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HOURLY OPTIMUM OPERATING STRATEGY OF FIXED AND SWITCHED CAPACITORS CONNECTED TO A DISTRIBUTION FEEDER

استراتيجية التشغيل السعوية المثلى لجموعة مكثفات ثابتة وموصلة متصلة بمغذى توزيع .

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فى هذا البحث تم تحديد القيمة السعوية واستراتيجية التشغيل المثلى لجموعة من المكثفات المتصلة مع مغذى توزيع عمودى وتم تقسيم المكثفات إلى قسمين : الأولى مكثفات ثابتة ويتم تشغيلها على مدار ٢٤ ساعة والأخرى مكثفات موصلة حيث يتم تشغيلها فى فترة الحمل الأعظم وتمت دراسة تأثير زمن توصيل المكثفات الوصلة على السعة الأمثل وتم أيضاً اختيار المكان الأمثل لتوصيلهما ، وقد أوضحت الدراسة القيم المثلى لحجم المكثفات الثابتة والموصلة وكذلك أمثل الأماكن لوضعهما على المغذى .

ABSTRACT

In this paper the hourly optimum operating strategy of the fixed and switched capacitor banks are studied. The hourly optimum fixed and switched capacitor banks is determined. The effect of switching time on the optimum sizes of banks is presented. The effect of banks location on the feeder is also illustrated.

Study shows that the maximum optimum bank sizes for a fixed and switched bankes are 1500, 767 KVAR. They are located at nodes 4,8 on a feeder.

INTRODUCTION

Power capacitors have been improved tremendously over the last 30 years or so, partly due to improvements in the dielectric materials and their more efficient utilization and partly due to improvements in the processing techniques involved. Capacitor sizes have increased from the 15-25 KVAR range to the 200-300 KVAR range (capacitor banks are usually supplied in sizes ranging from 300-1800 KVAR). Now days, power capacitors are much more efficient than those of 30 years ago and are available to the electric utilities at a much lower cost per kilovar. In general, capacitors are getting more attention today than ever before, partly due to a new dimension added in the analysis: change out economics [1].

Kilovars, as well as kilowatts, must be provided to the customer as part of a utility's electricity service, and the analysis of the technically most desirable and economically most attractive way to supply this reactive power requirement is on of the system planner's objectives. Where as the kilowatts can *supplied only from an energy source or power plant, kilovars are automatically produced as well as consumed by the electric network itself. This, of course, results from the inherent shunt-capacitive and series-inductive characteristics of the transmission lines. For this reasons planning of the reactive power supply is subjected to a greater range of system variables [2].*

A technique is developed for solving the voltampere reactive (VAR) compensation problem under uncertain operating conditions. The technique employs chance-constrained programming (CCP), and transforms the problem into a standard linear programming problem. In providing optimal allocation of VAR supports, busbars with unacceptably high probability of violating voltage limits are identified and assigned appropriate chance-constraints. Two cases are considered using the new technique. In the first case, capacitive compensation is evaluated for peak load conditions. Inductive compensation is considered in the second case, assuming light load conditions [3].

A proposed methodology for finding the degrees of series capacitor and shunt-reactor compensation is used to increase the power transfer capability of the over-head power transmission existing rights of way and to get adequate control of steady state voltage and reactive power requirements. This methodology is based on assumed system design criteria and takes into consideration several schemes of compensation [4].

Results of transposition study carried out on the 654 Km Muja-Kalgoorlie 220 Kv radial transmission system are presented. Voltage control and stabilization of this network is achieved with the installation of three saturated reactor type static VAR compensators. By suitable line transposition, it is shown how voltage imbalances at the static voltage capacitors locations can be reduced to ensure minimal negative phase sequence current loading on the saturated-reactors [5].

In this paper the hourly-optimum operating strategy of the fixed and switched capacitor banks are determined. The capacitors are connected with a radial feeder supplying a time varying loads.

PROBLEM FORMULATION

A problem here is a determination of optimum fixed and switched capacitor banks. The capacitors are connected with a radial feeder supplying a time varying loads. The feeder consists of 9 sections is supplied from a substation. The time-varying loads are varied through a day period. They are connected with a feeder through it's length at each node.

Grainger and Lee are proposed a method for determing optimum capacitor size to minimize energy loss in the feeder. They have proposed that the connected load to the feeder have fixed values during a day period . In this paper the optimum fixed and switched capacitor sizes are hourly determined for a definite locations on the feeder. capacitor sites were changed and new sizes were calculated.

Let M and N be the sets of indices of fixed and switched capacitor banks, respectively. If the i^{th} bank is switched one, it will be represented as $i \in N$. Let LP and LE denote the peak power and energy loss reductions which result from the capacitor's placement. Then LP is given by [6,7].

