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Reduction of Losses in Distribution Systems

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***Abstract*—Efficiency of power system depends on the distribution system. Distribution system provides the final link between the high voltage transmission system and the consumers. A distribution circuit normally uses primary or main feeders and lateral distributors. The main feeder originates from the substation, and passes through the major load centers. Lateral distributors connect the individual load points to the main feeder with distribution transformers at their ends. Transfer of electric energy from the source of generation to the customer via the transmission and distribution networks is accompanied by losses. The majority of these losses occur on the distribution system. In a well-run system, total transmission and distribution system losses are on the order of 9% and of this 2-3% are in the distribution system. In the developing world equivalent numbers are total losses of 15% and distribution losses in the 5-7% range. Distributed Generation (DG) plays an important role for reduction of losses in distribution systems. This paper presents a collection of discussions about basic technical segments of electric distribution technology. However, there are also significant improvements that can be accomplished through improved reliability and quality of service.**

***Index Terms*— Power loss reduction, Voltage profile, Radial distribution system, Distributed Generation.**

I. INTRODUCTION

Electrical power is transmitted by high voltage transmission lines from sending end substation to receiving end substation. At the receiving end substation the voltage is stepped down to a lower value (say 66kV or 33kV or 11kV). The secondary transmission system transfer power from this receiving end substation to secondary substation. A secondary substation consists of two or more step down power transformers together with voltage regulating equipments, buses and switchgear. At the secondary substation voltage is stepped down to 11kV. The portion of the power network between a secondary substation and consumers is known as distribution system. The distribution system can be classified into primary and secondary system. Some large consumers are given high voltage supply from the receiving end substation or secondary substation.
The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals. The main feeder runs from the low voltage bus of the secondary substation and acts as the main

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source of supply to sub feeders, laterals or direct connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted. The distribution transformers for a large multi storied building may be located within the building itself. At the distribution transformer the voltage is stepped down to 400V and power is fed into the secondary distribution systems.

The secondary distribution system consists of distributors which are laid along the road sides. The service connections to consumers are tapped off from the distributors. The main feeders, laterals and distributors may consist of overhead lines or cables or both. The distributors are 3 phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. Most of the residential and commercial consumers are given single phase supply. Some large residential and commercial consumers get 3 phase supply. The service connections of consumers are known as service mains. The consumer receives power from the distribution system.

The main part of distribution system includes [1]:

(i) Receiving substation

(ii) Sub- transmission lines

(iii) Distribution substation located nearer to the load centre

(iv) Secondary circuits on the LV side of the distribution transformer

(v) Service mains

Unlike main EHV-AC transmission systems the distribution systems have several service lines, several distribution transformers and associated primary and secondary circuitry and one or two receiving substations. Unlike transmission systems, distribution systems are more complicated and have to face more problems like voltage drop during peak load time and voltage rise during off peak load. In addition to above problems, distribution transformer is overloaded during most of the period.

Distributed Generation (DG), a term generally used for small-scale generations, provides solution to most of these new challenges. Recent developments in small renewable/clean generation technologies such as wind turbines, photovoltaic, fuel cells, micro turbines and so on has given distribution utilities' attention to possible changes in distribution system infrastructure and policy by deploying DG in distribution systems. S. Kansal et al. [7, 8] presented an analytical, particle swarm optimization (PSO) and hybrid approach for finding the optimal size of DGs at many buses of primary distribution system and optimal locations related to optimal sizes of DGs for reduction of losses in distribution systems.

II. DISTRIBUTION SYSTEMS CLASSIFICATION AND SCHEMES

The part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the substation fed by the transmission system and the consumer's meters. It generally consists of feeders, distributors and the service mains as follows;

(i) Feeders: A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tapings are taken from the feeder so that the current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.

(ii) Distributor: A distributor is a conductor from which tapings are taken for supply to the consumers. The current through a distributor is not constant because tapping are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 10% of rated value at the consumer's terminals.

(iii) Service mains: A service mains is generally a small cable which connects the distributor to the consumer terminals.

