SECONDARY FAULT CURRENTS AT THE SERVICE ENTRANCE

D. J. Ward, Application Engineer
General Electric Company
1 River Road
Schenectady, New York

55th Annual Electric Meter School and Conference
University of Florida, Gainesville, Florida
May 19-23, 1980

SECONDARY FAULT CURRENTS AT THE RESIDENTIAL SERVICE ENTRANCE

D. J. Ward, General Electric Co., Schenectady, N. Y.

INTRODUCTION

Available fault currents on distribution systems have always been on the increase. This is due to a number of reasons, including the use of larger conductors and transformers, higher voltage distribution systems, more interconnections on the transmission systems and, of course, more connected generation.

Fortunately, the large increases in fault currents that utilities are experiencing on their primary system have a relatively small influence on the available fault currents at the residence.

However, the trend towards the use of larger distribution transformers with the present levels of impedances to serve larger loads in residences has caused the available fault current at the service entrance equipment to become higher. In particular, the use of very large distribution transformers, located close to the service entrances of garden and high-rise apartments, could result in high available fault currents at the service entrances.

The effect that these available fault currents might have on meter and service entrance protective equipment ratings is of concern to the electrical industry.

AVAILABLE FAULT CURRENTS

A 1980 EEI report, "The Management of Secondary Distribution Fault Currents", presented some interesting survey results on available fault currents. Sixty-six member companies, which serve approximately 41.6 million residential customers, estimated the available secondary fault currents at residential service entrances installed in a 12-month period to be in the following ranges:

1. "Only 2.2% of the utilities' new single family residential units have available fault currents in excess of 10 kA.
2. Approximately 5.3% of the utilities' new mobile home installations have available fault currents in excess of 10 kA.
3. Approximately 31% of the utilities services to new garden-type apartments have available fault currents in excess of 10 kA, with 3.7% of these in excess of 22 kA.
4. Approximately 68% of the utilities' services to new high-rise apartments have available fault currents in excess of 10 kA with 28% of these in excess of 22 kA."

The available fault current at the service entrance is affected by the source impedance, the impedance of the distribution transformer, the service cable impedance and the impedance of the meter. A short circuit study was undertaken which included a range of distribution transformer sizes and several different secondary conductor sizes and lengths. The schematic diagram used for secondary fault calculations is shown in Figure 1.

1. Primary - A single-phase distribution transformer was considered connected phase-to-ground to a 12.5 kV primary system. The available primary short circuit current was assumed to be equivalent to 20,000 amperes at 34.5 kV. It is felt that this value of source impedance will yield conservative results when applied to most distribution voltages. As the

calculation will illustrate, the predominant impedance is found in the distribution transformer and the secondary conductors. Whether the available primary short circuit current value is 20,000A at 34.5 kV or infinite has relatively little effect on the final answer. As an example, for a 50 kVA transformer with 50 feet of #4/0 service cable, the 240V bolted fault current at the service entrance is 7229A with 20,000A available (at 34.5 kV) on the primary and 7255A for an infinite bus. This is only 26A more.

2. Distribution Transformer - The % IR and % IX values used in the study are for 7200V transformers and are shown below:

Oil-Filled Distribution Transformers

kVA	%IR	%IX	%IZ
25	1.2	1.7	2.08
37.5	1.3	1.9	2.30
50	1.1	1.8	2.11
75	1.0	2.1	2.33
100	1.0	2.1	2.33
167	1.0	2.0	2.24
250	1.0	2.3	2.51

Impedances for higher voltage transformers will be slightly larger.

Half-winding impedances for the 25 kVA through 100 kVA transformers were taken as 1.5 times IR and 1.2 times IX on the transformer kVA rating as the base; for the 167 kVA and 250 kVA transformers, these values were 1.5 times IR and 2.0 times IX, again on the transformer kVA rating as the base.

3. Service-Cable - All cables between the distribution transformer and the residence were assumed to be aluminum and triplex construction.

