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Performance Enhancement of Low Voltage Distribution Network in Developing Countries using Hybrid Rehabilitation Technique

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ABSTRACT

Majority of the developing countries are facing problem of low supply voltage coupled with shortage of electrical energy. There is a growing concern for ways and means to preserve the existing resources and optimize the performance of EPDS (Electric Power Distribution System). Poor condition of distribution network, utilization of low current carrying capacity conductors with overloading is mainly causing the voltage drop, power loss and energy loss in the LVDN (Low Voltage Distribution Networks). Most of developing countriesare encountered with financial problems to ward up gradation of the existing network. Under such circumstances, it is essential to optimize the low voltage distribution network using innovative approach to design the LVDN.

In thiswork, ahybrid rehabilitation techniqueis used for the performance improvement of LVD utilities network. Most of the availablealgorithms areconsidering the distribution networks with balance distributed load andunity power factor. The proposed methodology has been applied to LVDN, working under randomly distributed load with low power factor. The technique is applied to improve the efficiency of LVDN in terms of power loss and voltage drop reduction. Optimization of three different circuits of village QutabFerozal, Banth and Pothi Mandra of IESCO, has been selected as a case study. The analysis has been performed using ELR (Energy Loss Reduction) and CADPAD (Computer Aided Distribution Planning and Design) software. Field visits have been conducted to acquire the real data of various LVDN configurations. Simulation results are validated with the actual data of the selected LVDN feeders and found within the permissible limits.

Key Words: **Energy Loss Reduction, Computer Aided Distribution Planning and Design, Electric Power Distribution System, Optimization of Low Voltage Distribution Networks, Radial Distribution Feeder.**

1. INTRODUCTION

To provide the electric utility service of required quality at the optimum cost, permissible voltage drop with minimum power and energy loss is vital. EPDS is a linkage between transmission system and LVDN. In LVD system, I^2R losses are mostlydue to low voltage and high current. These losses represent the largest consumption in electrical power system [1]. Different techniques of power loss reduction exist in the

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literature. Some of them are feeder reconfiguration, placement of capacitor, grading of conductor, high voltage distribution system and optimal placement of distributed generator. Mostly, feeder reconfiguration is applied for eliminating line resistive losses in the distribution system [2]. The optimal application of capacitor in LVDN significantly reduces the voltage drop, minimize the power loss, release feeder capacity, increase power factor and compensate reactive power [3]. The implementation of ALT (Automatic Load Transfer) switch may provide some potential benefits including voltage regulation, maximum utilization of available assets and power loss reduction. However, the application of ALT switch depends upon the network reconfiguration and load connected [4]. Power loss is more than 10% in developed countries, whereas, it is more than 20% in developing countries. However, ideally power loss in any distribution system must not exceed 6% [5].

Majority of the distribution networks are assumed to be complicated because of frequent power outages. The end customers always encountered the problems of voltage drop and power loss [6]. An evolutionary algorithm, called as DFR (Distribution Feeder Reconfiguration) has been proposed in [7]. The algorithm minimizes the power loss and the operating cost of distributed generation. However, it will be effective, only when the network is of radial nature and the transformer capacity, bus voltage and the network thermal limits are within the acceptable limit. Optimization techniques used for optimum size and location of capacitor placement in the distribution network can be divided into different categories. Few of them are; AI (Artificial Intelligent), conventional and hybrid intelligent techniques [8]. In the conventional techniques sufficient time is needed for convergence. Majority of the AI and hybrid intelligent optimization methods are complicated and uneconomical to implement practically. The aggregate technical and commercial losses are estimated to be 25-30% [9]. The electric utilities are trying to bring these losses below 15%, using various innovative techniques.In order toimprove the power quality and the efficiency of the LVDN, priority should be given to the up-gradation, customer orientation, decentralization of embedded generation and theft control in the distribution system.In general, load is inductive, hence with the increase of inductive load, the power factor of the LVDN decreases. Reduced power factor increases the distribution system complexities in terms of reduced system capacity, voltage regulation, power factor penalties, and increased voltage drop and energy losses, especially at the customer terminals [10].

Many electric utilities are facing the problem of voltage drop and energy loss. The distribution networks of developing countrieslike Pakistan are long, deteriorated and overloaded with unbalanced loads. The maximum allowed voltage variation is ±5% as stated in the IEEE standards. The power loss and voltage drop adversely affects the efficiency of the LVDN. To improve the efficiency of LVDN, a strategic planning is required. The voltage drop and power loss mostly varies with the pattern of loading on the distribution feeder [10]. Different techniques are used to minimize the issues related to power loss and voltage drop. Majority of the EPDNs are radial in configuration. The developing countries of the world are facing the obstacles in mitigating and avoiding the non-technical losses.

The implementation of AMI (Advance Metering Infrastructure) technique with smart meters, control these losses up to some extent [11]. Increasing the power factor of LVDN can significantly minimize the lossesalong with average loading of the LVDN. In many cases, excessive distribution loss occurs on account of illegal connection and non-technical losses (pilferage). Under such circumstances, unpaid energy bills are responsible for creating liquid cash crunch and reduce the revenue collection efficiency. A reasonable investment and application of managerial measures are needed to minimize such distribution losses [12]. Shifting of distribution transformers to their optimal locations and the installation of capacitor banksin the LVDN will not only improve the voltage profile but also enhance the useful life of EPDS equipment [13].

Loss reduction and increased system capacity may be achieved by efficiently altering the condition of sectionalizing switches [14]. However, such method of reconfiguration is effective only for radial distribution networks. In Pakistan, primary distribution voltage level is 11kV. Near the customer terminal 11kV is stepped-down through step-down transformer to low voltage level (400V, three phase and four wires). The voltage between any phase and neutral is 230Vand between two phases is 400V. Single phase is used for light-load whereas; three phases are used for heavy-load forresidential and commercial consumers. Usually low voltage distribution is carried out through three phase four wires, two phase three wires and single phase two wires system. The existing distribution system in Pakistan consists of large three phase 11kV distribution feeders with three phase lines. Mostly in LVDN, voltage drop occurs due to the utilization of low current carrying capacity conductors and long length. The loss of energy in the LVDN exists due to commercial and technical losses. Technical losses include energy dissipation in the line conductors and equipment involved in distribution of electric power. The commercial losses are mainly because of pilferage and error in the measuring equipment. These losses depend upon the load density, configuration of LVDN and the energy pattern used.

To keep the voltage of LVDN within acceptable range and to eliminate power loss, numerous techniques including distributed generation at strategic location, application of electrical storage devices as well asproperly designed and operated embedded generation can be used effectively [15]. Using proper size of standard conductor with appropriate parameters minimizes theelectrical power consumption; enhances the voltage regulation, reduces the power loss and improvesthe performanceof electrical equipment [16]. It has been observed that majority of transformers are without energy meters and average consumption is estimated which lead to an error in the estimation of energy. In most of the LVDN, the voltage variations are more than 10%. Inductive loads, especially induction motors draw higher current at reduced voltage for the constant output, causing significant voltage reduction in the LVDN. The full load current drawn by the induction motor is 15% when the voltage drop of LVDN is 10%. Similarly for the same voltage drop, the line loss increases to 20% and the starting torque decreases by 19% in the LVDN [16].

Because of rapid increase in population, the LVDNs are growing larger and stretched too farresulting in deteriorated system voltage regulation [17]. Detailed analyses delineate that maximum losses are owing to the LVDN part of the power system. As per one estimate it accounts for 80-90% of the total transmission and distribution losses [18]. The initiative for improving the LVDN includes system up-gradation, preventive maintenance, rectification of defective switch gears as well as loose termination at substations and checking proper operation of capacitors banks.To balancethe load, single phase three wire lines are replaced by three phase five wires lines. To increase voltage regulation another low tension circuit is constructed for low voltage lines having current larger than 75A and length more than 5 kM.

