CHAPTER VI

VOLTAGE SOLUTION

Voltage Solution System is devided into 8 parts. They are:-

6.1. Input.

6.2. Voltage calculation.

6.3. Power and reactive power calculation.

6.4. Injection current for power and fixed reactive power correction.

6.5. Injection current for power and Synchronous condensor correction.

6.6. Injection current for off-nominal ratio transformer.

6.7. Method of estimating the value of off-nominal ratio transformer.

6.8. Selection of actual value of off-nominal ratio transformer.

This system can be discussed into two major groups without the input part.

The first group consists of part 6.2 to 6.6. It is about the convergent method when the conditions are specified.

The second part consists of part 6.7 6.8, dealing with the tap change selection.

These two parts must be worked together, for new estimated value of tap changes, the convergent method is needed. The final result is that the voltage is at its limit or tap change exceeds its limit. Unfortunately, these 8 parts can not be put together, because of the limitation of the computer size.

It is finally decided that this section must be devided into two programmes. The first one comprises the first six parts and part 6.7. When the estimated value of the transformers have been obtained, they are put into the second part which comprise of the 1st six parts and 6.8. Then the actual tap-change and the final voltages will be obtained, and will be used for the output programme.

There is a correction, part 6.2 to part 6.6, whenever any busbar is considered. Tap change will be considered at a certain cycles after all busbars have been considered.

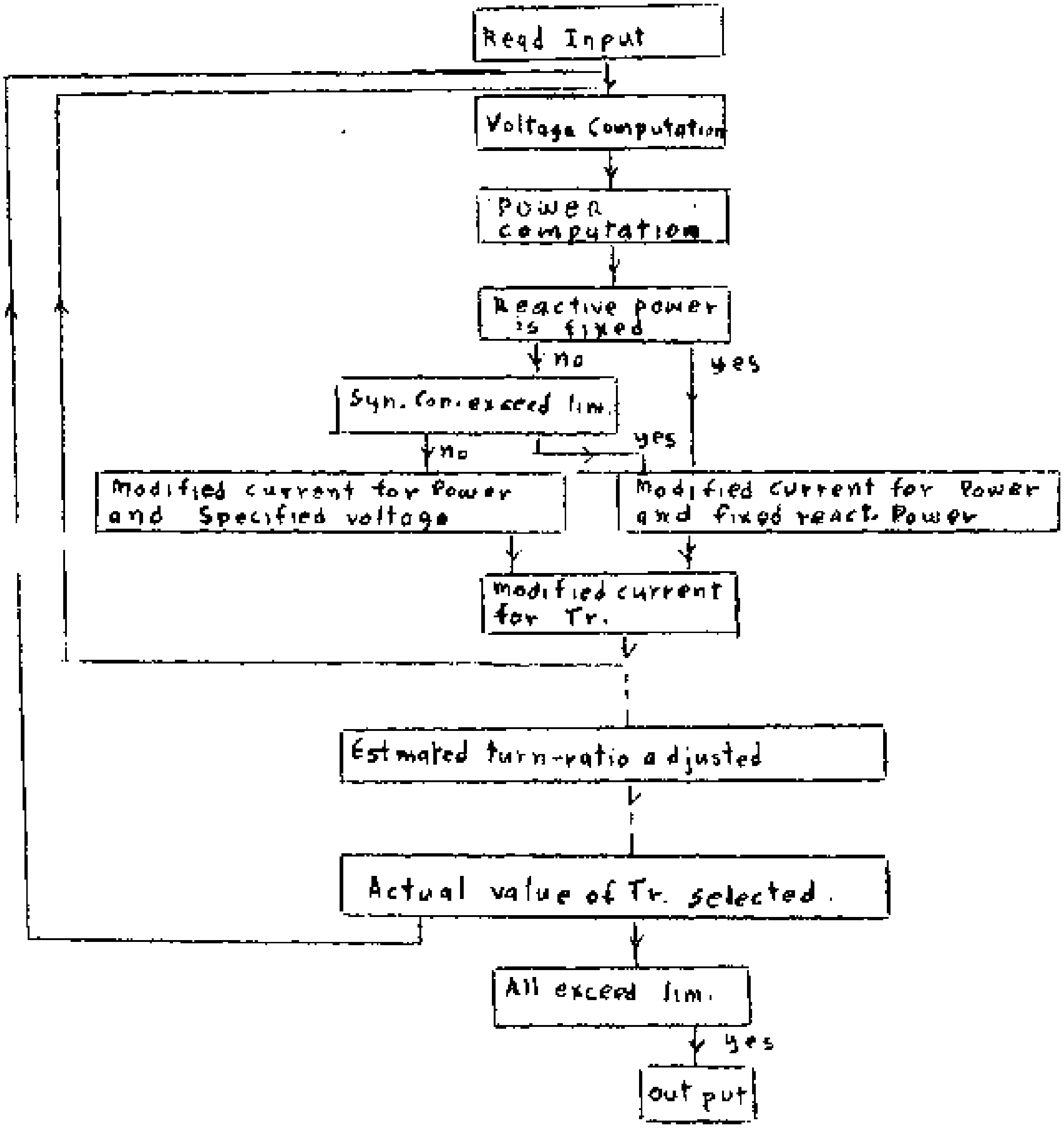


Fig. 10 Flow Diagram of a Voltage Solution System

6.1 Input.

The input of this system is quite complicated. Data must be carefully prepared, even though the programme is arranged as simply as possible.

They consist of;

1.) A set of active and reactive power. Generator and load have a different sign, and the data is their summation. Generator has a positive sign, load has a negative sign. Synchronous condenser is defined in terms of SX(m), the maximum limit, SN(m) , the minimum limit. Reactive power is also defined in terms of SN(m) and SX(m), but the values of SX(m) and SN(m) are the same. In case of a synchronous condenser and rective power or load are the same on both SX(m) and SN(m) but maximum synchronous component on SX(m) and minimum synchronous. component in SN(m).

