F. OTHER REFERENCES

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Section 2.1.8 has not been updated since December 2000. Please refer to the on-line version for updates prior to using. InFPL/Power Systems/Reliability/DEO/Publications/DERM

2.1.8 TRANSFORMER LOADING

A. GENERAL

There are two factors limiting the level to which the designer would normally load a transformer. These factors are voltage drop and overheating.

A given transformer has many "overload" ratings, depending upon the conditions under which it operates. The same load which could be safely carried on a cold winter night could seriously overload a pole mounted transformer on the hottest day of summer. Factors other than ambient temperature affect the overload rating. These are the load duration (or duty cycle), wind velocity, the presence or absence of rain or direct sunlight on the transformer, and the color of its paint. A transformer subjected to many years of severe loading and lightning strokes is not likely to have the capabilities of a new unit.

The term "overload" has had many interpretations within the Company and the industry. The interpretations usually infer premature failure of the transformer or excessive voltage drop, or both. At FPL, when loading causes excessive transformer voltage drop, the problem is routinely handled. However, when a transformer is known to be carrying in excess of rated kVA, questions often arise as to its ability to continue operating safely.

The balance of this section will be devoted to loading based on thermal restrictions.

The heat input into a transformer is due to the following:

11. I^2R loss due to load current. This is referred to as copper loss.
12. Hysteresis and eddy current losses in the iron laminations, mainly, but also including losses in the iron of the tank and supporting structure. These represent the main part of the "no load" loss. They are constant, regardless of the load.
13. A small I^2R loss due to exciting current is included in "no load loss".
14. Dielectric loss, in the enamel, paper, porcelain and oil. This is small and is also part of the no load loss.
15. Heat input due to sunlight or other radiated heat. This will depend on the exposure to direct sunlight and the properties of the paint.

To get rid of this heat, the transformer core and coil are immersed in an oil dielectric insulating and cooling medium. Channels are provided so the oil can flow through the coils and next to the core for good heat transfer. In distribution transformers, circulation is by means of convection currents. Hot oil from the central area, where the core and coils are, rises. This displaces oil outward and downward, forcing it to pass by the outer cooling surfaces of the tank.

The tank wall, together with any cooling tubes or fins provided, becomes a heat exchanger. It gives up the heat received from the hot oil to the outer atmosphere. Some of our transformers are dry-type. In these, the heat passes directly from the core and coil to outside air circulated through the core and coil by convection.

The efficiency of the transformer design represents a balance between full-load and no-load losses; the amount of oil, the area of the heat transfer surfaces, and the type of paint. These balances must be reached with the economics of the design kept in mind.

The copper loss is very sensitive to load since the watts going into heat energy vary as the square of the current. It is impossible to cool all parts of the winding equally. There will be one spot in the winding which, under load, gets hotter than any other spot in the transformer. This is called the "hottest-spot", and becomes one limitation on transformer load.

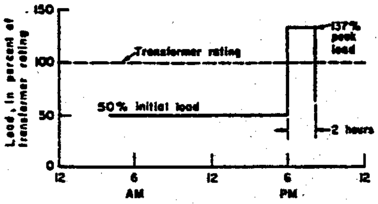
The mass of iron, copper, paper, oil, and steel in the transformer all have specific heat coefficients which introduce a time lag into any change in temperature. In addition, the cooling surfaces are continually getting rid of heat by convection and radiation. A transformer lightly loaded prior to a peak load will have a lower "hottest-spot" temperature than one carrying full load prior to the same peak load. Thus the shape of the load curve over a 24 hour period has a great effect on what peak load may be permitted on a transformer.

For winter loading, since the ambient temperatures are lower than the summer, additional load can be placed on the transformer. Strip heating loads are to determine the size of the transformer if the strip heating + full electric base load is more than 70% above the A/C + full electric base load. For example, suppose that the total winter load for a customer is determined to be 17 kVA and his total summer load is determined to be 10.6 kVA, which load should be considered to size a transformer? The answer is obtained by taking the ratio between winter and summer loads; ratio = 17 kVA/10.6 kVA = 1.60. This ratio indicates that the winter load is 60% of the summer load. Therefore, the summer load should be used to size the transformer. Unless overriding factors exists, the summer load should be used when the ratio borders on 1.70.

