LOAD FLOW ANALYSIS OF ELECTRICAL DISTRIBUTION SYSTEMS USING THE DIGITAL COMPUTER

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INTRODUCTION

Electronic computers are widely used in the solution of the problems of science and engineering. This use is based on their ability to operate at great speed, to produce accurate results, to store large quantities of information, and to carry out long and complex sequences of operations without human intervention. The analysis of a large complex electrical distribution network is a "natural" for these machines.

All major utility companies have, or have access to, one of these computer programs and use them daily in their design and load distribution control. In certain instances, they have assisted customers by running one-shot system analyses for design or major modification, when computer time was available. In the past few years, however, the number of customers with large centralized properties, waterflood operations, and water source facilities has increased considerably; during this same time the utility companies' "inhouse" computer loads have also increased considerably. This has led to the imminent necessity for customer-owned computer programs.

The purpose of this paper is to discuss one of these typical programs, from inception to interpretation. The program developed will be purely hypothetical and may, or may not, fit a given system; the technique, however, will be valid for almost any system.

DISCUSSION

Program Utility

First, the role of the computer must be defined. The computer is not going to be asked, "How shall this system be designed?" but rather, "How will the system perform under this set of conditions, if constructed and operated in this manner?" The computer cannot enumerate the design considerations, specify the operating conditions to be investigated, or determine the goals. It can, however, predict the performance of the engineer's choices.

Second, what is desired from the computer (program)? This will vary among companies; for this presentation, several of the more common requirements will be assumed, (refer to Fig. 1):

1. Are the conductors overloaded, and are the loads relatively balanced; what is the current in each segment of the system?
2. Will adequate voltage be available for the farthest load in the system?
3. For the location of power factor adjustment devices, where is the major reactance in the system?
4. Are the optimum conductors installed; what are the I^2R losses in each segment of the system?
5. What will be the performance of the system with future changes in loading, line routing, voltage, etc.?

Program Construction

Several methods can be followed to develop a program of this type. Additionally, there are several mathematical formulas that can be used to produce the desired information. The best program should be the one that will produce *acceptable* results with minimum computer run time. Precision costs money, as do extensive table look-ups. With a little planning, an acceptable program can probably be developed that uses each step (or formula) to develop data for each succeeding formula in a smooth, consecutive or-

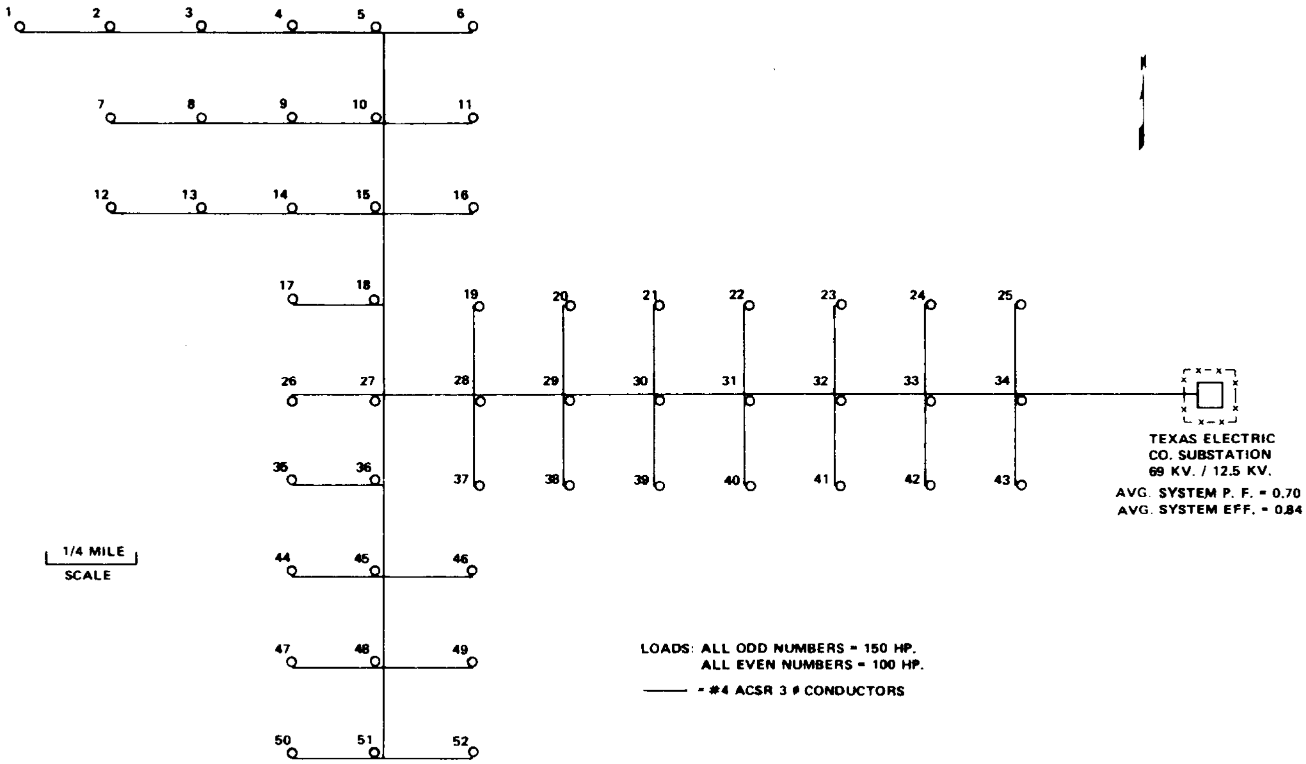


FIG. 1—EXAMPLE OILFIELD ELECTRICAL SYSTEM - "CURRENT CONSTRUCTION"

der, without extensive subroutines and table look-ups.