The resistance and reactance of both the phase and neutral conductors were taken as follows:

Size	Resistance @ 25°C Ohms/1000'	Reactance Ohms/1000'
#2	.266	.0297
1/0	.168	.0297
4/0	.0838	.0277
350	.0507	.0271
500	.0356	.0265
2-500	.0178	.0133

The #2 cable might be representative of a 100A service; the 4/0 representative of a 200A service; and 2-500 kcmil representative of a 167 kVA transformer serving an apartment when sized according to the National Electrical Code.

4. Meter - The meter impedance for the I-70, 200A meter in the 200A socket has the lowest impedance when compared with the 200A meter or the 100A meter in the 100A socket and, therefore, it was used. The 240V impedance used was a resistance of 0.001005 ohms and a reactance of 0.001146 ohms. The 120V impedance was taken as one-half the 240V value.

A sample calculation of symmetrical fault current is shown in Fig. 2. First, all values of resistance and reactances were expressed in per unit (p.u.) on the distribution transformer base. The total impedance between the source and the fault was then determined. The p.u. impedance divided into 1 p.u. voltage gives the times normal current. This, multiplied by normal current, is the short circuit current in amperes.

Figures 3, 4 and 5 show symmetrical fault current matrices with 50 kVA, 167 kVA, and 250 kVA oil-filled distribution transformers, respectively.

METERS

ANSI C12-1975, Code for Electricity Metering, requires that a meter shall have a withstand level of 7,000 amperes peak (rms 4950) for six cycles, with a percent registration change of not more than 1.5% on both full load and light load (with the full load to be tested first to minimize any residual magnetism effect). In addition, the meter is required to withstand a 60 Hz rms symmetrical fault current for four cycles, as shown below, without any mechanical damage or reduction in the insulation level:

Class 100 meter - 10,000 amperes
Class 200 meter - 12,000 amperes

A natural question is, are these realistic values in view of the fault currents shown in Figs. 3, 4 and 5? They probably are, because the faults that we're normally concerned with are those on the load side of the protective devices. Because of the usual short distance and good shielding of the circuit between the meter and the service entrance protective device, it seems reasonable to consider only short circuit currents through the meter created by faults on the load side of the protective device.

To make the calculation from Fig. 2 a bit more realistic, we need to include the additional impedance of the residential wiring for the vast majority of faults seen by the meter. Consider, for example, faults on a 15A branch circuit with #14 copper wire. The conductor resistance was taken as 2.68 ohms/1000' and the reactance as 0.03052 ohms/1000'. The effects of just adding a few feet of residential conductor are quite dramatic, as shown in Fig. 6.

People who specialize in protective devices say that the plug fuse, when called upon to operate for a heavy fault, will pass only a fraction of the short circuit current available. Similarly, the molded case breaker contacts blow open on heavy faults and the full available fault current just doesn't flow. In fact, our tests show that, for approximately 10,000 rms symmetrical amperes available, the peak let-through current for plug fuses rated 15 to 30A ranged from 1600 to 4000A peak. For 15-20A residential type molded case breakers, the current ranged from 3400 to 5000A peak. All of these devices had a total clearing time of 1/2 cycle or less.

Both the additional impedance of the residential wiring and the "current-limiting" effect of plug fuses and molded case breakers should explain why meters in service cables are not subjected to extremely high peak currents during faults in residences.

SERVICE ENTRANCE EQUIPMENT

Protective devices in service entrance equipment are applied on the basis of the available symmetrical short circuit current at the point of application. This requirement is recognized in the National Electrical Code, 1978 Edition, which states: "Service equipment shall be suitable for the short-circuit current available at its supply terminals" (Art. 230-98).

Residential service entrance equipment, at the present time, is available in circuit breaker load centers rated from 100 to 200A with both 10,000A and 22,000A short circuit ratings.

The differential in contractor's cost for service entrance equipment rated 10,000A vs. 22,000A short circuit rating is about $18 for 100A rated service and $76 for 125 to 200A rated service. The cost to the ultimate customer might be twice these values, but these contractor's costs will be used for this discussion.

OVER-ALL ECONOMICS

An examination of the matrix in Fig. 3 will show that, for a service-cable no larger than #4/0 (200A service) in size and a minimum length of approximately 25 feet, the bolted 120V fault current (slightly larger than the 240V fault) will not be larger than 10,000A. Thus, since 25 feet is a reasonably conservative length and since the fault currents decrease for smaller transformer sizes, it could be concluded that the service entrance equipment with a short circuit rating of 10,000A could be used for all single-family residential loads served by transformers rated 50 kVA and less.