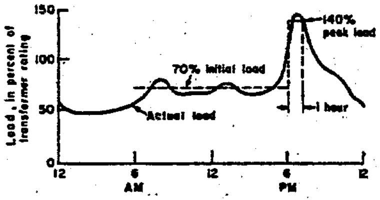
Most distribution transformers serve loads which are not continuous and vary widely over a 24 hour period. ANSI C57.91 shows a method of approximating these load cycles by rectangular blocks of different heights. See Figure I. The ordinates for the rectangular load curve are found by taking hourly demand readings in the lower pre-peak period, and at more frequent intervals in the peak period. The square root of the sum of the squares of the demands for the appropriate time period gives the ordinate. The duration of the peak may be chosen by inspection, but if the rectangular peak is not 90% of the highest 30 minute demand, the peak must be shortened. This precaution is to keep the hot spot in the winding from getting too hot. This curve is then converted into a curve where the ordinates are expressed in percent of rating.

The normal load cycle of distribution transformers consists of a relatively low load during the greater part of the day, with one or more peaks lasting from a few minutes to a few hours. Such a characteristic permits operating the transformer at loads in excess of its continuous self-cooled rating during short-time peaks. This is because the heat storage capacity of the transformer insures a relatively slow increase in internal temperature.

A daily load cycle might be pictured as a simple rectangular curve consisting of an initial load and a peak load as follows:



The actual daily load cycle is not usually this simple but fluctuates like the solid line below:



In order to use a loading guide, the actual load cycle must be converted to a thermally equivalent, simple rectangular load cycle as shown by the dotted lines. This is done in two steps.

1. Initial Load

A rough approximation can be obtained using the formula:

$$\text{Equiv. Initial Load} = 0.29\sqrt{L_1^2+L_2^2+L_3^2+\cdots L_{12}^2}$$

where L_1, L_2, L_3 etc. is the average load, by inspection, for each one-hour interval of the 12-hour period preceding the peak load. In the curve above, this would be 70 percent of the transformer rating.

2. Peak Load

$$\text{Equiv. Peak Load} = \sqrt{\frac{L_1^2t_1+L_2^2t_2+\cdots L_n^2t_n}{t_1+t_2+\cdots t_n}}$$

where L_1, L_2, etc., are the various load steps in percent, per unit, or in actual kva or current and t_1, t_2, etc., are the duration of these loads, respectively. The estimated duration of the peak has considerable influence over the rms peak load. When the duration is overestimated, the rms peak load may be considerably below the maximum peak demand. In the curve above, the equivalent peak load was figured at 140 percent of the transformer rating for one hour.

FIGURE I - EQUIVALENT LOAD CURVE FOR TRANSFORMERS

Reference: GET-2485 K

The following loading guide is for self-cooled, oil-immersed transformers. The loadings are based solely on thermal and insulation-aging considerations so that voltage regulation and load losses must be considered separately by the operator for a particular system. These latter factors, perhaps not serious for loads moderately above rating, become increasingly important at higher loadings thermally permissible for short durations and low ambients.

Daily Peak Loads in Per Unit of Nameplate Rating to
Give Minimum of Twenty Years Life Expectancy