The acceptable regulation limit for LVD circuit is 6% and for high voltage distribution network is 8%. Over-loaded transformer extracts needless high iron losses. Low power factorin low voltagelines, also contributes high distribution losses [18-19]. In distribution circuit having low power factor, the current drawn is maximum consequently the loss is proportional to the current. The reduction of losses in LVDN can be considered as source of energy. The reconfiguration of LVDN can play a significant role in reducing the line losses and improving the voltage profile. This in turn notonly reduces the system operating cost but also minimizes the temperature of the line components, as a result the "phenomena of aging" in the system insulation and failure rate of components are reduced [20]. A fast restoration strategy based on the feeder dispatch control system for feeder reconfiguration has been proposed by Lin and Chin [21]. The method is capable of minimizing losses in the distribution network. However, the proposed method is complicated as a lot ofcomputational work is required which may affect the end results adversely. Power loss in EPDS increases the temperature of various electrical components leading to insulation failure [22]. Configuration management is used to reduce the distribution network losses. However, it is a discrete optimization problem for which the radial structure of the feeder is required [23].

In this research work, three low tension distribution networks of Mandara Feeder, Rawalpindi Sub-Division and IESCO, Islamabad, Pakistan has been taken as a case study. The analyses have been carried out using hybrid rehabilitation technique. Different rehabilitation techniques have been studied and emphases have been given to upgrade the existing outdated LVDN using hybrid rehabilitation technique. The results are verified and are within the permissible limits.

2. MAIN CAUSES OF VOLTAGE DROP AND POWER LOSS

Mostly LVDN comprises of inductive loads. Reactive power is essentially needed to magnetize the Inductive loads. It has been observed that heat loss in LVDN conductors causes significant voltage drop. Most of the developing countries are deficient in financial resources and populated with heavily overloaded distribution network and undersized conductors. Unfortunately, there is no proper method used in these countries for accurate field data collection. Most of the data collected is based on the information provided by the customer's application forms which is mostlyless than the actual demand. Due to lackof latest design and simulation facilities, there are significant chances of error in load forecasting and data collection of LVDN. On the bases of in accurate information, the LVDN becomes overloaded resulting in excessive power loss and voltage drop in the electric power distribution network.

It has been observed that during the data collection in the field survey, mostof the LVDN transformers on load ranging from 40-50% have maximum efficiency. In majority of Utility Companies, the LVDN transformers along with secondary circuitsare responsible for prominent power loss and voltage drop.In the distribution company of Pakistan WAPDA (Water and Power Development Authority), approximately 60% of distribution transformers are unbalanced. Unbalanced load on distribution transformer enhances the heat losses from 5-6%. LVDN loads are mostly designed as constant current. The power loss equation for LVDN can be written as:

$$\Delta P_{TF} = \sum_{i=1}^{N} R_i I_i^2 \quad (1)$$

The overall power losses are:

$$\Delta P = \Delta P_{TF} + \sum_{j=1}^{N_b} R_j I_j^2 \quad (2)$$

Where R_i is Resistance of the i^{th} transformer, R_j is Resistance of j^{th} branch, N is Substation where transformers of A_i rated power are installed, N_b is Branches of distribution network, and I_i, I_j are the relevant currents.

The service cables are of shorter length, hence have minimum effect on voltage drop and power loss of LVDN. During the field survey of the rural areas it has been noticed that the majority of the domestic customers load are connected through a single service cable. Under such circumstances the quality of electric supply is affected badly. Error in the data collection, nature of LVDN load, equipment design, layout of the installation, weak maintenance of LVDN and low power factor are the key factors of power loss and voltage drop in LVDN.

Nominal voltage ratings in pu (per unit) system:

V(nom) = 1.00 pu

V(max) = 1.05 pu

V(min) = 0.95 pu

Where V(nom) is the nominal voltage pu, V(max) is the maximum voltage pu, and V(min) is the minimum voltage pu.

Considering simply the magnitude of voltage, the VPI (Voltage Profile Improvement) for i[th] node may be depicted as:

$$VP_i = \frac{(V_i - Vmin)(Vmax - V_i)}{(Vnon - Vmin)(Vmax - Vnom)} \quad (3)$$

Where V_i is the pu voltage at i^{th} node.

Resultant voltage profile index is

$$VP_i = \frac{1}{N}\sum_{i=1}^{n} VPi \quad (4)$$

Where N is the number of the nodes.

To obtain more precise results, a weighting factor is introduced based on the importance of different loads. For equally weighted node weighting factor is taken as 1. Under such circumstances Equation (3) can be re-written as:

$$VP_{2i} = \frac{(V_i - Vmin)(Vmax - V_i)LiWi}{(Vnon - Vmin)(Vmax - Vnom)\sum_{W=1}^{n} LiWi} \quad (5)$$

Where VP_{2i} is the per unit voltage at i^{th} node with "weighting factor", (W_i), L_i is the load providedat ith node.

The voltage profile index illustrated in Equation (5) maybe expressedas:

$$VP_2 = \sum_{i=1}^{n} V_i L_i W_i \quad (6)$$

The general expression for voltage profile of the EPDS can be rewritten as:

$$VP = \sum_{i=1}^{n} V_i L_i W_i \quad (7)$$

Where VP is the voltage profile, V_i is the voltage of ithnode in pu, L_i is the load supplied at ith node, n the number of the node, and W_i is the weighting factor of the ith node.

Practically, it has been observed that the common expression used for voltage profile is applicable when voltages of all the nodes are within the acceptable range of ±5% of the normal voltage rating [24]. Per unit"voltage profile index" is 0 at 0.95 and 1.05. It has the highest value 1.0 when voltages of all the nodes are at their usualnormal values. However, in case of any voltage decrease or increase exceeding the normal value, the "voltage profile" of the LVDN changes drastically, showing the precise picture of the LVDN.

In the competitive environment, the distribution companies are passing through the era of deregulation and with the advent of sophisticated telecommunication facilities, the consumers are aware of the power quality issues. Reduction of power loss improves the tension profile in the nodes, enhances the safety and reliability of the distribution network and ensures the uninterruptible power supply. Mostly, it is observed that by enhancing the voltage profile of LVDN, the active power and reactive power losses are minimized and the overall performance of the LVDN is increased. Power factor and voltage along the distribution network also changes during the peak hours. Under such situation, it is necessary to increase the efficiency of LVDN by minimizing the power lossand voltage drop effectively. The LVDN is checked against as a minimum requirement in predetermined planning criteria. It ensures specified standard guidelines for LVDN.

Haphazard planning of distribution network causes lengthy LVDN instead of shortest path to a locality, which increases the voltage drop and power loss in EPDS. The transformers location has considerable effect on the voltage drop. Non-optimal location of distribution transformer may also increase the power loss and voltage drop in the LVDN.Mostly, the dimension of conductor used for line connectors between secondary distribution circuit, the transformers terminals and the secondary distribution circuit is much lower than the standard capacity. Also, the conductor used between tee-off lines and main distribution line is of smaller size than the distribution line conductor itself. The application of substandard jointing practices is another key factor of increased voltage drop and power loss in LVDN. In many of cases, loose joints and connectors of smaller size also causes the large amount of hidden power losses and voltage drop in LVDN. Current leakage in an EPDS not only causes the service interruption but also enhances the voltage drop and power loss in LVDN. Violation of standard clearance between distribution line conductors and earth contributes to power loss and voltage drop. Practically it is observed that the loss estimation is mostly inaccurate. In developing countries only 30% of the total energy consumed is metered [25]. Loads in rural areas are rarely metered and metering is generally limited to thickly populate urban areas. The non-availability of comprehensive data is the main obstacle for computing the losses in distribution system. Under such circumstances, the electric utilities need to evolve loss estimation mechanism which should be reliable enough to convince the regulatory commission [25].

