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Title Planning and Executing a Power Distribution System Voltage Changeover

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The power distribution system voltage changeover described in the thesis is that of changing a three-phase delta system to three-phase four-wire wye. The changeover is accomplished by installing a fourth conductor, which becomes the system neutral conductor, and then reconnecting to wye all transformers in the system including the substation transformer. A voltage changeover of this nature increases the system capacity threefold in terms of both per cent voltage drop and power loss.

The voltage changeover described is predicated on the ability to reconnect delta connected transformers to wye. There are some transformers, both substation power transformers and distribution transformers, that cannot be reconnected to wye for satisfactory and proper utilization on the wye system. All transformers associated with the system must be separately reviewed with respect to voltage classification, connection of coils and type of core to assure that all unadaptable transformers can be replaced. All other components not adaptable to the wye system must also be replaced.

In order to successfully complete a voltage changeover the planning engineer must thoroughly acquaint himself with all the characteristics of the system in order that he can 1. determine the appropriate time for making the changeover, 2. prepare detailed plans for the changeover covering not only the physical changes required to meet code requirements, but also the plans for executing all phases of the changeover with a minimum of expense and a maximum of crew efficiency.

The final execution of the changeover is accomplished by first grounding one phase conductor of the ungrounded delta system to the newly installed neutral conductor at a point near the substation. All single-phase transformers are then connected between the two ungrounded phase conductors and the neutral. The circuit is then opened at the substation, the grounding jumper removed and all three-phase equipment disconnected. As soon as the substation is reconnected to wye the feeder is energized to restore all single-phase service. The three-phase transformer banks and other equipment are then reconnected and restored to service. Load balance is accomplished by reconnecting as many single-phase laterals as are necessary.

PLANNING AND EXECUTING A POWER DISTRIBUTION SYSTEM VOLTAGE CHANGEOVER

by

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PREFACE

To meet the service requirements of a steadily growing load on its system, an electric utility is confronted with the problem of not only determining the most economical voltage level for its service area, but also with the problem of accomplishing at a minimum of expense any indicated changes to its existing system. Frequently a change in voltage level is indicated. Sometimes additional substations with no change in voltage level are found to be the most economical solution. The economies of distribution systems involve so many variables and objectives that no fixed rules can be set up and applied to all cases. The final answer to the problem is not always governed by economic considerations. Frequently practical considerations such as code clearance requirements, safety, operation, maintenance, trees and maximum number of customers desired on a feeder, dictate the final choice of voltage level that should be used.

As the title on this thesis indicates, its scope is to point out some of the engineering problems involved in the planning and execution of a voltage changeover. The problem dealt with is that of converting a three wire delta connected system to four wire wye. The intent of this thesis is not to point out all of the problems that can arise in any voltage changeover of this nature. Rather, it is hoped that the general considerations discussed will serve to point out the need for carefully considering any system in terms of its own characteristics before a voltage changeover is executed. The treatment of the problem herein is therefore general in nature.

The method of executing the final reconnection as outlined in the section "Executing the Changeover" can cause interference to communication circuits due to the effect of grounding one of the phase conductors. This method of executing a changeover must be applied only when preliminary testing or past experience indicate that harmful voltage levels will not be impressed on adjacent communication systems.

In presenting this thesis the author wishes to acknowledge the help and guidance in planning voltage changeovers that he has received from Messrs. Corbett McLean, C. L. Brown, P. R. Oldenburg, A. E. Bond and R. J. Davidson, all of the Engineering Division of Pacific Power and Light Company.

PLANNING AND EXECUTING A POWER DISTRIBUTION SYSTEM VOLTAGE CHANGEOVER

Chapter I

PRELIMINARY ENGINEERING CONSIDERATIONS

1. Introduction. The power distribution system voltage changeover described in this thesis is that of changing a three-phase delta system to three-phase four-wire wye. By adding one conductor and reconnecting the transformers on the new system from phase to neutral, all existing transformers can be used. This is possible because the phase to neutral voltage on the wye system is equal to the nominal voltage that existed between phases on the delta system. A conversion of this nature increases the system capacity three-fold in terms of per cent voltage drop over the three-phase portion of the feeder. The ability to economically increase the voltage on a delta distribution system in this manner permits existing systems to keep abreast of the constantly growing loads being experienced by all utilities. The purpose of this thesis is to describe in detail the preliminary engineering considerations, planning and final execution of such a conversion.

A conversion from delta to wye is normally dictated by economic studies which show that the cost of such a conversion will result in power savings and increased system capacity that cannot be economically duplicated by any other means. In addition, practical considerations of clearances, safety, operation, maintenance, trees and number of customers that would be involved in an outage must meet good operating standards.

2. Description of the Voltage Changeover. The voltage changeover from delta to wye is predicated on the ability to reconnect delta connected transformers to wye. This includes not only the substation transformer, but also the distribution transformers connected to the feeder. There are certain exceptions to the ability to reconnect three-phase transformer installations at the substation and on the feeder for proper and satisfactory utilization on the wye system. These exceptions will be covered separately in the sections which deal with the considerations that must be given at the substation and on the feeder. A simple sketch showing a delta power distribution system and the same system reconnected to wye by the addition of a neutral conductor is illustrated by Figures 1 and 2 respectively. These two figures in addition to showing the transformer reconnections at the substation and on the line graphically indicate how the system voltage level has

been increased by this reconnection.

3. Objectives of a Changeover. The need for making a delta to wye changeover may be predicated on one or more of the following: (1) to provide thermal relief to overloaded line conductors; (2) to correct a condition of excessive voltage drop or regulation; (3) to provide feeder capacity to meet the requirements of growing load.