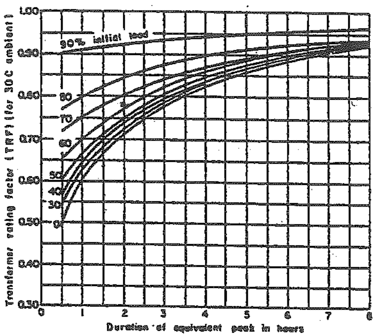
Peak Load Time in Hours	Cooling—Self-Cooled or Water-Cooled (OA or OW) (1)																
	Continuous Equivalent Load in Percent of Rated kva Preceding Peak Load																
	50 Percent						75 Percent						90 Percent				
	Ambient in Degrees C						Ambient in Degrees C						Ambient in Degrees C				
	0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40
1	2.52	2.39	2.26	2.12	1.96	1.79	2.40	2.26	2.12	1.96	1.77	1.49	2.31	2.16	2.02	1.82	1.43
2	2.15	2.03	1.91	1.79	1.65	1.50	2.06	1.94	1.82	1.68	1.52	1.26	2.00	1.87	1.74	1.57	1.26
4	1.82	1.72	1.61	1.50	1.38	1.25	1.77	1.66	1.56	1.44	1.30	1.09	1.73	1.62	1.50	1.36	1.13
8	1.57	1.48	1.39	1.28	1.18	1.05	1.55	1.46	1.36	1.25	1.13	0.96	1.53	1.44	1.33	1.21	1.02
24	1.36	1.27	1.18	1.08	0.97	0.86	1.36	1.27	1.17	1.07	0.97	0.84	1.35	1.26	1.16	1.07	0.95

FIGURE II

Transformer Rating Factor

The loading guide gives peak and initial loads in terms of transformer rating but it is customary to express the daily load cycle in terms of actual peak load. For example, the curve on the previous page could be stated as an initial load of 50 percent (70 ÷ 140 × 100) followed by 100 percent peak load for one hour.

Transformer Rating Factor



The chart on this page assists in determining the transformer size for serving a given load cycle. For example, assume a peak load of 58 kva for four hours following an initial load of 35 kva or 60 percent of the peak. Locating 60 percent initial load and four hours peak duration on the chart, you get a TRF of 0.86. Multiplying this by the 58-kva peak indicates a 50-kva transformer will serve this load cycle satisfactorily.

LOAD FACTOR

FIGURE III
TRANSFORMER RATING CORRECTION FACTORS
Reference - GET - 2485K

Using this curve, we determine the equivalent constant load in percent of transformer rating which preceded the peak load and also the peak duration. The proper table in ANSI C57.91 will give us the allowable peak for a given loss of life.

IEEE Standards 345-1972 (ANSI C57.100-1974) "Standard Test Procedure for Thermal Evaluation of Oil-Immersed Distribution Transformers" discusses minimum life expectancy of distribution transformers. The load on distribution transformers follows daily and annual cycles. Thus, the peak thermal loading occurs for a relatively small portion of just a few days during the annual cycle. The cumulative time at or above the rated hot spot temperature is small compared to the elapsed time. Thermal degradation is a function of temperature and time at that temperature. Thus, transformer life (elapsed time) in service should be very much greater than the life determined by an essentially continuous loading. Experience and tests indicate that an insulation system good for 60,000 hours (7 years, approximately) at rated load should give satisfactory life under the normal cyclic loading it will see in service. Acceptable thermal aging performance may be assumed if the hot-spot temperature at rated load (as defined in IEEE Std. 1-1969) does not go above that indicating a life expectancy of 60,000 hours, by the test procedure outlined in ANSI C57.100-1974.

It is not practical to have many different loading tables to cover all of the possible circumstances previously mentioned. Neither is it practical nor economical to conduct an in-depth study on every transformer suspected of being overloaded. This is especially true of very small transformers where the cost of an individual detailed analysis could exceed the price of the transformer. Large expensive transformers obviously warrant investigation if an overload is suspected.

In what follows, this section gives you some loading rules, based on average conditions, and influenced by the techniques described in ANSI C57.91. This section on Transformer Loading will answer the following two questions:

15. New installations for new loads; how do we size the transformer for anticipated load?
16. Existing installations; how much should we load them before increasing the transformer size?

Note: Loading of transformers on the Miami Secondary Network is a special situation and is not covered here.