A distribution system may be classified according to:

(i) Nature of current: According to nature of current, distribution system may be classified as:

(a) DC distribution system

(b) AC distribution system

Now-a-days AC system is universally adopted for the distribution of electric power as it is simpler and more economical than direct current method.

(ii) Type of construction: According to type of construction, distribution system may be classified as:

(a) Overhead system

(b) Underground system

The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

(iii) Scheme of connection: According to scheme of connection, distribution system may be classified as:

(a) Radial system

(b) Ring main system

(c) Inter-connected system

Each scheme has its own advantages and disadvantages.

A. Connection Schemes of Distribution Systems

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used [2]:

(i) Radial System: In this system, separate feeders radiate from a single sub-station and feed the distributors at one end only. Figure 1 (a) shows a single line diagram of a radial system for DC distribution system in which a feeder OC supplies a distributor AB at point A. Obviously, the distributors are fed at one point only i.e. point A in this case. Figure 1 (b) shows a single line diagram of radial system for AC distribution system. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of load. This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks:

(a) The end of the distributor nearest to the feeding point will be heavily loaded.

(b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the sub-station.

(c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes. Due to these limitations, this system is used for short distances only.

(ii) Ring main system: In this system, the primaries of distribution transformers from a loop. The loop circuit starts from the sub-station bus-bars, makes a loop through the area to be served, and returns to the sub-station. Figure 2 shows the single line diagram of ring main system for AC distribution system in which sub-station supplies to the closed feeder LMNOPQRS of the feeder through distribution transformers. The ring main system has the following advantages:

(a) There are less voltage fluctuations at consumer's terminals

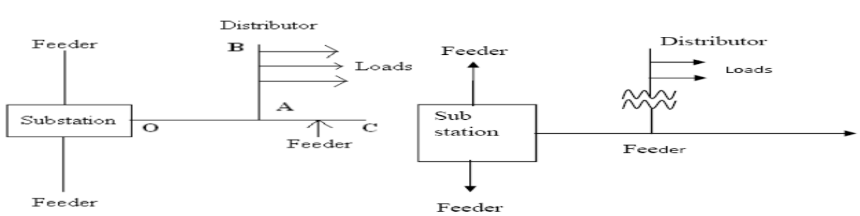
(b) The system is very reliable as each distributor is fed via two feeders.

In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

(iii)Interconnected system: When the feeder ring is energized by two or more than two generating stations or sub stations, it is called inter-connected system. Figure 3 shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two sub-stations S1 and S2 at points D and C respectively. Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers. The interconnected system has the following advantages:

(a) It increases the service reliability.

(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.



(a) Distribution for DC Systems (b) Distribution for AC Systems

Figure 1. Single line diagram of Radial System [2]

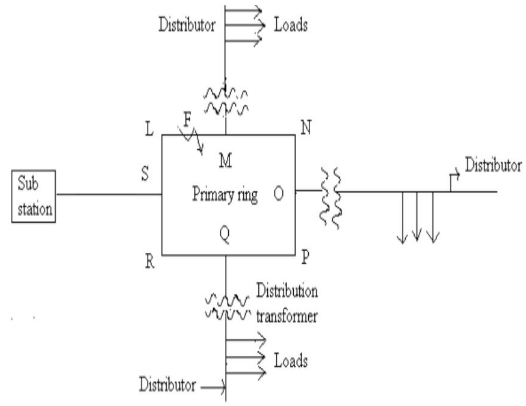


Figure 2 Ring Main Systems [2]

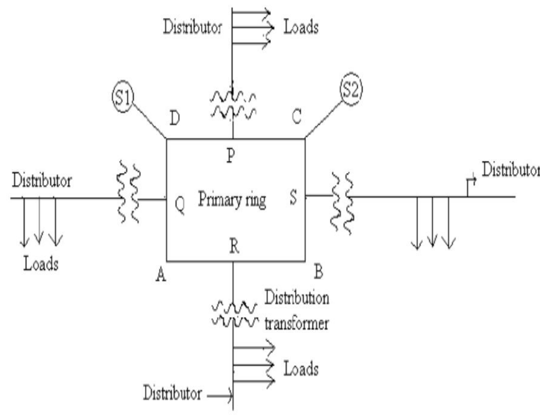


Figure 3 Interconnected Systems [2]

III. DISTRIBUTED GENERATION

From the definition, the DG takes into consideration the generation units not supplying the reactive power and locates near to customer or end user. But, there is no specific definition for capacity of the DG. Only categories are declared as follows.