The manner in which a changeover accomplishes the above objectives is explained in part by the voltage square rule which states that doubling the voltage on a system reduces the per cent power and voltage losses to one quarter of the original losses. In changing from delta to wye, the phase to phase or line voltage is increased by the square root of 3. For such a change, the voltage square rule indicates that the per cent power and voltage losses are reduced to one-third of the original values. For example, reconnecting the delta system to wye increases the line voltage from E to the square root of 3 E volts. For the same load conditions the line current is reduced from I to $I \div \sqrt{3}$ amperes. Since the ratio of the two currents varies inversely by the square root of 3, and power losses are equal to, $P = I^2R$ watts, where R is equal to the total line resistance of all three phase conductors, it can readily be seen that squaring of the current, results in a power loss in the wye system of one-third that of the losses in the delta system. Similarly the voltage drop in the wye system is reduced from IZ volts in the delta system to $(I \div \sqrt{3})Z$ volts in the wye system, where Z is the effective line impedance. However, since in the wye system the voltage has increased by the square root of three and the voltage drop has decreased by the square root of three, the per cent voltage drop has been reduced one-third. This means that for a given allowable maximum voltage drop the conversion from delta to wye will permit three times the load to be carried over the existing line conductors. This statement holds true only if the load increase is uniform over the entire feeder area. Load increases on a feeder must always be considered in terms of distance coverage and area coverage. This is true not only because load growth is not uniform, but also because feeder load areas are frequently increasing. For a feeder which is experiencing a load increase due entirely to a uniformly increased area coverage with a load density equal to that of the original feeder, the load that can be covered within the per cent voltage limitations desired is approximately doubled rather than tripled as indicated above. (2 - pp 586-587) However, if the conversion has been predicated on thermal capacity of the line conductors the permissible load increase is 1.73 times. Analysis of the basic formula $KVA = \frac{\sqrt{3}EI}{1000}$ which expresses the apparent power in a three-phase circuit will readily indicate the reason for this.

4. <u>Substation Considerations</u>. In the preliminary engineering considerations that must preceed the planning and execution of a voltage changeover consideration must first be given to the substation with respect to adaptability to a voltage changeover. The first step in this phase is to review a one line wiring diagram of the substation which indicates the type and kind of all electrical equipment connected in the circuit. The following points must be analyzed:

A. Power Transformer. What are the voltage ratings of the coils in the transformers? How are the coils to be connected to provide the voltages indicated? The answers to these questions are important. If the primary side of the transformer is wye connected and the secondary side is connected delta, reconnecting the secondary side to wye as required will result in a wye-wye connection that is undesirable because of the inherent neutral instability of such a connection. (5 - pp 36-38) Core type three-phase transformers provide a means for magnetic coupling between phases which result in reduction of the residual third harmonic in wye-wye connections as well as appreciably stabilizing the neutral. In shell type three-phase transformers and single-phase transformers, magnetic coupling is not present between phases and these transformers must be replaced to avoid a wye-wye connection. If replacement is to be made with a core type three-phase transformer, the connection of which will result in a wye-wye connection, a delta connected tertiary winding should be considered to reduce third harmonics and to further stabilize the neutral.

For feeders served directly off the bus of a generating station the generator connection must be determined. Many generators are wye connected. In such an event, reconnection to the higher voltage level is impossible and a delta-wye interconnecting transformer bank must be installed.

Auto transformers that form the power supply, present a problem especially if connected wye-wye. Such a connection is undesirable because of the neutral instability and excessive regulation from unbalanced single-phase loads (5 - pp 91-94).

A practical consideration at this time is the capacity of the transformer itself. Does it have the capacity to carry the load anticipated in the next few years? If it does not, replacement at this time will eliminate the possibility of a future outage at the time it is finally replaced.

B. Circuit Breaker. The substation breaker controlling the feeder must be analyzed for adequacy of insulation and interrupting capacity for the new voltage level. Should the breaker meet present requirements, consideration should be given future increases in substation fault duty that may result from reinforcement of the transmission system. Obsolete breakers should be evaluated in terms of service reliability and replacement with modern reclosing circuit breakers considered. The newer type of circuit breaker utilizing bushing type current transformers could materially reduce the substation investment as well as resulting in design simplification by the elimination of separate current transformers.

C. Metering. The metering on the normal three-phase delta connected system consists of two element polyphase metering. Such metering is accurate under all conditions and requires but two current and two potential transformers used in conjunction with a two-element polyphase meter. Connecting the system to wye will require that the metering installation be altered. To secure accurate meter registration under all conditions a three element polyphase meter used in conjunction with three current and three potential transformers is required. Reasonable metering accuracy on the wye system can be secured by the use of the conventional two element polyphase meter together with three current and two potential transformers. This method, however, gives accurate meter registration only when the phase voltages are balanced. The type of metering decided upon must be evaluated in terms of how much capital expenditure is justified to produce a metering installation consistent with the degree of meter accuracy required.

Metering installations can be made very elaborate and designed to record all types of load data and conditions. They can also be made quite simple consisting of a kilowatt hour meter with a demand register, an ammeter, a voltmeter and a wattmeter. Added refinements are a matter of both necessity and preference by the utility.

D. Insulation. The average one line wiring diagram will not indicate the type of insulation used to support the bus conductors. A field check will normally be required to verify the adequacy of the present insulation. Insulation requirements are increased by the square root of 3 and this increased voltage stress must be adequately provided for.

E. Regulation. The delta system requires but two single-phase regulators to provide balanced phase voltages. Occasionally three single-phase regulators are used to secure a 50 per cent boost in regulation over that provided by two similar regulators. For the first condition, one regulator must be added for use on the wye system. For the second condition, the three regulators need only be reconnected to wye if the range of the reconnected bank meets the regulation requirements.

In the event regulation is provided by a three-phase regulator, it can be used only if it has been designed for use at the higher voltage. If not, it must be replaced. In a well-planned system, the possibility of a changeover will have been considered and suitable regulators will have been provided. In the event the regulator has been designed for the new voltage level, it must be inspected to determine if it has a suitably tapped transformer in the voltage control circuit. The regulator will now be used at its full capacity whereas it had been used at reduced kva rating on the delta system.