3. HYBRID REHABILITATION TECHNIQUE

In the competitive environment, the distribution companies are encountered with the pressure of deregulation in the electric industry. The fast communication media has created power quality awareness among the customers. Under such circumstances, it has become necessary for distribution companies to optimize their LVDN so that the voltage drop and power loss must be minimum as much as possible. During the design of EPDS some assumptions like uniform conductor size, constant loads, equal spacing, uniform load distribution and unity power factor are adopted to make the model more acceptable. However, in actual life scenario, such assumptions are difficult to adopt. Keeping in view of these facts, cumbersome job is needed by distribution engineers in the real world of EPDS. Many issues including the technical, operational, economic, social and environmental are faced during the application of hybrid rehabilitation technique. On the other hand, the implementation of hybrid technique provides remarkable assistance to avoid:

- Excessive voltage drop.
- Huge power loss.
- Unscheduled load shedding.
- Frequent failure in protective system
- Financial loss to customers as well as to electric utilities.

In such scenario, hybrid rehabilitation technique provides considerable relief to EPDS in a very economical way. While executing the hybrid technique, the calculation of segment data is of immense importance. The input information directly affects the precision and accuracy of the simulation results. LVDN is bifurcated into small sections called segments. The analysis of the distribution system provides the voltage drop and power loss for different nodes and segments of LVDN.

The incremental power loss for "n" segment is:

$$\Delta P_{loss} = \int_{x=n}^{n+1} \frac{dI^2}{dt} \theta_{n+1} R_{n,n+1} d_x \tag{8}$$

The total power loss for "n" segment is:

$$P_{loss} = \int_0^1 \frac{dI^2}{dt} \theta_{n+1} R_{n,n+1} d_x + \int_0^2 \frac{dI^2}{dt} \theta_2 R_{1,2} d_x + .. \int_n^{n+1} \frac{dI^2}{dt} \theta_{n+1} R_{n,n+1} d_x \tag{9}$$

$$P_{loss} = \sum_{i=0}^{n} \frac{dI^2}{dt} \theta_{i+1} R_{i,i+1} \tag{10}$$

Where I = 0,1,2,…n Indicate the number of the feeder segment.

"n" segment incremental voltage drop for is:

$$dV_x = \int_{xs=n}^{n+1} \frac{dI}{dt} \theta_{n+1} Z_{n,n+1} d_x \tag{11}$$

At distance "x", the voltage drop from sending end of the feeder is:

$$V_{drop}(x) = V_s - V_x \tag{12}$$

The voltage drop in the respective segment is:

$$V_{drop,n+1} = \frac{dI}{dt} \theta_{n+1} Z_{n,n+1} \tag{13}$$

Total voltage drop is:

$$V_{drop} = V_s - V_r \tag{14}$$

The input data can be provided either by the user or through file depending upon the requirements of the user. The data include; number of nodes, rated voltage of the circuit, the type of circuit, length of segment and load connected to each node. The software used for hybrid technique has the capability to calculate the voltage drop, segment current, power loss, node voltage and energy loss. IEEE standards allow only the ±5% variation in the magnitude of rated value at all the nodes of distribution network [24]. The proposed technique is applied in the following five stages.

In first stage, the input data on prescribed format is provided either through user or file. The technique applied is capable of calculating all segment parameters automatically based upon the input information.

In second stage, the analysis is carried out to investigate whether the power loss and node voltage are within the allowable range. If the results are within the specified range, the consumer has the choice to keep the output within the file which used to generate the power loss curves, voltage profile and other analyses.

In third stage, it executes if power loss and voltage drop of all nodes are out of range, identify those nodes and change the type of conductor between those nodes. Evaluate the output results.

In forth stage, if power loss and the nodes voltage drop are again out of allowable limit, then the optimal placement of the capacitor is carried out. Investigate the output results.

In fifth stage, observe whether the power loss and nodes voltage drop are within the permissible limit or not. If the power loss and node voltage drop are still out of allowable limits then shifting of transformer to its optimal location is carried out.

The flowchart diagram depicted in Fig.1 delineates all the five stages of the hybrid rehabilitation technique. The modular programming approach has been used for the technique. It is flexible in its application and user can change any input according to his own needs and requirements as and when required. The technique can be implemented through the following steps:

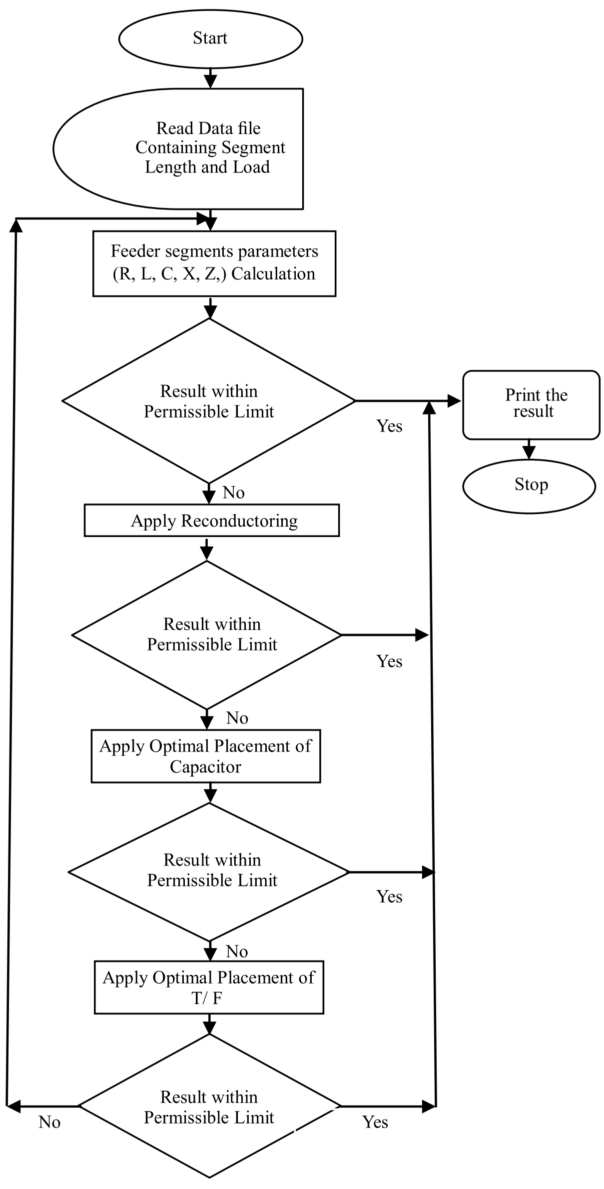

FIG. 1. A FLOW CHART DIAGRAM OF HYBRID REHABILITATION TECHNIQUE USED FOR OPTIMIZATION OF LVDN

(i) Choose the problematic low voltage distribution circuit.

(ii) Feed input data on prescribed format.

(iii) Ensured the voltage drop limit (±5% of the rated value) for each node.

(iv) If the node voltage drop is out of range, identify such nodes and change the type of conductor between such nodes. Evaluate the node voltage drop.

(v) If the node voltage drop is still out of limit, change the placement of capacitor to its optimal location. Investigate the results.