Figure 4 indicates that the available fault currents for 167 kVA distribution transformers are below 10,000A for short, #2 service-cable (100A service) lengths, but that available fault currents are in the 10,000 to 22,000A range for short service-cable lengths of #4/0 (200A service) size. Similar comments apply to 75 kVA and 100 kVA distribution transformers. Hence, single-family residences requiring 200A service supplied by these transformer sizes should have service entrance equipment rated 22,000A, unless something is done to reduce the available short circuit current.

The available short circuit current can be reduced to below 10,000A by installing more impedance in the system. This permits the use of the lower rated service entrance equipment. Two ways that this might be done are either to put more impedance in the distribution transformer, which would affect all customers, or lengthen the service-cable where necessary, which would affect a few customers.

Higher Impedance Transformers - For #4/0 service-cable (200A service) 25 feet long, it would take approximately 2.4% impedance for a 75 kVA transformer, 3.3% impedance for a 100 kVA transformer, and 4.8% impedance for a 167 kVA transformer to keep available short circuit current below 10,000A. It is estimated that the net cost of the higher impedances in these transformers would be an average of between $6 and $100, depending on kVA size per transformer - provided these impedances were set as standard for all transformers built in these ratings. It should be noted that there are no standard impedance ranges in the ANSI Standards for units 500kVA and below.

If the industry were to decide to reverse the trend towards today's transformer impedances, the following system design factors should also be considered for the use of higher impedance transformers:

1. Higher voltage regulation can adversely affect all customers.
2. Voltage flicker during motor starting also will be greater.
3. Limitation on transformer loading may be required due to higher voltage regulation.
4. Strict recordkeeping may be required to keep it from being used interchangeably with the present impedance units.

Extra Service-Cable - A simple way to reduce the short circuit current at the service entrance equipment is to add extra service-cable for those customers with services too short to keep the available short circuit current below 10,000A. This would probably be for an average of two customers per transformer. This extra length should be installed as a "hairpin" rather than coiled to eliminate the possibility of heating.

An examination of the fault currents for the 75 kVA, 100 kVA, and 167 kVA transformers indicates the length of service-cable required to keep the available short circuit current below 10,000A. This information for the #4/0 service-cable is plotted in Fig. 7.

At least one utility is able to install #4/0 aluminum service-cable, covering materials and labor, for $1.11 per incremental foot of underground and $0.95 per incremental foot for overhead. To be more precise, the cost of the additional losses should also be considered.

A disadvantage of this technique is that it gives more service-cable exposure. In addition, the secondary losses will increase. The advantage is that only a few customers are involved and they are the ones who have the shortest service-cable run and are least likely to have voltage regulation or flicker problems. This method affects the voltage regulation to a few, rather than to all, customers.

Cost Comparison - Assuming an underground system with 8-200A single-family dwelling units per transformer, a comparison of the additional cost for the various methods of handling the available short circuit currents for 75 kVA, 100 kVA, and 167 kVA transformers was made. The alternatives considered were to: (1) use the 22,000A short circuit rated service entrance equipment, (2) use higher impedance transformers, so that 10,000A short circuit rated equipment can be used, and (3) install extra length of service-cable to keep the short circuit current below 10,000A. The results are summarized in Table I.

It will be noted from Table I that the overall economics are in favor of holding the available short circuit current down to 10,000A. Of the two alternatives used to accomplish this, the higher impedance transformer is the least expensive alternative. However, it should be recognized that this does affect the voltage regulation for all customers, making the extra cable more attractive.

As an example of what this means - if a 167 kVA transformer is used to supply 8 all-electric homes and nothing is done to keep available fault currents down to 10,000A, then the contractor is required to spend an additional $144 minimum total for these homes (the cost to the customers could be up to twice this amount). The supplier (utility) could keep the available fault current down to 10,000A for these 8 homes by spending from approximately $100 to $149, total.