2.) A set of specified voltage busbars and their allowable limits.

On the two terminals of the transformer, a load side, B, should be at the nominal voltage, and a very small allowance, in this case .01%, is provided.

The otherside, a generator, has much larger allowance, in Y.E.A. case it exceeds 6%.

In case of terminal without transformer, there is no test for busbar voltages error, since busbar voltages depend upon the terminal power.

3. A set of transformer connection and transformer admittance. There is two busbar numbers between a specified transformer, the first one is A busbar.

4. A set of initial injected current. This $I_{m(k)}$ is obtained from the input programme.

5. A set of inversed matrix. This is an impedance matrix inverted from the admittance matrix, obtained from the matrix inversion programme.

6.2. Voltage Computation.

Busbar voltages are the results of the matrix multiplication between the system admittance matrix and a column of total injection current

$$\begin{pmatrix} Z_{11} & Z_{12} & \cdots\cdots & Z_{1n} \\ Z_{21} & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ Z_{n1} & Z_{n2} & \cdots & \cdots \end{pmatrix} \begin{pmatrix} I_1 \\ \cdot\cdot \\ \cdot\cdot \\ \cdot\cdot \\ \cdot\cdot \\ I_n \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ \cdot\cdot \\ \cdot\cdot \\ V_n \end{pmatrix}$$

Hence, the busbar voltage is determined from

$$V(I) = \sum_{K=1}^{n} Z_{IK} . I_K$$

$$\text{or} \quad VP(I)+jVQ(J) = \sum_{K=1}^{n} (R(I,K)+jx(I,K)(IP(K)+ jIQ(K)) \quad (6.1)$$

6.3. Power Calculation.

It has been shown previously that the total injected current consists of three components.

1. Intial injected current, I_m. This can be regarded as a system data, and does not creat any power for load or generator.

2. Injection current, I_s. This is a representation of generator, load or synchronous condenser depending on the sign and kind of power.

Hence $$S = V^*(K) \times I_s(K)$$

or $$P+jQ = (VP(K)-jVQ(K))(I_sP(n)+jI_sQ(K)) \quad (6.2)$$

3. Injection current, I_A of I_B. This amount of current is added to compensate the off-ratio transformer effect when the same nominal ratio impendance matrix is still used. In this report it is referred to as HCP(j)+jHCQ(j) of a particular busbar.

Hence the busbar injection power can be found

$$S = V^*(K) \times (I(K) - I_m(K) - HC)$$

$$\text{or} \quad P+jQ = (VP(K)-jVQ(K))((IP(K)-I_mP(K)-HCP)+j(IQ(K)-I_mQ(K)-HCQ)) \quad (6.3)$$

where HCP+jHCQ is an I_A or I_B depending on the connection.

6.4. Power correction injected current for constant reactive power.

This part is considered solely on a load or generater which is constant. The main purpose of correction is to keep the calculated power as close to the specified values as possible. The busbar voltage depends on the load or generater, and can not be corrected.

If $PG(m)+jQG(m)$ is a specified load or generater at node m, $SP(m)+jSQ(m)$ is a computer load or generater.

$$\therefore \Delta P = PG(m)+jQG(m) \quad - \quad SP(m)+jSQ(m)$$

Power that should be increased from the calculated power

$$\Delta SP = PG(m) - SP(m)$$

$$\Delta SQ = QG(m) - SQ(m)$$

In case of itteration method, the busbar voltage at that cycle of calculation, $V_{(m)}$, can be used in the equation

$$\Delta SP + j\Delta SQ = V^*_{(m)} \cdot \Delta I_s$$

$$= (VP(m) - jVQ(m))(\Delta IP + j\Delta IQ)$$

$$\Delta IP_s + j\Delta IQ_s = (\Delta SP + j\Delta SQ)/(VP(m) - jVQ(m))$$

$$\Delta IP_s = (\Delta SP \times VP(m) - \Delta SQ \times VQ(m)/(VP^2(m) + VQ^2(m)) \qquad (6.4)$$

$$\Delta IQ_s = (\Delta SP \times VQ(m) + \Delta SQ \times VP(m)/(VP^2(m) + VQ^2(m)) \qquad (6.5)$$

These amount of current is added to the total injection current. This injection current is adjusted every iteration until the final results exceed the limits of specified power.

6.5. Calculation of residual currents for a variable reactive power busbar.

A generator busbar or synchronous condenser busbar, on which the busbar reactive power can be varied, can be considered by the following method.

This method is used to try to keep the voltage and the active generated power at a predetermined values.

Suppose the voltage at a busbar after the n^{th} cycle is V_n, and that a current Is_{n-1} was injected in the previous cycle. The power calculated is

$$P_n = R(Is_{n-1} \cdot V_n^*)$$

Therefore ΔP (the correction power at the busbar) is

$$\Delta P = P - P_n$$

where P = desired power at the busbar.