F. Relays. The relaying on a delta system does not provide for ground fault relaying. One conductor on such a system can be grounded with no effect other than to collapse the electrostatic field of the conductor with respect to ground. Grounding of a second phase conductor will produce a phase to phase fault, the fault current of which will actuate the phase relays. On wye systems, grounding of any one phase conductor will produce a phase to ground fault. To protect the wye system from such fault currents the installation of a ground relay is desirable.

The current setting of the ground relay can be set for a very low current value limited only by the degree of unbalanced load current that normally will be present. A low setting on this relay is desirable, especially on long feeders of small conductor size when phase to ground fault currents at the feeder extremities are of such small values as to be either below the settings of the phase relays, thus failing to actuate them, or approximately equal to the setting of the phase relays, thus permitting the fault current to persist for some time before trip out.

The introduction of the ground relay, in addition to providing further protection to the system from fault currents, provides a basis for coordinated fusing on the feeder itself. Such a fusing program is almost mandatory in that faulted line sections can be effectively isolated from the remainder of the feeder without causing the substation breaker to trip to lockout. A successful coordination scheme requires a modern type substation breaker, the first trip setting for which is instantaneous. Transient faults are thus cleared by the station breaker and persistent faults are then isolated by the related line coordinated fuse.

The changeover provides an excellent time for the evaluation of present relaying. All old style relaying, which will not fit into future planning, should be replaced at this time.

G. Bus Conductors. The bus conductors need to be evaluated in terms of present and future fault duty as well as peak load currents, to eliminate future annealing or fusing. The standards used to determine the conditions under which conductor replacements are to be made are not uniform and are subject to individual interpretation.

5. Line Considerations. The distribution feeder itself presents some interesting problems with respect to a changeover. These problems are for the most part practical in nature and may require the

expenditure of considerable funds for adapting the feeder for the higher voltage level. The general problems involved are as follows:

A. Change in Code Classification. Converting a system from delta to wye increases the system voltage by the square root of three. This increase in voltage may bring the system voltage into a higher voltage classification in the governing construction codes, thus necessitating respacing of circuits and increasing the separation of the phase conductors. A typical example is afforded in a changeover from 7200 volts delta to 12,470 volts wye in the State of Washington. The Washington Rules for Electrical Construction provide for a change in code classification at 7500 volts. For circuits exceeding 750 volts but less than 7500 volts, the separation of conductors supported by pin insulators shall be not less than 12 inches. For circuits in the 7500 to 15,000 volt bracket, the conductor separation shall be not less than 22 inches. These same rules for the above two voltage classifications indicate that for cross-arm separation of primary and secondary circuits, three feet separation is required in the lower bracket while seven feet separation is required for the upper bracket. The National

Electrical Safety Code indicates a change in voltage classification at 8700 volts. The required cross-arm separation for primary and secondary circuits is, however, four feet for both 750 to 8700 volts, and 8700 to 15,000 volts. From the above, it can be seen that the delta system would have a cross-arm separation of four feet based on the National Electrical Safety Code. The conversion to 12,470 volts will result in the need to lower all secondary cross-arms to 7 feet to conform to the Washington Rules for Electrical Construction. Also, in areas inside of incorporated city limits in Washington, the system neutral conductor must be installed on the pole in such a manner that it is not less than thirteen inches to the center of the pole. Since no such provision is made for areas outside incorporated cities, the National Electrical Safety Code takes over and the neutral can be fastened directly to the face of the pole, irrespective of pole diameter.

The above three considerations represent the major code problems involved in a changeover from 7200 volts delta to 12,470 volts wye. They are not all of the problems involved, but serve to illustrate that for any voltage changeover, the existing circuit must be analyzed in terms of the governing code for the voltage classification resulting from the changeover.

B. Insulation. The voltage stress on the insulation on a system is increased by 73 per cent in terms of line to line voltage, because of a delta to wye changeover. Due to the presence of the grounded neutral, the voltage stress to ground is no greater at all times than the maximum voltage stress to ground on the delta system with one conductor grounded. Generally, the insulation on the delta system will be adequate for the wye system. For the reason that the insulation level, especially on older lines, may result in borderline levels on the wye system, consideration for replacement should be given such insulators. Replacement may not be necessary from a theoretical point of view, but the practical consideration of insulator contamination and the possibility of pole fires resulting from voltage stresses, must be considered. Economic conditions may dictate that borderline insulation levels provided by existing insulators be accepted on a calculated risk basis.

Another factor to consider is the insulation rating of all cables connected to the system. All belted cables having a voltage rating equal to that of the delta system, must be replaced. Single conductor cables or multiple conductor cables, each conductor of which has insulation sufficient to provide for maximum phase to ground voltage on the delta system with one phase grounded, may be used on the new system. The reason for this is obvious when the construction of a belted cable is considered. By providing just enough insulation on each cable so that the combined insulation thickness of each pair of phases provides the necessary phase insulation, it can be seen that the insulation to ground is one half that of the phase-to-phase insulation. To protect the cable for full voltage stress to ground, such as can occur on a delta system with one phase grounded, a belt of insulation is placed over the three-phases to make up the difference.

C. Neutral Conductor. The National Electrical Safety Code specifies that primary and secondary circuits may utilize a single conductor as a common neutral, if such conductor has at least four ground connections in each mile of line, the ground resistance of each not exceeding three ohms for water pipe connections nor 25 ohms for artificial grounds. Practice in this region generally indicates a total of eight grounds per mile to compensate for the wide range of ground resistances that are common. Connections to city water mains are not generally acceptable to the various cities and thus cannot always be counted upon.

Common practice indicates that the neutral conductor shall be the same size and kind as the primary phase conductors for phase conductors having conductivity equal to or less than No. 6 copper. For primary conductors, the size of which exceeds No. 6 copper, the neutral is generally one standard size smaller. For secondary circuits having greater conductor capacity than the primary, the related neutral in this portion is based on one standard size smaller than the secondary phase conductors. Another exception must be made adjacent to the substation where fault currents may be of such magnitude that the neutral conductor could be fused. All conductors radiating from the substation should be of sufficient capacity to withstand fault duty. Configuration of the neutral grid is also a factor in selecting neutral conductor sizes.

