ECONOMICAL OPTIMIZATION OF CONDUCTOR SELECTION IN PLANNING RADIAL DISTRIBUTION NETWORKS

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Abstract - A new computer algorithm and program is presented for selection of optimal conductor type and size for each feeder segment. An acceptable voltage profile is maintained along the entire feeder of the network while obtaining an objective of minimizing the total cost, which consists of capital investment, and cost of feeder losses, etc. Node numbering scheme and node connection sequence selection have been proposed to determine the node current and voltage drop for each individual node and termination end of each feeder branches and power loss of each segment of the feeder. If the conductor size available fail to satisfy the user defined constraints the designer can rerun the program after making the relevant changes to the inventory database. The proposed method has been successfully applied in the solution of an example of distribution network that is presented.

Keywords: Distribution networks, Heuristic optimization technique, Power losses, Optimal Conductor, Economical Optimization.

I. INTRODUCTION

The high investment cost of electricity distribution systems and the increasing cost of energy, equipment and labor has caused design engineers to look for more efficient planning methods and techniques to reduce these costs [1]. Attention has focused on reducing cost through optimizing the conductor profile. Planners must determine the optimal cable. Heuristic method is partially used for economical optimization of cable size and type of distribution feeders as solution technique.

Some of the important objectives of economical optimization of conductor selection are

- minimizing total cost considering investment cost and power loss cost.
- achieving acceptable voltage level
- maintaining line capacity limit.

The factors of systems costs, voltage quality and losses are directly related to the network configuration. The financial justification of the solution in each selection of cable is related and therefore these factors are considered.

II. CONNECTION SEQUENCE SELECTION METHOD

Systematic numbering of nodes and branches is an essential criterion for selection of economical optimization of cable of distribution network and it is essential for node sequence selection. There are three types of nodes in considering distribution network:

- load substation nodes
- joint node between two feeders
- source substation node

Load substation nodes are to be numbered at first. On completion of the numbering of all the load substation nodes joint nodes have to be numbered. There are three types of joint nodes. Joint node of

- two or more than two load substation nodes
- two or more than two joint nodes
- load substation node and joint node

The joint node number that is nearer to source substation must be higher than any other number of joint node in a same branch of feeder route.

The last number will be source substation node. It is essential to follow this procedure of numbering and if this procedure is followed, it will be easy to find out the node number of the demand load substations, joint nodes and source substation.

On completion of the numbering of all nodes it is needed to arrange the node sequence selection. Figure 4.2 shows the typical distribution network. Total number of load substations is 17. Joint node numbers are 18 to 27. 28 is the source substation node in Fig 1.

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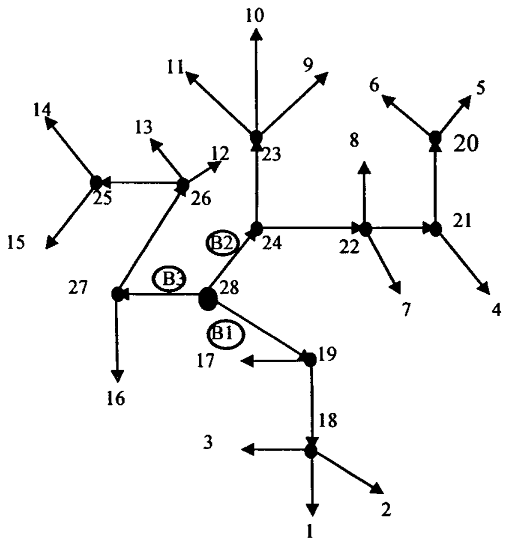

Fig. 1: Typical Distribution Network

For each feeder branch it is needed to mention the connecting node numbers. The node to node connection sequence will be

18-->1	18-->2	18-->3	19-->17	19-->18
20-->5	20-->6	21-->4	21-->20	22-->7
22-->8	22-->21	23-->9	23-->10	23-->11
24-->23	24-->22	25-->14	25-->15	26-->12
26-->13	26-->25	27-->16	27-->26	28-->19
28-->24	28-->27			

There are three main branches B1, B2, B3 in Fig.1. The joint node number 24 is the nearest number of the source substation in B2 branch. According to procedure 24 is the highest number than any other joint node number of B2 branch. The joint node 24 consists of two branches. There is only one joint node 23 in one branch. In another branch there are three joint nodes. According to procedure of systematic numbering the joint node number 22 is the nearest node. The number of other joint nodes is selected same way.