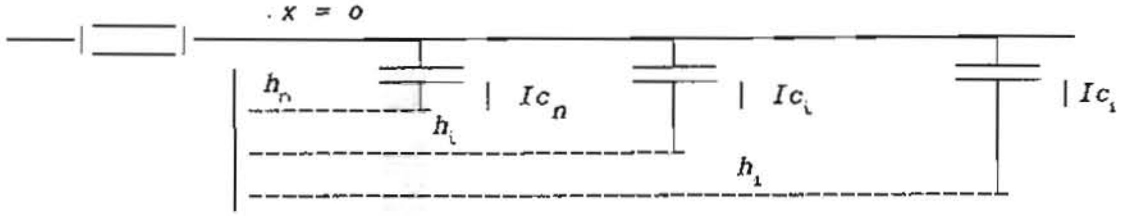


Fig.1 Capacitor locations and current ratings carry subscripts numbered as shown.

$$\begin{aligned} Lp = [&\int_o (I_o\, F(x))^2\, r\, dx - (\int_o^{h1\,nn} (I_o\, F(x) - \in_{j=1} Ic_j)^2\, r\, dx\; + \\ &\in_{i=1}^{n-1} \int_{h_{i+1}}^{h_i} (I_o\, F(x) - \in_{j=1}^{i} Ic_j)^2\, r\, dx + \int_{h1}^{1} (I_o\, F(x))^2\, r\, dx)] \text{-----} (1) \end{aligned}$$

The energy loss reduction can be written in the form of

$$\begin{aligned} LE = 3 &\int_o^{T_o} (I_o(t)\, F(x))^2\, r\, dx - (\int_o^{hn} (I_o(t)\, F(x) - \in_{j=1}^{n} Ic_j)^2\, r\, dx \\ &+ \in_{i=1}^{n-1} \int_{hi+1}^{hi} (I_o(t)\, F(x) - \in_{j=1}^{i} Ic_j)^2\, r\, dx + \int_{hi}^{1} I_o(t)\, F(x))^2\, r\, dx))dt \\ &+ 3 \int_{T_o}^{T} (I_o(t)\, F(x))^2\, r\, dx - (\int_o^{hn} I_o(t)\, F(x) - \in_{j=1}^{n} Ic_j)^2\, r\, dx \\ &+ \in_{i=1}^{n-1} (I_o(t)\, F(x) - \in_{\substack{j=1 \\ j \in M}}^{i} Ic_j)^2\, r\, dx + \int_{hi}^{1} I_o(t)\, F(x))^2\, r\, dx))dt \quad (2) \end{aligned}$$

Where

$I_o(t)$ is the time-varying reactive load current over the load cycle of duration T at the substation end of the normalized equivalent uniform feeder of resistance r ohms/unit length

T_o Interval over which switched banks are operated

F(x) The normalized feeder reactive current function [6,7]

$$F(x) = \in_{x \le \tau \le 1} I(\tau)/I_o \qquad (3)$$

and, for continuously distributed loads

$$F(x) = \int_x^1 I(\tau)/I_o\, d\tau$$

$$r = \in_{i=1}^{k} L_i\, r_i \qquad (4)$$

Where

L_i is the length of section i in meter

r_i is the resistance in ohms of section i
h_i is the per unit distance measured from substation to a point i on the feeder and is equal to:

$$h_i = \in_{1}^{i} L_{ui} \qquad (5)$$

$$L_{ui} = L_i \; r_i / r_j \; * \; L_u \qquad i = 1, 2, 3, \quad , k$$

L_u is the total length in meters of the equivalent uniform feeder

$$L_u = \in_{i=1}^{k} L_i \; r_i \; / \; r_j \qquad (6)$$

Where r_j is the resistance of the option section j

DETERMINATION OF THE OPTIMUM BANK SIZES

If the locations of the fixed and switched banks, and if the switching time of the switched banks is predetermined, the bank sizes can be determined by solving the following set of linear equations for I_c:

$$[H] \; [I_c] = [D] \qquad (7)$$

*Where $I_c = [I_{c1}, I_{c2}, \ldots\ldots I_{cn}]^t$ is the n dimensional column vector to be determined, the n*n matrix and the n-dimension column vector D are given as follows [8]:*
For $i \geq j$,

$$H_{ij} = \begin{cases} - h_i \; (K_p + K_e \; T) & \text{if both } i \text{ and } j \in M \\ - h_i \; (K_p + K_e \; T_s) & \text{otherwise} \end{cases} \qquad (8)$$