In case of conductor fusing due to faults, it is desirable that the phase conductors fail and leave the neutral intact. This condition is approached adjacent to the substation by matching the neutral to the primary conductor. The grounds on the neutral then give it greater capacity than the primary phase wire. If high ground resistances are present, the neutral size must be carefully considered. For example, should the neutral open for any reason at a time when, say, 25 amperes are flowing in it, and a path through ground around the break is 50 ohms, the voltage that would exist across the break is then 1250 volts.

The above illustration is sufficient to make any lineman realize that if for any reason it is necessary to cut a common neutral conductor, a jumper must be installed around the cut before it is made.

The National Electrical Safety Code specifies that grounding conductors shall have a current carrying capacity of not less than one-fifth of the conductor to which it is attached, and in no case less than No. 8 copper. Standardization on No. 6 copper as the size of grounding conductor, thus permits its use over a large range of conductor sizes.

Grounds on lightning arresters are treated separately and by code must not be less than No. 6 copper. Also, in order to adequately protect the equipment the arrester is associated with the size of ground conductor which shall be equal in size to the primary drops to the equipment being protected. If the arrester leads are smaller than the drop wires, they may not be able to carry the surge current that always follows high voltage surges.

D. Three-Phase Transformer Banks. All three-phase transformer banks existing on the delta system must be analyzed for adequacy on the wye system. The more important considerations are as follows:

1. Grounding of the wye of wye-delta banks. The neutral point shall be left ungrounded to avoid transformer burnouts due to overload. The grounding of the wye permits the bank to circulate enough current to balance any primary voltage unbalance that may exist. The bank may also under fault conditions, supply damaging ground fault currents to the primary fault. (8 - pp 3-4) Also, should one primary fuse open, the grounded wye point would permit the bank to deliver normal secondary voltage thus exposing the bank to possible overload. The neutral point shall be left floating, i.e., not grounded on all closed wye-delta banks.

2. Load Division. In wye-delta transformer banks, the presence of the isolated wye permits any single-phase load that the bank may be carrying to divide 2/3 through the common transformer and 1/3 through each of the two other transformers. (5 - pp 48-56) For this reason, the common transformer shall have a capacity equal to 1/3 that of the three-phase load plus

2/3 that of the single-phase load. The two power transformers shall each have a capacity equal to 1/3 of the three-phase load and 1/3 of the single-phase load. This factor must be carefully considered because in a delta-delta connected bank the load division is based on the relative impedance of each transformer. In a delta-delta connection a very large common transformer can be banked with two small transformers if the per cent impedances of all three transformers are equal or nearly so. The reason for this is apparent when the bank is considered as two impedances in series and paralleled with the impedance of the common transformer.

3. Type CSP Transformers. These transformers should not be used in wye-delta connections with the primary neutral point ungrounded. The floating neutral will, with one secondary breaker open, give rise to unbalanced voltages, because opening of the delta permits shifting of the neutral (9 - p 6). This problem is generally not encountered because the use of such transformers is also avoided on delta-delta connections where such banks serve combined 3-wire single-phase and three-phase loads. (9 - p3)

4. Closing of Open Wye-Open Delta Banks. Closing of such banks should be considered in those

cases where neutral current unbalance cannot be balanced out by other similar banks rotated on the three phases. The unbalance produced by such a bank is the same as though the entire load were served single phase. The limitations of such banks must also be considered from the standpoint of economics and resultant voltage unbalance, especially on four-wire delta connected secondary systems. (3 - pp 2-8)

5. Open wye-open delta three-phase banks are treated similarly to open-delta banks with respect to required transformer capacity to serve a load. The power transformer must have a capacity equal to 58% of the three-phase load. The common transformer must have the same capacity plus additional capacity equal to any single-phase load it may be carrying.

F. Capacitor Banks. The delta-connected capacitor bank must be reconnected to wye. In making such a reconnection, the problem of whether or not to ground the neutral point must be considered. Good engineering practice dictates that the neutral point be grounded contrary to the common practice of many utilities not to ground the neutral point. Experience has shown that delta-connected or floating-wye-connected capacitor banks served from grounded-wye or four-wire distribution systems, can result in abnormal voltage conditions incident to single-phase switching or broken conductors. The abnormal voltage conditions may occur as either low or high voltages, the former often accompanied by reversed phase rotation. Solid grounding of the neutral will eliminate abnormal voltages and reversal of phase rotation (4 - pp 84-87). The effect of capacitor banks can be disregarded with respect to voltage over-correction if the original bank was adequately designed for the delta system. It has been previously pointed out that for a given load, the per cent voltage drop is reduced to one-third by the changeover to wye. For exactly the same reasons, the effect of a capacitor bank is reduced to one-third of its per cent voltage correction capabilities on the delta system.

F. Three-Phase Motor Protection. Three-phase motors served from wye-delta transformer banks should be protected by three overload relays, one in each phase (6 - pp 10-11). The reason, briefly, is due to the fact that single-phasing of the primary supply can result in double normal current in one phase of the motor circuit. If in the case of two element protection, should the double current value occur in the unprotected phase, motor burn-out can occur. This problem is recognized in the National Electrical Code which specifies that three-element protection is desirable but optional. The action to be taken by the utility with respect to existing motors served by the system is a matter of company policy.

G. Customer Owned Primary. In a voltage changeover any customer owned primary must be treated in the same manner as the utility owned facilities. The customer should be fully appraised of the problem for the reason that the benefits of such a changeover may result in sufficient benefits to him to share a portion of the expense. Any extensive privately owned system, the conversion cost of which is great, may justify the installation of a 1/1 interconnecting transformer bank.