To start, compile a list of the information that is desired from the program:

1. Current in each segment (I_L)
2. Voltage drop in each segment (E_D)
3. Voltage at each point in the system (E_L)
4. KVA in each segment (KVA)
5. KW in each segment (KW_L)
6. KVAR in each segment (KVAR)
7. I^2R Losses in each segment (KW_P)
8. I^2R Losses in each segment ($/Mo.)
9. Total System, KW_P and $/Mo.
10. All data at a Coincidence Factor (C.F.) of 1.0, and
11. All data at one other Coincidence Factor, to be variable.

Assuming the simplest formulas have been found to be adequate for this program:

$$I_L = \frac{(HP.)(746)}{\sqrt{3}(E_L)(P.F.)(EFF.)} \qquad \text{(2nd. Run: X C.F.)}$$

$$E_D = (I_L)(Z_{3\phi})(L)$$

$$KVA = \frac{\sqrt{3}(I_L)(E_L)}{1000.}$$

$$KW = (KVA)(P.F.)$$

$$KVAR = \sqrt{(KVA)^2-(KW)^2}$$

$$KW_P = \frac{3(I_L)^2(R)(L)}{1000.}$$

$$\$/MO. = (KW_P)(720)(\$/KWH)$$

Examination shows these formulas can form a logical and workable sequential path if all the required terms can be supplied as discrete input data.

A second list should now be compiled, of the information that can readily be supplied as input data:

1. HP of connected loads (HP.)
2. System Feedpoint Voltage (initial E_L)
3. Average system power factor (P.F.)
4. Average system efficiency (EFF.)
5. Segment lengths (L)
6. Conductor resistance (R)
7. Avg. power cost ($/KWH.)
8. The desired coincidence factor (C.F.)

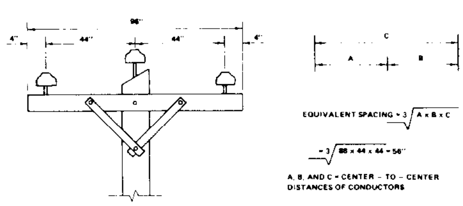
Viewing this list, all the required terms can readily be supplied except $Z_{3\emptyset}$, the 3-phase impedance of each segment.:

$$Z_{3\phi} = \sqrt{3}(R \cos \theta + X \sin \theta)$$

X = line reactance, based on the equivalent spacing.[1]

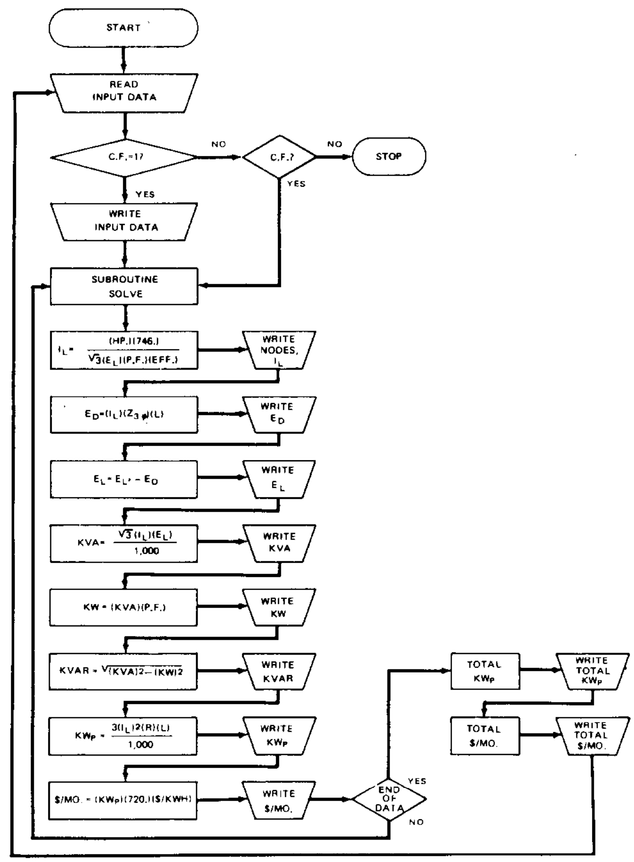
The simplest way to avoid table look-ups and develop discrete input data for this term is to construct a wire table, for the type construction being used, similar to the following:

" THREE – PHASE IMPEDANCE "
– CONVENTIONAL PRIMARY CONSTRUCTION –



AWG./MCM	APPROX. AMP. CAP. NORM	APPROX. AMP. CAP. MAX	R: RESISTANCE OHMS/1,000 FT	X: REACTANCE OHMS/1,000 FT 56" EQUIV SPACING	$Z_{3\phi}$ 1.0 P.F.	$Z_{3\phi}$ 0.95 P.F.	$Z_{3\phi}$ 0.90 P.F.	$Z_{3\phi}$ 0.85 P.F.	$Z_{3\phi}$ 0.80 P.F.	$Z_{3\phi}$ 0.75 P.F.	$Z_{3\phi}$ 0.70 P.F.	$Z_{3\phi}$ 0.60 P.F.
# 6 ACSR	55	85	0.675	0.161	1.169	1.196	1.174	1.141	1.103	1.061	1.017	0.924
# 4 ACSR	75	120	0.425	0.159	0.736	0.784	0.782	0.770	0.753	0.733	0.710	0.661
# 2 ACSR	110	165	0.267	0.158	0.462	0.524	0.536	0.538	0.535	0.529	0.521	0.497
# 1/0 ACSR	150	225	0.168	0.157	0.291	0.360	0.381	0.390	0.396	0.398	0.398	0.393
# 2/0 ACSR	175	260	0.134	0.155	0.232	0.303	0.326	0.339	0.347	0.351	0.354	0.354
# 3/0 ACSR	210	305	0.106	0.151	0.183	0.250	0.271	0.265	0.293	0.299	0.302	0.305
# 4/0 ACSR	245	355	0.084	0.143	0.145	0.214	0.239	0.256	0.265	0.273	0.279	0.285
266.8 ACSR	290	410	0.066	0.121	0.114	0.174	0.177	0.208	0.217	0.224	0.230	0.236
336.4 ACSR	340	480	0.053	0.119	0.091	0.152	0.173	0.187	0.197	0.205	0.211	0.220
477.0 AA	475	590	0.037	0.117	0.064	0.124	0.146	0.161	0.173	0.182	0.189	0.201
556.5 AA	465	645	0.032	0.115	0.055	0.115	0.137	0.152	0.164	0.173	0.181	0.193
795.0 AA	605	820	0.022	0.112	0.038	0.097	0.119	0.135	0.147	0.157	0.165	0.178

The next step is to construct a flowchart based on the foregoing information:



Input Format

For ease in listing, the input data should be divided into two groups: (1) Data common to each segment, and beginning data (such as system feedpoint voltage), and (2) Data peculiar to each individual segment:

COMMON/BEGINNING DATA	SEGMENT DATA
1. SYSTEM I.D.	1. SEGMENT I.D.
2. SYSTEM FEEDPOINT VOLTAGE	2. RESISTANCE/UNIT LENGTH
3. AVG. SYSTEM POWER FACTOR	3. 3Ø IMPEDANCE/UNIT LENGTH
4. AVG. SYSTEM EFFICIENCY	4. CONDUCTOR I.D.
5. AVG. POWER COST/KWHR.	5. SEGMENT LENGTH
6. COINCIDENCE FACTOR	6. LOAD HP.

An input data coding form can now be constructed similar to that shown in Fig. 2.

Output Format

For ease in printing out, the output data should appear in the same order as written out by the computer; this will require a Coincidence Factor

" INPUT DATA CODING FORM "

" LOAD FLOW ANALYSIS OF ELECTRICAL DISTRIBUTION SYSTEMS "

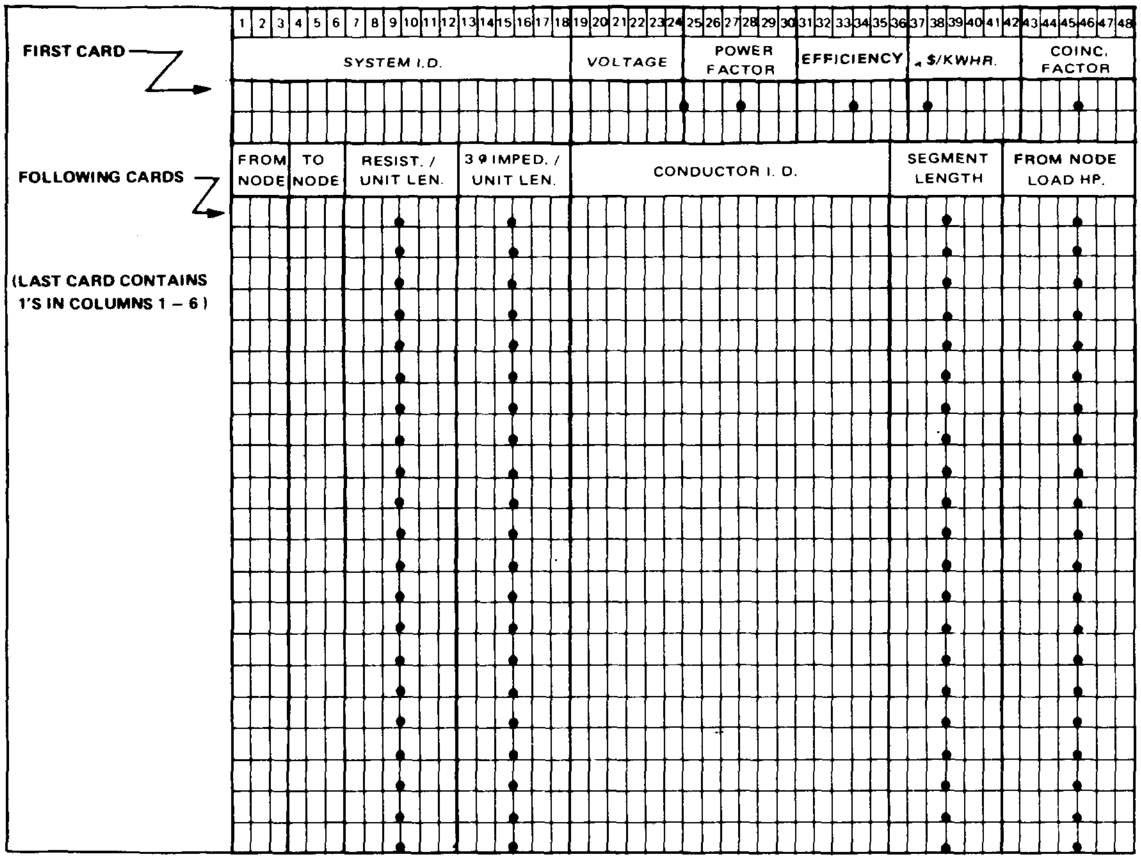


FIG. 2

sub-heading and 10 data columns:

EXAMPLE OILFIELD

ASSUMING A COINCIDENCE FACTOR OF 0.70

FROM NODE	TO NODE	CURRENT AMPS.	VOLTAGE DROPS	VOLT. AT FROM NODE	KVA	KW_L	KVAR	LOSSES KW_P	LOSSES $/MO.
							TOTALS →		

Utilizing the foregoing data, the program can now be written. Since there are so many different computer languages and each computer programmer has his own thoughts on how a program should be written, this paper will not attempt to present detailed programming. For illustration purposes, however, a run has been made for the example system in Fig. 1 (Tables 1 and 2). This run purposely assumes #4 ACSR conductors throughout, resulting in an obviously undersized, overloaded configuration.