1. Micro distributed generation with capacity larger than 1 W and less than 5kW
2. Small distributed generation with capacity larger than 5kW and less than 5MW
3. Medium distributed generation with capacity larger than 5MW and less than 50MW
4. Large distributed generation with capacity larger than 50 MW and less than 300MW

Various artificial intelligence techniques like Genetic Algorithms, Artificial Neural Network, Simulation Algorithm, Fuzzy, PSO, Ant Algorithm, Shuffled Bat algorithm have been employed as tools for solving optimal capacitor allocation to minimize the power loss, improvement in the voltage profiles and other economic benefits [7, 8, 9, and 10].

IV. DISTRIBUTION TRANSFORMER

The objective of this survey is to find ways to reduce the distribution transformer losses. In order to reduce these losses, three methods have been investigated. The first method investigates the effects of electromagnetic shields upon distribution transformer tank losses. In today's competitive market, accurate estimation and subsequent reduction of the stray loss by shielding techniques could give a competitive advantage. The second method show how the transformer losses could vary during its manufacturing process. The dielectric losses can be reduced if the transformer manufacturer carries out an adequate drying process. The third method deals with the core joints. Core joints play an important role in the performance of transformer cores. Due to the importance of improved electrical core performance, transformer manufacturers and research institutions are very active in the development of better electrical steel and the optimization of the core design parameters. Of the various materials required to build a transformer, the electrical steel comprises the largest investment [3].

In this study, the effect of the following two factors is considered: (a) overlap length and (b) number of laminations per step or group. The data presented in this work will be helpful for a practicing engineer in the transformer industry.

A. Reduction of Stray Losses using Electromagnetic Shields

In a shell-type transformer the windings are surrounded by the core & the leakage flux is high in the tank walls, which causes high-power losses. The main effort to reduce load losses has concentrated in the area of stray losses. A reduction of the magnetic flux is required to reduce these losses. Placing a physical barrier, called a shield, between the electromagnetic field source and the region of interest can accomplish this purpose. Shielding materials include magnetic and electric conducting materials. Magnetic materials are high permeability material and shield by a mechanism called "flux shunting." In this case, the flux from a source is diverted into the magnetic material and away from the region to be shielded. Electric materials are highconductivity materials and shield by a phenomenon known as “eddy-current cancellation.” In this case, currents are induced in the conductor, which create magnetic fields that partially cancel those from the source.

The main load-losses are the I^2R losses. The stray losses arise from eddy currents induced in metallic parts of the transformer; for instance, in clamps and in tank walls. Therefore, good understanding of stray losses and their reduction mechanisms are necessary for improving the transformer design. The stray losses are a function of many factors including physical geometry of the cores and windings, voltage class, and the material used in the tank construction. The stray losses increase with the growing of transformer rating. Hence, the application of shielding in very small transformers is not attractive to reduce stray losses. A magnetic shield comprises a large number of packets of aluminium laminations mounted on the vertical sides of the steel tank. The height of the aluminium shield is equal to the height of the steel tank and the separation between the laminations is of the order of 0.3 mm. The process of lining the steel tank wall of the transformer with aluminium foil is rather time-consuming [4].

The load loss and stray loss are measured under three conditions: (a) without shield, (b) with aluminium shield of 1.2 mm of thickness, (c) with aluminium shield thickness of 10 mm. It is observed that stray losses are increased by 20.9% when the 10-mm aluminium shield is not used. On the other hand, there was little change in the losses between the 1.2-mm shield and the unshielded case, since the depth of penetration is larger than the aluminium shield thickness so the magnetic flux density reaches the carbon steel. For the case of steel tank when the depth of penetration is less than the steel-wall thickness, the half thickness of the plate, the inner part of the plate remains unmagnetized, and the magnetic fluxes as well as the eddy currents are confined to a layer of depth on the plate surface. Placing aluminium shielding in the internal tank wall reduces the stray losses because induced currents of considerable magnitude in the shielding produce a magnetic field that partially cancels the incident field. In other words, the magnetic flux density induced is opposed to the magnetic flux density incident. The superposition of induced field and incident field gives a total field, which is repelled from the tank superficies. It is important to recognize that the previous phenomenon occurs regardless of the application of aluminium shielding.