GARDEN AND HIGH-RISE APARTMENTS

Multi-family dwelling units in garden and high-rise apartment buildings can be served by many different system patterns. One thing common to most schemes is that the transformer is usually large, like a 167 or 250 kVA size, and the distance between the transformer and the protective devices for the circuits going to or in the dwelling units is normally fairly short.

The various system patterns used will generally fall into two classifications: (1) primary metering with the distribution transformer arranged so that individual apartment circuits are run directly from the transformer secondary to a circuit breaker load center in each apartment, Fig. 8, or (2) secondary metering where the transformer is connected by heavy cables to a metering panel from which individual circuits are run to a circuit breaker load center in each apartment, Fig. 9.

A look at Figs. 4 and 5 for 167 kVA and 250 kVA transformers respectively, reveals the following maximum available short circuit currents for various system patterns when the cable length is 10':

Cable Size	Service Size	Short Circuit Current	
		167 kVA	250 kVA
#2	100A	18,300A	21,400A
4/0	200A	22,500A	27,500A
2-500kcmil	Metering Panel	24,800A	30,800A

This suggests that service entrance requirements for multi-family dwelling units should be examined as individual cases because of the large magnitudes of available short circuit currents and the large variations in design that can exist.

It doesn't seem practical here to reduce the available short circuit current to 10,000A by increasing the length of service-cable as was suggested for the single-family dwelling unit case because of the short space between the transformer and the circuit breaker load center or metering panel. Nor does increasing the transformer impedance seem to be the best answer. It would be necessary to increase the 167 kVA transformer impedance to 6.5% (an impractical amount) to reduce the maximum available short circuit current to less than 10,000A.

Examination of the above tabulation shows that the use of 22,000/10,000A short circuit rated circuit breaker load centers in the apartments will be adequate protective devices for 100A service. For cases where the available short circuit current is above 22,000A, the use of low voltage current-limiting fuses could be the most economical solution.

Current-limiting fuses are rated for 100,000A symmetrical interrupting capacity (SIC), and, when properly applied, they can protect downstream breakers so that 10,000A SIC rated breakers can be used in locations where the available short circuit current is as large as 100,000A. These cases, however, should be examined on an individual basis.

A couple of examples will illustrate how this can be done. Take the case of primary metering, Fig. 8, where 200A services are required and 25,000A short circuit current is available. The use of a safety switch equipped with current-limiting fuses in each circuit to an apartment will not only be an adequate protective device at the head end of the circuit, but it also makes possible the use of a 10,000A SIC rated circuit breaker load center in each apartment. Another case might be where a secondary metering panel, Fig. 9, is used and 31,000A short circuit current is available. A main switch equipped with 800-1200A current-limiting fuses on the panel will give protection to the metering panel. Since a 200A current-limiting fuse is the maximum size that will protect a 10,000A short circuit rated circuit breaker load center, another set of current-limiting fuses is required for each circuit going to an apartment. This can be accomplished by employing a safety switch equipped with the appropriately rated current-limiting fuse in each apartment circuit as it leaves the metering panel.

CONCLUSIONS

The available short circuit current at residential meters and service entrance equipments is largely determined by the distribution transformer and secondary distribution system design. These currents can be completely controlled by varying the impedance in this part of the system.

ANSI meter standards for accuracy and damage due to fault currents through the single-phase meter appear to be satisfactory for faults on the load side of service entrance equipment. Since the meters in production today meet these standards, it appears that the meter poses little apparent risk of obsolescence.

A full line of service entrance circuit breaker load centers are available for short circuit currents that can appear in residences. However, from an overall point of view, money can be saved if the electric supplier will keep the fault current below 10,000A for single-family dwelling units in order to take advantage of the lower cost 10,000A short circuit rated breaker load center. This might be accomplished for the greatest number of advantages if the service-cable is lengthened where necessary to control available short circuit current.