(vi) If the node voltage drop is again out of range, change the placement of transformer to its optimal location. Observe the limits of node voltage drop.

(vii) If the node voltage drops are still out of permissible limit, repeat the process from step iii to vi until the desired results are obtained.

(viii) Save the results in the data file and take the print.

The hybrid rehabilitation technique can be implemented on any problematic low voltage distribution circuit in a very cost effective manner.

4. CASE STUDIES

In this research work, low voltage distribution network of three villages namely Qutab Ferozal, Banth and Pothi-Mandra of Mandra Feeder, Rawilpindi Sub-Division IESCO, Islamabad have been selected as case study. With the help of concerned staff, the data has been collected through actual field survey. The analyses have been carried out by providing the following input data through CADPAD computer software.

- Length between the successive nodes and type of conductor.
- Load connected in kVA at each node.
- Rating of installed capacitor if any.
- The maximum value of the current.
- Value of bus voltage.
- Value of existing power factor.
- Value of load factor.

The node is the point on the distribution network at which either a T-off is emanating, a load/transformer is connected or the type of conductor changes. The software generates data base file from the aforementioned data to run the load flow analysis. Based upon the input data, the computer software can automatically performs the following calculations for existing and proposed conditions. However, the system parameters can be modified as and when required.

- Cumulative load connected in kVA at each node.
- Current passing through each segment of the distribution network.
- Percentage load connectedat each section of the distribution network.
- Voltage drop at each node of the distribution network.
- Power loss in each segment of the distribution network in kW.
- Total power loss in the distribution system.
- Total percentage power loss.

Program allows:

- Installation of new capacitor at optimal places of the network.
- Re-conductoring of the identified network segments.
- Shifting of identified transformers to optimal location.
- Segment data modification.

The applied software is very flexible. User can modify/ enhance it as per required parameters because of its modular programming approach. The software program can optimizes solution for LVDN having balance/ unbalance electric loads. The user can feed input data to the software either through keyboard or file depending upon the needs and requirements. After an optimized solution, it calculates total voltage drop and power loss for entire feeder. It can identify the optimal location of capacitor and transformer. On the output, the user can opt to save the output which can be used to generate the graphs and other analyses. The results are tested and verified which are within the permissible limits.

4.1 Case Study-1

Applying CADPAD software, load flow analysis of 100 kVA transformer of village Qutab Ferozal has been carried out. Using the available data,the single line diagram of LVDNis generated as shown in Fig. 2. The network consists of 28 nodes. The total length of the circuit is 2.307kM. Data collected through field visits is depicted in Table 1. The number of three phase and single phase consumers are 5 and 157, respectively. The information gathered indicates that ACSR ant conductor with current carrying capacity of 211 amperes has been used. The voltage profile of Fig. 3 delineates that there is a maximum voltage drop of 16% at node number 25 of the LVDN which exceeds the IEEE permissible limit of ± 5%. The curve of Fig. 3 indicates that voltage drop up to node number 7 is within the acceptable range for existing system analysis, whereas voltage drop behind node number 7 increases sharply and reaches to maximum value of 16% at the tail end of the nodes. The voltage profile curve expresses significant improvement in the voltage drop reduction. The application of software proposes the shifting of 100kVA transformer from node number 1 to its optimal location of node number 9 and installation of two capacitors, each of 15 kVAR rating at node number 10 and 18, respectively.The implementation of proposed rehabilitation techniques brings the voltage dropwithin the permissible limit of ± 5% as shown in the proposed voltage profile of Fig.3.

The power curve of existing system is depicted in Fig. 4. Thoroughinvestigation of the curve shows that there is maximum power loss of 2.134, 2.114 and 2.037 kW at node number 9, 8, and 7, respectively. The total power loss is 8.314 kW which has been reduced to 0.8kW, providing a net saving of 7.541 kW. The maximum power loss at node number 9, 8, and 7 is due to maximum current flow at these nodes.

The energy loss calculations for LVDN of village Qutab Ferozal are shown in Table 2. These calculations are for the period of one month. Total units sent through transformer are 27828 kWh. The units consumed through 162 consumers are 15993kWh. The total loss of energy is 11835kWh. The technical loss of energy calculated is 2463kWh. The other loss is 9372kWh. In this way, the percentage of technical loss, other loss and total loss of energy is 8.85, 33.68 and 42.535%, respectively.

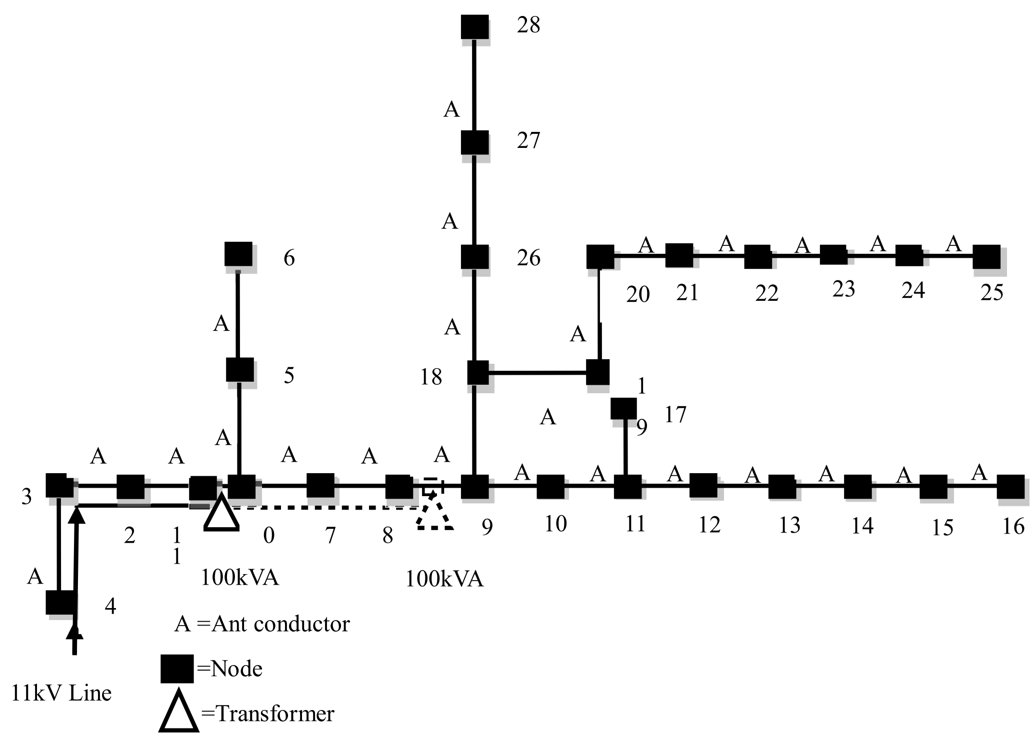

FIG. 2. SINGLE LINE DIAGRAM OF LVDN OF QUTAB FEROZAL, RAWILPINDI SUBDIVISION (PAKISTAN)

TABLE 1. LOAD FLOW ANALYSIS FOR 100KVA TRANSFORMER OF QUTABFEROZAL RAWALPINDI SUBDIVISION IESCO ISLAMABAD (PAKISTAN)

