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EQUATIONS HELP DETERMINE LARGEST MOTORS THAT CAN BE CONNECTED ON UTILITY LINES

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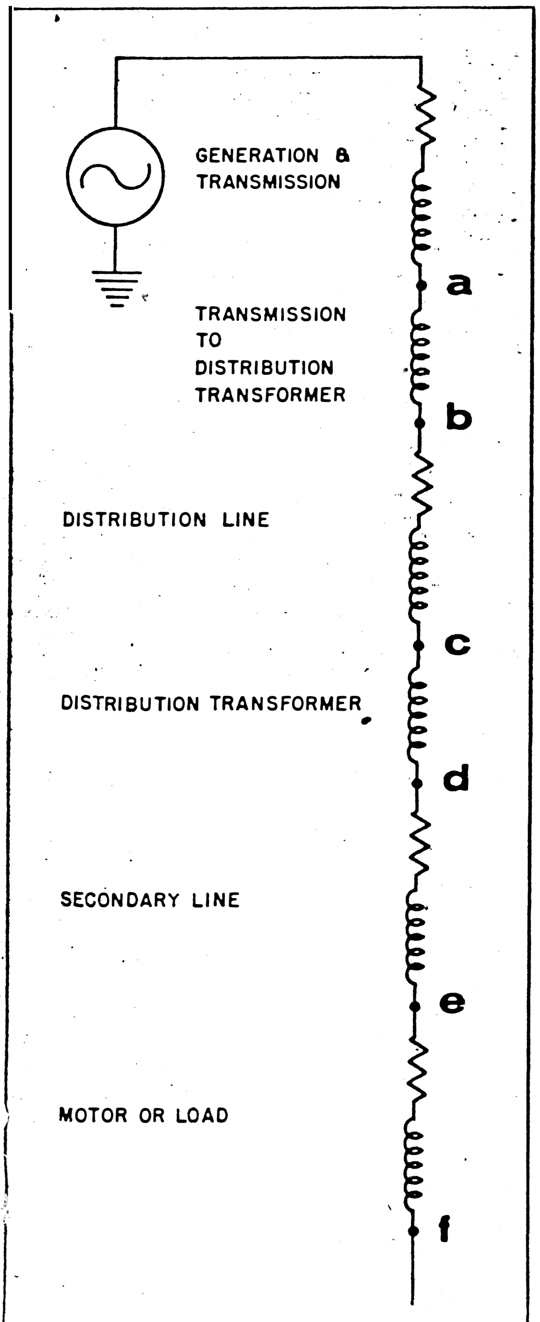

Fig. 1 One-line diagram r[illegible]e[illegible]nts th

TO SIMPLIFY CALCULATIONS for determining the maximum size of three-phase motors that can be connected at any point on a utility distribution system, three equations were developed. The analysis, based on starting Mva and voltage dip, hasminimized time necessary to perform computations. In addition, the method has been proved by test results to be accurate within 2%.

Because most utility systems are constantly changing, a simple method for determining feeder capacity at any location is desirable. Where the system impedance is high, the largest size motor that can be connected is usually limited by the effect of voltage dip during motor starting. The tendency to use a rule-of-thumb method usually is overly conservative and results in unnecessary restrictions in motor size. On the other hand, long and tedious calculations are some-times made to accurately •determine voltage dip at various points during motor starting.

The simplified, highly accurate analysis developed by the author, requires only basic data and equipment' that are readily available. This method is most easily applied to radial distribution system analysis, but is equally effective on looped systems. Line capacitors and distribution loads are considered to be fixed values in this analysis.

VALUES OF VOLTAGE DIP during motor starting can be calculated from the following equation:

$$\%\ V\ \text{dip} = \frac{LRM}{F} \times 100$$

where:

LRM = locked-rotor Mva at point on the system where motor will be located.

F = maximum three-phase faults in Mva at any point on the system where voltage dip is to be determined.

The usual method for arriving at per-unit values for a utility system is used in this analysis (see Fig. 1). Maximum three-phase fault (F) that can occur on a system is calculated from the following equation:

$$F = \frac{Mva_{base}}{Z_{pu}}$$

where:

Mva_{base} = common Mva base used to represent the system in a one-line diagram as shown in Fig. 1.

Z_{pu} = per-unit impedance of the system to the point analyzed.