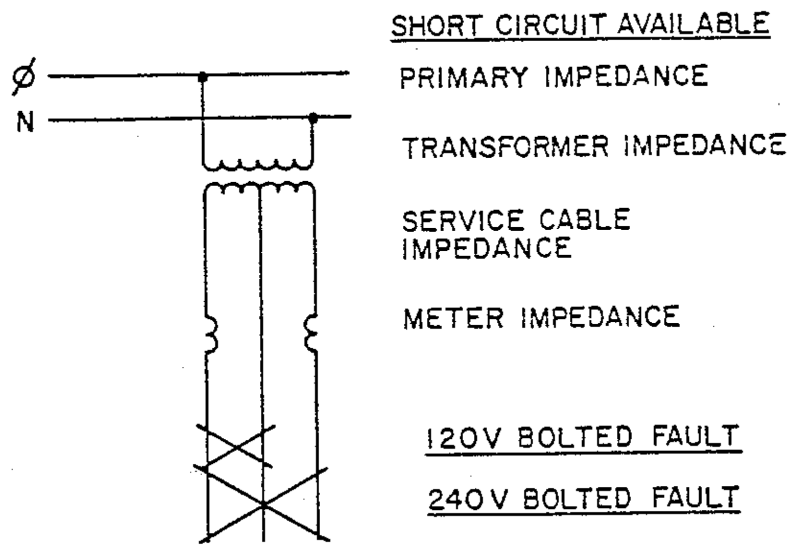
It appears that short circuit current at multi-family dwelling units should be handled on an individual basis. The proper use of current-limiting fuses in these applications makes it possible to obtain satisfactory protection with 10,000A short circuit rated circuit breaker load centers in the apartments where the available short circuit currents are greater than 22,000A.

6/4/80

TABLE 1
ADDITIONAL COSTS-$/TRANSFORMER

(TOTAL FOR 8 HOMES)

	CONT'S COST	SUPPLIER'S COST	
	(1) SERV. ENT. EQ.	(2) HIGH IMPEDANCE TRANS.	(3) EXTRA CABLE-NORMAL IMP.
TRANS. kVA	22,000 A OVER 10,000 A	ADDITIONAL IMPEDANCE	EXTRA CABLE (2-CUST.)
75	$144-608	$ 6	17.76
100	$144-608	$ 28	82.14
167	$144-608	$100	148.74



SCHEMATIC DIAGRAM

FIG. 1

P.U. IMPEDANCE, 167 kVA BASE

	240 V BOLTED FAULT		120 V BOLTED FAULT	
	R	X	R	X
SOURCE	.00003	.00043	.00003	.00043
167 kVA	.01	.02	.015	.04
50′, # 4/0	.02430	.00803	.09720	.03212
1-70 METER	.00291	.00332	.00583	.00665
BOLTED FAULT	.03724	.03178	.11806	.0762
	Z = .04896		Z = .14216	

$$I_{SC} = \frac{1}{Z} \times \frac{167}{.24}$$

$$= \frac{1}{.04896} \times \frac{167}{.24} = 14{,}213 \text{ AMPERES}$$

$$I_{SC} = \frac{1}{Z} \times \frac{167}{.12}$$

$$= \frac{1}{.14216} \times \frac{167}{.12} = 9790 \text{ AMPERES}$$

FIG. 2

FIG. 3 SINGLE PHASE FAULT CURRENT
50.0 KVA TRANSFORMER Z = 2:11%

240 V LINE TO LINE AMPERES

LEN. (FT)	UNDERGROUND #2	1/0	4/0	350	500	2-500
0	9253	9253	9253	9253	9253	9253
5	8673	8854	9016	9079	9108	9180
10	8122	8472	8786	8909	8967	9108
25	6705	7439	8147	8432	8567	8897
50	5061	6087	7229	7730	7971	8566
75	4015	5101	6472	7126	7448	8257
100	3310	4368	5843	6602	6987	7969
125	2809	3809	5316	6146	6577	7698
150	2437	3372	4870	5745	6212	7445
200	1923	2736	4162	5077	5588	6983
500	843	1270	2193	2963	3469	5071

120 V LINE TO GROUND AMPERES

0	13922	13922	13922	13922	13922	13922
5	11264	12065	12816	13119	13263	13584
10	9285	10549	11847	12398	12662	13262
25	5901	7504	9584	10618	11140	12379
50	3600	4971	7195	8535	9268	11136
75	2578	3694	5730	7118	7928	10115
100	2005	2933	4751	6098	6924	9263
125	1640	2431	4054	5331	6143	8541
150	1387	2074	3533	4733	5520	7923
200	1059	1603	2809	3864	4588	6918
500	438	677	1256	1833	2275	3920