Node		Section Length (kM)	3-ϕ Load (kVA)	1-ϕ Cons kVA	kVA	Cumulative kVA	Conductor	Amperes	Load (%)	Voltage Drop (%)	Voltage Drop (prop) (%)	P.Loss (%)	P.Loss (prop) (%)
From	To												
0	1	0.002	0	2	1.00	82.00	A	145.0	69	0.1	0.1	0.084	0.004
1	2	0.076	0	5	2.50	10.00	A	17.7	8	0.5	0.5	0.048	0.004
1	5	0.091	0	3	1.50	9.00	A	15.9	8	0.6	0.6	0.046	0.003
1	7	0.085	0	2	1.00	62.00	A	109.6	52	3.2	3.2	2.037	0.050
2	3	0.073	2	8	5.00	7.50	A	13.3	6	0.8	0.8	0.026	0.005
3	4	0.084	0	5	2.50	2.50	A	4.4	2	0.9	0.9	0.003	0.003
5	6	0.091	3	10	7.50	7.50	A	13.3	6	1.0	1.0	0.032	0.032
7	8	0.091	0	2	1.00	61.00	A	107.9	51	6.5	4.5	2.114	0.004
8	9	0.095	0	10	5.00	60.00	A	106.1	50	9.9	4.9	2.134	0.003
9	10	0.085	0	5	2.50	17.50	A	30.9	15	10.8	4.9	0.162	0.002
9	18	0.061	0	8	4.00	37.50	A	66.3	31	11.2	4.8	0.535	0.080
10	11	0.088	0	6	3.00	15.00	A	26.5	13	11.6	4.5	0.123	0.040
11	12	0.085	0	10	5.00	10.00	A	17.7	8	12.1	4.9	0.053	0.040
11	17	0.061	0	4	2.00	2.00	A	3.5	2	11.7	4.8	0.001	0.001
12	13	0.055	0	3	1.50	5.00	A	8.8	4	12.3	4.7	0.008	0.008
13	14	0.088	0	3	1.50	3.50	A	6.2	3	12.5	4.8	0.007	0.007
14	15	0.088	0	1	0.50	2.00	A	3.5	2	12.6	4.8	0.002	0.002
15	16	0.088	0	3	1.50	1.50	A	2.7	1	12.7	4.6	0.001	0.001
18	19	0.095	0	8	4.00	23.50	A	41.6	20	12.5	4.6	0.328	0.100
18	26	0.098	0	8	4.00	10.00	A	17.7	8	11.8	4.3	0.061	0.051
19	20	0.091	0	9	4.50	19.50	A	34.5	16	13.5	4.7	0.216	0.116
20	21	0.091	0	5	2.50	15.00	A	26.5	13	14.3	4.6	0.127	0.120
21	22	0.088	0	7	3.50	12.50	A	22.1	10	14.9	5.0	0.086	0.060
22	23	0.085	0	5	2.50	9.00	A	15.9	8	15.4	5.0	0.043	0.030
23	24	0.095	0	4	2.00	6.50	A	11.5	5	15.8	4.9	0.025	0.010
24	25	0.091	0	9	4.50	4.50	A	8.0	4	16.0	4.9	0.012	0.020
26	27	0.091	0	5	2.50	6.00	A	10.6	5	12.1	4.3	0.020	0.001
27	28	0.095	0	7	3.50	3.50	A	6.2	3	12.3	4.2	0.007	0.003

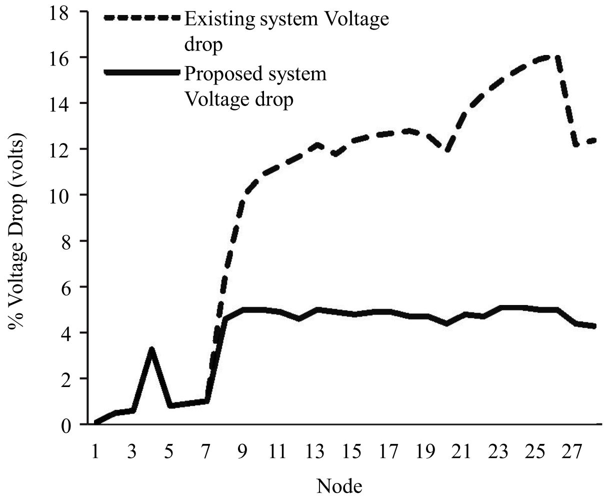

FIG.. 3. VOLTAGE PROFILE OF LVDN OF QUTAB FEROZAL, RAWILPINDI SUBDIVISION (PAKISTAN)

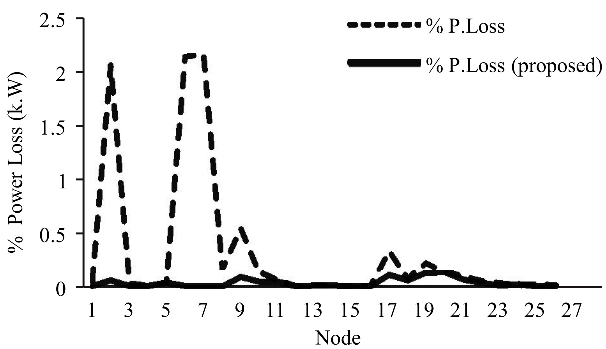

FIG. 4. POWER LOSS CURVE OF LVDN OF QUTAB FEROZAL, RAWILPINDI SUBDIVISION (PAKISTAN)

TABLE 2. ENERGY LOSS CALCULATIONS FOR VILLAGE QUTAB FEROZAL RAWALPINDI SUB-DIVISION (PAKISTAN)

No.	Reading	Units (kWH)
1.	Units sent through transformer	27828
2.	Units billed	15993
3.	Total loss	11835
4.	Technical loss	2463
5.	Other loss	9372
6.	Technical loss	8.85%
7.	Other loss	33.68%
8.	Total loss	42.53%

4.2 Case Study-2

The single line diagram of LVDN of village Banth of Mandra Feeder, Rawilpindi Sub-Division IESCO, Islamabad is depicted in Fig. 5. The network consists of 40 numbers of nodes. The total length of the LVDN is 1.713kM. ACSR ant conductor of 211 Ampere current carrying capacity is used up to node number 16 and PVC cable is applied for all rest of the nodes. The data collected by field survey is depicted in Table 3. The number of three phase and single phase consumers connected with LVDN of 100kVA transformer are 3 and 152, respectively.

The voltage profile of Fig. 6 indicates that there is maximum voltage drop of 10.7, 10.6 and 10.1% at node number 16, 15 and 14 respectively. The drop at node number 1-4, 7, 8, 10, and 24 is within the acceptable range of IEEE ± 5%. The voltage drop at all the remaining nodes is beyond the IEEE permissible value.The application of CADPAD software suggested the change of PVC cable to ACSR ant conductor of 211 ampere of current carrying capacity. The re-conductoring of identified nodesbrings the voltage drop within IEEE standard of ± 5%.The voltage profile for existing and proposed system is shown in Fig. 6. The power loss curve for existing and proposed system is presented in Fig. 7. The curve indicates the maximum power loss of 0.328kW at node number 1.The maximum flow of load current causes the maximum power loss at initial nodes.

The energy loss calculations for LVDN of village Banth are shown in Table 4. Total units sent through transformer of 100kVA are 33820 kWh. The units charged through 155 consumers are 22687kWh. The total loss of energy is 11133kWh. The technical loss of energy calculated is 872kWh. The other loss is 10261kWh. In this way, the percentage of technical loss, other loss and total loss of energy is 2.58, 30.34 and 32.92% respectively.

4.3 Case Study-3

The single line diagram of LVDN of village Pothi-Mandra Rawalpindi Sub-Division IESCO, Islamabad is presented in Fig. 8. The circuit is 1.22kM long, having 22 numbers of nodes. ACSR ant conductor having a current capacity of 211 amperes is used. The data collected through field visit is shown in Table 5.The number of three phase and single phase consumers connected with 100kVA transformer of LVDN are 1 and 179, respectively.