Interpretation

Interpretations are many and will vary depending on the company. For this presentation several of the more common factors will be evaluated.

At a Coincidence Factor of 0.70, run No. 1 (Table 2) shows over 2200 volts difference between the feedpoint voltage and the run voltage at well No. 1 (an 18% drop); radiation losses alone are in excess of $4700 per month.

Conductor resizing will be done on an economic basis rather than on voltage drops. First, a graph will be constructed (Figure 3) of the economic current-carrying capacity of each conductor for this particular project, based on maximum present value profit, taking into consideration both the construction cost differential and the radiation I^2R loss differential.[1,3] From this curve, the optimum conductor size can quickly be selected, based on the line currents in each segment of the system.

Run No. 2 (Tables 3 and 4) with optimum conductor sizes shows slightly over 700 volts difference (less than a 6% drop) and radiation losses reduced to $565 per month.

Assuming $26,500 capital construction costs, reconductoring should payout in 6-1/2 months with a present value profit, before taxes, over a 10-year period, of $296,900, $273,600, and $253,000, at interest rates of 10, 12, and 14% respectively.

If desired, adequate starting voltage at well No. 1 can quickly be evaluated by making one more run, plugging in the starting horsepower equivalent of the 150-hp motor

$$\left[\text{HP.} = \frac{(\text{I START})(\sqrt{3})(E_L)(\text{P.F.})(\text{EFF.})}{746} \right]$$

then subtracting the transformer voltage drop.

The locations for the 2140 KVAC capacitors, required to raise the average system power factor to 0.90, can now be selected. Scanning the system reactance, points A, B, and C, Fig. 4, appear to be the most preferred; one-third the required capacitance, or roughly 700 KVAC, can be installed at each of these locations.

Options

Any number of options can be utilized in the construction of this program depending on permissible computer time and complexity. A few of these options worthy of mention are:

1. Closed-loop system analysis utilizing the Gauss-Seidel method for solving simultaneous equations [2]
2. Automatic calculation of available starting voltages under worst-case conditions
3. By means of table look-ups, wire sizes could be computer-optimized.
4. For feeder and lateral protection design, fault current calculations could be computed and printed out.[3,4]
5. Utilizing a series of table look-ups, the more accurate (and complex) formulas could be utilized.[3,4]

REFERENCES

1. General Electric "Distribution Data Book," GET-1008K, Dec. 1965.
2. McCracken, D.D.: "A Guide to Fortran IV Programming," John Wiley & Sons Inc., Aug. 1965.
3. "Standard Handbook for Electrical Engineers," Fink and Carroll, 1968.
4. Westinghouse "Electrical Transmission and Distribution Reference Book," 1964.

