Identification of Power Losses in High and Low Tension Distribution Systems in Pakistan

S. Katyara, M.A. Shah, B.S. Chowdhary

***Abstract* — Power Loss in the utility distribution system is the key factor to identify the reliability and economy of Distribution Companies (DISCOs). The power loss depicts the state of electric meter evaluation systems along with the efficacy of the distribution network. Since the Pakistan is a developing country, and due to the lack of load management system, it is facing daunting load shedding and frequent power interruptions. Even though the power theft is a key factor to this loss but the technical losses caused by traditional distribution networks and their unplanned operations contribute significantly to power losses.**

This research work accounts for the power losses in the distribution network of Sukkur Electric Power Company (SEPCO) distribution network due to significant load imbalance and their mitigation methods. Since the mitigation of power loss in the distribution network is a complex issue, which requires an extensive qualified personnel and huge expenditure. But this research presents more economic method for power loss reduction called load balancing method. After Analyzing SEPCO distribution network, it has been observed that less attention was paid to phase loading problems. In order to reduce the methodological power loss by load balancing, some calculating algorithms are used to find out the load imbalance. Along with SEPCO network, it is recommended that load balancing is also necessary for all the other distribution companies in Pakistan. It is observed via the calculations performed in this research that the power loss on the low tension side was reduced from 283.89 kW to 222.29 kW and 5.89 kW on high tension side of one of the SEPCO distribution networks. The results obtained in this paper revealed that by implementing the proposed method, a significant amount of power loss can be avoided. This subsequently increases the system efficiency and proves to be an economical solution for both the parties i.e. the user and the supplier.

***Index Terms* — Mitigation technique, Phase load balancing, Power loss reduction, SEPCO distribution network, Symmetrical Components**

I. INTRODUCTION

Power losses occurring in utility distribution network undoubtfully are affecting its performance in financial manner and also cause reduction in the useful power output. Power utility consumers in Pakistan are facing unscheduled long-term power interruptions due to daunting energy crisis caused by increased load demand and huge power losses. There are two broad categories of power losses i.e. technical and non-technical losses [1]. Technical losses are caused by current interaction with resistance, commonly known as Ohmic losses, while non-technical losses are due to mismanagement and unplanned administrative procedures.

Sukkur Electric Power Company (SEPCO) is one the main electricity distribution companies in Pakistan, that supplies electricity to the most of lower part of Sindh Province in Pakistan. Generally performance of Pakistan's power sector is badly affected by the problem of power losses and particularly in SEPCO distribution network. According to 2015 survey by NTDC, SEPCO is the top most distribution company contributing to power losses.

Power loss (P_{Loss}) calculation in distribution network is typically calculated by deducting billed power (P_{Billed}) from the supplied power ($P_{Supplied}$) as shown in (1) [2].

$$P_{Loss} = P_{Suppled} - P_{Bill} \qquad (1)$$

Three phase balanced power system is usually described by equal current flows in all the three phases at the same voltage [2-3]. Unbalancing in Electrical system network can be initiated by one of following reasons

1. Unequal loading on different phases.
2. Tripping of power lines and partial operation of power lines and equipment.
3. Unequal system parameters in various phases.

Imbalanced loading and associated voltage in power network are mainly caused by domestic single phase devices of small power rating [4]. The quantity of such domestic appliances is large in number and needs to be distributed equally in all the phases to avoid imbalances in loads. Imbalanced loading does not only contribute to the increased power losses but also causes reduction in efficiency [5-6], increase in heating, reduction in effective torque and reduction in the speed of synchronous induction motors. Imbalance loading may cause transients in a particular phase and unnecessary line tripping and current magnitude in a particular phase may reach to higher value and since the ohmic loss in power changes with the magnitude of current [7].

Zero sequence voltage (V_0) and current (I_0) along with negative sequence voltage (V_2) and current (I_2) are the results on imbalance loading [8] and may cause increased power loss and affects the performance and operation of distribution network. The zero and negative sequence currents (I_0 & I_2) cause increased power loss in power system branches while zero and negative sequence voltages (V_0& V_2) result in increased power loss in the sectional region of power system branches [9].