The feeder number is considered as the end node number of the feeder segment. As an example, 18 to 1 is a feeder segment. Node number 1 is end node. So the feeder number will be 1. Similarly, 28 to 24 is a feeder segment. The feeder number will be 24. The source substation node is 28. In this case, source substation feeder is not considered in this program.

III. PROBLEM FORMULATION

Problem formulation is arranged by using following considerations.

If total demand node number is D_{nn} and total joint node number is J_{nn} then

$$J^{nn}_{1st} > D^{nn}_{nth} \tag{1}$$

If source substation is S_{st} th node number then

$$S_{st} > J_{nn} + D_{nn} \tag{2}$$

A. Distance Calculation

Node to node distance depends on the horizontal (x) and vertical (y) co-ordinates of the nodes that are connected to each other. To determine the distance between two substations, at first it is needed to select the location of the substations. After mentioning the location of substations by using geographical co-ordinates then the distance between two nodes is [2]

$$D_{ijk} = \sqrt{[(x_j - x_k)^2 + (y_j - y_k)^2]} \tag{3}$$

where,
i is the feeder segment number
j, k are the nodes which are connected to each other.

Total distance of a possible complete route of n no. of load substations

$$D^n = \sum_{i=1}^{n} D_{ijk} \tag{4}$$

where, n is total feeder number.

B. Selection of Substation Transformer Rating

The approximate value of the load substation transformer is

$$T^l_i = D_i / e^t_i \tag{5}$$

By using T^l_i associated standard rating of transformer, T^{aL}_i of load substation is selected.

The actual efficiency of ith load substation transformer is

$$e^{at}_i = 1 - (P^o_i + P^l_i) / T^{aL}_i \tag{6}$$

By using e^{at}_i the new value of the load substation transformer is

$$T^{nL}_i = D_i / e^{at}_i \tag{7}$$

If $T^{nL}_i \leq T^{aL}_i$ then T^{aL}_i will be the actual load substation transformer, otherwise the previous procedure will be continued.

C. Selection of Source Substation Transformer

The rating of transformer of the source substation is

$$T_{SS} = \sum_{i=1}^{n} T^{nL}_I \tag{8}$$

where, i is the demand node number
n is the total number of the demand node.

By using T_{SS} associated standard rating of transformer T_{aSS} of source substation will be selected. T_{aSS} is the standard rating of the source substation transformer in kVA.

The efficiency of the source substation transformer is

$e_{ss} = 1 - (P_{oSS} + P_{lSS})/T_{aSS}$ (9)

By using e_{ss} the new approximate value of the source substation transformer is

$T_{nSS} = T_{SS} / e_{ss}$ (10)

If $T_{nSS} \le T_{aSS}$ then T_{aSS} will be the actual source substation transformer, otherwise the previous procedure will be continued.

D. Determination of Voltage Drop Limitation

Voltage drop is considered as percentage of voltage level of network. The allowable voltage drop in volt of the network will be

$A_{vd} = V_{dl} * V_L$ (11)

E. Determination of Interest Rate Factor of Total Cost

It is generally accepted that, it is better to hold a sum of money now rather than have the money sometimes in the future. This is because money held elsewhere may be unavailable in the future. A sum of money invested at an interest of p% per annum will produce S_t at the end of Fln years in accordance with the formula [3]

$S_t = S_o (1 + p/100)^{Fln}$ (12)

It is easy to determine the cost of power losses considering the interest rate at the end of Fln by using $(1 + p/100)^{Fln}$. It can be identified in the following way

$I_{rf} = (1 + p/100)^{Fln}$ (13)

F. Determination of Feeder Route of Each Substation Node

If S_i denotes the set of substations of the feeder route of i substation node and N_1, N_2, N_3, ... N_n are substations of the set and N_1 is connected N_2, N_2 is connected N_3 and so on. The set will be

$S_i = \{N_1, N_2, N_3, ... N_n\}$ (14)

The node number of substations of the set can be selected as follows:

$N_1 = N_j$ (15A)

Where, j = i.

$N_2 = \{ N_j X_{jk} \} = N_{j1}$ (15B)

Where, j = { i,.................. n }
k = { i+1, i+2 ....n}
j1 = node number of N_2.