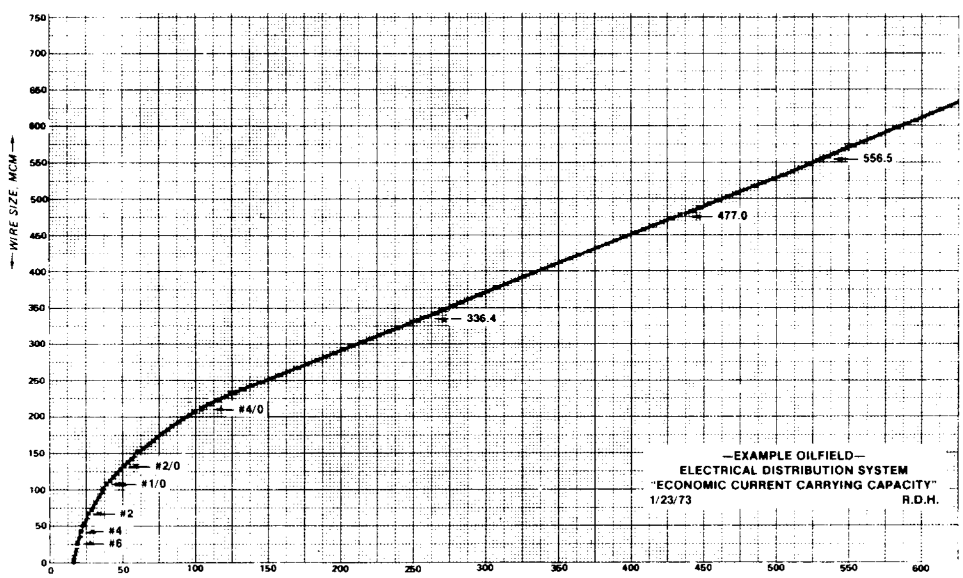


FIG. 3

TABLE 1—EXAMPLE OILFIELD

SYSTEM VOLTAGE- 12500.0 POWER FACTOR- .700 EFFICIENCY- .840 COST PER KWHR- $ .00800

I N P U T D A T A

FROM NODE	TO NODE	RESISTANCE/ UNIT LENGTH	3Ø IMPEDANCE/ UNIT LENGTH	CONDUCTOR I.D.	SEGMENT LENGTH	FROM NODE LOAD HP.
1	2	.425	.710	#4 ACSR	1.320	150.000
2	3	.425	.710	#4 ACSR	1.320	100.000
3	4	.425	.710	#4 ACSR	1.320	150.000
4	5	.425	.710	#4 ACSR	1.320	100.000
6	5	.425	.710	#4 ACSR	1.320	100.000
5	10	.425	.710	#4 ACSR	1.320	150.000
7	8	.425	.710	#4 ACSR	1.320	150.000
8	9	.425	.710	#4 ACSR	1.320	100.000
9	10	.425	.710	#4 ACSR	1.320	150.000
11	10	.425	.710	#4 ACSR	1.320	150.000
10	15	.425	.710	#4 ACSR	1.320	100.000
12	13	.425	.710	#4 ACSR	1.320	100.000
13	14	.425	.710	#4 ACSR	1.320	150.000
14	15	.425	.710	#4 ACSR	1.320	100.000
16	15	.425	.710	#4 ACSR	1.320	100.000
15	18	.425	.710	#4 ACSR	1.320	150.000
17	18	.425	.710	#4 ACSR	1.320	150.000
18	27	.425	.710	#4 ACSR	1.320	100.000
26	27	.425	.710	#4 ACSR	1.320	100.000
50	51	.425	.710	#4 ACSR	1.320	100.000
52	51	.425	.710	#4 ACSR	1.320	100.000
51	48	.425	.710	#4 ACSR	1.320	150.000
47	48	.425	.710	#4 ACSR	1.320	150.000
49	48	.425	.710	#4 ACSR	1.320	150.000
48	45	.425	.710	#4 ACSR	1.320	100.000
44	45	.425	.710	#4 ACSR	1.320	100.000
46	45	.425	.710	#4 ACSR	1.320	100.000
45	36	.425	.710	#4 ACSR	1.320	150.000
35	36	.425	.710	#4 ACSR	1.320	150.000
36	27	.425	.710	#4 ACSR	1.320	100.000
27	28	.425	.710	#4 ACSR	1.320	150.000
19	28	.425	.710	#4 ACSR	1.320	150.000
37	28	.425	.710	#4 ACSR	1.320	150.000
28	29	.425	.710	#4 ACSR	1.320	100.000
20	29	.425	.710	#4 ACSR	1.320	100.000
38	29	.425	.710	#4 ACSR	1.320	100.000
29	30	.425	.710	#4 ACSR	1.320	150.000
21	30	.425	.710	#4 ACSR	1.320	150.000
39	30	.425	.710	#4 ACSR	1.320	150.000
30	31	.425	.710	#4 ACSR	1.320	100.000
22	31	.425	.710	#4 ACSR	1.320	100.000
40	31	.425	.710	#4 ACSR	1.320	100.000
31	32	.425	.710	#4 ACSR	1.320	150.000
23	32	.425	.710	#4 ACSR	1.320	150.000
41	32	.425	.710	#4 ACSR	1.320	150.000
32	33	.425	.710	#4 ACSR	1.320	100.000
24	33	.425	.710	#4 ACSR	1.320	100.000
42	33	.425	.710	#4 ACSR	1.320	100.000
33	34	.425	.710	#4 ACSR	1.320	150.000
25	34	.425	.710	#4 ACSR	1.320	150.000
43	34	.425	.710	#4 ACSR	1.320	150.000
34	53	.425	.710	#4 ACSR	2.640	100.000

TABLE 2—EXAMPLE OILFIELD, RUN NO. 1

ASSUMING A COINCIDENCE FACTOR OF 0.70:

FROM NODE	TO NODE	CURRENT AMPS	VOLTAGE DROPS	VOLT. AT FROM NODE	KVA	KW_L	KVAR	LOSSES KW_P	LOSSES $/MO.
1	2	6.2	6.0	10274.4	110.3	77.2	78.8	.066	$ .38
2	3	10.3	10.0	10280.4	183.0	128.1	130.7	.185	$ 1.06
3	4	16.4	16.0	10290.4	292.3	204.6	208.7	.472	$ 2.72
4	5	20.5	20.0	10306.4	365.9	256.2	261.3	.738	$ 4.25
6	5	4.1	4.0	10322.5	73.3	51.3	52.3	.030	$ .17
5	10	30.8	30.0	10326.5	550.9	385.6	393.3	1.661	$ 9.56
7	8	6.2	6.0	10324.5	110.9	77.6	79.1	.066	$ .38
8	9	10.3	10.0	10330.5	184.3	129.0	131.6	.185	$ 1.06
9	10	16.4	16.0	10340.5	293.7	205.6	209.7	.472	$ 2.72
11	10	6.2	6.0	10350.5	111.1	77.8	79.4	.066	$ .38
10	15	57.5	56.0	10356.5	1031.4	722.0	736.4	5.786	$ 33.33
12	13	4.1	4.0	10384.5	73.7	51.6	52.6	.030	$ .17
13	14	10.3	10.0	10388.5	185.3	129.7	132.3	.185	$ 1.06
14	15	14.4	14.0	10398.5	259.3	181.5	185.1	.362	$ 2.08
16	15	4.1	4.0	10408.5	73.9	51.7	52.7	.030	$ .17
15	18	82.1	80.1	10412.5	1480.6	1036.4	1057.1	11.808	$ 68.02
17	18	6.2	6.0	10486.6	112.6	78.8	80.4	.066	$ .38
18	27	92.4	90.1	10492.6	1679.2	175.4	178.9	14.945	$ 86.08
26	27	4.1	4.0	10578.6	75.1	52.6	53.7	.030	$ .17
50	51	4.1	4.0	10436.5	74.1	51.9	52.9	.030	$ .17
52	51	4.1	4.0	10436.5	74.1	51.9	52.9	.030	$ .17
51	48	14.4	14.0	10440.5	260.4	182.3	186.0	.362	$ 2.08
47	48	6.2	6.0	10448.5	112.2	78.5	80.1	.066	$ .38
49	48	6.2	6.0	10448.5	112.2	78.5	80.1	.066	$ .38
48	45	30.8	30.0	10454.5	557.7	390.4	398.2	1.661	$ 9.56
44	45	4.1	4.0	10480.6	74.4	52.1	53.1	.030	$ .17
46	45	4.1	4.0	10480.6	74.4	52.1	53.1	.030	$ .17
45	36	45.2	44.0	10484.6	820.8	574.6	586.1	3.572	$ 20.57
35	36	6.2	6.0	10522.6	113.0	79.1	80.7	.066	$ .38
36	27	55.4	54.0	10528.6	1010.2	707.1	721.2	5.380	$ 30.99
27	28	158.1	154.1	10582.6	2897.8	2028.5	2069.1	43.757	$ 252.04
19	28	6.2	6.0	10730.7	115.2	80.6	82.2	.066	$ .38
37	28	6.2	6.0	10730.7	115.2	80.6	82.2	.066	$ .38
28	29	174.5	170.1	10736.7	3245.0	2271.5	2316.9	53.321	$ 307.13
20	29	4.1	4.0	10902.9	77.4	54.2	55.3	.030	$ .17
38	29	4.1	4.0	10902.9	77.4	54.2	55.3	.030	$ .17
29	30	188.9	184.1	10906.9	3568.5	2498.0	2548.0	62.465	$ 359.80
21	30	6.2	6.0	11085.0	119.0	83.3	85.0	.066	$ .38
39	30	6.2	6.0	11085.0	119.0	83.3	85.0	.066	$ .38
30	31	205.3	200.1	11091.0	3943.7	2760.6	2815.8	73.801	$ 425.10
22	31	4.1	4.0	11287.1	80.2	56.1	57.2	.030	$ .17
40	31	4.1	4.0	11287.1	80.2	56.1	57.2	.030	$ .17
31	32	219.7	214.2	11291.1	4296.5	3007.6	3067.8	84.495	$ 486.69
23	32	6.2	6.0	11499.3	123.5	86.5	88.2	.066	$ .38
41	32	6.2	6.0	11499.3	123.5	86.5	88.2	.066	$ .38
32	33	236.1	230.2	11605.3	4704.8	3293.4	3359.3	97.602	$ 562.19
24	33	4.1	4.0	11731.5	83.3	58.3	59.5	.030	$ .17
42	33	4.1	4.0	11731.5	83.3	58.3	59.5	.030	$ .17
33	34	250.5	244.2	11735.5	5091.6	3564.1	3635.4	109.846	$ 632.71
25	34	6.2	6.0	11973.6	128.6	90.0	91.8	.066	$ .38
43	34	6.2	6.0	11973.6	128.6	90.0	91.8	.066	$ .38
34	53	266.9	520.4	11979.6	5537.8	3876.5	3954.6	249.449	$1436.82
							TOTALS	823.919	$4745.77

TABLE 3—EXAMPLE OILFIELD

SYSTEM VOLTAGE- 12500.0 POWER FACTOR- .700 EFFICIENCY- .840 COST PER KWHR- $ .00800

I N P U T D A T A

FROM NODE	TO NODE	RESISTANCE/ UNIT LENGTH	3Ø IMPEDANCE/ UNIT LENGTH	CONDUCTOR I.D.	SEGMENT LENGTH	FROM NODE LOAD HP.
1	2	.425	.710	#4 ACSR	1.320	150.000
2	3	.425	.710	#4 ACSR	1.320	100.000
3	4	.425	.710	#4 ACSR	1.320	150.000
4	5	.425	.710	#4 ACSR	1.320	100.000
6	5	.425	.710	#4 ACSR	1.320	100.000
5	10	.267	.521	#2 ACSR	1.320	150.000
7	8	.425	.710	#4 ACSR	1.320	150.000
8	9	.425	.710	#4 ACSR	1.320	100.000
9	10	.425	.710	#4 ACSR	1.320	150.000
11	10	.425	.710	#4 ACSR	1.320	150.000
10	15	.084	.279	#4/0 ACSR	1.320	100.000
12	13	.425	.710	#4 ACSR	1.320	100.000
13	14	.425	.710	#4 ACSR	1.320	150.000
14	15	.425	.710	#4 ACSR	1.320	100.000
16	15	.425	.710	#4 ACSR	1.320	100.000
15	18	.084	.279	#4/0 ACSR	1.320	150.000
17	18	.425	.710	#4 ACSR	1.320	150.000
18	27	.084	.279	#4/0 ACSR	1.320	100.000
26	27	.425	.710	#4 ACSR	1.320	100.000
50	51	.425	.710	#4 ACSR	1.320	100.000
52	51	.425	.710	#4 ACSR	1.320	100.000
51	48	.425	.710	#4 ACSR	1.320	150.000
47	48	.425	.710	#4 ACSR	1.320	150.000
49	48	.425	.710	#4 ACSR	1.320	150.000
48	45	.267	.521	#2 ACSR	1.320	100.000
44	45	.425	.710	#4 ACSR	1.320	100.000
46	45	.425	.710	#4 ACSR	1.320	100.000
45	36	.134	.354	#2/0 ACSR	1.320	150.000
35	36	.425	.710	#4 ACSR	1.320	150.000
36	27	.084	.279	#4/0 ACSR	1.320	100.000
27	28	.053	.211	#336.4 ACSR	1.320	150.000
19	28	.425	.710	#4 ACSR	1.320	150.000
37	28	.425	.710	#4 ACSR	1.320	150.000
28	29	.053	.211	#336.4 ACSR	1.320	100.000
20	29	.425	.710	#4 ACSR	1.320	100.000
38	29	.425	.710	#4 ACSR	1.320	100.000
29	30	.053	.211	#336.4 ACSR	1.320	150.000
21	30	.425	.710	#4 ACSR	1.320	150.000
39	30	.425	.710	#4 ACSR	1.320	150.000
30	31	.053	.211	#336.4 ACSR	1.320	100.000
22	31	.425	.710	#4 ACSR	1.320	100.000
40	31	.425	.710	#4 ACSR	1.320	100.000
31	32	.053	.211	#336.4 ACSR	1.320	150.000
23	32	.425	.710	#4 ACSR	1.320	150.000
41	32	.425	.710	#4 ACSR	1.320	150.000
32	33	.053	.211	#336.4 ACSR	1.320	100.000
24	33	.425	.710	#4 ACSR	1.320	100.000
42	33	.425	.710	#4 ACSR	1.320	100.000
33	34	.037	.189	#477.OMCM AA	1.320	150.000
25	34	.425	.710	#4 ACSR	1.320	150.000
43	34	.425	.710	#4 ACSR	1.320	150.000
34	53	.037	.189	#477.OMCM AA	2.640	100.000