B. TRANSFORMER INSTALLATION DESIGN

General. For transformer installations to serve new loads, the transformer size should be matched to a load equal to about 110% of its nameplate rating. Considering minimal load growth and the overload capability of a transformer, it is reasonable to design for a 20 year change out time.

In distribution design, voltage drop is a major consideration. In some situations, voltage drop and "flicker" may prevent full use of a transformer's thermal capability (see Section 2.2.1).

It has been stated that a transformer can be severely overloaded for a short period of time without exceeding its rated temperature rise. However, ANSI-C57.91 recommends that the short time loading not be allowed to exceed 250% except during an emergency. This limitation is necessary to avoid damage to the insulation at the "hottest spot" in the winding. This loading is just at or above the point where the fuse should blow on most FPL overhead transformers with standard fusing as shown in DCS I-19.

Future load growth on a new transformer installation is considered to be negligible. Transformer loading should therefore be kept to approximately 110% of nameplate rating.

C. RESIDENTIAL SUBDIVISIONS

1. Pole Mounted Installations - New Transformer Station

In choosing a transformer size, it is usually necessary to consider the technical and economic aspects of several combinations of transformer and secondary. Typical design problems are dealt with in detail in Section 4.3.2 of this manual.

2. Adding New Load to Existing Residential Transformer

It is often necessary to connect a new customer or customers to an existing transformer secondary installation. It may be possible to do this without changing out the transformer. As a general rule for residential subdivisions, customers may be added to the secondary as long as the new summer loading will not exceed 150% of transformer rating. More detailed information on this subject is given in Section 4.3.2.

3. Pad mounted, URD Subdivision

The design of the transformer-secondary system for URD subdivisions is covered in Section 5.5.1, "Residential URD Systems". Transformer loading is also covered. Transformer loading for the majority of cases should be based on serving a maximum number of customers from a transformer as shown in Section 5.5.1 Table III. This practice has validity for underground systems that may not be applicable to overhead installations.

4. Existing Installations - Load Evaluation

Presently, all transformer loading should be monitored by Transformer Load Management (TLM). The TLM system provides a calculated transformer loading by converting kWhr consumption to kVA demand.

When needed, transformer replacement, should be based on TLM data. If TLM information is not available, the following information can be used as a guide to residential transformer loading. The information is structured to cover average conditions; it is expected that a small percentage of cases will noticeably vary from the average.

Measured loading on existing residential transformers should be limited to 160% of rated kVA during hot weather and 190% if measured during extremely cold weather. Excessive voltage regulation will occur in a few cases with these loading limits.

Most often this will be at locations near the electrical end of a rural feeder and/or at the end of a long secondary bus. Where this happens, the loading limits of 160% and 190% must be reduced. It is assumed the load readings will be taken at approximate time of daily peak, and will be representative of a one hour demand period. Discard any momentary current peaks. While the 160% and 190% allowable load may seem high to some personnel, in most cases, the transformer will not be damaged. The transformer temperature does not rise to destructive levels during the short time the "overload" is carried. It should be noted that modern transformers carrying rated load operate at case temperatures in the order of 50°C, or higher; this will seem hot to the touch, but is not by itself any cause for concern.

Continuous loading in excess of a transformer's rating will of course shorten its life. This fact alone is not necessarily undesirable when economics are considered. It can be shown in come cases that a cost of a slight reduction in transformer life is more than offset by reduced capital investment.

For lack of any other means of checking loading, TLM principles may be applied manually. See SPO Procedure #21640.4. When estimating transformer load by this method, consider increasing transformer size if loading exceeds 200%. An actual load check of the suspect units is recommended.

D. TRANSFORMER INSTALLATIONS FOR LARGE INDUSTRIAL OR COMMERCIAL LOADS

1. New Installations

These installations are expensive and warrant attention to obtain accurate and complete load information.

Some points to consider:

a) Type service required; voltage, phase, ampacity, delta or wye secondary.
b) List of equipment, mode of operation, power factor, voltage, phase, amperes, and approximate load factor.
c) Transformers to be in vault or overhead?
d) Type of motor starting equipment if large motors present.
e) See also Service Planner Operations Procedures - SPO Procedure #21640 through #21640.6.