and for $i < j$

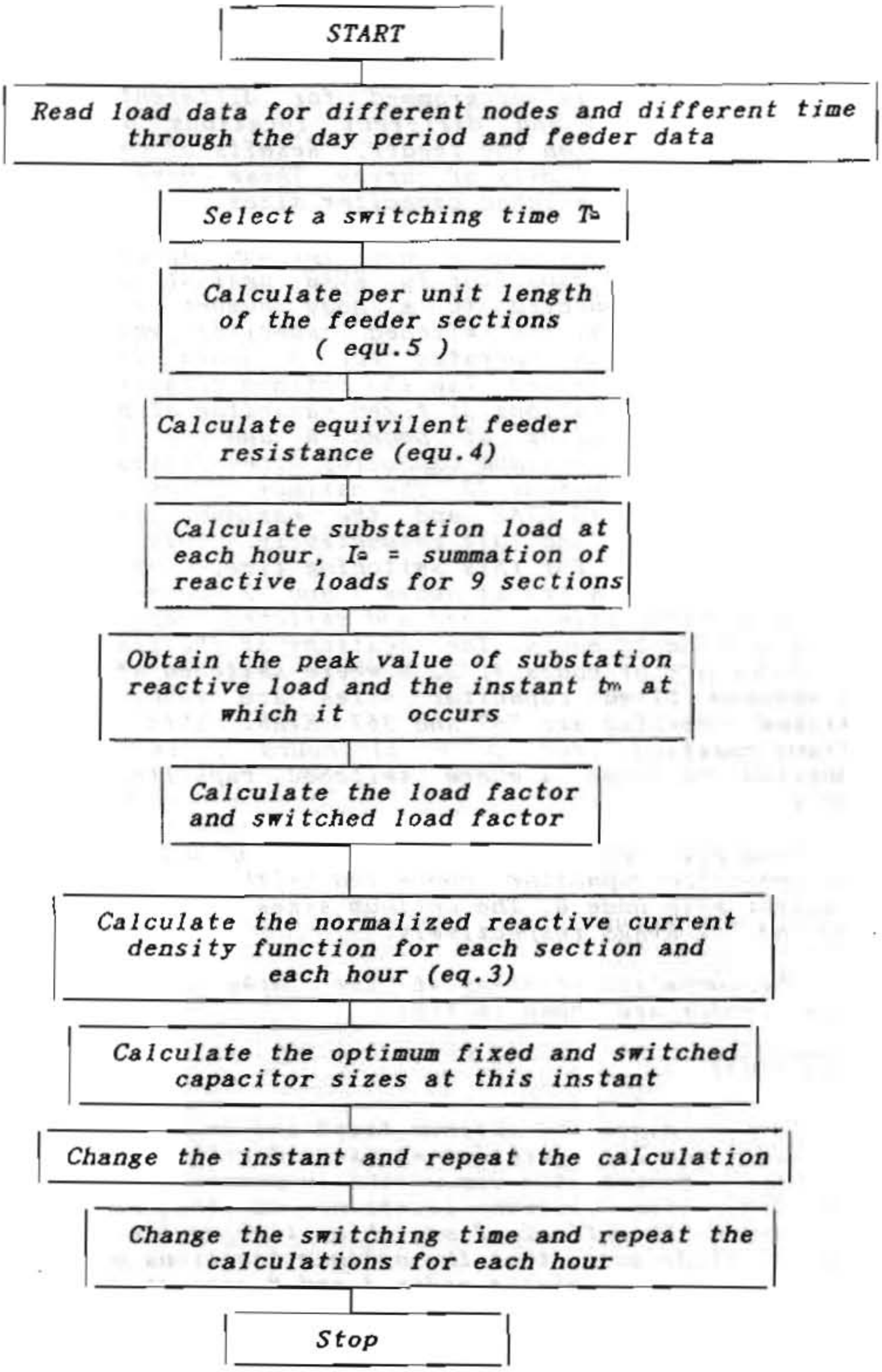
$$H_{ij} = \begin{cases} - h_j \; (K_p + K_e \; T) & \text{if both } i \text{ and } j \in M_n \\ - h_j \; (K_p + K_e \; T_s) & \text{otherwise} \end{cases} \qquad (9)$$

$$D_k = \begin{cases} -(K_p + K_e \; T \; L_f) \int_0^{h_k} I_s \; F(x) \; dx - K_{cf}/2 \; r & \text{if } K \in M_n \\ -(K_p + K_e \; T_s \; L_{fs}) \int_0^{h_k} I_s \; F(x) \; dx - K_{cs}/2r & \text{if } K \in N \end{cases} \qquad (10)$$

The constants K_p, K_e, K_{cf}, K_{cs} and T are chosen as follows:
K_p = .329/KW/day, K_e = 15 mills/KWH, K_{cf} = \$ 3.5/three-phase KVAR
K_{cs} = \$ 6/three-phase KVAR, T = 24 hours
L_f is the daily load factor
L_{fs} is the switched load factor