Chapter II

PLANNING THE CHANGEOVER

1. Introduction. In order to assure success in the voltage changeover of a system the planning engineer must : (1) acquaint himself thoroughly with the characteristics of the system; (2) prepare thorough and detailed plans for all phases of the changeover; (3) make sure that all personnel engaged in the preliminary line construction and final changeover understand the plans, the objectives, and the method by which these objectives are to be reached. There is no substitute for good and adequate planning by the engineer. Neither is there any substitute for preparing the construction crews for their participation in the program. The human element is actually one of the most important phases and requires that the engineer's knowledge be passed on to the crew foremen firmly but in an unobtrusive manner.

2. System Load Characteristics. The system load characteristics dictate the need for a voltage changeover. The need may result from the presence of excessive voltage regulation or line conductors loaded to and or in excess of their thermal capacities. In

either of these two cases the need is urgent and quick action is required. For systems following a well planned program such cases seldom arise. Irrespective of which condition exists the time of the changeover must be so scheduled as to effect the least possible number of customers. This factor generally indicates that the changeover be made at a light load period. If the feeder is small few distribution transformers are involved and if sufficient manpower is available the actual reconnection may take place at a daily light load period. For large and extensive feeders requiring not only a great deal of preliminary line construction, but also the reconnection of a large number of transformers the changeover must be made during the seasonal light load period. The time of the changeover cannot be determined until the system load curve data has been analysed to determine the system load pattern from both a seasonal and a daily basis.

3. Manpower Requirements. Once the need for a conversion has been determined and the time is selected for the actual changeover the manpower requirements must be determined. The amount of work involved in preparing a system for a voltage changeover and that involved in the reconnection period can generally be

closely estimated in advance by engineering personnel acquainted with the system. The manpower requirements fall into three groups: 1. The man hours required to prepare the necessary engineering plans, 2. The man hours of preliminary construction, 3. The man hours involved in the reconnection period. These preliminary estimates are then used as a basis for setting up a job schedule for the completion of each of the above steps in order that each step can be accomplished as planned. If the man hours involved are great and available manpower to complete each step as planned is not available the manpower will have to be increased or obviously the whole program will be delayed.

4. Preliminary Estimate of Material Requirements. The availability of material to accomplish the changeover as scheduled must be determined in advance to assure that the estimated items required can be purchased and be on hand as required. Substation transformers are made to order and for this reason such equipment must be placed on order well within the manufacturers' ability to deliver. All special items of equipment or material, large stocks of which are carried neither by the utility nor by the distributor, must be ordered well in advance. A preliminary estimate of the

material and equipment required can be readily made from office records and the purchasing department can thus be advised well in advance in order that the necessary orders can be placed as required.

5. Engineering and Cost Estimating. This phase of the changeover is divided into two categories: 1. preparing the substation plans and cost estimate and, 2. preparing the detailed plans and cost estimate of the conversion of the distribution circuit. The work involved in these two steps is briefly outlined as follows:

A. Substation. The necessary substation revisions must be designed and appropriate drawings made. Once all the plans are completed the cost estimate should be prepared. At this time the preliminary material list supplied the Purchasing Department should be checked and corrections made as required.

As soon as drawings for the substation changes are printed copies should be issued to the field for job planning. A preliminary field check is necessary to determine how best to effect the substation additions. The work involved in making these changes requires careful planning to: 1. reduce outage time to a minimum, 2. to plan adequate safety precautions,

3. to coordinate this work with the changeover of the distribution circuit.

B. Distribution Circuit. Generally the work involved in this phase is of a more detailed nature. Each pole and each span of conductor requires individual attention. The fielding is done on this basis. Usually it is desirable to number each pole and to number the field notes accordingly. All the work necessary on each pole to accomodate the neutral conductor, to meet code or insulation requirements because of the change in voltage level, and to provide adequate clearances to foreign circuits, railroads, highways, etc., must be determined on location. Crossing conflicts of a particularly involved nature may require the preparation of a crossing profile to determine if pole changeouts are necessary to meet code requirements. In urban and suburban areas the neutral conductor shall be installed in the secondary position. To accomplish this pole changeouts are common. In rural areas the neutral may or may not be run in the secondary position. If it is run in the secondary position it may on occasion be placed on the primary crossarm to get over an obstruction.

In conjunction with the above work the phasing of all corners and transpositions shall be noted. All transformer locations, sizes, type of connection and phases to which each transformer is connected shall be recorded.

The locations of all other equipment such as regulators, capacitors, underground cables, primary metering, etc. shall be noted and identified as to size, capacity and phase connections. Full identification of the primary metering equipment will have to be made from office records.

Upon completion of the fielding of the circuit data a complete set of drawings showing all work required must be drawn up. When this is done the final cost estimate shall be prepared and the preliminary material list supplied the Purchasing Department checked for possible revisions.

Upon completion of the cost estimates for the work involved at the substation and on the distribution circuit they should be analysed to determine if the preliminary estimate of the time required to ready the substation and the feeder for the conversion was reasonably accurate. Some revision in job planning will undoubtedly be required.

The detailed maps prepared for the voltage changeover shall include a phasing map which shows the final transformer phase connections. This is essential in order that good load balance be maintained throughout the length of the feeder. Any unbalanced currents will return via the neutral conductor. Since this neutral conductor is in parallel with the ground residual currents will, if of sufficient magnitude, cause interference to adjacent communication circuits. The phasing map may in addition show the desired phase connections to secure proper phase sequence on all three-phase transformer banks. This latter step is not too essential in most cases. On any transformer banks the phase sequence of which is incorrect require the reversal of two leads to accomplish the proper rotation. For simultaneous single-phase and three-phase loads served from the same bank care must be taken when reversal is done on the secondary side not to interchange the third phase conductor with either of the two single-phase legs.