FIG. 4 SINGLE PHASE FAULT CURRENT
167.0 KVA TRANSFORMER Z = 2.24%

240 V LINE TO LINE AMPERES

LEN. (FT)	UNDERGROUND #2	1/0	4/0	350	500	2-500
0	25726	25726	25726	25726	25726	25726
5	21657	22903	24021	24453	24656	25180
10	18251	20400	22460	23280	23664	24654
25	11864	14909	18593	20274	21085	23190
50	7270	9993	14213	16571	17793	21078
75	5202	7442	11407	13952	15359	19298
100	4042	5910	9494	12021	13496	17783
125	3302	4896	8116	10547	12028	16479
150	2791	4176	7081	9388	10843	15348
200	2130	3224	5634	7688	9052	13485
500	878	1359	2518	3664	4528	7755

120 V LINE TO GROUND AMPERES

0	27030	27030	27030	27030	27030	27030
5	19252	21527	23647	24462	24840	25893
10	14110	17273	20779	22253	22941	24835
25	7460	10337	14827	17304	18562	22077
50	4101	6035	9790	12443	13976	18550
75	2819	4238	7250	9656	11165	15948
100	2146	3262	5743	7872	9282	13963
125	1732	2650	4750	6637	7936	12405
150	1452	2231	4048	5734	6929	11154
200	1097	1694	3122	4505	5522	9271
500	444	693	1314	1965	2484	4583

FIG. 5 SINGLE PHASE FAULT CURRENT
250.0 KVA TRNASFORMER Z = 2.51%

240 V LINE TO LINE AMPERES

LEN. (FT)	UNDERGROUND #2	1/0	4/0	350	500	2-500
0	32517	32517	32517	32517	32517	32517
5	26309	28195	29890	30543	30848	31661
10	21357	24462	27526	28752	29325	30844
25	12988	16862	21906	24314	25485	28607
50	7640	10773	16016	19159	20830	25473
75	5380	7847	12511	15725	17567	22923
100	4145	6155	10230	13303	15166	20816
125	3370	5059	8639	11513	13333	1.9050
150	2838	4292	7470	10141	11889	17552
200	2157	3292	5873	8180	9766	15152
500	883	1370	2563	3769	4697	8272

120 V LINE TO GROUND AMPERES

0	33944	33944	33944	33944	33944	33944
5	22329	25616	28786	30016	30582	32184
10	15544	19671	24590	26746	27757	30575
25	7783	11049	16565	19853	21576	26501
50	4187	6247	10468	13666	15594	21560
75	2858	4337	7600	10359	12162	18106
100	2168	3318	5954	8324	9954	15578
125	1746	2686	4891	6952	8419	13656
150	1462	2256	4148	5965	7291	12148
200	1102	1708	3181	4644	5748	9942
500	445	695	1324	1990	2528	4737

EFFECT OF RESIDENTIAL WIRING ON FAULT CURRENT

(CIRCUIT OF FIG. 2)