$N_3 = \{ N_j X_{jk}\} = N_{j2}$ (15C)

Where, j = { j1,.................. n }
k = { j1+1, j2+2 ......n }
j2 = node number of N_3.

$N_{n-1} = \{N_j X_{jk}\} = N_{j(n-2)}$ (15)

Where, j = {j (n-1),.................. n}
k = {jn, j(n+1)............. n }
j(n-2) = node number of $N_{(n-1)}$.

In the above cases,

n is total number of substations of network

X_{jk} = 1 if there exists no connection between j and k if there exists connection between j and k which is not toward source substation

X_{jk} = 0 if there exists connection between j and k which is toward source substation.

G. Calculation of Load Current and Joint Node Current

The number of transformer may be used more than one considering the capacity of the source substation, T_{aSS}. The individual current carrying capacity of nth load substation is

$I_n^{th} = T^{dl}_n / (\sqrt{3}V_L)$ (16)

The current carrying capacity of ith joint node substation is

$$I^{jt}_i = \sum_{j=i-1}^{1} I_j X_{ij} \quad (17)$$

where, X_{ij} = 1 if there exists connection between i and j toward end node

X_{ij} = 0 otherwise.

H. Calculation of Power Loss

The power loss of jth feeder segment of the feeder branch of ith load substation route is

$P^l_{ij} = 3(I_j)^2 R_{ij} D_{ij}$ (18)

The total line loss in kW of a possible complete feeder route of n number of load substations is

$$P_{TLn} = \sum_{i=1}^{m} \sum_{j=1}^{bn} P^l_{ij} \quad (19)$$

Total power losses is

$$P_{tpl} = (\sum_{i=1}^{n} P^o_i) + P_{oSS} + F_{loss} \{ P_{TLn} + P_{lSS} + (\sum_{i=1}^{n} P^l_{i}) \} \quad (20)$$

where, n is the total no. of load substation.

In this case demand loss is same for all possible complete routes of the feeders. For this reason demand loss is ignored. All fixed cost is also ignored.

I. Calculation of Voltage Drop of Each Node

The individual voltage drop of ith feeder branch between the demand load substation node j and the load substation node k is

$V^d_{ijk} = \sqrt{3} I_i D_{ijk} (R_{ijk} \sin Q + X_{ijk} \cos Q)$ (21)

The voltage drop of ith end node of feeder branch and the joint node will be

$$V^d_i = \sum_{j=i+1}^{n} (V_i + V_j X_{ij}) \quad (22)$$

where, X_{ij} = 1 if there exists connection between i and j towards source substation

X_{ij} = 0 otherwise.

J. Cost Calculation

Cable cost of jth feeder segment of the feeder branch of ith load substation route is
$C^{cb}_{ij} = D_{ijk} C^{cpk}_{ij} (1+ I_{rpy}/100)^t$ (23)

Total cable cost of the network is

$$C_{tcc} = \sum_{i=1}^{m}\sum_{j=1}^{bn} C^{cb}_{ij} \quad (24)$$

Cable installation cost of jth feeder segment of the feeder branch of ith load substation is
$C^{int}_{ij} = D_{ijk} C^{ipk}_{ij} (1+ I_{rpy}/100)^t$ (25)
where, $t = Fln$

Total cable cost of the network is

$$C_{tic} = \sum_{i=1}^{m}\sum_{j=1}^{bn} C^{int}_{ij} \quad (26)$$

Total power loss cost is
$C_{tpl} = 8760 P_{tpl} C_{kwh} I_{rf}$ (27)

Total variable cost of the network is
$T_{vcn} = C_{tcc} + C_{tic} + C_{tpl}$ (28)

K. Selection of Cable Size and Type

The type and size of cable depend on voltage level and required current flow and current density in the feeder. The type and size of cable are selected from table of standard cable according to the input voltage level of the feeder and current flow of the feeder.

Primary selection of cable size and type:

Current flow of ith feeder is I_i and I_{rated} is current of standard cable, C_i. I_{rated} is also equal or nearly greater than I_i compare to other rated current of standard cable. The cable size and type of ith feeder will be C_i as primary selection.