Therefore a current 1 should be further injected at the busbar to provide this additional power P according to the following equations:

$$\Delta P = R(\Delta I + V_n^*) \qquad (34)$$

or $$\Delta P = \Delta I_p V_p + \Delta I_q V_q \qquad (35)$$

where $$\Delta I_p + j\Delta I_q = \Delta I \qquad (36)$$

For any junction m, we have,

$$V_m = Z_{m1} V_1 + \ldots\ldots\ldots Z_{mm} I_m + \ldots\ldots Z_{mn} I_n \qquad (38)$$

where Z_{m1} to Z_{mn} constitute the m^th row of inverse of Y

Ignoring the effect of changes at other busbars, a change in voltage ΔV will be produced by this change in current ΔI such that

$$\Delta V = \Delta V_p + j\Delta V_q = \Delta I Z_{mm}$$

Therefore $$\Delta V_p + j\Delta V_q = (\Delta I_p + j\Delta I_q)(R + jX) \qquad (39)$$

where $$Z_{mm} = R + jX$$

Therefore $$\left.\begin{aligned} \Delta V_p &= \Delta I_p R - \Delta I_q X \\ \Delta V_q &= \Delta I_q R + \Delta I_p X \end{aligned}\right\} \qquad (40)$$

As this change in voltage is to be such that the final voltage has a magnitude V :

$$|V_n + \Delta V| = |V|$$

$$\text{or } |V_p + jV_q + \Delta V_p + j\Delta V_q| = |V| \tag{41}$$

$$\text{or } V_p^2 + \Delta V_p^2 + 2V_p \Delta V_p + V_q^2 + 2V_q V_q + \Delta V_q^2 = |V|^2$$

Neglecting ΔV_p^2 and ΔV_q^2 and noting that

$$V_p^2 + V_q^2 = |V_n|^2$$

$$2V_p \Delta V_p + 2V_q \Delta V_q = |V|^2 - |V_n|^2 = \delta \tag{42}$$

Substituting for V_p and V_q from equs. (40)

$$2V_p(\Delta I_p R - \Delta I_q X) + 2V_q(\Delta I_p X + \Delta I_q R) = \delta \tag{43}$$

From equation (35)

$$\Delta I_p = \frac{\Delta P - \Delta I_q V_q}{V_p} \tag{44}$$

substituting for ΔI_p in eqn.(43), and solving for ΔI_q

$$\Delta I_q = \frac{2\Delta P(V_p R + V_q X) - \delta V_p}{2|V_n|^2 . X} \tag{45}$$

I_p can then be calculated using eqn. (44).

6.5.1. Corrected injection current selection.

The value of busbar voltage is influenced by a busbar reactive power. The synchronous condenser is terminated to compensate for the effect of reactive load, it will raise the terminal voltage. For the fixed reactive power busbar, the injected corrected current is used through out . In the case of variable defined reactive power, (if the value of calculated reactive power exceeds the defined limit, while the voltage is not) then the best voltage can be obtained.

Hence, when the calculated reactive power exceeds the fine limits of a max. or min. defined value, with a tendency to go over the limits, the corrected injection current for fixed defined reactive power is chosen with that max. or min. defined value as a limit. When the calculated reactive power is out of limit, busbar voltage will be examined first. If the corrected reactive power tends to go into limit with a better voltage value, the method for variable reactive power is used, if not the method for fixed reactive power is used trying to keep the calculated reactive power to the limit.

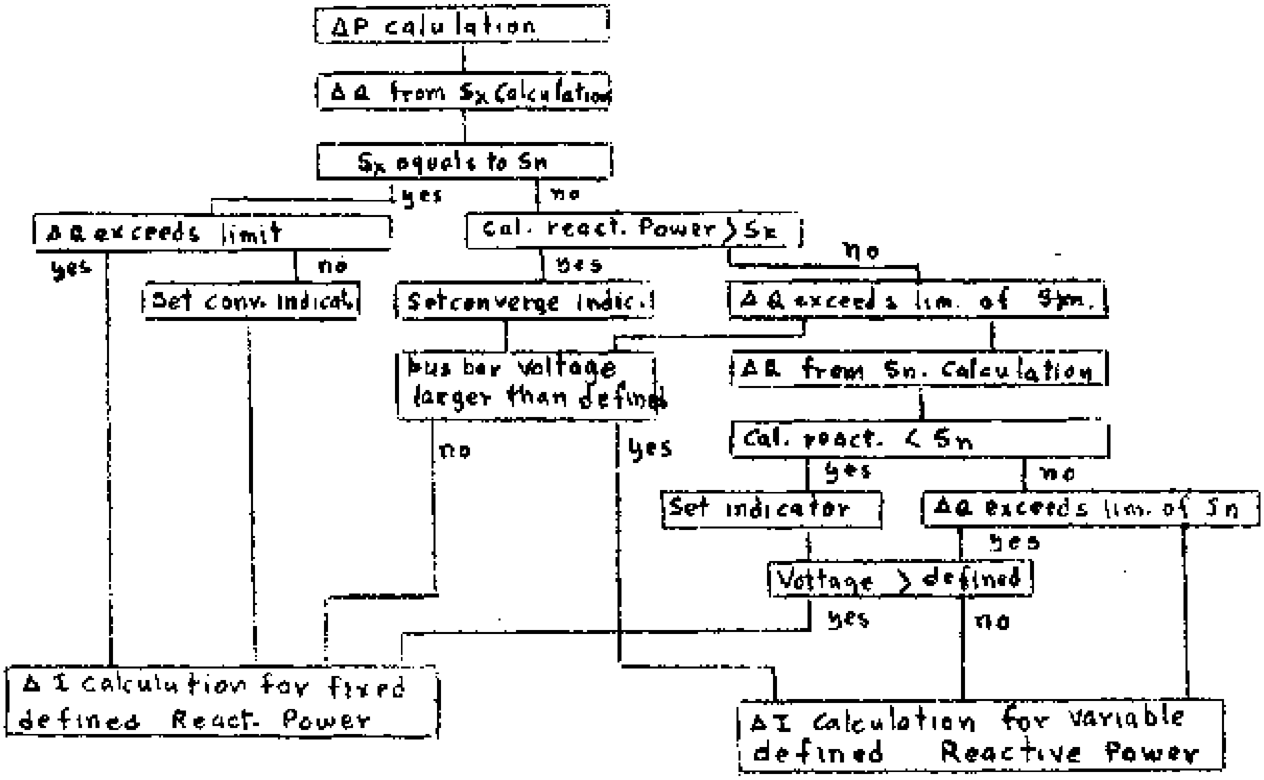


Figure 12 Flow diagram of selecting Δ I calculation method.