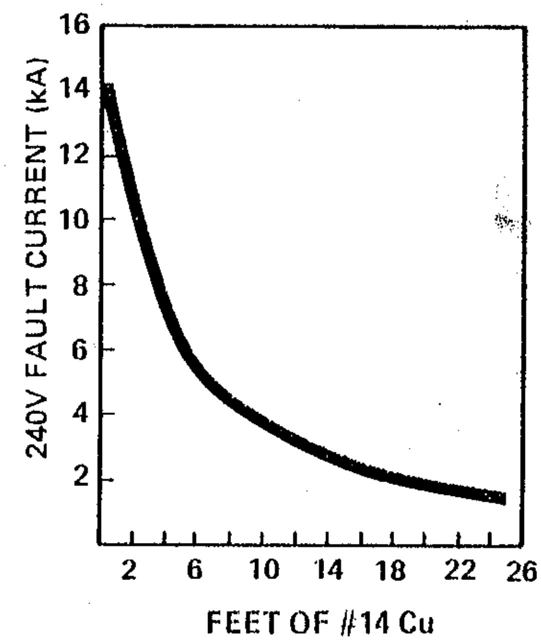


FIG. 6

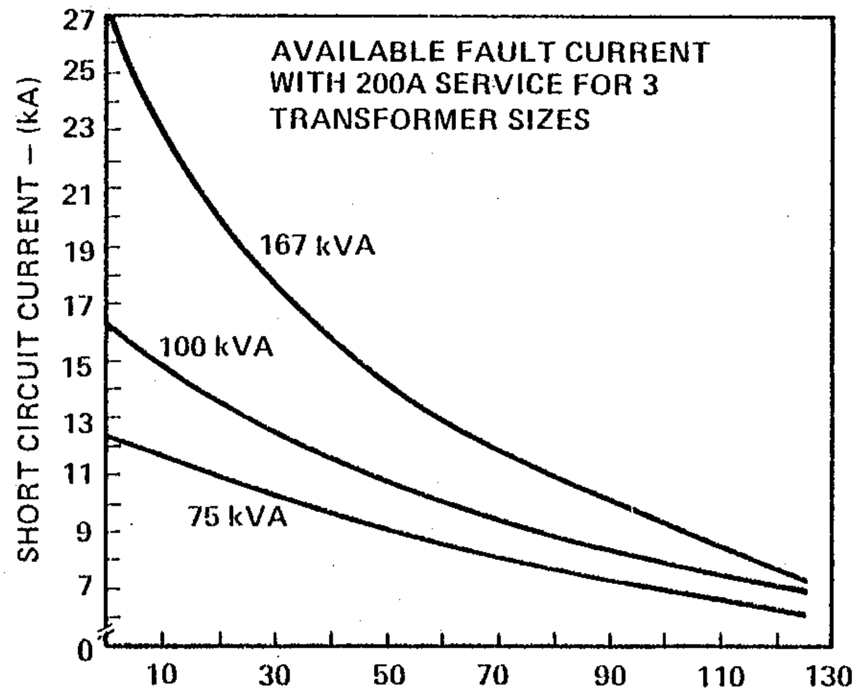

AVAILABLE FAULT CURRENT
WITH 200A SERVICE FOR 3
TRANSFORMER SIZES
167 kVA
100 kVA
75 kVA
SHORT CIRCUIT CURRENT — (kA)
27
25
23
21
19
17
15
13
11
9
7
0
10
30
50
70
90
110
130
4/0 AL. SERVICE — CABLE LENGTH — FEET