TABLE 4—EXAMPLE OILFIELD

ASSUMING A COINCIDENCE FACTOR OF 0.70:

FROM NODE	TO NODE	CURRENT AMPS	VOLTAGE DROPS	VOLT. AT FROM NODE	KVA	KW_L	KVAR	LOSSES KW_P	LOSSES $/MO
1	2	6.2	6.0	11790.9	126.6	88.6	90.4	.066	$ .38
2	3	10.3	10.0	11796.9	210.5	147.4	150.3	.185	$ 1.06
3	4	16.4	16.0	11807.0	335.4	234.8	239.5	.472	$ 2.72
4	5	20.5	20.0	11823.0	419.8	293.9	299.8	.738	$ 4.25
6	5	4.1	4.0	11839.0	84.1	58.9	60.1	.030	$ .17
5	10	30.8	22.0	11843.0	631.8	442.3	451.1	1.043	$ 6.01
7	8	6.2	6.0	11833.0	127.1	89.0	90.8	.066	$ .38
8	9	10.3	10.0	11839.0	211.2	147.8	150.8	.185	$ 1.06
9	10	16.4	16.0	11849.0	336.6	235.6	240.3	.472	$ 2.72
11	10	6.2	6.0	11859.0	127.4	89.2	91.0	.066	$ .38
10	15	57.5	22.0	11865.0	1181.6	827.1	843.6	1.144	$ 6.59
12	13	4.1	4.0	11859.0	84.2	58.9	60.1	.030	$ .17
13	14	10.3	10.0	11863.0	211.6	148.1	151.1	.185	$ 1.06
14	15	14.4	14.0	11873.0	296.1	207.3	211.4	.362	$ 2.08
16	15	4.1	4.0	11883.0	84.0	58.8	60.0	.030	$ .17
15	18	82.1	31.5	11887.0	1690.3	1183.2	1206.9	2.334	$ 13.44
17	18	6.2	6.0	11912.5	127.9	89.5	91.3	.066	$ .38
18	27	92.4	35.4	11918.5	1907.4	1335.2	1361.9	2.954	$ 17.01
26	27	4.1	4.0	11949.9	84.9	59.4	60.6	.030	$ .17
50	51	4.1	4.0	11870.7	84.3	59.0	60.2	.030	$ .17
52	51	4.1	4.0	11870.7	84.3	59.0	60.2	.030	$ .17
51	48	14.4	14.0	11874.7	296.2	207.3	211.4	.362	$ 2.08
47	48	6.2	6.0	11882.7	127.6	89.3	91.1	.066	$ .38
49	48	6.2	6.0	11882.7	127.6	89.3	91.1	.066	$ .38
48	45	30.8	22.0	11888.7	634.2	443.9	452.8	1.043	$ 6.01
44	45	4.1	4.0	11906.7	84.6	59.2	60.4	.030	$ .17
46	45	4.1	4.0	11906.7	84.6	59.2	60.4	.030	$ .17
45	36	45.2	22.0	11910.7	932.4	652.7	665.8	1.126	$ 6.49
35	36	6.2	6.0	11926.6	128.1	89.7	91.5	.066	$ .38
36	27	55.4	21.2	11932.6	1145.0	801.5	817.5	1.063	$ 6.12
27	28	158.1	45.8	11953.9	3273.3	2291.3	2337.1	5.457	$ 31.43
19	28	6.2	6.0	11993.7	128.8	90.2	92.0	.066	$ .38
37	28	6.2	6.0	11993.7	128.8	90.2	92.0	.066	$ .38
28	29	174.5	50.6	11999.7	3626.7	2538.7	2589.5	6.650	$ 38.30
20	29	4.1	4.0	12046.2	85.5	59.9	61.1	.030	$ .17
38	29	4.1	4.0	12046.2	85.5	59.9	61.1	.030	$ .17
29	30	188.9	54.7	12050.2	3942.5	2759.8	2815.0	7.790	$ 44.87
21	30	6.2	6.0	12099.0	129.9	90.9	92.7	.066	$ .38
39	30	6.2	6.0	12099.0	129.9	90.9	92.7	.066	$ .38
30	31	205.3	59.5	12105.0	4304.3	3013.0	3073.3	9.203	$ 53.01
22	31	4.1	4.0	12160.4	86.4	60.5	61.7	.030	$ .17
40	31	4.1	4.0	12160.4	86.4	60.5	61.7	.030	$ .17
31	32	219.7	63.6	12164.4	4628.8	3240.2	3305.0	10.537	$ 60.69
23	32	6.2	6.0	12222.1	131.2	91.8	93.6	.066	$ .38
41	32	6.2	6.0	12222.1	131.2	91.8	93.6	.066	$ .38
32	33	236.1	68.4	12228.1	5000.4	3500.3	3570.3	12.172	$ 70.11
24	33	4.1	4.0	12292.5	87.3	61.1	62.3	.030	$ .17
42	33	4.1	4.0	12292.5	87.3	61.1	62.3	.030	$ .17
33	34	250.5	65.0	12296.5	5335.0	3734.5	3809.2	9.563	$ 55.08
25	34	6.2	6.0	12355.5	132.7	92.9	94.8	.066	$ .38
43	34	6.2	6.0	12355.5	132.7	92.9	94.8	.066	$ .38
34	53	266.9	138.5	12361.5	5714.4	4000.0	4080.6	21.717	$ 125.09
							TOTALS	98.164	$ 565.43