Economical cable size and type are selected after primary selection of cable size of all feeder routes. Total number of feeder type and size are considered in the following way:

If N_{cs} is the total number of standard cable size and type of data bank and N^{ps}_{ij} is the number of primary selection of jth feeder of the feeder branch of ith load substation then the difference between N_{cs} and N^{ps}_{ij} will be

$D^t_{ij} = N_{cs} - N^{ps}_{ij}$ (29)

The final selection of cable size and type will be selected between N^{ps}_{ij} and N_{cs}.

Maximum voltage drop of the feeder route of load substations has to be determined after primary selection of cable size and types of all feeder branches.

According to descending order of voltage drop of feeder route of load substations the cable size and type of each feeder segment of feeder route of load substations are determined.

Cable size and type of all feeder segments are selected which are economic after justification of all feeder type and size of feeder segment of all branches.

L. Notations

J^{nn}_{1st}	is the 1st joint node number
D^{nn}_{nth}	is the last node number.
D_{ijk}	is the distance of ith feeder that is connected Between jth and kth node
x_j, x_k	are the horizontal co-ordinates of j and k nodes respectively
y_j, y_k	are the vertical co-ordinates of j and k nodes respectively.
T^l_i	is the ith load substation transformer in kVA
D_i	is maximum load demand of ith load substation in kVA
e^t_l, T^{aL}_i	are the approximate efficiency and the selected standard rating of ith load substation
e^{at}_i	is the actual efficiency of T^{aL}_i
P^o_i, P^l_i	are iron loss and cu loss of T^{aL}_i respectively
e_{SS}	is efficiency of T_{aSS}
P_{oSS}, P_{lSS}	are iron loss and cu loss of T_{aSS} in kW respectively
V_{dl}	is voltage drop limitation as percentage of the voltage level of the network
V_L	is voltage level of the network.
S_o	is the present invested money.
Fln	is feeder life of network
N_n	indicates the source substation
T^{dl}_n	is nth demand load substation transformer.
I_j	is current flow of jth feeder in amperes
R_{ij}	is resistance of jth feeder segment of the feeder branch of ith load substation route in ohm/km.
m	is the demand load substation number
bn	is the feeder no. of the feeder branch of ith load substation.
F_{loss}	is loss factor.
R_{ijk}	is resistance of ith feeder between jth and kth node in ohm/km
Q	is power factor of the feeder.
V_j	is jth node voltage drop that can be load node voltage drops or joint node voltage drops
I_{rpy}	is interest rate per year of bank
C^{cpk}_{ij}	is cable cost per km of jth feeder segment of ith demand load substation route.
C^{ipk}_{ij}	is cable installation cost per km of jth feeder segment of ith load substation route.
C_{kwh}	is cost per kWh.

IV. SOLUTION TECHNIQUE

The programming structure of economical selection of cable size and type of each feeder segment are shown in Fig. 2.

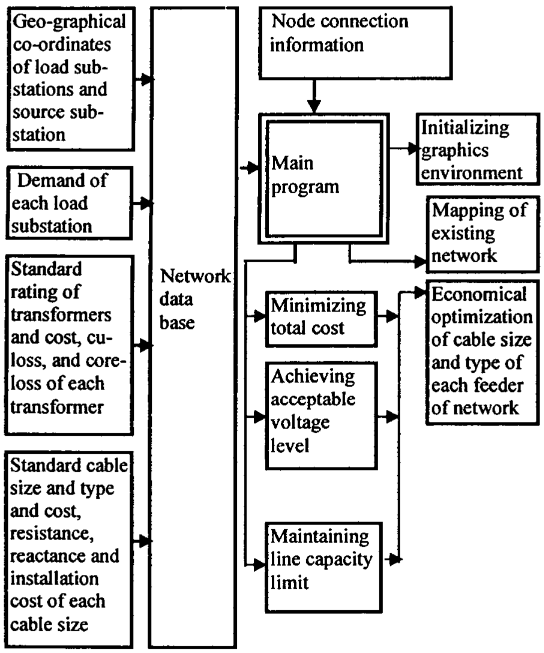

Fig. 2: Programming structure

At first it is needed to find out the programming technique of determination of feeder route of each node of the network for solving economical optimization of conductor selection in planning radial distribution networks. Solution technique is shown as below:

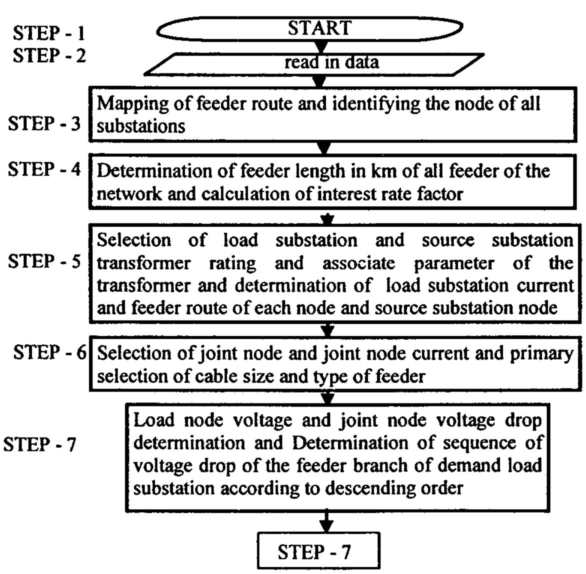

Fig. 3: Flowchart of solution programming (Continued)

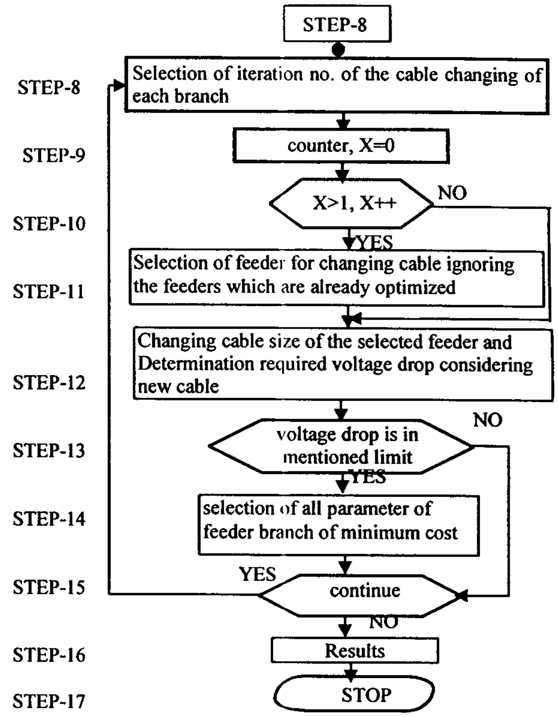

Fig. 3 : Flowchart of solution programming

Total number of demand load substation, standard cable size for the corresponding current rating [5], cost of the cable \$/meter, installation cost of the cable line in \$/meter, standard rating of transformer, core loss, copper loss and cost of the transformer of the standard table, location of load substations and source substation by using geographical co-ordinates, cost of energy loss in \$/kWh, loss factor, approximate life of feeder line, ratio factor between x, y co-ordinate and geographical co-ordinate etc. are required in this program.

V. RESULTS

An example is considered which is radial distribution network. The area is considered 576 square km. The network is consisting of 52 nodes. One is source substation node, 33 number are demand node substations and next are joint nodes. Mapping of distribution network of the example and results are shown in the Fig. 4 and Table 1 respectively.

Table 1

Feeder Number (FN), Node Voltage Drop (NVD) in volts, Line Loss (LL) in kW, Node Current (NC) in amps., Demand Load (DL) in kVA, Required Transformer Rating (RTR) in kVA, Optimum Cable Size and Type (OCST)

FN	NVD	LL	NC	DL	RTR	OCST
1	357.29	3.57	52.97	1000	1250	300UCA11
2	344.18	1.45	26.52	500	630	185UCA11
3	358.41	0.97	13.25	250	300	70UCA11
4	335.68	0.42	5.31	100	200	25UCA11
5	326.07	0.33	5.31	100	200	25UCA11
6	348.79	0.99	15.92	300	500	70UCA11
7	308.01	0.33	5.31	100	200	25UCA11
8	310.74	0.70	15.92	300	500	70UCA11

Table 1 (Continued)