The voltage profile of LVDN is depicted in Fig. 9. The detailed investigation delineates that there is maximum voltage drop of 15.8, 15.7, 15.6, and 15.1% at node number 15, 14, 13, 12, and 11, respectively. The voltage at remaining nodes is within the permissible limit of 5%. The implementation of CADPAD software proposes the installation of one number capacitor of 10 kVAR rating at optimal location of node number 10.

The proposed curve of Fig. 9 indicates that the voltage at all the nodes is within the acceptable limits of ± 5%. Power curve of Fig. 10 shows that there is maximum power loss of 0.293 and 0.284kW at node number 2 and 3, respectively. Application of 10kVAR capacitor reduces power loss to 0.05kW or below at all the nodes of LVDN.

The energy loss calculation for LVDN of village Pothi-Mandra has also been carried out for a period of one month. The units sent through transformer were 9851kWH. The units charged through80 consumers connected with the transformer were 7912kWH. Total loss was 1939kWH and technical losses calculated through the application of software were 143kWH. Other loss was 1796kWH. Percentage of technical loss, other loss and total loss were 1.45, 15.23 and 19.68%, respectively. The detail of energy loss calculation is presented in Table 6.

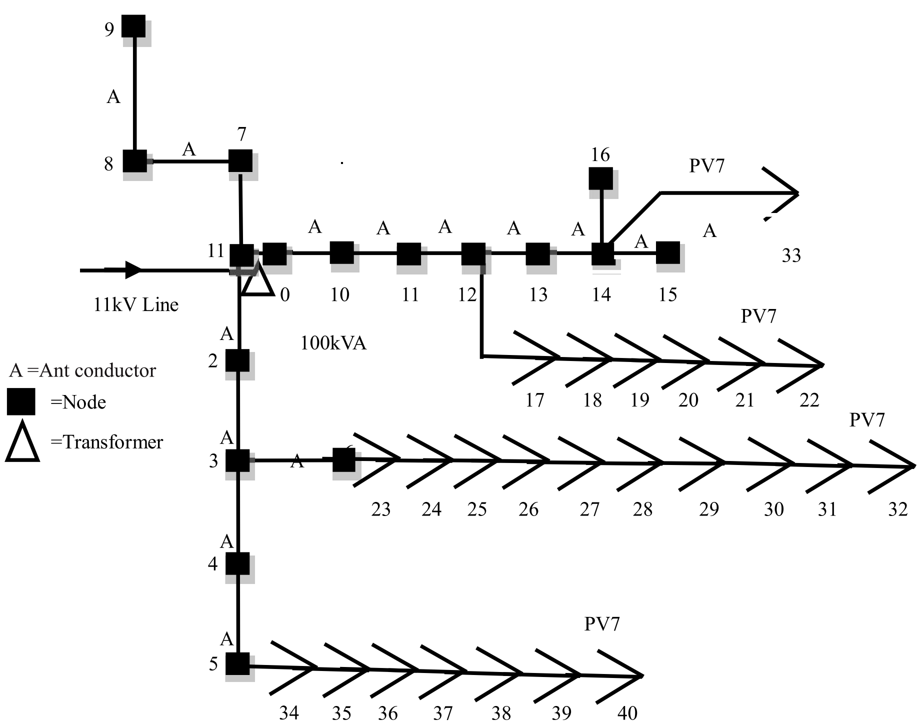

FIG. 5. SINGLE LINE DIAGRAM OF LVDN OF BANTH, RAWILPINDI SUBDIVISION (PAKISTAN)

TABLE 3. LOAD FLOW ANALYSIS FOR 100KVA TRANSFORMER OF BANTH (MANDRA) RAWALPINDI SUBDIVISION IESCO ISLAMABAD (PAKISTAN)

Node		Section Length (kM)	3-ϕ Load (kVA)	1-ϕ Cons kVA	kVA	Cumulative kVA	Conductor	Amperes	Load (%)	Voltage Drop (%)	Voltage Drop (prop) (%)	P.Loss (%)	P.Loss (prop) (%)
From	To												
0	1	0.002	0	0	0.00	77.00	A	155.0	73	0.10	0.10	0.328	0.002
1	2	0.085	0	0	0.00	29.50	A	59.00	28	1.80	1.50	0.187	0.004
1	7	0.061	0	1	0.05	8.00	A	16.00	8	0.40	0.40	0.101	0.003
1	10	0.082	0	0	0.00	40.00	A	80.00	38	2.30	1.30	0.030	0.020
2	3	0.088	0	0	0.00	11.50	A	23.00	11	2.50	1.50	0.010	0.001
2	6	0.095	0	0	0.00	18.50	A	36.00	17	2.90	1.20	0.002	0.001
3	4	0.088	0	0	0.00	11.50	A	23.00	11	3.20	1.00	0.123	0.0 20
4	5	0.091	0	0	0.00	11.50	A	23.00	11	3.90	2.90	0.112	0.010
5	34	0.030	0	2	1.00	11.50	PV7	23.00	72	5.90	5.00	0.054	0.040
6	23	0.014	0	2	1.00	18.00	PV7	36.00	113	4.30	4.00	0.034	0.030
7	8	0.091	1	6	3.00	07.50	A	15.00	7	0.90	0.50	0.016	0.010
8	9	0.091	0	8	4.00	04.00	A	08.00	4	1.10	1.00	0.007	0.005
10	11	0.088	0	0	0.00	40.00	A	80.00	38	4.60	4.00	0.139	0.130
11	12	0.085	2	8	4.00	40.00	A	80.00	38	6.90	5.00	0.098	0.080
12	13	0.091	0	5	2.50	27.50	A	55.00	26	8.60	4.50	0.129	0.020
12	17	0.018	0	2	1.00	7.50	PV7	15.00	47	7.70	5.00	0.158	0.150
13	14	0.091	0	0	0.00	25.00	A	05.00	24	10.1	4.50	0.012	0.010
14	15	0.095	0	15	7.50	07.50	A	15.00	7	10.6	4.30	0.143	0.040
14	16	0.095	0	20	10.00	10.00	A	20.00	9	10.7	5.00	0.069	0.060
14	33	0.095	0	15	7.50	07.50	A	15.00	7	10.6	4.00	0.137	0.130
17	18	0.012	0	1	0.50	06.50	PV7	13.00	41	8.10	3.50	0.127	0.120
18	19	0.012	0	3	1.50	06.00	PV7	12.00	38	8.50	5.00	0.038	0.035
19	20	0.009	0	4	2.00	04.50	PV7	09.00	28	8.70	4.10	0.069	0.065
20	21	0.018	0	3	1.50	02.50	PV7	05.00	16	9.00	4.30	0.153	0.006
21	22	0.009	0	2	1.00	01.00	PV7	02.00	6	9.10	5.00	0.155	0.003
23	24	0.006	0	3	1.50	17.00	PV7	34.00	106	4.90	4.50	0.123	0.004
24	25	0.009	0	1	0.50	15.50	PV7	31.00	97	5.70	5.00	0.036	0.006
25	26	0.014	0	2	1.00	15.00	PV7	30.00	94	6.90	4.00	0.019	0.005
26	27	0.018	0	4	2.0	14.00	PV7	28	88	8.3	5.00	0.328	0.050
27	28	0.014	0	5	2.5	12.00	PV7	24	75	9.3	3.00	0.187	0.008
28	29	0.012	0	7	3.5	9.5	PV7	19	59	9.9	3.50	0.101	0.010
29	30	0.009	0	5	2.5	6.0	PV7	12	38	10.2	3.80	0.030	0.007
30	31	0.009	0	4	2.0	3.5	PV7	7	22	10.4	4.50	0.010	0.006
31	32	0.009	0	3	1.5	1.5	PV7	3	9	10.5	4.80	0.002	0.001
34	35	0.012	0	1	0.5	0.5	PV7	21	66	6.6	5.00	0.123	0.003
35	36	0.012	0	4	2.0	2.0	PV7	20	63	7.3	2.40	0.112	0.012
36	37	0.009	0	5	2.5	2.5	PV7	16	50	7.7	2.00	0.054	0.020
37	38	0.012	0	4	2.0	2.0	PV7	11	34	8.1	5.00	0.034	0.010
38	39	0.014	0	3	1.5	1.5	PV7	7	22	8.4	4.50	0.016	0.005
39	40	0.018	0	4	2.0	2.00	PV7	4	13	8.6	5.00	0.007	0.005