Having obtained this data, determine as closely as possible the expected demand, and duration of peak demand.

Normally, use single phase transformers up through 167 kVA to form a three phase bank. In some cases, if the size of the load requires banks to be paralleled, 3 phase units may be considered. If there is possibility of growth, design the vault and bus so another unit may be added easily.

Consider the possibility of ferroresonance, as discussed in Section 2.9.2 of this manual.

If a large wye-delta bank is to be used to serve both single and three phase load, the transformer serving the lighting and other single phase load will usually be larger than the other transformers. Assuming unequal power factors for the single phase load and the three phase load, the loading on the smaller transformers will not be equal. The transformer loads may be calculated by the following equations.

$L_A = 1/3\ (4s^2 + T^2 + 4ST \cos(\varphi_T - \varphi_S))^{1/2}$ -- Equation 1

$L_B = 1/3\ (S^2 + T^2 + 2ST \cos(\varphi_S - \varphi_T + 60^\circ))^{1/2}$ -- Equation 2

$L_C = 1/3\ (S^2 + T^2 + 2ST \cos(\varphi_S - \varphi_T + 60^\circ))^{1/2}$ -- Equation 3

Where S = single phase load in kVA; φ_s = single phase power factor angle.

T = Three phase load, kVA; φ_T = Power Factor angle, three phase load.

L_A = Load on Transformer A across which single phase load is connected.

L = Load on transformer B connected to phase lagging the phase to which transformer A is connected by 120°.

L_C = Load on third transformer, C.

Usually it is sufficiently accurate, when selecting transformer sizes, to assume

$L_A = 1/3\ T + 2/3S$ -- Equation 4

$L_B = L_C = 1/3T + 1/3S$ -- Equation 5

An advantage of the wye-delta bank, with wye point not grounded, is that the wye point will shift to allow the bank to compensate for primary voltage unbalance. It will furnish balanced voltages to a balanced three phase load. Single phase load will cause some unbalance in voltage.

Wye-wye banks may have single phase loads distributed equally between phases, so they can have equal loads on each transformer. If transformer impedances are equal the wye-wye bank will not cause unbalanced voltages for balanced loads. However, it will not correct for primary feeder voltage unbalance. Pad mounted transformers are available with the wye-wye connection, but not with the closed delta connection.

Regardless of the type of bank used, the transformer sizes should be chosen to match the proposed transformer load as closely as possible. Loading on the transformers should not exceed 110% of nameplate rating initially.

If the transformers are in a vault, ventilation must be provided.

If there are large motors present, consideration must be given to possible flicker problems (see Section 2.2.1).

The larger transformers will have top-oil temperature gauges. These should be monitored by persons visiting the vault to see that temperature limits are not exceeded.

2. EXISTING TRANSFORMERS SERVING INDUSTRIAL AND COMMERCIAL LOADS - LOAD EVALUATION

This discussion is intended to cover the loading of only the larger and more expensive transformers. In almost all cases, customers served by these transformers have a demand meter. A customer's demand history often provides valuable insight into a suspected transformer overload.

Transformer capacity should be increased if any of the following conditions are noted:

f. The kW billing demand records indicate that 105% of the rated transformer kVA has been exceeded for 3 or more months of the year.

g. The transformer is carrying near rated load and the top oil temperature gauge indicates a temperature of 100°C or greater for 65° C rise transformers, or 90° C for 55° C rise transformers.

h. When a transformer serves more than one customer and any one customer's demand equals or exceeds the transformer rating.

Provided the transformer is in good condition, replacement need not be made an emergency under the above conditions. Extreme cases excepted, only slight loss of transformer life will result if the transformer is replaced during normal working hours.

The above loading guide presumes an average customer's power factor of 0.85. The 105% loading translates to 105%/0.85 or 124% of rated kVA. The loading limits are lower than those suggested for residential transformers to allow for the longer duration of peak loads of industrial and commercial customers.