B. Reduction of dielectric losses in no-load test

The no-load losses $P_{(no\text{-}load)}$ include the eddy-current losses (P_e), the hysteresis losses (P_h) and the dielectric losses (P_d). Since the no-load current will be very small compared to the full load value, the I^2R losses in the windings will be negligible. Therefore,

$$P_{(no\text{-}load)} = P_e + P_h + P_d \qquad (1)$$

The no-load losses of the active-element (set core winding) are higher than the no-load losses of the completed transformer because when the active-element is tested, its insulation contains a high content of moisture, which causes high dielectric losses. The dielectric losses are determined by the expression:

$$P_d = V^2 w \tan\delta\, C \qquad (2)$$

Where V is voltage (V), w is angular frequency (rad/s), $\tan\delta$ is delta tangent and C is capacitance of the configuration [5].

C. Impact of joints design parameters of wound core in distribution transformer losses

There are few manufacturing-parameter definitions which are exclusive for the wound-core distribution-transformer family as follow;

• Step or book: Set of laminations, which can vary between 4 and 25 and this set of laminations form a cycle as first four laminations (from top to bottom) may form a step.

• Air gap (g): The air gap is the separation between lamination and lamination in the direction of rolling. In the practice, this value is less than 3 mm.

• Overlap (L): The overlap is the length between the half points of the air gaps of two laminations contiguous in the rolling direction. The typical range of this parameter is 1 to 2 cm.

• Lamination thickness (T): Grain oriented silicon steel is graded according to the American iron and steel institute (AISI) designations.

• Insulation thickness: Grain oriented electrical steels are coated with C-2 coating or C-5 over C-2 coating. Typical C-2 coating thickness is 0.0001 cm per surface. Whenever C-5 is applied over C-2 coating, the thickness of C-5 coating is approximately 0.0001 cm per surface for wound-core distribution transformer. A safe value of interlamination resistance must be maintained to prevent stray losses in the core.

The laminations are in succession in order to obtain a higher mechanical stability. If the joints are rigid and strong, it prevents them from coming apart under severe operation conditions, and also diminishes the noise, from vibrations during the operation of the transformer. Most of the technical papers have analysed the stacked transformer cores [6].

Until now, little attention has been paid to wound transformer cores. The objective of these measurements is to investigate the effects of core-parameter changes on wound-core losses in a distribution transformer. In order to comply with manufacturing limitations, the number of laminations per step is increased. Conversely the overlap lengths are decreased and the net result of these opposing factors results in no change. Therefore it is observed that when the number of laminations per one group is increased, core losses are slightly increased.

V. CONCLUSIONS

This paper presents a collection of discussions about basic technical segments of electric distribution technology. However, there are also significant improvements that can be accomplished through improved reliability and quality of service. It is concluded from survey that optimal placement of DG plays a significant role in reducing the distribution power losses and improving the voltage profile of the distribution system.

It is the result of a literature study & intends to give the recommendations which will be helpful for practicing engineers in the transformer industry. The electromagnetic shields of the transformer prevented the penetration of the magnetic stray flux in the magnetic materials, where high losses would be induced. The study also demonstrated that the dielectric losses are important in no-load loss in the transformer when the transformer insulations have high water content. It is known that minimum losses occur when the rolling direction coincides with flux magnetic lines, but this condition is not satisfied in the core joints since the joints air gaps cause local disturbances of magnetic flux. It is observed that the number of laminations per step does not have much effect on the core losses. This is because as the number of laminations was increased, the overlap length was decreased in order to comply with manufacturing limitations.

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