6. Final Arrangements. Now that the preliminary planning and all estimates for the cost of making the voltage changeover have been completed construction on the preliminary work shall start as scheduled. Timing of this phase of the work is most important if

but small latitude is permissible in the period during which the final reconnections should be made. This period depends on the characteristics of each circuit and can vary from a month or more to a week-end or a daily off-peak period. Should the planning indicate a long outage time on the circuit during the reconnection period consideration should be given to load transfer to adjacent circuits. The ability to transfer load depends on: (1) the ability to carry the load satisfactorily on the adjacent circuit and; (2) that the circuit arrangement be such that it lends itself to reducing the amount of the circuit to be reconnected in the first cut. It is preferable that the final changeover be so planned that it be done a section at a time to reduce the details that must be watched. Transfer of load to other circuits will normally permit progressive and convenient cuts starting at the substation being changed over and progressing outward into the adjacent substation area.

Chapter III

EXECUTING THE CHANGEOVER

1. Introduction. The voltage changeover is divided into two basic steps: (1) preparatory work and; (2) final reconnection. Both of these steps include the substation and the power distribution line. The preparatory work on both of these units must be so planned and so coordinated that all work is brought to completion at the time selected for the voltage changeover.

2. Preparatory Work. The work involved in preparing a power distribution system for a voltage changeover does not normally follow any definite order and varies with each system. The general steps of this work are as follows:

Install the continuous multigrounded neutral and connect to the substation ground grid.

Change out necessary poles for proper ground clearance of neutral or line conductors.

Reframe all poles and replace crossarms where necessary to meet code requirements.

Change out insulators as required.

Check phase sequence on the secondary side of all three-phase transformer banks and identify each phase conductor by a tag marked in accordance with the markings of the phase sequence indicator adopted for use in the changeover.

Install temporary by-pass cables at all locations where cable changes are required and replace the existing cable.

Install sectionalizing and feeder tie switches.

Install sectionalizing fused disconnects in the feeder main stem and on all laterals where necessary to aid the changeover. Insofar as is practical these locations should be selected to fit into a coordinated fusing program if such a program is being considered.

Replace all closed delta-delta three-phase transformer banks with inadequately proportioned single-phase and three-phase capacities with transformers of proper size ratios for isolated wye-delta operation. (See Preliminary Engineering Considerations for explanation)

Replace all transformers equipped with secondary breakers in proposed isolated wye-delta three-phase banks with conventional transformers. (See Preliminary Engineering Considerations for explanation)

At existing regulator installations consisting of two single-phase regulators that are to remain for use on the wye system move the third matching regulator into position. Install all necessary risers, etc. to reduce the reconnection time in the changeover. If existing three-phase regulators involved are inadequate for the wye system, install the new regulator at an adjacent location or have it on location and ready for replacement.

Prepare the substation for the changeover. All equipment such as power transformers, breakers, regulators, potential and current transformers relays, etc. can be placed in position when possible leaving only the final reconnection for wye operation. For such cases where a new substation has been built the only problem is that of completing the new substation on schedule. If a new substation or a portable substation are involved the outage time required to reconnect the existing facilities is reduced from several hours to the length of time required to transfer the load after the feeder has been readied for the load transfer. Substations having two or more paralleled transformer banks can generally be readied one transformer at a time. This will require splitting the bus and temporarily carrying all the load on the remaining transformer or transformers and related substation equipment.

By careful planning and timing serious overloads can generally be avoided. If serious overloads cannot be avoided and the load cannot be transferred to other stations a lengthy outage must be planned for.

3. The Changeover. The final steps in the changeover follow a chronological order. To expedite this final phase of the changeover program all preliminary work that can be accomplished ahead of time shall be completed. The work itemized above under Preparatory Work is general only. Each system must be reviewed in terms of its own characteristics. Similarly the normal sequence of the steps in a voltage changeover are as indicated in Figure 3 which indicates the five basic steps. A detailed explanation of these steps as related to the changeover is as follows:

Test each line conductor of the delta system for accidental grounds. A desirable method is to utilize a potential transformer having a primary voltage rating equal to the nominal voltage of the delta system. A small single-phase distribution transformer is sufficient. Connect one primary terminal of the transformer to the common neutral at any convenient location. Connect a voltmeter across the secondary terminals. The second primary terminal should then be connected to one phase conductor of the primary and the voltage indicated on the voltmeter recorded. In a similar manner voltage readings shall be taken on each of the two remaining phase conductors. Identical voltage readings on all three phases indicate that no conductor is grounded. A small voltage unbalance will normally be noted. This unbalance of the neutral point is due to unbalanced load conditions found on all feeders serving single-phase loads. If one conductor is grounded the voltage on this phase will be zero or approximately so and the voltage noted on each of the remaining two phases will indicate full line voltage to ground.

If a ground is detected it must be located and removed before any further work is done!

As soon as it has been determined that the phase conductors are free of grounds the selected phase conductor of the feeder to be converted to wye shall be jumpered to the multigrounded neutral at a convenient point near the substation. The jumper must be located on the load side of the substation to permit normal functioning of the substation equipment. Grounding the selected phase at the transformer terminals would for example allow current to by-pass the relay in the grounded phase. It would also provide a closed circuit of low impedance having an impressed voltage equal to the per cent voltage output of the substation voltage regulator. In the case of single-phase regulators this can be avoided by grounding the common phase. Grounding the selected phase outside of the substation avoids these problems. The jumper must have sufficient current carrying capacity to carry the sum of the single-phase currents in the two ungrounded conductors when all single-phase transformer installations have been removed from the grounded phase and reconnected to the remaining two phases.

Connect all single-phase transformers to the common neutral and one of the two ungrounded phase wires. A short outage will be necessary on those transformers connected between the two ungrounded phase conductors. To facilitate this operation it is desirable to use a voltage indicating device to identify the "hot" conductors and the grounded conductor. This step provides a check on the phasing map and reduces the possibility of injury to operating personnel during this phase of the changeover. Care should be taken to balance the load between the two ungrounded phases as shown on the phasing map. At this time one cutout shall be removed, the transformer ground permanently connected to the multigrounded neutral and the grounded side of the transformer permanently connected to the neutral.