At 2 Q is the difference between the maximum reactive power difined and the calculated reactive power.

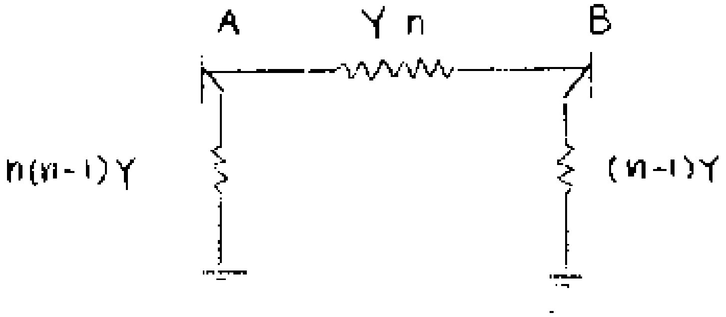
If S_x is equal S_n, it shows that the reactive power difined is a fixed one. Thus the path 4 is selected, and passes to 12. If the value of reactive power does not exceed the limit the indicator will be recorded.

At step 5, the calculated reactive power which is higher than the maximum allowable will be passed to step 6 with an indicator recorded. The one which is lower will be tested at 7 that if it is in the fine limit of Max. defined value. If it is, step 6 is chosen. The busbar voltage will be considered at step 6, and the appropriate method is selected.

Step 9 through 11 is the same as 5 through 6, but minimum reactive defined power is used in placed of the Max. value.

6.6 Residue current for compensation of an off-nominal ratio transformer.

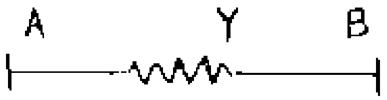
When a tap of a transformer is changed to an off-nominal ratio, the nodal and mutual compenents of an admittance matrix will be altered.



π equivalent of an off-nominal transformer

A solution of 4 busbars at nominal-transformer may be

$$\begin{array}{llllllll} I_1 & = & Y_{11} & Y_{12} & Y_{13} & Y_{14} & V_1 & 1) \\ I_2 & & Y_{21} & Y_{22} & Y_{23} & Y_{24} & V_2 & 2) \\ I_3 & & Y_{31} & Y_{32} & Y_{33} & Y_{34} & V_3 & 3) \\ I_4 & & Y_{41} & Y_{42} & Y_{43} & Y_{44} & V_4 & 4) \end{array}$$



Admittance representation of a nominal transformer

If there is a transformer between busbar 1, busbar 3, with busbar 1,an A node, and busbar 3, a B node.

$$Y_{13} = Y_{31} = -Y$$

At off-nominal value, the mutual admittance will be changed to be $Y'_{31} = Y_{13} + Y - nY$

and nodal admittance will become

$$Y'_{11} = Y_{11} - Y + n(n-1)Y + nY$$

$$= Y_{11} - Y + n^2Y$$

$$Y'_{33} = Y_{33} - Y + (n-1)Y + Yn$$

Hence the 1st busbar equation become

$$I'_1 = Y'_{11}V'_1 + Y_{12}V'_2 + Y'_{13}V'_3 + Y_{14}V'_4$$

$$= Y_{11}V'_1 + (n^2Y-Y)V'_1 + Y_{12}V'_2 + Y_{13}V'_3 + (Y-nY)V'_3 + Y_{14}V'_4$$

$$= Y_{11}V'_1 + Y_{12}V'_2 + Y_{13}V'_3 + Y_{14}V'_4 + (n^2Y-Y)V'_1 + (Y-nY)V'_3$$

$$\text{or } I'_1 - I_A = Y_{11}V'_1 + Y_{12}V'_2 + Y_{13}V'_3 + Y_{14}V'_4$$

$$\text{where } I_A = (n^2Y-Y)V'_A + (Y-nY)V'_B$$

$$= (n-1)Y((n+1)V'_A - V'_B)$$

The 3_{rd} bushar equation become

$$I_3' = Y_{31}'V_1'+Y_{32}V_2'+Y_{33}'V_3'+Y_{34}V_4'$$

$$= Y_{31}V_1'+Y_{32}V_2'+Y_{33}V_3'+Y_{34}V_4'+(Y-nY)V_1'$$

or $$I_3'+I_B = Y_{31}V_1'+Y_{32}V_2'+Y_{33}V_3'+Y_{34}V_4'$$

where $$I_B = (nY-Y)V_A'$$

The first approximate I_A and I_B will be started with V_A and V_B which are the voltages of the latest cycle. The residue current obtained in the first cycle may not be the right corrected value, but it will converge in the later cycle, the results will be obtained at any precision desired.

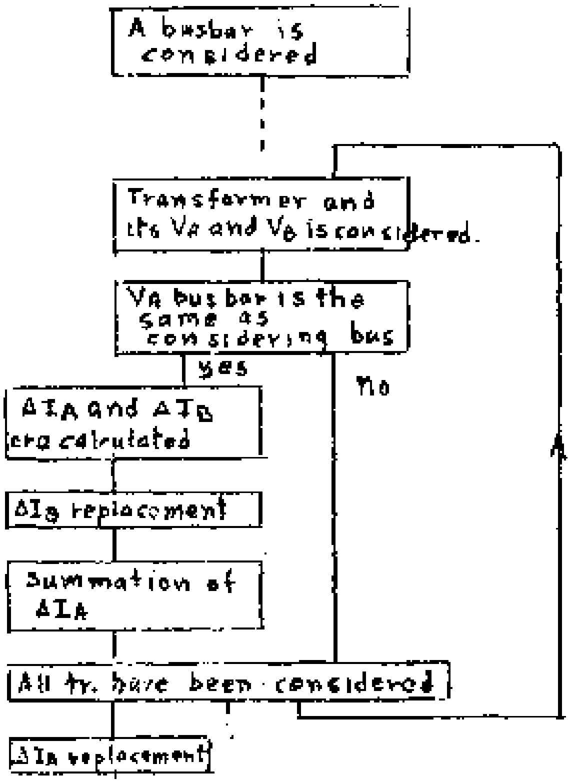


Figure 13 Flow Diagram of transformer residue current correction.