Special cases too numerous to list will arise which may require transformer replacement. These situations should be decided on the judgment of experienced personnel.

E. SMALL COMMERCIAL CUSTOMERS

1. New Transformer Installations

These customers usually have a large single phase load, with a small three phase load.

Obtain data from the customer which will allow you to establish the single phase and the coincident three phase demand. An open-wye, open-delta bank is a good way of serving this type of load. It is not likely to give ferroresonance problems. Under some combinations of single and three phase load it will give more nearly balanced voltages than will the closed wye-delta. It will not compensate for unbalanced primary voltages, and will cause some voltage unbalance when the load is a balanced three phase load.

Open-wye banks in an area should be apportioned as equally as possible to the three phases, to prevent unbalanced line currents.

The open-wye, open-delta bank should be satisfactory at 4 kV for all three phase loads below 37 kVA; at 13 kV for three phase loads 75 kVA and below and at 23 kV for all loads except very large three phase loads. At 23 kV, ferroresonance is a consideration and is avoided by the use of an open-wye, open-delta bank.

The transformer supplying the single phase lighting load should be connected to the leading phase. The load on this transformer will be:

$$L_L = (S^2 + {}^{T2}/_3 + {}^2/_3 \quad ST \cos(\varphi_T - \varphi_S + 30°))^{1/2} \text{ -- Equation 6}$$

Install E

and the load on the "kicker" transformer will be:

$$L_K = \quad {}^1/_3 \quad T = 0.577T \text{ kVA -- Equation 7}$$

Inst

Assuming $PF_3 = 0.8$ and $PF_1 = 0.95$, from Equation 6

$$L_L = (S^2 + \quad T\ 2/3 \quad + 0.76\ ST)^{1/2}$$

Insta

suppose S = 30 kVA

T = 15 kVA

$$L_L = ((30)^2 + \frac{(15)^2}{3} + 0.76\,(30 \times 15))^{1/2}$$

Install E

$$= (900 + 75 + 342)^{1/2} = (1317)^{1/2} = 36.3 \text{ kVA}$$

In most cases, it will be sufficiently accurate to say $L_L = S + 0.577T$.

$L_K = 0.577 \times 15 = 8.7$ kVA.

This would call for a 37 1/2 and a 7 1/2 or 10 kVA transformer.

If a pad mounted installation is required, we do have a number of duplex open-wye, open-delta units we would like to use up. If you do not have the right size duplex unit, you may use two single phase pad mounted transformers - See FPL DCS I-68.

There may be cases where 4 wire, three phase, service at 120/208 volts, or 277/480 volts is required. This may be furnished from three pole mounted aerial type transformers, or in underground areas from the same transformers equipped with cover mounted potheads and located in a customer-furnished vault. In appropriate areas, three phase pad mounted transformers are available.

Initial loading allowed on an open-wye, open-delta bank depends on the type of three phase load it is serving. As mentioned before, some unbalanced voltage is caused when serving a balanced three phase load. This is not much of a problem for a lightly loaded motor, or one which runs intermittently for short periods. For a heavily loaded three phase motor, which runs for long periods at a time, unbalanced voltages can cause overheating and failure. This situation is often found in commercial three phase refrigeration motors, deep well pumps, and in three phase unitary air conditioning units. When the bank is serving this type of load, it is suggested that the initial design loading of the transformer carrying the lighting load be limited to 90% of nameplate. The kicker transformer may be loaded 100% of nameplate.

Both transformers may be loaded initially to 100% of nameplate capacity if:

a. There are none of the described types of loaded three phase motors, or

b. The rating of the described type of loaded three phase motors is small compared to the bank capacity (say 1/4 or less of the transformer capacity).

If service is from a wye-wye bank, initial design loading may be equal to nameplate rating.