FLOW CHART

The hour by hour fixed and switched capacitor sizes are determined by using the following steps:


START
Read load data for different nodes and different time through the day period and feeder data
Select a switching time T_s
Calculate per unit length of the feeder sections (equ.5)
Calculate equivilent feeder resistance (equ.4)
Calculate substation load at each hour, I_s = summation of reactive loads for 9 sections
Obtain the peak value of substation reactive load and the instant t_m at which it occurs
Calculate the load factor and switched load factor
Calculate the normalized reactive current density function for each section and each hour (eq.3)
Calculate the optimum fixed and switched capacitor sizes at this instant
Change the instant and repeat the calculation
Change the switching time and repeat the calculations for each hour
Stop

RESULTS

The problem is programmed for different values of a switching time, T_s, and different locations of a fixed and switched capacitors on the feeder. Results of calculation are represented in the family of curves. These curves illustrate the optimum fixed and switched capacitor sizes.

Fig.2 represents hour by hour optimum capacitor size for a fixed and switched capacitor in KVAR against time. The fixed capacitor is connected to a node number 2 where switched capacitor at node 5. The switched capacitor which is operated during peak period operates for 3 hours (switching time). Figs.3,4 are illustrated also the optimum capacitor sizes for T_s = 3 hours and the locations of fixed capacitor at nodes 4 , 3 and the switched capacitor at nodes 8 and 7. The three figs. represent that the maximum capacitor sizes (fixed and switched) occurs at a time instant 23. The maximum fixed capacitor sizes are 3233, 3333, 1815 KVAR and the maximum switched capacitor sizes are 4oo, 467 and 1074 respectively. This means that the optimum locations ,for this switching time, for the fixed and switched capacitors are at nodes 3 and 7 respectively. Fig.5,6 are represented optimum fixed and switched capacitor sizes for switching time 11 hours. The locations of the fixed capacitor on the feeder are at nodes 4, 2, 8 where switched at nodes 8 and 5. The maximum fixed capacitor sizes are 1500, 3367 KVAR and switched capacitor are 767 and 367 KVAR. This means that the optimum position ,for T_s = 11 hours , is fixed capacitor connected to node 4 where switched capacitor is connected to node 8.

From all figs., the optimum locations and optimum switching time are fixed capacitor connected with node 4 and switched capacitor with node 8. The optimum sizes of these capacitors are 1500 and 767 KVARS respectively.

The operation strategy of the banks for different sites on the feeder are shown in figs.

CONCLUSIONS

In this paper the optimum fixed and switched capacitor sizes are determined The operation strategy for the fixed and switched capacitors through the day period is presented. The hour by hour bank sizes for various locations on the radial feeder is illustrated. The effect of switching time on the bank sizes is studied. Study shows that the optimum locations of a fixed and switched banks are at the nodes 4 and 8 respectively. Besides the maximum optimum bank sizes for fixed and switched capacitors are 1500 and 767 KVARS. The optimum switching time is 11 hours.