When a motor is connected to a system as shown in Fig. 1, the starting or locked-rotor Mva (LRM) is calculated by assuming a three-phase fault at point "f", the motor location. The locked rotor Mva is computed from the equation:

$$LRM - \frac{Mva_{base}}{\Sigma Z_{pu} + Z_{pu\text{-}m}}$$

where:

ΣZ_{pu} = the per-unit system impedance at the motor terminals.

$Z_{pu\text{-}m}$ = per-unit locked-rotor motor impedance.

Note: Impedances must be added vectorially.

Per-unit locked-rotor motor impedance ($Z_{pu\text{-}m}$) is calculated from the following formula:

$$Z_{pu\text{-}m} = \frac{Mva_{base} \times 1000}{\sqrt{3} \times kv_m \times I_{LR}} \left(\frac{kv_m}{kv_L}\right)^2$$

where:

kv_m = motorname plate voltage

I_{LR} = motorname plate locked-rotor current

kv_L = nominal voltage of line feeding the motor

A voltage profile of typical voltage dips along a utility system, such as the one illustrated in Fig. 1, is shown in Fig. 2. Table I contains calculated per-unit values (100-Mva base) for a 20-hp compressor that was started on a 208-v system. The three-phase motor had a 220-v rating and locked-rotor current of 386 amps. Locked-rotor power factor was estimated at 30%. Actual voltage dip at the motor terminals during starting was 4.37% compared to the calculated value of 4.47%.

The approach presented in this article can be further simplified by using a fault-current calculating wheel, impedance curves or tables and standard values of locked-rotor current. END

TABLE I—CALCULATED PER-UNIT VALUES ON UTILITY SYSTEM WITH 20-HP COMPRESSOR ADDED

System Components	R_{pu}	X_{pu}	ΣR_{pu}	ΣX_{pu}	ΣZ_{pu}	F_{mva}	$\%V_{dip}$
138 kv system	—	—	.0122	.0729	.0739	1355	—
138/12.4 kv transformer	—	.3675	.0122	.4404	.4408	267	—
12.4-kv line	.3613	.4331	.3735	.8735	.9500	105	.119
12.4/208 kv transformer	—	14.66	.3735	15.53	15.5	6.45	1.95
Secondary line	23.77	10.55	24.14	26.08	35.6	2.81	4.47
Motor	248	722	272	748	796	.126	—

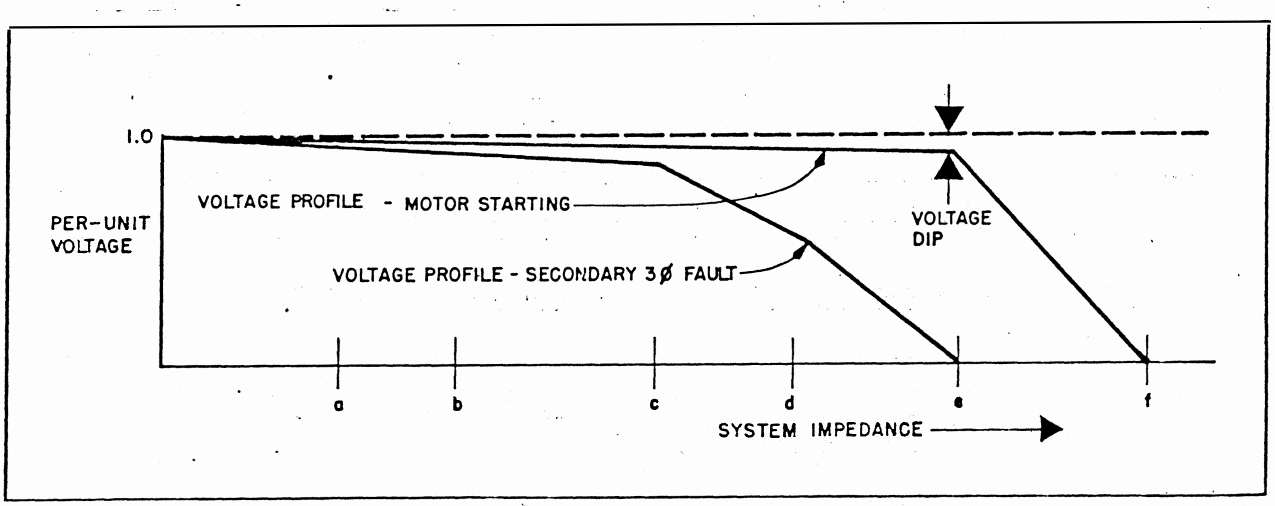

Fig. 2. Voltage profile of the system shown in Fig. 1 under motor-starting and three-phase-fault conditions.