Tap change correction is performed every time a busbar is considered. All transformer will be considered one after another. When one is picked up, its A terminal will be examined whether it is the same busbar considering. If they are not the same, the next transformer will be chosen. In case of the same busbar, ΔI_A and ΔI_B correction will be worked out.

ΔI_B will be replaced the previous values of this transformer which were obtained in the previous consideration instantly. They will be replaced in their busbar total injection current and regarded as the transformer corrected injected current constants for that busbars.

ΔI_A of all transformers is added together, and will be replaced the previous values when all transformers have been considered.

6.7.a. Method of estimating the tap change value.

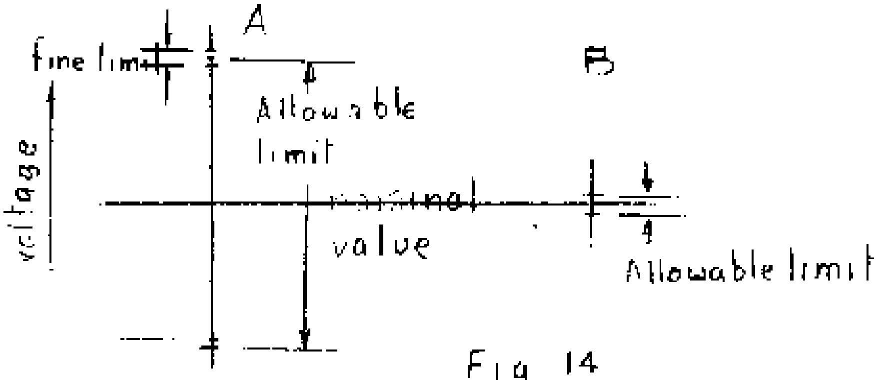


Fig 14

Transformer is usually used to keep the voltage at a load busbar to a specified value. The other busbar has no necessity to keep the voltage within a fine limit.

Hence, the purpose of adjusting the tap-change is to keep the load terminal voltage whithin the closed limit of the nominal value, and in the same time the other busbar voltage must not exceed its limit.

The busbar which receives a power has quite a large limit, it may exeeed 6%. The voltage at this busbar must not exceed the limit, since it may cause a damage.

Behavior of a transformer.

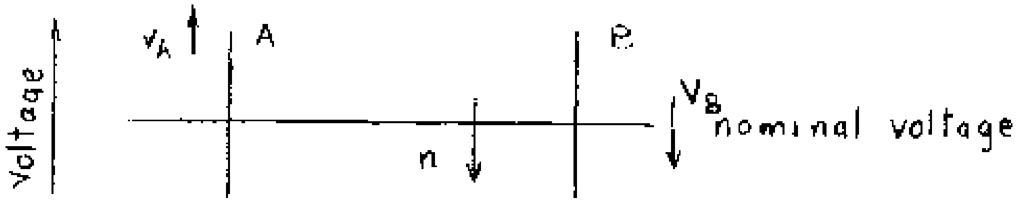


Fig. 15

In a complicated power system, as in the example, which is in the Ward and Hale(ii) report, the behavior of a transformer cannot be predicted exactly. Since load busbars of a transformer are connected to others, tap changing would cause a direct effect to them. If the ratio is raised the load terminal busbar will be raised, then the next busbar must be raised to keep the power flow constant. In this case, at first the power input terminal voltage may fall to a certain value and then raise. No formula can be supplied to complete the correction.

In this method, a simple theory is used to find tap changing, and the behavior of both busbars are examined closely.

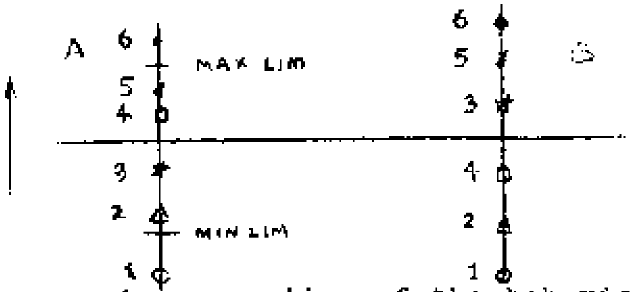


Fig. 16

An assumption of the behavior of the tap change is that

n	V_B	V_A
decreased	decreased	increased
increased	increased	decreased

1. A tap will be adjusted to keep V_A and V_B equal. When they are equal, difference of their values is less than a certain limit, V_A will be adjusted to its limit if V_A lies between its Max. and Min. limit.

2. If V_B is lower, a tap will be adjusted to keep V_A and V_B equal. And then if V_A still lies in its limits the tap will be changed further until defined V_A is obtained or V_B exceeds its lower limit depending which condition is obtained before.

3. Tap will be adjusted until the defined V_B is obtaine

4. As in case 3.

5. If V_B is higher, V_A and V_B will be adjusted to be equal first. If V_A still lies in its limits, V_B will be adjusted further to be the defined value if V_B has not reached it Max. limit before.

6. V_A and V_B will be adjusted to be equal. If V_A lies in its limits, it will be the same as in (5).

All transformer are considered one after another.

