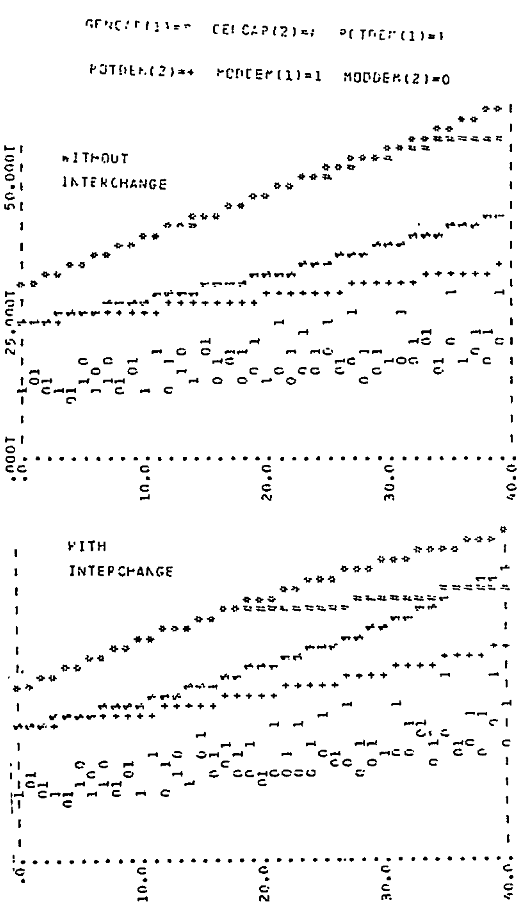

Figure 8: Energy Capacity and Demand Movement (Scenario 1)

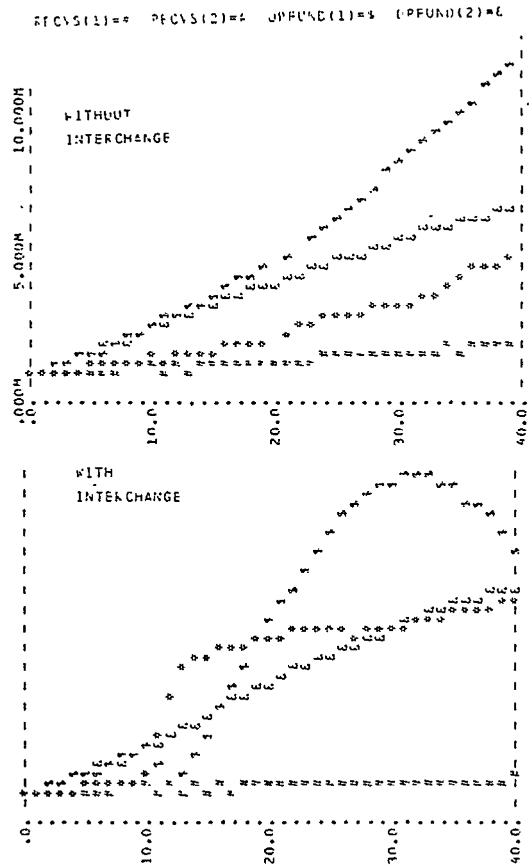

Figure 9: Financial Status (Scenario 1)

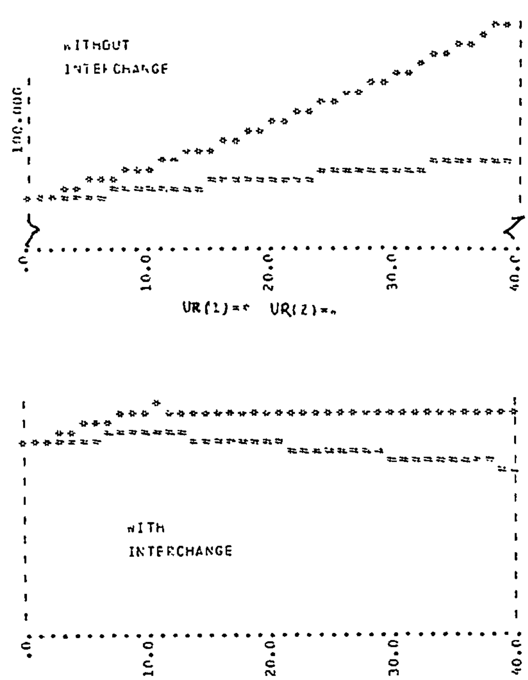

Figure 10: Utility Rate Movement (Scenario 1)