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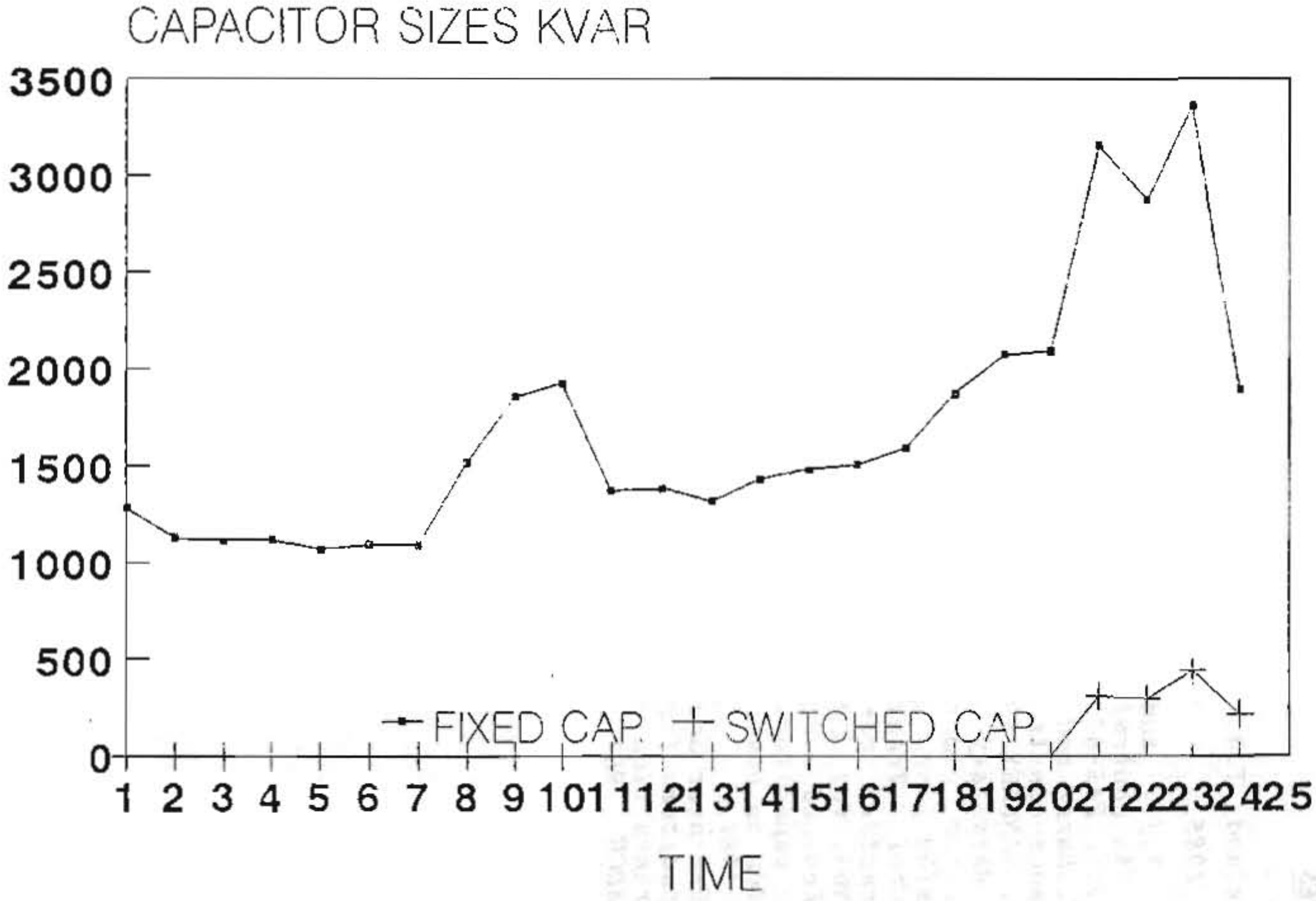