Superposition of V_0 and V_2 results in deviation of voltage angle in different phases and this angle might cross the limits

S.katyara and M.A Shah, Department of Electrical Engineering, Sukkur IBA, B.S. Chowdhary, Department of Electrical Engineering, Mehran UET, Jamshoro. Email: 11elattitude@gmail.com. Manuscript received July 8, 2016; revised on Aug 25, 2016; accepted on Sep 17, 2016.

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[10]. The superposition of I_0 & I_2 results in increased total current in various phases that causes reduction in the declared capacity of overhead lines, cables, transformers and other system elements.

System balancing may be implemented by mitigation of zero and negative sequence voltages and currents [11]. On system's well organized load duration curve, reduction in systematic voltage imbalance can be done by balancing the loads in all phases of system through transition period of load from overload phases to underload phases. Equal load distribution does not constantly reduce the imbalance parameter to the required point. In those cases it is necessary to install phase shifting transformers, star connected capacitor banks or any other balancing facility. For balancing single phase loadings, circuits using inductive loads are established. It is so much economical to use capacitive balancing networks which do not only balance the loads but also provide reactive power compensation.

In order to reduce imbalance in three phase four wire distribution network of 11 kV feeder of 132 kV grid Station Larkana, SEPCO, method was implemented, so that the zero sequence impedance (Z_0) and zero sequence current (I_0) in the system should be decreased. The mitigation of I_0 is done through load relocation [12]. Load balancing is done through circuits in which transformers operating in parallel should be linked on the low tension side of windings. In the overhead line system, Z_0 is reduced by increasing line length while in cable Z_0 is reduced by increasing its cross sectional area based on economic calculations of technical standardization [13].

II. LOAD BALANCING CALCULATIONS FOR SEPCO NETWORK

Electrical Distribution system is responsible for supplying three phase as well as single phase loads. Some countries have single phase transformers and laterals for supplying single phase loads. While in Pakistan single phase loads are supplied by three phase four wire distribution system that causes imbalance in distribution system. Along with imbalance created by single phase loads, three phase loads may also develop imbalance state due to open or short circuit conditions in both three-phase and single phase.

The one line diagram for SEPCO network developed in PSS-SINCAL softwre is shown in Fig-1, comprises 70 grid stations. Each grid station is supplying electricity in its respective territory of lower Sindh. For technical realization, the 132 kV Grid Station Larkana was considered in this research and this idea may be applied to the whole network and even to all of the DISCOs in Pakistan then. This proclamation has been proved by current level of power