2. Existing Installations - Load Evaluation

Several of these small commercial customers may be grouped on one transformer, or each may be isolated. Drug stores, 7-11's, neighborhood hardware stores, restaurants with gas cooking, general stores, neighborhood men's and women's clothing stores, and others would come under this heading. Their load would be reasonably constant, and in most cases would last for 8 hours or more with minor peaks of shorter duration. If demand meters are not present, load checks must be made when overload is suspected; see SPO Procedure 21640.5. Many of this type of customer are served from open wye - open delta banks where overloading will aggravate any existing voltage unbalance.

If there are no pending complaints of unbalanced voltage conditions, transformers may be loaded to 150% of nameplate kVA before changeout is indicated.

F. IRRIGATION AND FROST CONTROL PUMPS OR FANS

1. New Transformer Installations

The load factors for these types of installations are low. In addition, the ambient temperature at the time the frost control equipment is used is low. This would indicate that a considerable overload may be allowed without damaging the transformer. Balanced against this is the fact that these services are essential to the grower when needed. If a transformer fuse blows when the frost control equipment is needed, the crop may be lost before the fuse can be replaced. It is advisable to follow the same rules for this type of service as for the new industrial and commercial loads. See D.1., this section.

2. Existing Installations - Load Evaluation

If there is a demand meter on the installation, assume a power factor of 0.85 and convert kW demand to kVA demand. If there is no demand meter, it may be necessary to make a test run so that the load current can be measured. As a last resort, consider the load to be the full nameplate kVA of the motor or motors. The transformer loading should not be allowed to exceed 170% of nameplate rating. If there has been operating trouble traceable to the bank, further investigation and load checks should be made. Be sure the trouble was due to the bank, and not feeder trouble.

G. NOTES ON TRANSFORMER LOAD MEASUREMENTS

16. Load Factor, based on transformer kVA =

$$\frac{\text{monthly kWh (Sum of all customers served)}}{\text{P.F. x Transf. kVA x hours in month}}$$

This gives you an idea of the average load on the transformer.

2.2.1 VOLTAGE REGULATION - MOTOR STARTING

The starting of large electric motors may cause a sudden change in the voltage of the distribution supply system. In order to determine the impact on customers connected to the supply distribution feeder, as well as all other customers on feeders connected to the same Power transformer at the Substation, it is necessary for the Planning Engineer to conduct a Motor Starting Study for large motors. The Planning Engineer will determine the distribution feeder service method and any required special Motor Starting equipment.

A. MOTOR STARTING CHART

The discussion which follows deals with the type of installations most frequently found. These are three-phase induction motors of 500 horse power or less with a rated nominal voltage of 480 volts or less. Full voltage starting is assumed. The effects of reduced voltage starting devices should be included in the final calculation if they are used.

The charts for 13 kV and 23 kV primary which follow were produced to give a reasonable approximation of voltage drop that can be expected during motor starting. They should be useful during negotiations with the customer for a proposed installation. Frequently during negotiations, insufficient information is known with which to make more exact calculations. The charts do not take into account the impedance of the transformer bank which will serve the motor. When the bank is included, the voltage fluctuation seen by the motor customer will be greater than shown by the charts. The fluctuation seen by other customers not served by the bank will be less than shown by the chart because the impedance of the transformer bank tends to reduce the motor starting kVA. To get a more accurate solution including the transformer impedance, calculations must be made, as shown under "Calculation Methods".

The use of charts is straightforward provided that the magnitude of the available primary fault current and the horsepower of the motor are known. The use of SynerGEE is the recommended preferred method.

1. Example Case Illustrating Use Of Chart - Figure 1:

The customer's proposed motor is a 300 horsepower induction motor. The FPL primary voltage is 7620/13200 volts, and the available primary fault current is 1951 amps. The 1951 amps could have been obtained from the SynerGEE Program Fault analysis report for the designated feeder. (For purposes of this illustration, it was derived by the expression 7620 volts/3.905 ohms, where the 3.905 ohms is the accumulated system impedance up to the transformer bank serving the motor.)