When a particular one is chosen in 1. The information about A busbar will be worked out, then step 4 is taken. In step 4, if the A busbar voltage is higher than the max. limit, I_Y is defined by 1. If it is in a fine limit of the max. limit voltage, I_Y is defined by 2. If its is lower than the lower limit voltage, IY is defined by 3. If it is in a fine limit of the min. limit voltage, I_Y is defined 4. And it is defined by 5 if it is between maximum and minimum limit. Hence the position of I_A voltage is defined completely with I_Y.

Then the information about B busbar is worked out and then step 9 is taken. At the 9th step and 10th, V_B is compare to V_A, if BV_B is bigger 11th step is chosen, 12th step for equal, 13th step for V_B is less. The selection of correction method is clearly enough in the flew diagram.

6.7.b. Method of finding a new off-nominal ratio.

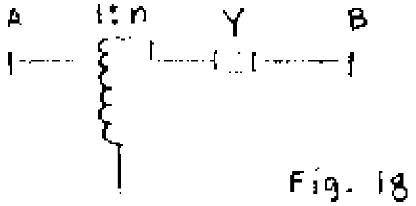


Fig. 18

Assumptions are made on this following method, and the results obtained from the assumed components checked carefully. A delay constant is used to reduce the effect caused by the correction components.

It is assumed that : $n = \frac{V_B}{V_A}$

So that $V_A = V_B/n$

In case of V_B is off the limit, and V_S is the defined value.