Disconnect one leg of the single-phase laterals that are connected to the ungrounded phase conductors and connect to the neutral. The grounded leg of the other single-phase laterals can be cut over to the neutral without a service interruption. No connection shall be left between the grounded phase conductor and the grounded conductor of single-phase laterals or the grounded conductor of three-phase laterals one conductor of which is to become the neutral. Connections shall be carefully made as shown on the phasing map.

Upon completion of the above two steps the grounded phase conductor will be carrying no single-phase load current. The only current remaining will be that of the three-phase transformer banks which up to now have not been touched. At this time the entire feeder should be field checked to ascertain that the grounded phase conductor is completely free of all single-phase load and that no connections to ground exist except for the jumper located near the substation. Failure to satisfactorily complete the above steps prior to energising the feeder from the wye connected substation will result in: 1. full line potential of the wye system being applied to any single-phase

transformers left across any two phase conductors,
2. cause a phase to ground fault if any grounded connections are left on the conductor which was temporarily grounded.

All three-phase transformer banks shall be checked for phase sequence and the secondary terminals marked to correspond with the phase-sequence indicators. This operation may be carried out in advance as a portion of the preliminary work or may be carried out in conjunction with the reconnections of the single-phase transformers. In either case the phase sequence must be determined ahead of the final changeover to enable proper phase sequence to be maintained after the conversion to wye is completed.

Upon completion of all the work outlined above the feeder is ready for the final voltage changeover. Select a time for the changeover when the least number of three-phase customers will be inconvenienced. Plan the steps to be taken at each location in order that service can be restored to the three-phase banks in the shortest possible time. It may be possible at locations where seasonal or intermittently used three-phase loads are concerned to open such banks ahead of time and reconnect them after the changeover to hasten restoration of service to the remainder of the system.

Immediately prior to the selected time for the changeover station one man at the substation near the grounding jumper on the grounded phase conductor and station crews at all three-phase transformer banks, regulator installations and capacitor banks. In the event these installations outnumber the manpower available distribute the crews at convenient locations to assure the quickest possible feeder coverage. Each crew in this latter case shall be carefully briefed concerning all equipment that is to be disconnected.

At the prearranged time selected for the changeover open the substation feeder breaker. When the feeder is dead, signal the man stationed at the jumper in order that the jumper can be safely removed. Cutouts to all three-phase transformer and capacitor banks shall be opened. All regulator banks shall be disconnected. All connections to underground cables shall be opened. All primary metering installations shall be disconnected as well as any other equipment that must be reconnected for wye operation.

Simultaneous to the above all necessary reconnections involved at the substation shall be completed. As much manpower as is practicable should be concentrated here to accomplish the reconnections in the shortest possible length of time. A portable substation can be used to excellent advantage in that the outage time on the feeder is then reduced to the time required to disconnect all the three-phase transformer and capacitor banks, cables and other equipment that needs to be reconnected for wye operation. The substation reconnections can then be made under normal working conditions and when ready the wye connected system being supplied by the portable substation transferred to it. This procedure may be reversed if desired by using the portable substation to carry the delta connected feeder thus allowing the substation to be reconnected in advance of the changeover. This latter condition would compare to those cases in which an entirely new substation is being provided.

As soon as the feeder has been freed of all three-phase connected equipment which needs to be reconnected for wye operation the feeder circuit breaker to the reconnected substation, portable substation or new substation shall be closed. Service to the single-phase load is thus restored in the quickest possible length of time.

Immediately upon disconnection of all three-phase equipment on the feeder reconnection of the equipment shall be started and accomplished as quickly as possible. All fuse links in the closed wye transformer banks must at this time be replaced with fuse links the size of which is based on current per individual phase because of the reduction of current through the fuses by the square root of 3. Closing of all cutouts or isolating switches must, however, be delayed until after the feeder is reenergized at wye. An exception must be made in the case of three-phase induction regulators the switching of which must be done on a deenergised circuit.

As each reconnected three-phase transformer bank is restored to service on the wye system it must be checked for proper phase voltages and phase sequence.

Primary metering installations shall be reconnected and necessary changes and additions accomplished as quickly as possible to avoid loss of meter registration when service is restored.

Upon restoration of service to all customers the feeder will be out of balance because one phase will be carrying no single-phase load. For the reason that permanent connections have been made on all of the single-phase transformer installations load balance must be accomplished by transferring single-phase laterals from the two loaded phases to the unloaded phase. This can generally be done if sufficient and adequately spaced single-phase laterals are available throughout the length of the feeder. If this condition does not exist some single-phase transformer connections will have to be changed. These steps must be considered in advance and the phasing map noted accordingly in order that proper load balance be secured. For the reason that the load balance shown on the phasing map assumes equal percentage transformer loading throughout the feeder at all times satisfactory load balance is normally arrived at. If, however, a closer balance is desired appropriate connections can be made by removing load from the phase or phases having the greater load and transferring it to the lightly loaded phase.

As soon as the feeder load has been restored to a balanced load condition all capacitor banks and regulator banks not previously reconnected shall be restored to service. Frequently reconnection of such equipment can best be delayed until this time because the time involved in such reconnections at an earlier time will either delay restoration of service to some three-phase transformer banks or prolong the period the feeder must operate in an unbalanced condition. The latter is especially important if the resulting load unbalance approaches the current settings of the line or ground relays. Temporary relay adjustments should be made as required, but not so as to expose the system to undesirable conditions.

The power distribution system voltage change-over described in this thesis is general in nature and is patterned after actual field experience experienced by the writer in voltage changeovers. No two systems or even two feeders supplied from the same substation can be treated alike. Each has its own peculiarities and must be so treated.