FN	NVD	LL	NC	DL	RTR	OCST
9	221.64	4.15	26.52	500	630	185UCA11
10	384.95	0.33	5.31	100	200	25 UCA11
11	390.22	0.49	10.60	200	250	70 UCA11
12	265.96	1.32	10.60	200	250	70 UCA11
13	322.54	2.13	7.96	150	200	25 UCA11
14	457.50	0.63	15.92	300	500	70 UCA11
15	439.88	0.19	5.31	100	200	25 UCA11
16	447.87	0.31	10.60	200	250	70 UCA11
17	447.87	0.31	10.60	200	250	70 UCA11
18	364.89	0.38	5.30	100	200	25 UCA11
19	374.20	1.31	26.52	500	630	185 UCA11
20	367.78	1.02	26.52	500	630	185 UCA11
21	483.66	1.07	26.52	500	630	185 UCA11
22	471.22	0.51	26.52	500	630	185 UCA11
23	549.65	0.24	5.31	100	200	25 UCA11
24	542.72	2.03	52.97	1000	1250	300 UCA11
25	535.37	1.21	15.92	300	500	70 UCA11
26	515.55	0.77	13.25	250	300	70 UCA11
27	516.47	0.43	26.52	500	630	185 UCA11
28	538.52	0.69	10.60	200	250	50 UCA11X
29	536.60	1.75	39.75	750	1000	300 UCA11
30	524.05	0.19	7.96	150	200	25 UCA11
31	415.67	0.69	15.92	300	500	70 UCA11
32	430.20	0.68	7.96	150	200	25 UCA11
33	444.21	1.11	15.92	300	500	70 UCA11
34	311.85	3.98	79.49			300 UCA11
35	278.08	21.63	98.06			300 UCA11
36	339.41	3.06	15.91			70 UCA11
37	280.54	0.71	21.23			120 UCA11
38	516.81	4.92	58.28			300 UCA11
39	459.79	11.85	111.33			300 UCA11
40	415.74	1.09	21.20			120 UCA11
41	413.80	1.01	21.23			120 UCA11
42	387.99	28.63	153.77			300 UCA11
43	262.47	38.75	196.25			300 UCA11
44	129.35	68.17	355.31			300 UCA11
45	344.92	2.53	53.04			300 UCA11
46	312.75	3.06	58.35			300 UCA11
47	367.89	1.49	39.82			300 UCA11
48	506.77	6.88	84.84			300 UCA11
49	452.05	18.50	114.02			300 UCA11
50	342.67	14.91	153.84			300 UCA11
51	277.33	87.29	212.20			300 UCA11

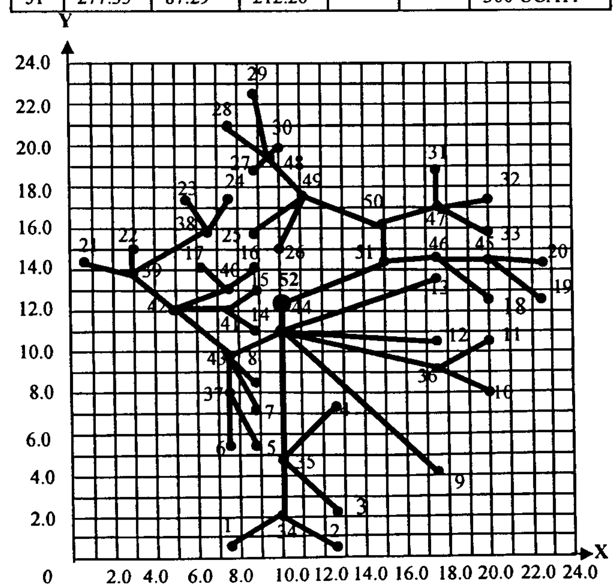

Fig. 4: Mapping of distribution network

X and Y are the geographical horizontal and vertical coordinates in km and 300UCA11 is mentioned maximum cable size in input database. The input voltage of the feeder route is considered 11 kV. The conversion ratio between geographical co-ordinate and x and y co-ordinate is assumed 0.05 km/division. The limitation of voltage drop is considered 5%.

VI. CONCLUSIONS

The task is that of selecting a conductor type for each feeder segment of a radial feeder which will minimize the sum of the cost of capital investment and the cost of feeder losses while maintaining an acceptable feeder voltage level and at the same time meeting all capacity requirements. The feeder voltage at every node in the feeder route must be above the acceptable level. This program satisfies all of these criteria.

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VIII. BIOGRAPHIES

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