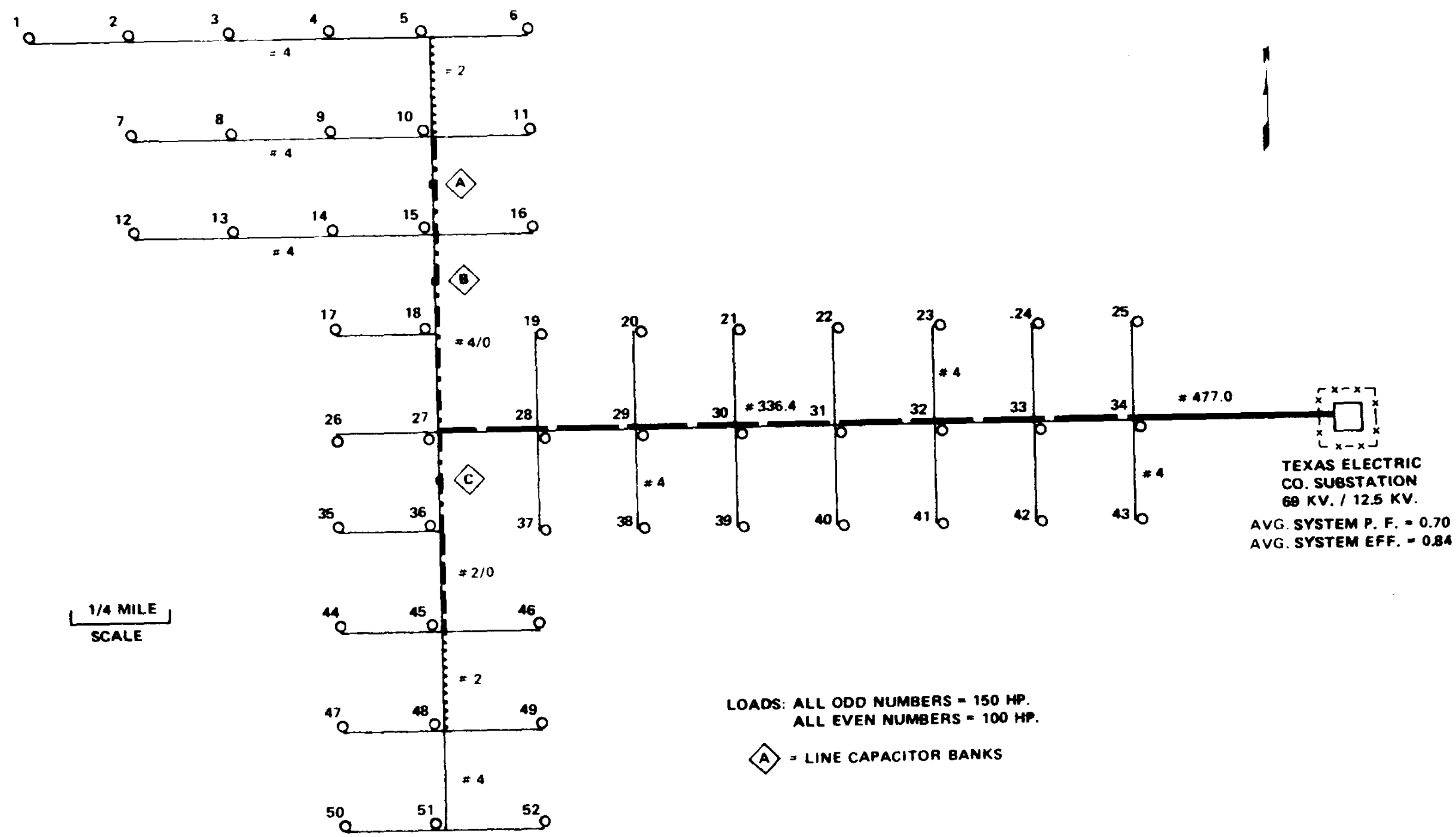


FIG. 4—EXAMPLE OILFIELD ELECTRICAL DISTRIBUTION SYSTEM-"FINAL DESIGN"