V_A may be assumed constant,

$$V_B/n = V_A = \text{constant}$$

$$\therefore V_{BO}/n_O = \text{constant}$$

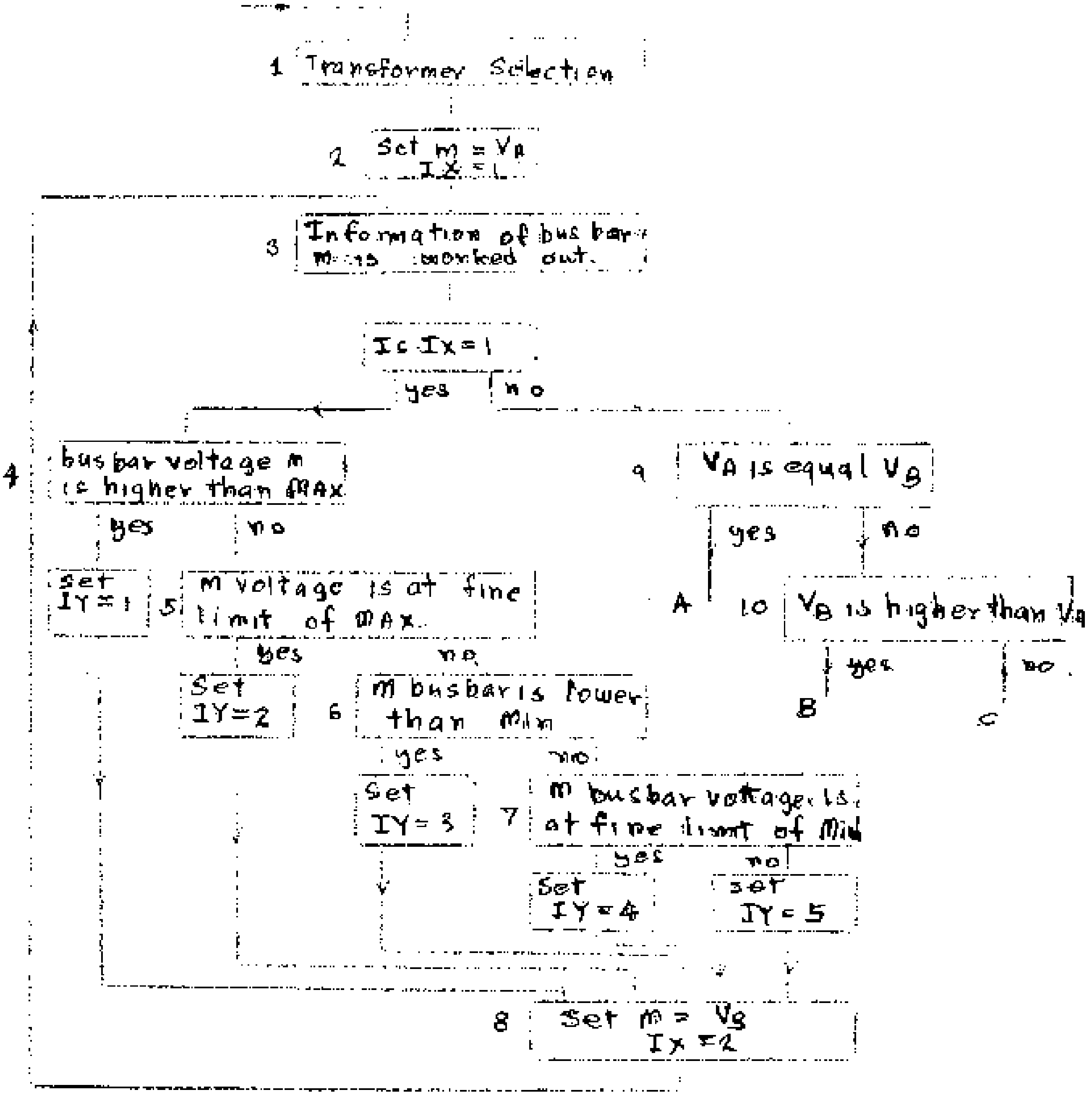


Figure 17(a) Flow Diagram of the method of estimating tap chang

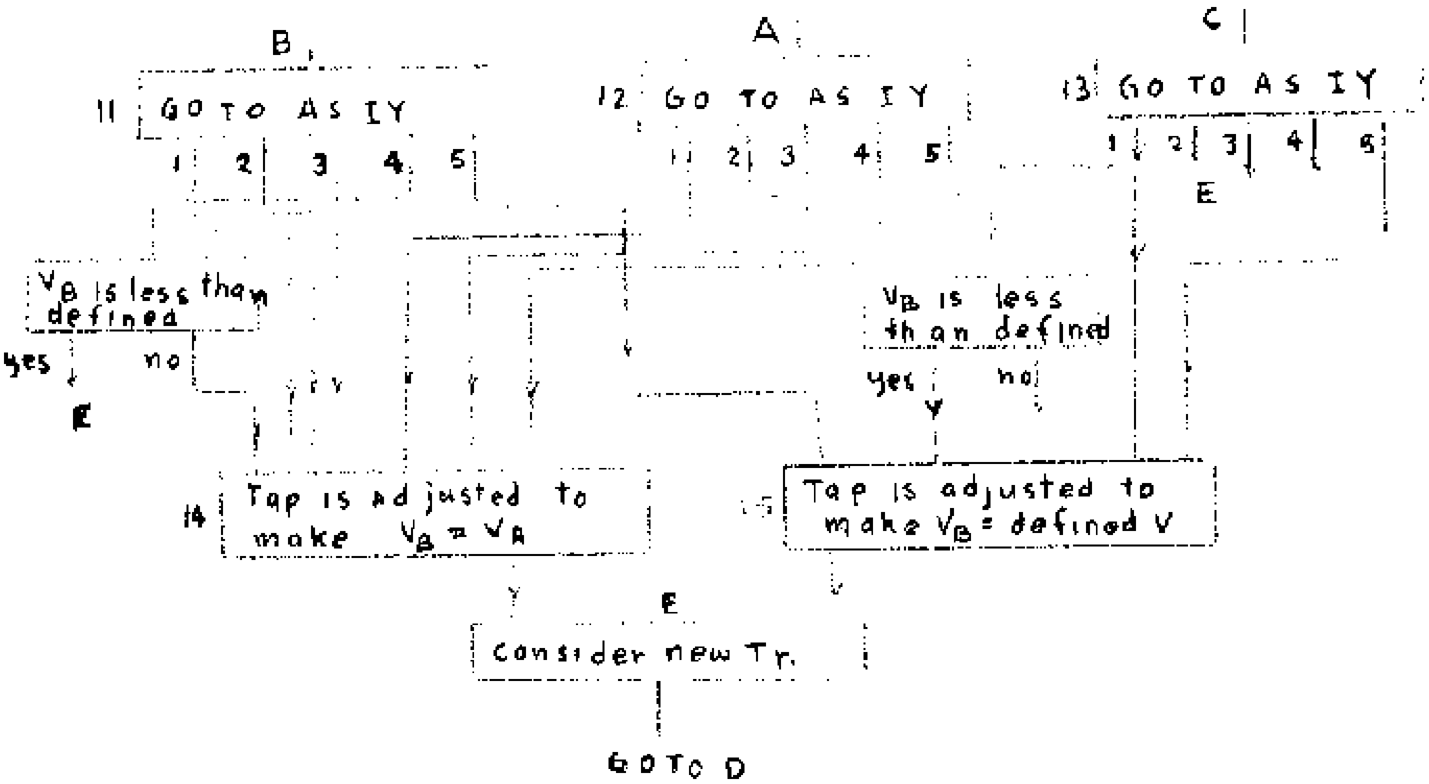


Figure 17.(b) Flow Diagram of the method of estimating tap change

Where V_{BO} and n_O are the value at off-defined voltage

then V_s/n_1 = constant

$$= V_{BO}/n_O$$

$$\therefore \quad n_1 = V_s \cdot n_O / V_{BO}$$

where n_1 is the desired off-nominal ratio

$$\therefore \quad n = (n_O - n_1) \cdot a$$

where a is a delay constant.

$$\therefore \quad \text{New off-nominal ratio} = n_O + \quad n$$

6.8. Actual transformer tap obtaining.

The transformer used in this report is based on the transformer belonging to Y.E.A.

There are five taps included nominal tap on the input terminal, maximum deviation voltage is ± 5% of the input voltage.

There are 31 taps included nominal tap on the input terminal, maximum deviation voltage is ± 10% of the output voltage.

Ex.

Input terminal

	tap No.	V. input	tap No.	V. input
nominal	3	230		
230 ± 11.5	2	235.75	4	224.25
230 ± 5.75	1	241.5	5	218.5

Output terminal

	tap No.	V. input	tap No.	V. input
nominal	16	69		
69 ± .46	15	69.46	17	68.54
± .92	14	69.92	18	68.08
± 1.38	13	70.38	19	67.62
± 1.84	12	70.84	20	67.16
± 2.3	11	71.30	21	66.70
± 2.76	10	71.76	22	66.24
± 3.22	9	72.22	23	65.78
± 3.6	8	72.68	24	65.32
± 4.14	7	73.14	25	64.86
± 4.6	9	73.60	26	64.40

	tap No.	V. input	tap No.	V. input
nominal	16	69		
69 ± 5.06	5	74.06	27	63.94
± 5.52	4	75.52	28	63.48
± 5.98	3	74.98	29	63.02
± 6.44	2	75.44	30	62.56
± 6.9	1	75.9	31	62.10

$$\text{Nominal turn ratio} = \frac{\text{Output voltage}}{\text{Input voltage}}$$

$$= 69/230$$

$$\therefore \text{Per unit turn ratio} = \frac{\text{Output voltage}}{\text{Input voltage}} \times \frac{230}{69}$$

$$= \frac{\text{Output voltage}}{69} \Big/ \frac{\text{Input voltage}}{230}$$

$$= 100 \pm \text{Output voltage \%} / 100 \pm \text{Input voltage \%}$$

$$\therefore \text{Nominal per unit turn ratio} = 100/100 = 1$$

$$\text{Maximum per unit turn ratio} = (100+10)/(100-5)$$

$$= 1.157895$$

$$\text{Minimum per unit turn ratio} = (100-10)/(100+5)$$

$$= .857143$$

In this voltage solution, the estimated off-nominal values have been obtained from the previous operation. These values may not be exist in the actual tap value. The problem is to select the nearest actual tap. These value may be the lower nearest of higher nearest depending upon the V_A voltage. If the V_A is at max. limit voltage, the higher nearest should be chosen, since V_A will change to the opposite direction to the transformer.