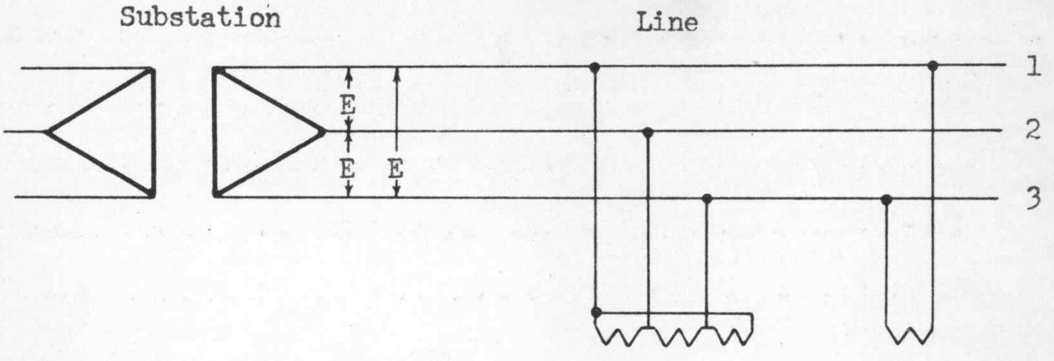


Fig. 1.- Sketch of a delta-connected distribution system showing phase voltage relationships and transformer connections.

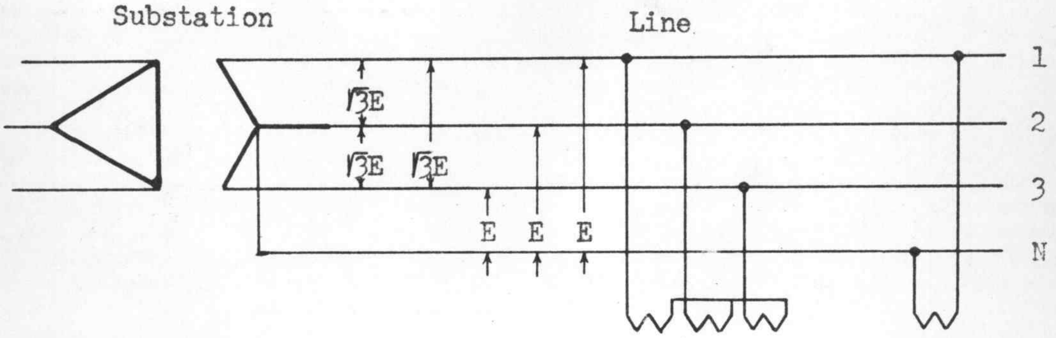
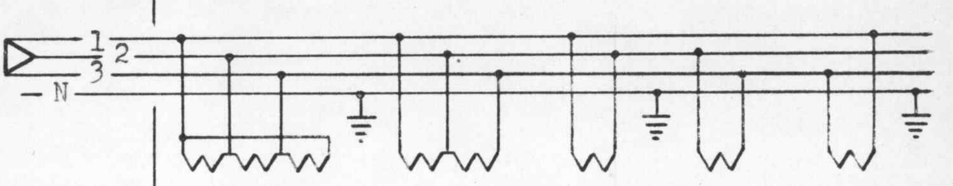
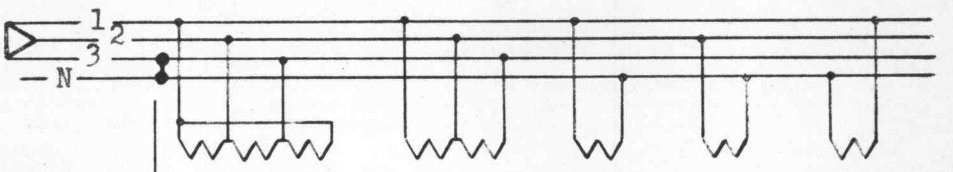


Fig.2.- Sketch showing the phase and line voltage relationship as well as the transformer connections after the delta system has been reconnected to wye.

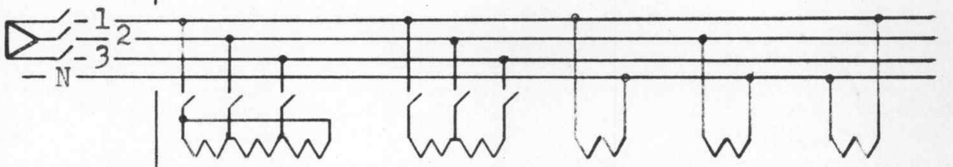
Substation | Line



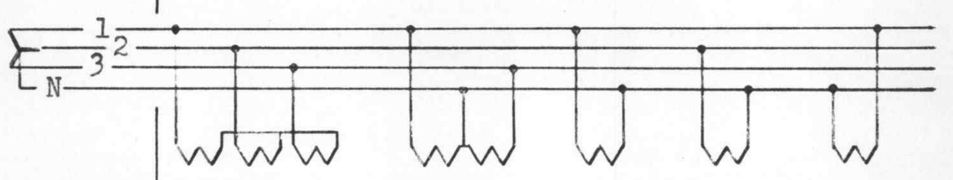
Step No. 1.- Establish the multigrounded neutral.



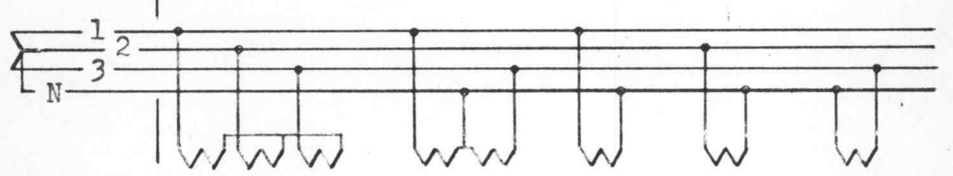
Step No. 2.- Ground phase No. 3 and connect all single-phase transformers between the neutral and phases 1 and 2.



Step No. 3.- Open all three-phase transformer banks and open the feeder circuit breaker at the substation. Remove grounding jumper.



Step No. 4.- Reconnect substation transformer to wye, close feeder circuit breaker and reconnect all three-phase transformer banks.



Step No. 5.- Balance the load between phases.

Fig. 3.- The five basic feeder voltage changeover steps.

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