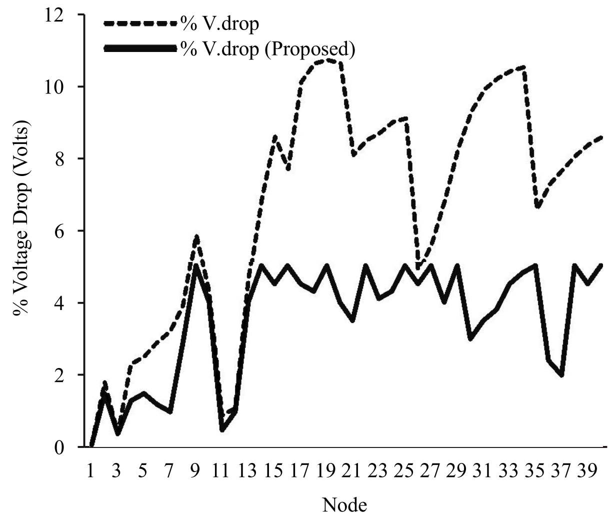

FIG.. 6. VOLTAGE PROFILE OF LVDN OF BANTH, RAWILPINDI SUBDIVISION (PAKISTAN)

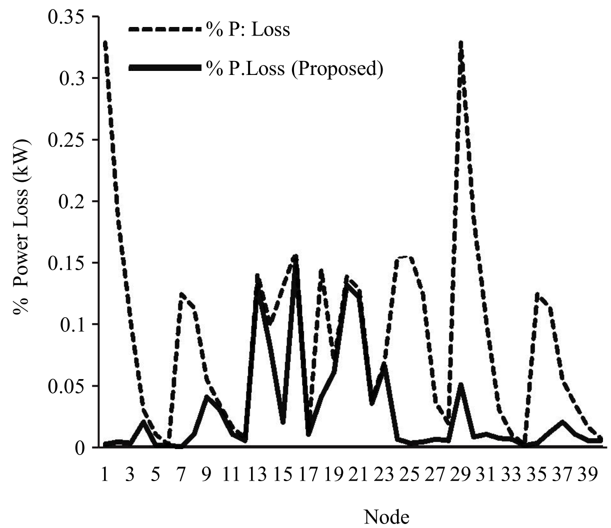

FIG. 7. POWER LOSS CURVE OF LVDN OF BANTH, RAWILPINDI SUBDIVISION (PAKISTAN)

TABLE 4. ENERGY LOSS CALCULATIONS FOR VILLAGE BANTH (MANDRA) RAWALPINDI (PAKISTAN)

No.	Reading	Units (kWH)
1.	Units sent through transformer	33820
2.	Units billed	22687
3.	Total loss	11133
4.	Technical loss	872
5.	Other loss	10261
6.	Technical loss	2.58%
7.	Other loss	30.34%
8.	Total loss	32.92%

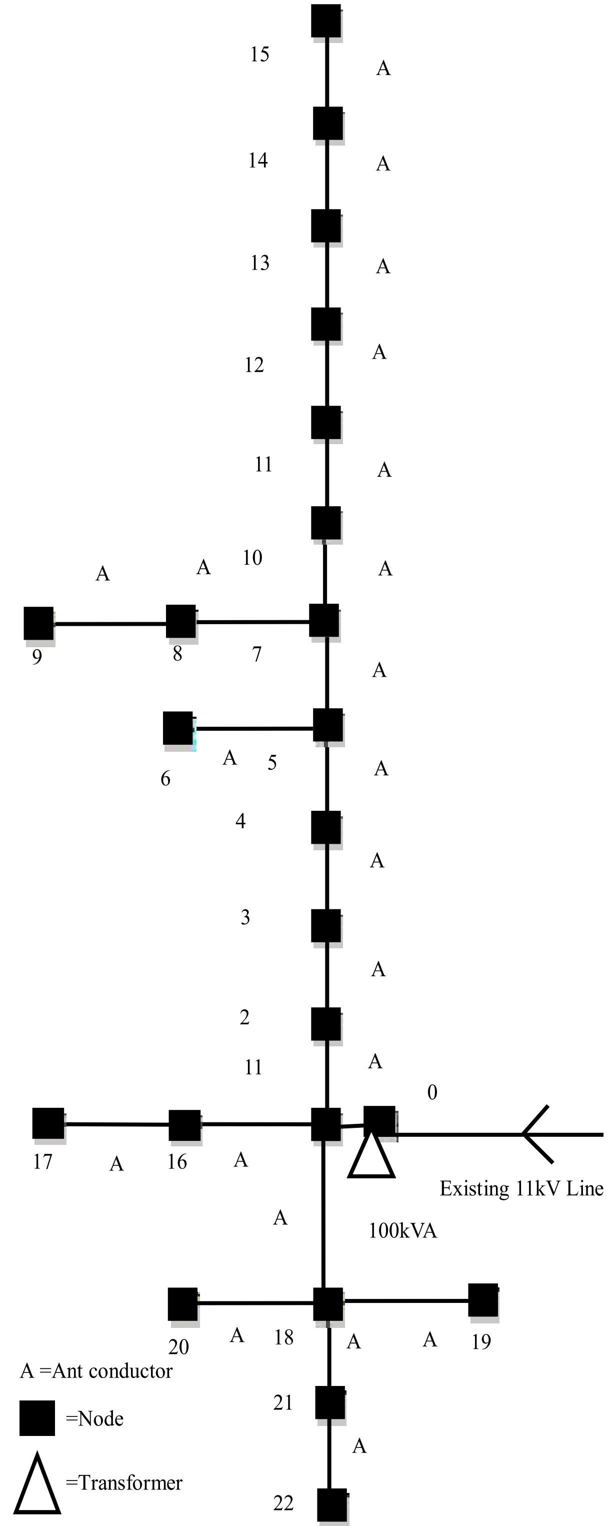

FIG.. 8. SINGLE LINE DIAGRAM OF LVDN OF POTHI-MANDRA, RAWILPINDI SUBDIVISION (PAKISTAN)

TABLE 5. LOAD FLOW ANALYSIS FOR 100KVA TRANSFORMER OF POTHI(MANDRA) RAWALPINDI SUBDIVISION IESCO ISLAMABAD (PAKISTAN)