The value of turn ratio is found from the previous formulae. Both voltages are first set at the minimum values and then increased step by step.

I_Y, the V_A position indicator, and T_R is read first. The next step T_r will be checked if it is equal to max. or min. value. If it is the next transformer will be considered. If it is not, min. primary voltage, maximum reference and min. reference will be set in step 5. And min. secondary voltage will be set at step 6. Turn ratio will be computed in step 7 and compared to the estimated value. If it is greater it will be compere with max. reference, and will be replaced the value of max. reference if it is lower. If the computed turn ratio is less than the read one, it will be compared with a min. reference. It will be replaced the min.

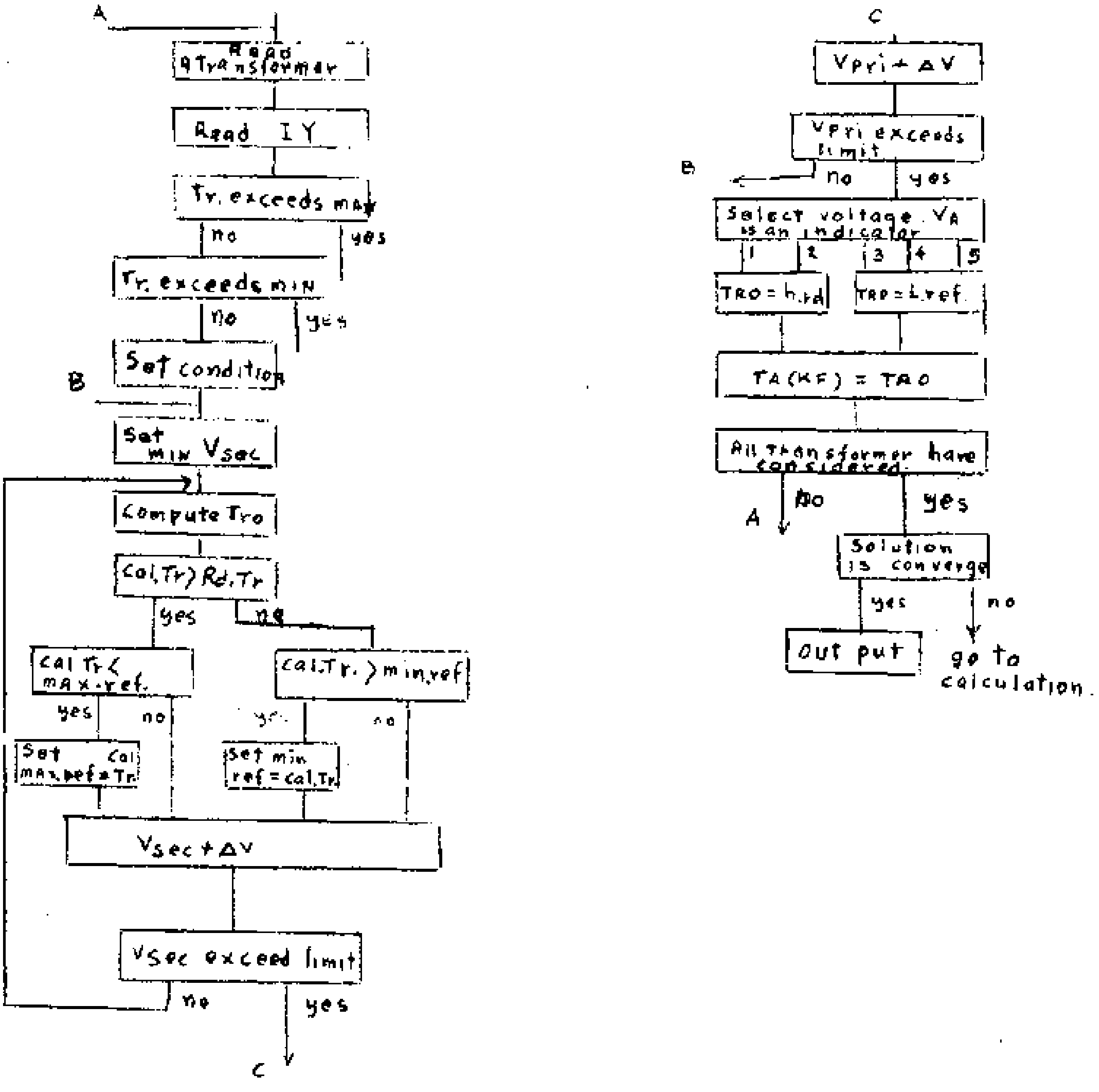


Figure 19 Flow diagram of a method of obtaining an actual transformer ratio.

reference value if it is greater. The primary and secondary voltage will be increased step after step, at each increment a turn ratio is computed and step 7 through 16 is performed. Finally the max. closest and minimum closest tap values will be obtained. The actual tap value will be selected according to the position of I_A in step 17 and 18. Then the new transformer is chosen. When all transformers have been corrected. The voltage solution will be recalculated until convergence is obtained.

6.9 Output of the voltage solution.

In the estimated turns ratio voltage solution, the output is the values of transformers and their I_A position indicaters.

In the actual turns ratio voltage solution the output is the values of voltages and the values of transformers.