FIG. 7

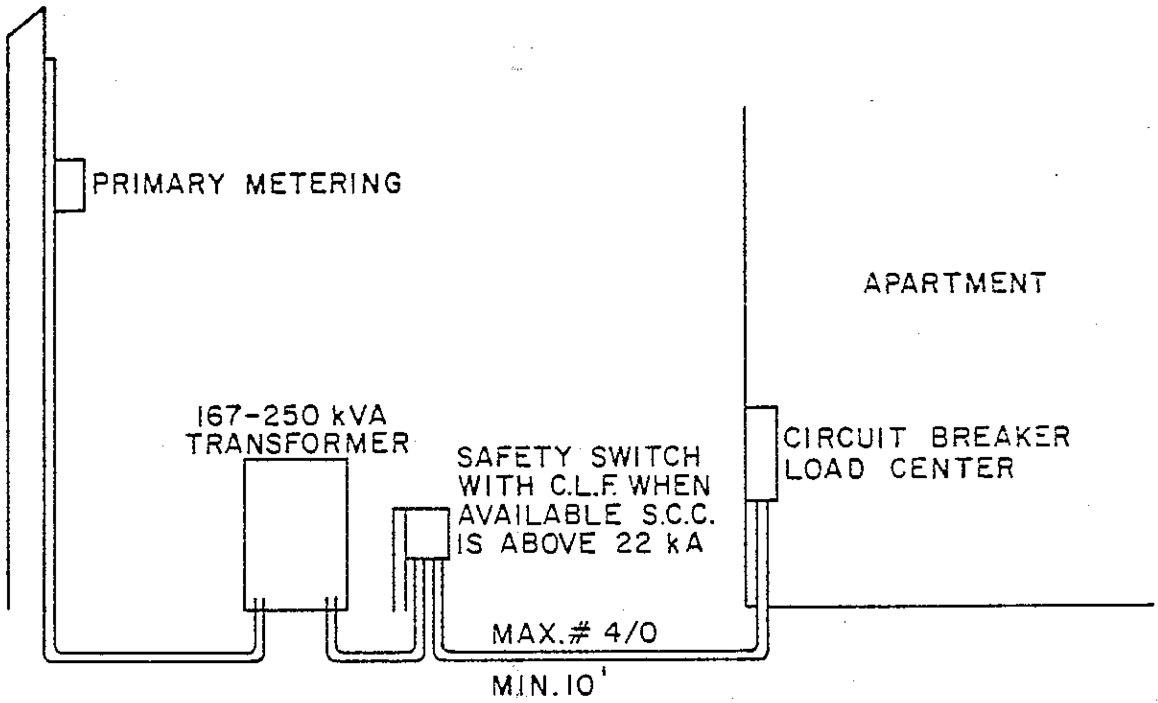


FIG. 8 PRIMARY METERED SUPPLY TO APARTMENTS

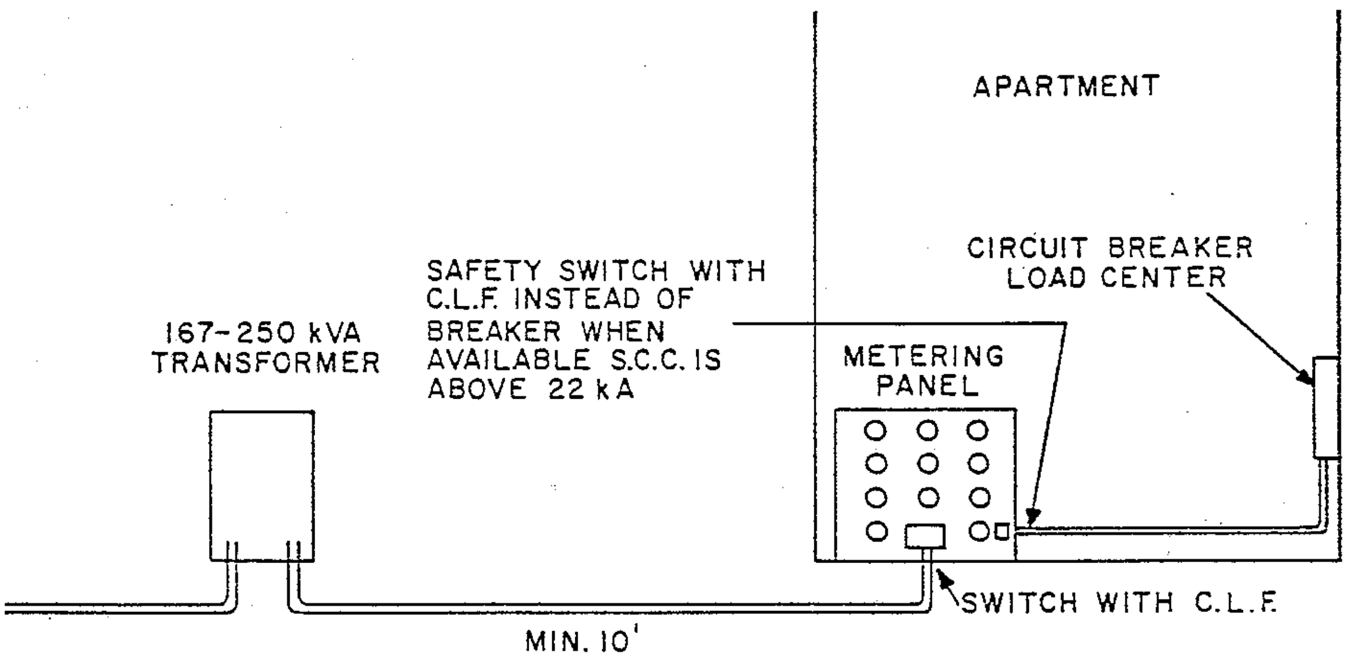


FIG.9 SECONDARY METERED SUPPLY TO APARTMENTS