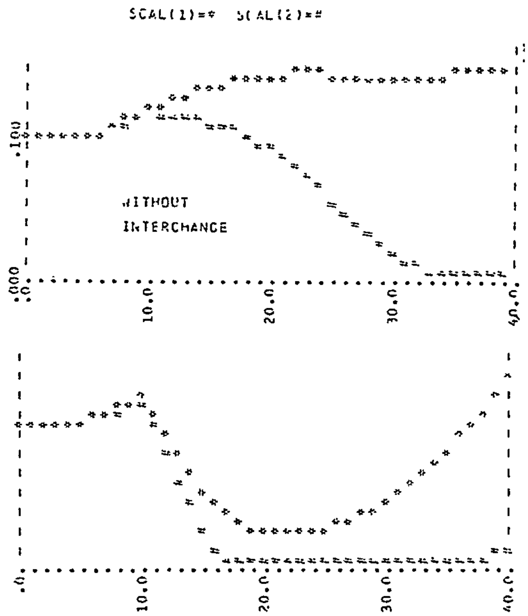

Figure 12: Construction Movement
(Scenario 1)

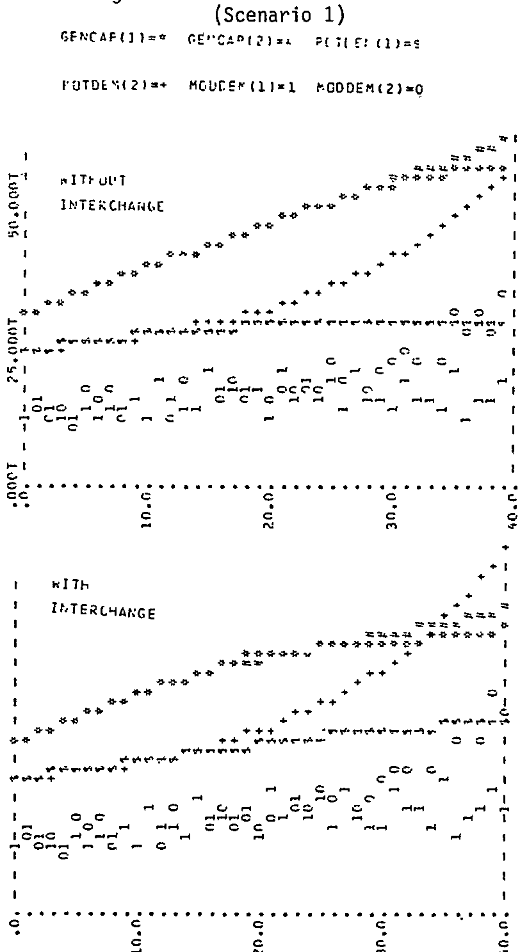

Figure 13: Energy Capacity and Demand
(Scenario 2)

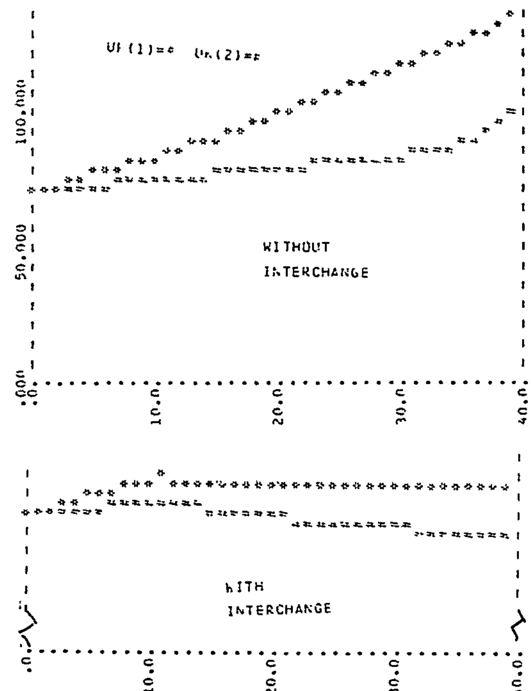

Figure 15: Utility Rate Movement
(Scenario 2)

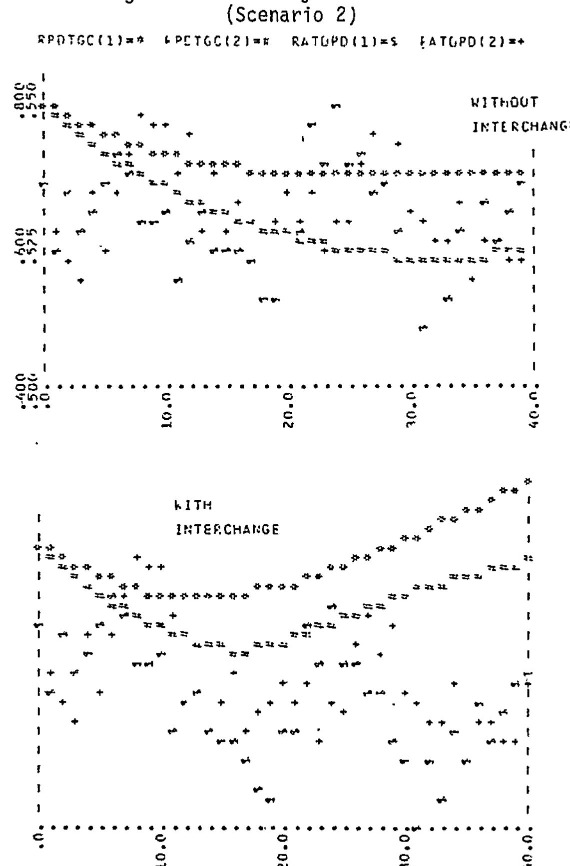

Figure 11: Load Factors (Scenario 1)