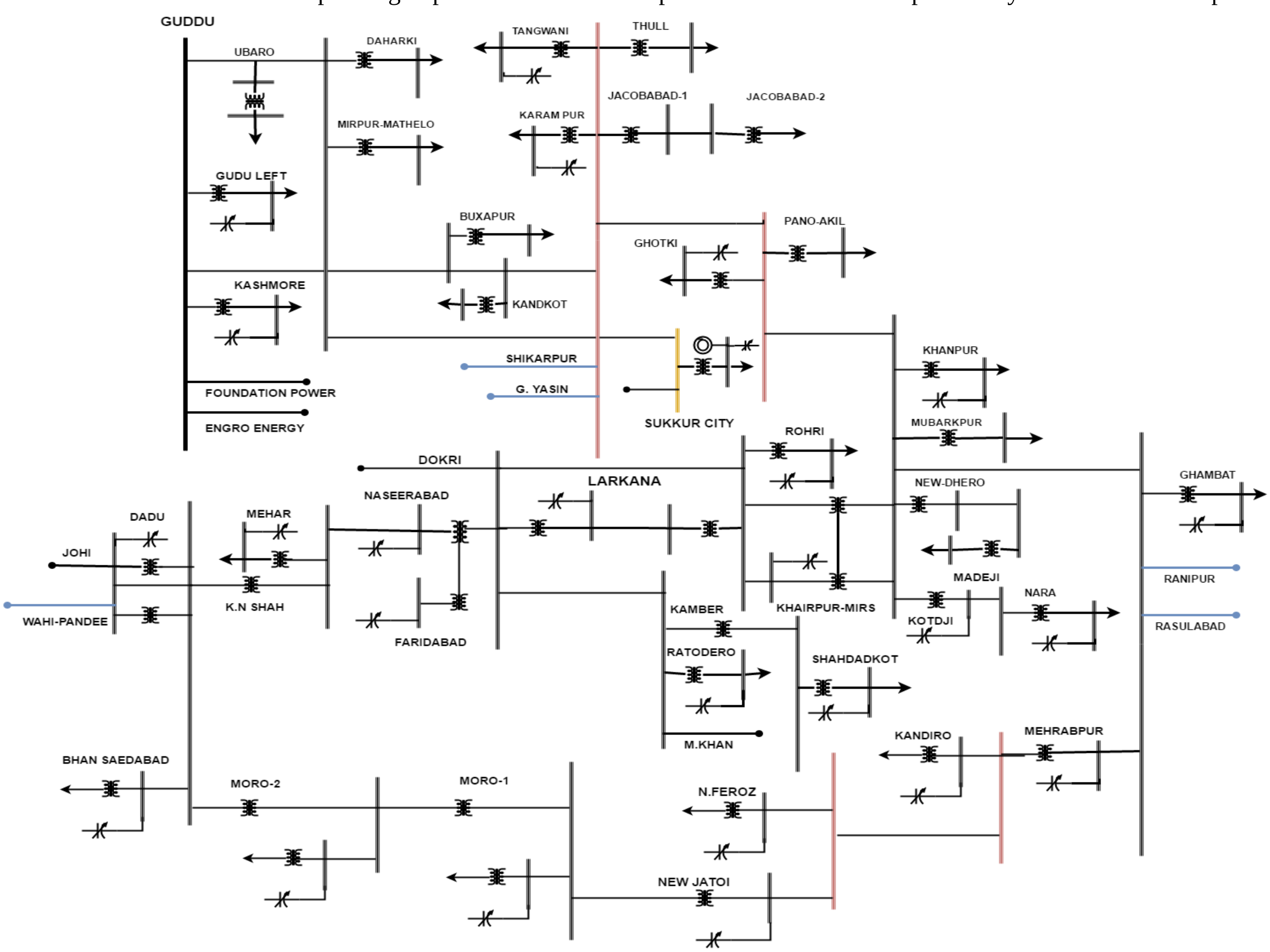

Fig. 1 One-line diagram of SEPCO network generated by E- Simulation

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losses in one of the 11 kV feeder of 132 kV Larkana Grid Station of SEPCO distribution network.

According to the survey conducted in 2015, it was found that power losses in the SEPCO distribution network of Larkana are 34.28 % [14], which is equal to around 1320 units loss per month. With an average unit cost of Rs. 15.00/ kWh, the annual wastage of money only for Larkana grid is approximately Billion Rs. 3.414 billions, which is due to technical power losses and power theft. These losses can be controlled by reducing technical losses proposed in this research.

The research addresses the goal of describing the influence of non-linear and imbalance loads on power system therefore one 132 kV Grid station Larkana is