FIG.2 OPTIMUM SIZE OF FIXED AND SWITCHED CAPACITOR BANKS LOCATED AT SEC. NO.2 AND SEC. NO.5 FOR SWITCHING TIME 3HOURS

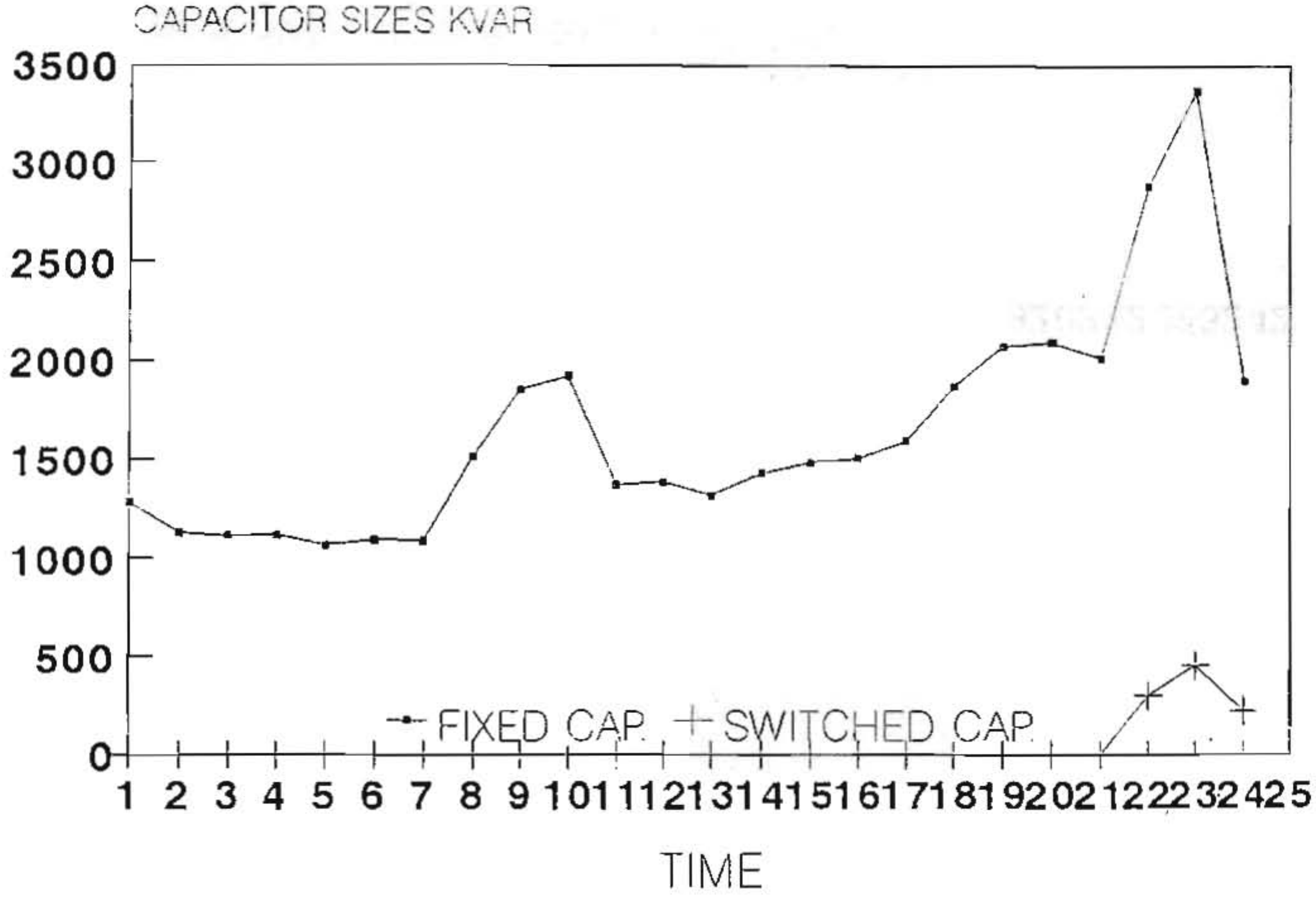

FIG.3 OPTIMUM SIZE OF FIXED AND SWITCHED CAP. BANKS LOCATED AT SECTIONS NO.4 AND SEC. 8 FOR SWITCHING TIME 3 HOURS