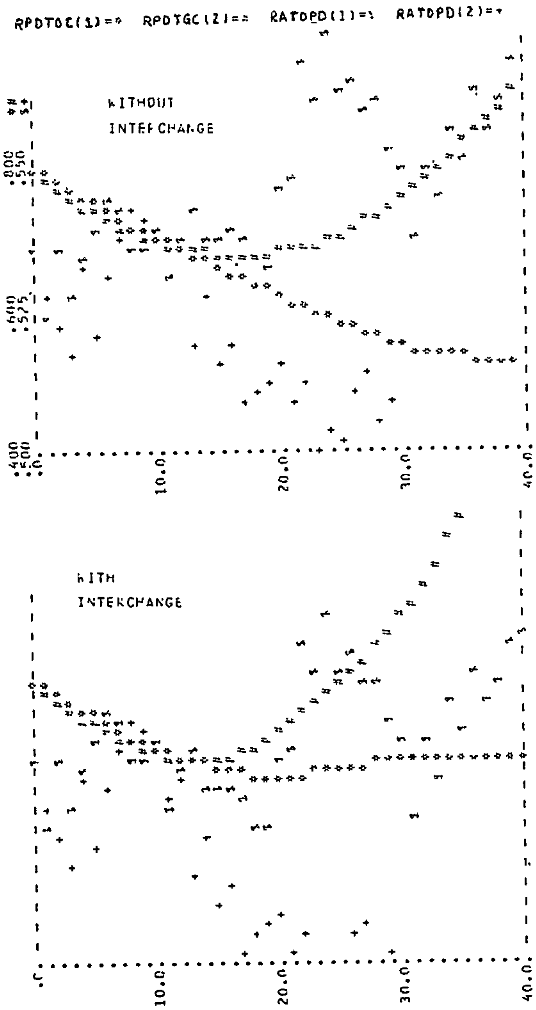

Figure 16: Load Factors (Scenario 2)

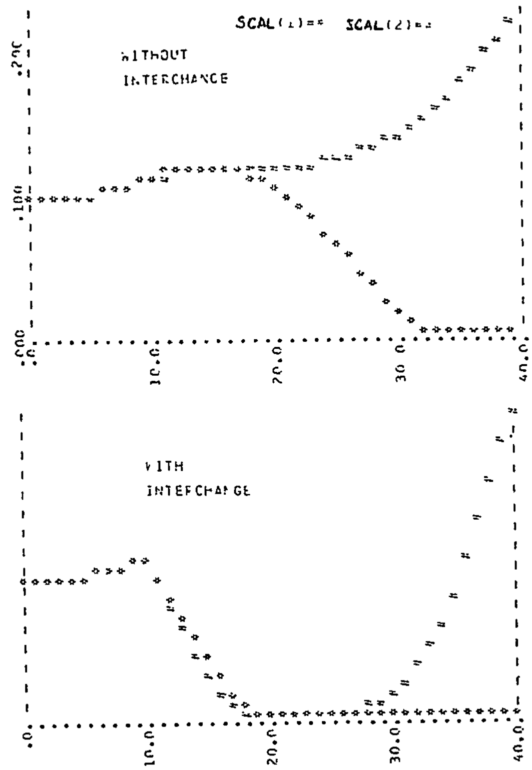

Figure 17: Construction Movement (Scenario 2)

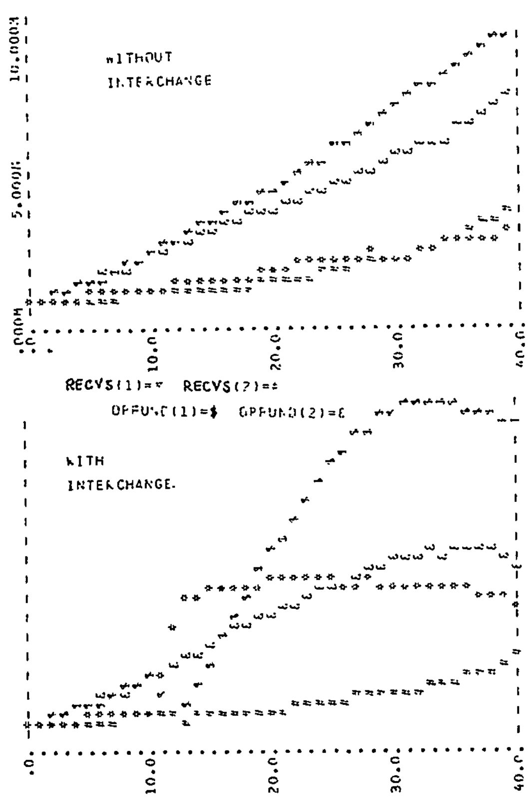

Figure 14: Financial Status (Scenario 2)

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