A line is drawn vertically upward on the 1951 amp line until it intersects the 300 hp motor curve. A line drawn horizontally to the right from the intercept point intersects the % voltage drop axis at about 3.75%. Thus the approximate primary voltage drop in this selected case is 3.75%. As will be shown later in this section, detailed calculations give an answer of 3.51% drop for the same case. The calculation however can only be done when dependable information becomes available which is usually later in negotiations.

B. CALCULATION METHODS

The motor starting calculations may be performed manually or by using the SynerGEE program. In either case, the data required for calculation is the same. Consult the SynerGEE training manual for details on running the program. Examples of the input and output screens from SynerGEE are found on Figures 2 through 4. Following is the methodology for performing the calculations manually. The accuracy of motor start voltage drop calculations depends mainly upon the accuracy of the furnished data and the attention to detail in its application.

For exacting work, the following must be known:

1. The Motor

a) Type, i.e., induction, synchronous or wound rotor.

b) Horsepower, design class and code letter OR locked rotor power factor and kVA.

c) Rated voltage.

d) The type of starter used and the frequency of starting.

2. The Supply Circuit

e) The resistance and reactance of the primary circuit and of the system. The information is available from Distribution Reliability Planning.

f) The resistance and reactance of the transformer bank serving the motor and of any appreciable secondary conductors between the transformer bank and the motor.

g) The actual - not nominal - secondary voltage at the transformer bank prior to the time the motor starts.

Since some of the above required data may not be available, or may not be constant, such as the primary voltage - assumptions have to be made in order to proceed with the calculations. The following assumptions have been made:

1. The equivalent impedance of the motor at standstill is constant over the range of voltages encountered at starting. This is not entirely correct. The magnetization curve of the motor's iron is not linear. Applying a correction factor proportional to ^{E}actual/^{E}rated gives a starting current somewhat low for actual voltages above motor rating, and somewhat high for voltages below motor rating.
2. The voltage at the motor prior to starting is equal to the normal voltage of the FPL transformer bank which serves the motor. For example, at a 480 volt installation, the transformer secondary voltage and the rated motor voltage is 480 volts. This will not necessarily be true because the transformer voltage can vary between 456 volts and 504 volts and remain within the 7-1/2% statutory limits. Also, the rated motor voltage could be 440 volts, 450 volts, 460 volts and perhaps others. If a great disparity between delivered and rated voltage exists, and its value is known, the effect can be accounted for. Adjust the inrush current proportional to the voltage, i.e., the ratio of delivered voltage to motor rated voltage. As noted above, this is not precisely true, but is accurate enough.
3. The driving voltage at the source remains constant.
4. For induction motors, the starting kVA and locked motor power factors are:

HORSEPOWER	STARTING kVA	STARTING P.F.
50	289	0.37
100	578	0.32
200	1155	0.25
300	1753	0.22
400	2311	0.20
500	2888	0.18

Motor start line disturbance solutions can be made either by the per unit system or by using ohmic values. Some approximation methods tend to disregard resistance values. This does not materially affect the answer when the X/R ratio is high, but the error increases in magnitude as the ratio decreases. This usually happens when conductor sizes decrease as the feeder lengthens. Those personnel skilled in voltage flicker approximation methods are aware of the foregoing and thus require no further comments. Therefore, only the ohmic method of solution will be illustrated.

3. Example

A proposed motor is a 300 horsepower, NEMA design (NEC Code Letter G) induction motor with a locked motor kVA of 1753 at 22% power factor. The primary voltage is 7620/13200 and the accumulated impedance up to the transformer bank is 1.25 + j 3.7 ohms. The transformer bank is 500 kVA (3 @ 167 kVA) with an impedance of 3.23 + j 6.75 ohms. All impedances are line to neutral values, primary side.

Equivalent line to neutral motor starting impedance, Zm

1753 kVA/3 = 584.33 kVA per phase

$Zm = (KV)^2/MVA = (7.62)^2/0.58433 = 99.37/\cos^{-1}(0.22)$ ohms