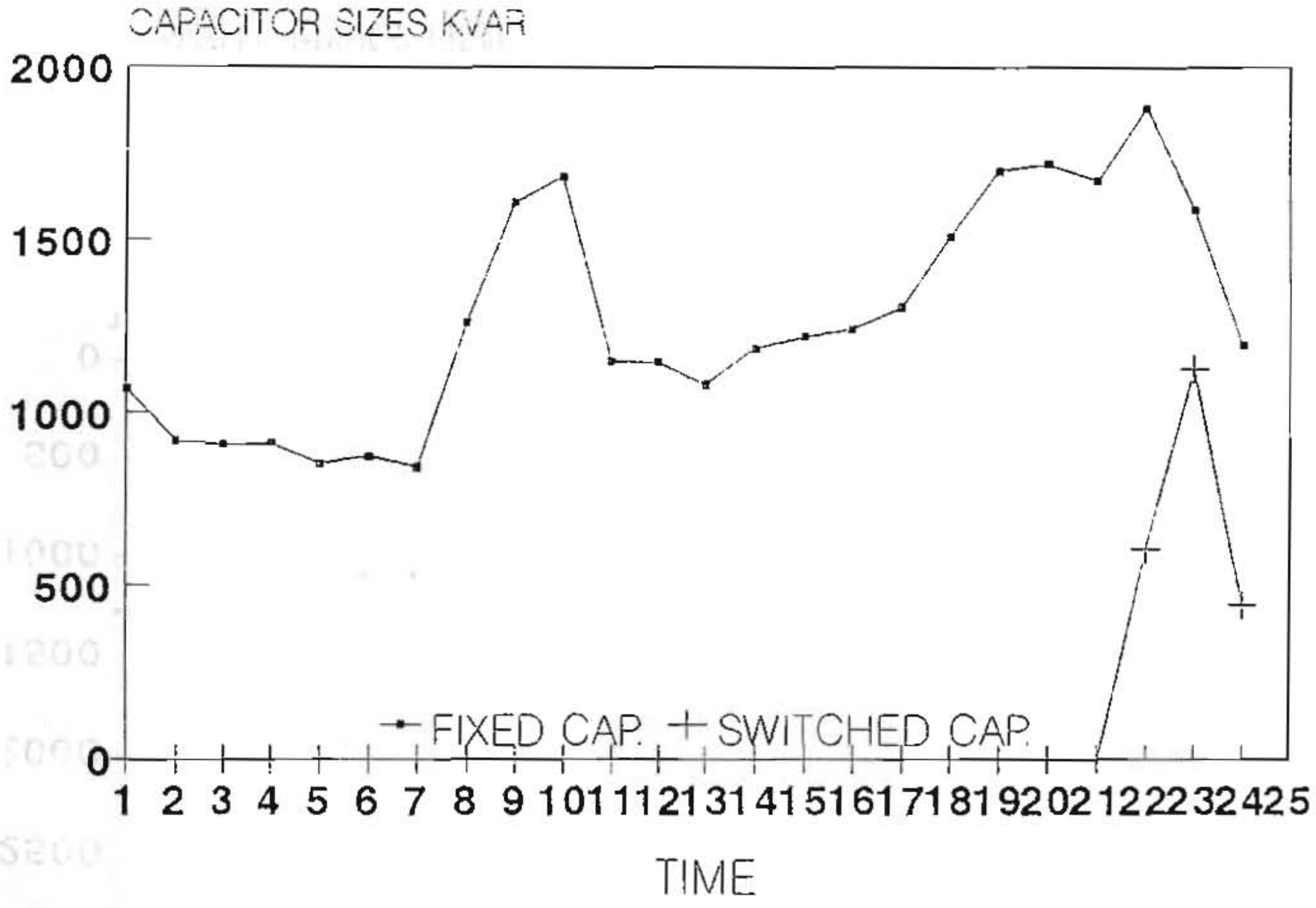

FIG.4 OPTIMUM SIZE OF FIXED AND SWITCHED CAPACITOR BANKS LOCATED AT SEC. NO.3 AND SEC. NO.7 FOR SWITCHING TIME 3 HOURS

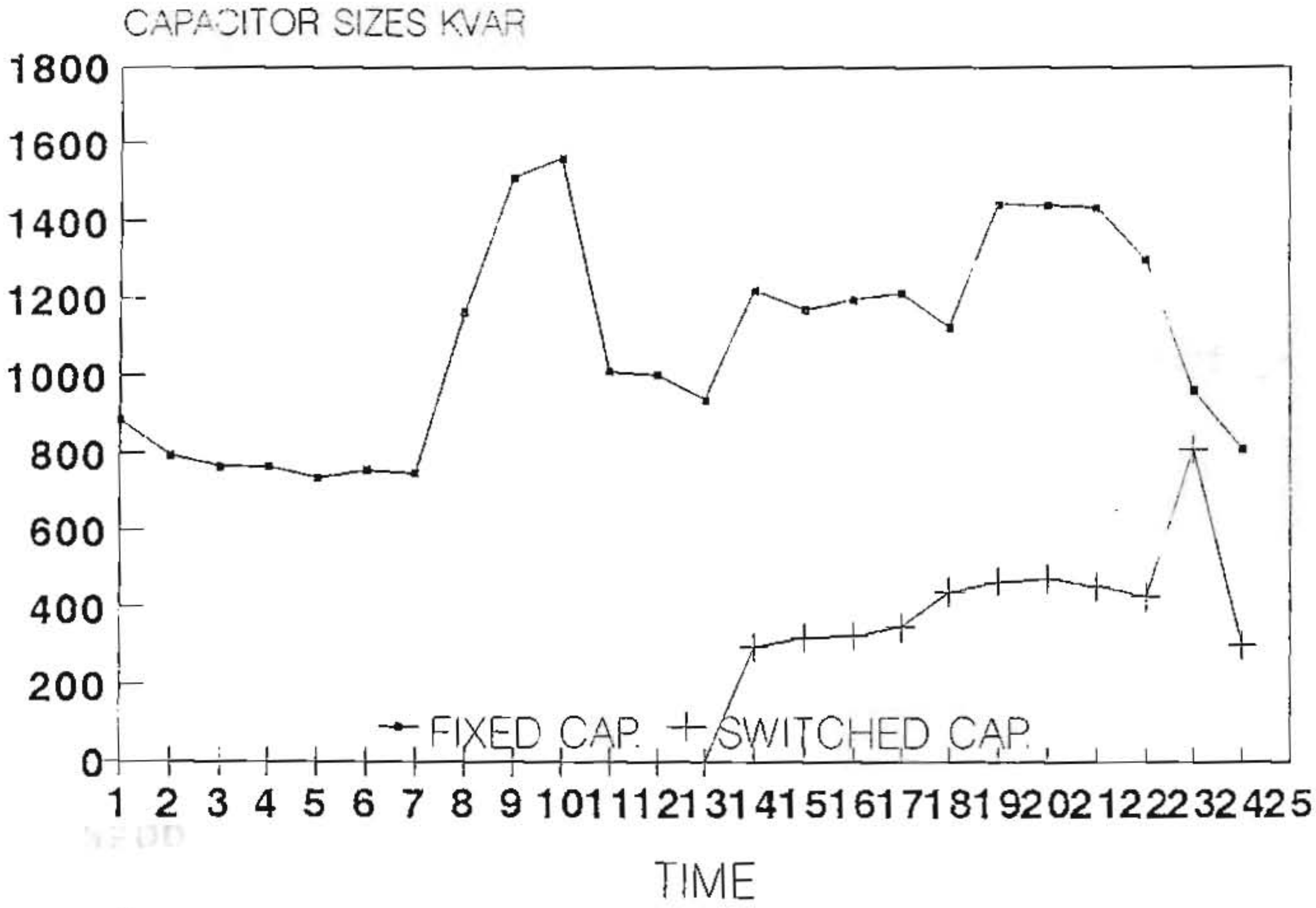