Node		Section Length (kM)	3-ϕ Load (kVA)	1-ϕ Cons kVA	kVA	Cumulative kVA	Conductor	Amperes	Load (%)	Voltage Drop (%)	Voltage Drop (prop) (%)	P.Loss (%)	P.Loss (prop) (%)
From	To												
0	1	0.002	0	0	0.0	39.5	A	57.0	27	0.0	0.0	0.013	0.012
1	2	0.061	0	1	0.5	34.0	A	49.1	23	1.0	1.0	0.293	0.009
1	16	0.061	0	4	2.0	3.5	A	5.1	2	0.1	0.1	0.003	0.001
1	18	0.061	0	0	0.00	2.0	A	2.9	1	0.1	0.1	0.001	0.001
2	3	0.061	1	9	4.5	33.5	A	48.3	23	0.2	0.2	0.284	0.003
3	4	0.058	0	3	1.5	28.5	A	41.1	19	2.8	2.5	0.195	0.050
4	5	0.055	0	5	2.5	27.0	A	39.0	18	3.5	3.0	0.167	0.007
5	6	0.058	0	2	1.0	1.0	A	1.4	1	3.5	3.1	0.000	0.000
5	7	0.061	0	1	0.5	23.5	A	33.9	16	4.2	4.0	0.140	0.010
7	8	0.058	0	3	1.5	4.0	A	5.8	3	4.3	4.1	0.004	0.003
7	10	0.058	0	8	4.0	19.0	A	27.4	13	4.7	4.2	0.087	0.050
8	9	0.055	0	5	2.5	2.5	A	3.6	2	4.4	4.3	0.001	0.001
10	11	0.061	0	10	5.0	15.0	A	21.6	10	15.1	5.0	0.057	0.050
11	12	0.058	0	8	4.0	10.0	A	14.4	7	15.4	4.5	0.024	0.020
12	13	0.058	0	5	2.5	6.0	A	8.7	4	15.6	5.0	0.009	0.005
13	14	0.055	0	3	1.5	3.5	A	5.1	2	15.7	4.2	0.003	0.002
14	15	0.058	0	4	2.0	2.0	A	2.9	1	15.8	4.0	0.001	0.001
16	17	0.055	0	3	1.5	1.5	A	2.2	1	0.1	0.1	0.001	0.001
18	19	0.058	0	1	0.5	0.5	A	0.7	0	0.1	0.1	0.000	0.000
18	20	0.005	0	1	0.5	0.5	A	0.7	0	0.1	0.1	0.000	0.000
18	21	0.005	0	1	0.00	1.0	A	1.4	1	4.5	4.0	0.000	0.000
21	22	0.058	0	2	1.00	1.0	A	1.4	1	5.0	4.8	0.000	0.000
21			0				A			5.6	5.0		

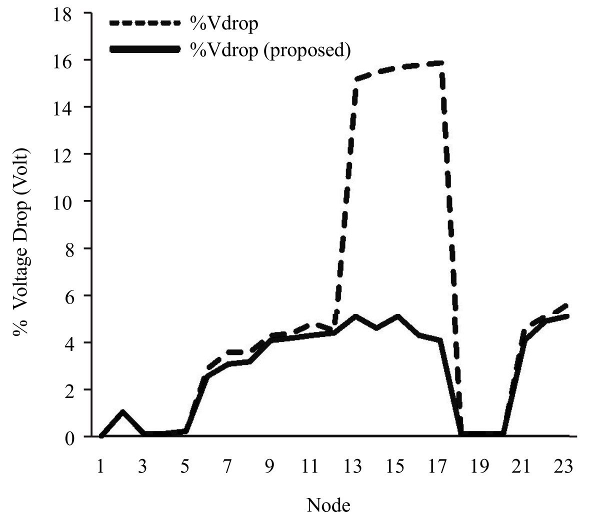

FIG.. 9. VOLTAGE PROFILE OF LVDN OF POTHI-MANDRA, RAWILPINDI SUBDIVISION (PAKISTAN)

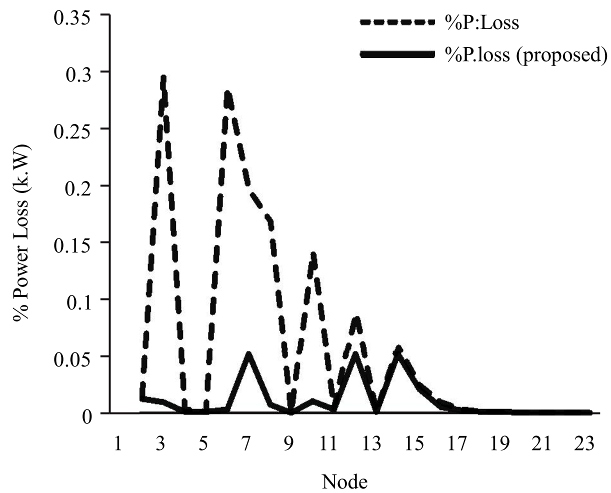

FIG. 10. POWER LOSS CURVE OF LVDN OF POTHI-MANDRA, RAWILPINDI SUBDIVISION (PAKISTAN).

TABLE 6. ENERGY LOSS CALCULATIONS FOR VILLAGE BANTH (MANDRA) RAWALPINDI SUB-DIVISION (PAKISTAN)

No.	Reading	Units (kWH)
1.	Units sent through transformer	9851
2.	Units billed	7912
3.	Total loss	1939
4.	Technical loss	143
5.	Other loss	1796
6.	Technical loss	1.45%
7.	Other loss	15.23%
8.	Total loss	19.68%

5. CONCLUSION

In the competitive and deregulated environment, electric utilities particularly belonging to developing countries are facing the energy crises throughout the world. This research paper proposesan innovative hybrid rehabilitation technique for problematic LVDN. Non-uniform distribution of load, varying power factor, loose joints, leakage current and the use of low current carrying capacity conductors are primarily responsible for voltage drop and power loss in low voltage distribution networks.

Three different overloaded LVDN have been analyzed, using the hybrid rehabilitation technique. The elaborative results are presented in the case studies. These results are verified and are within the permissible limits. Because of modular programming approach,the technique is simple in structure, flexible and easy to implement. Load forecasts are made on the basis of load data. Majority of the data collected is based on the information provided by the customer's application forms which is usually not 100% accurate. On the basis of incorrect data, the complexities arise during the design of LVDN.The hybrid rehabilitation technique can calculate different segments data automatically. The application of technique not only eliminates the problem of node voltage drop and power loss but significantly increases the stability of such LVDN. Results in the case studies delineates that the technique can be applied both for identifying the problematic nodes as well as the optimal placement of capacitors and distribution transformers. The technique can be utilized effectively to enhance the performance of LVDN. The end customers can be benefited significantly by integrating the technique with LVDN.

6. NOMENCLATURE

AMI	Advance Metering Infrastructure
ALT	Automatic Load Transfer
DFR	Distribution Feeder Reconfiguration
ΔP_{TF}	Power loss in Distribution Transformer
ΔP	Overall Power Loss
P_{loss}	The Total Power Loss for "n" Segment
R_i	Resistance of the i^{th}Transformer
R_j	Resistance of j^{th}Branch.
N_b	Branches of Distribution Network
I_i, I_j	The Relevant Currents
CADPAD	Computer Aided Distribution Planning and Design
ELR	Energy Loss Reduction
EPDS	Electric Power Distribution System
IESCO	Islamabad Electricity Supply Corporation.
IEEE	Institute of Electrical and Electronic Engineering
LVDN	Low Voltage Distribution Networks
L_i	Supplied Load at i^{th} Node per Unit
N	Number of the Nodes.
V(nom)	Nominal Voltage per Unit
V(max)	Maximum Voltage per Unit
V(min)	Minimum Voltage per Unit
VP1	Voltage Profile Improvement
V_i	Any Voltage per Unit at i^{th}Node
V_s	Sending End Voltage of the Distribution Network.
V_{drop}	Total Voltage Drop
V_r	Receiving End Voltage of the Distribution Network
VP_{2i}	Voltage Profile at i^{th}Node with W_i
W_i	Weighting Factor
WAPDA	Water and Power Development Authority

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