FIG.5 OPTIMUM SIZE OF FIXED AND SWITCHED CAPACITOR BANKS LOCATED AT SEC NO.4 AND SEC. NO.8 FOR SWITCHING TIME 11 HOURS

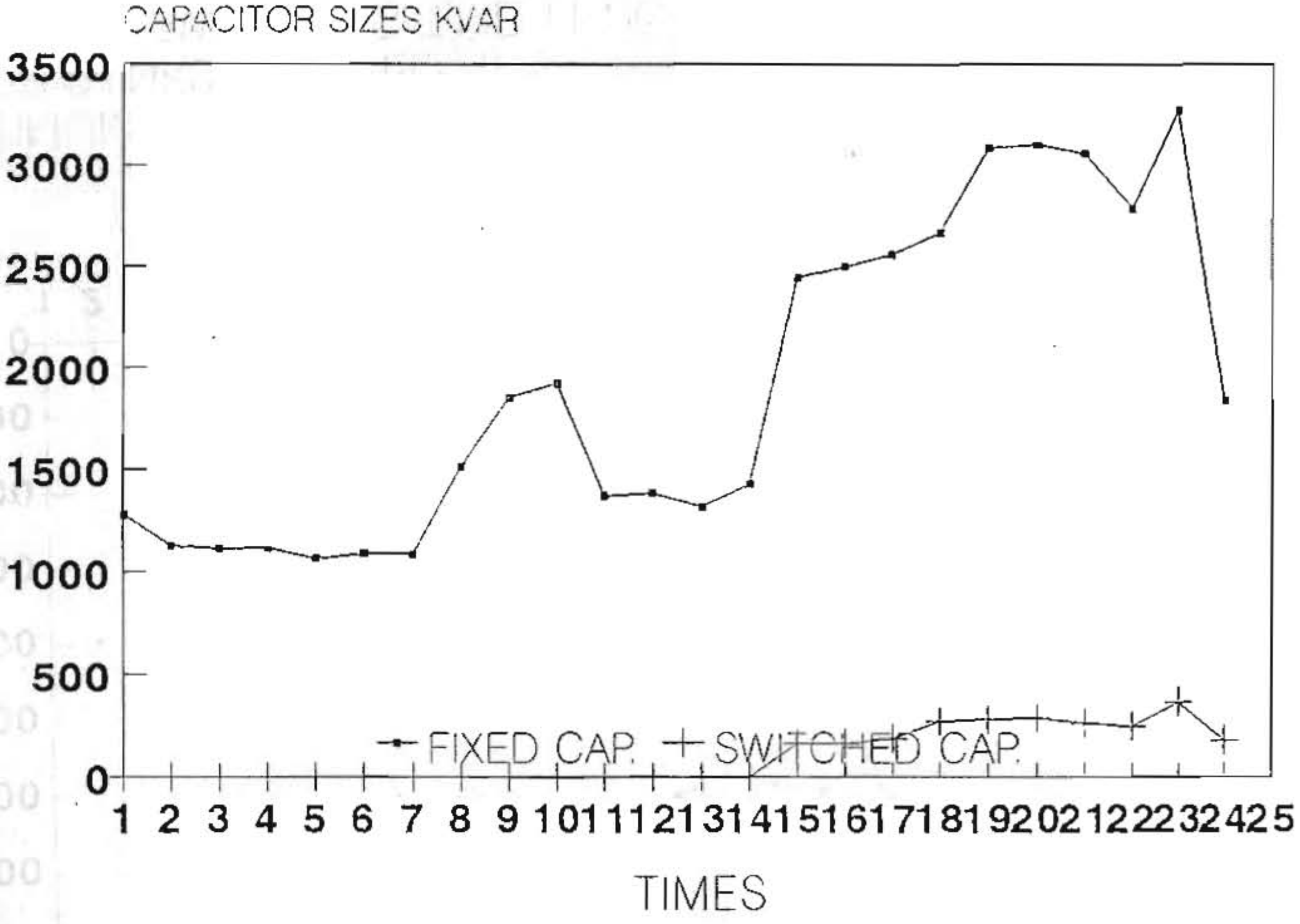

FIG. 5 OPTIMUM SIZE OF FIXED AND SWITCHED CAPACITOR BANKS LOCATED AT SEC. NO.2 AND SEC. NO.5 FOR SWITCHING TIME 11 HOURS