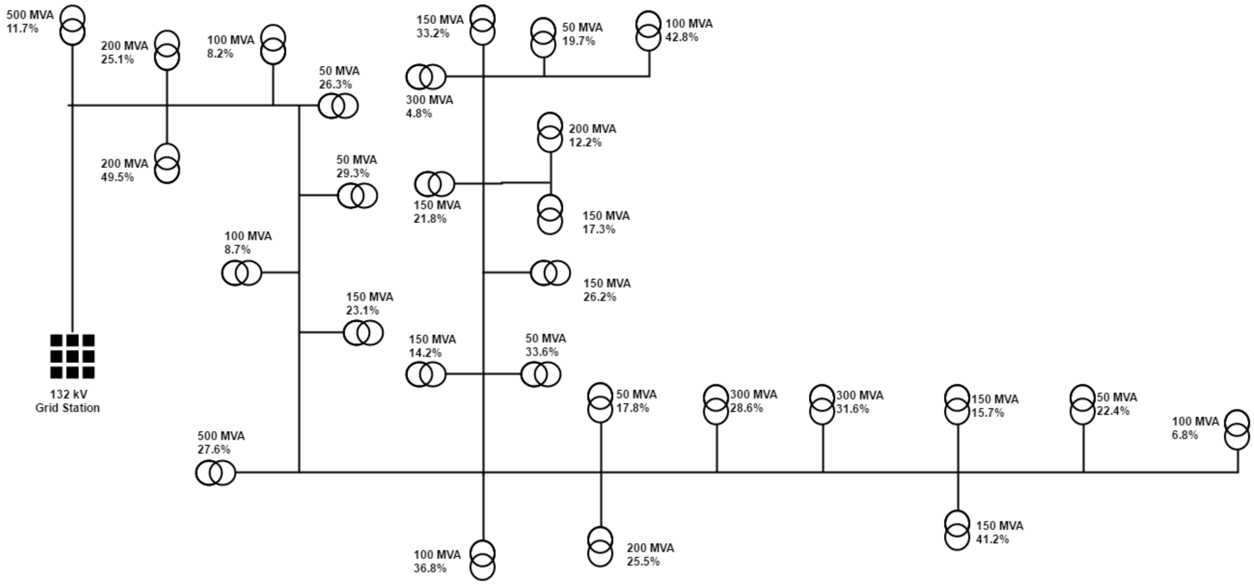

Fig. 2. 11 kV Dhari Distribution Feeder from 132 kV Larkana Grid Station

selected from SEPCO distribution network, which supplies power to mainly Larkana district and its nearby surroundings. In this connection, one 11 kV Dhari feeder is taken into consideration at initial stage and that concept can be implemented on whole SEPCO network The under consideration 11 kV Dhari feeder is actually the distribution side for power consumers that supplies electricity to 28 transformers around its surroundings as shown in Fig.2.

Fig. 2 shows that all the 28 transformers supplied by Dhari feeders are overloaded unreliably during summer days and hence maximum imbalance can be recorded during this span of time.

III. RESULTS & DISCUSSIONS

In this research work PSS-SINCAL software has been used to visualize the real time distribution network of SEPCO. PSS-SINCAL software is SIEMENS based German tool, which is commonly used to perform load flow studies, voltage dips and sigs calculation, short circuit analysis, power loss evaluation at different stages of power system etc.

In order to calculate the power losses occurring due to imbalance load distribution, the proposed balancing method used is described. Before implementing this method, the losses on low tension side distribution feeder accumulated by all the transformers were 283.89 kW. But after the application of load balancing method, the power losses reduced to 222.29 kW as shown in Table-2. Table-1 illustrates the rating of different transformers installed over Dhari feeder.

TABLE 1. Transformers' Ratings for 11 KV Dhari feeder of 132 KV LARKANA Grid Station (SEPCO)

Quantity	Transformer's Rating (KVA)	Total Capacity (KVA)
6	50	300
5	100	500
8	150	1200
4	200	800
3	300	900
2	500	1000
	Total	4700

The main purpose of above discussed calculations is to decrease the amount of technical power losses occurring in SEPCO distribution network in Larkana area. Power Transformer losses (E_T) consist of no-load losses (ΔE_{NL}) and load losses (ΔE_L) [16].

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Therefore, mathematically it can be shown as:

$$\Delta E_T = \Delta E_{NL} + \Delta E_L \quad \text{kWh} \qquad (2)$$

Equation (2) [1] calculates power losses for transformers and since power loss at no load which is actually due to magnetizing current can be calculated by (3)

$$\Delta E_{NL} = \Delta W_{NL} \times T \times 10^{-3} \quad \text{kWh} \qquad (3)$$

Where ΔW_{NL} is the idle no load loss obtained from the name plate of Transformer in kW and T is the running time of transformer in hours.
Load power losses can be calculated by (4) [1]

$$\Delta E = \frac{[\{(E_P^2 + E_Q^2)\times k_f^2\}\times R_{EQ}]}{[V_{EQ}^2 \times T]} \qquad (4)$$

Where E_p and E_Q are the active and reactive powers appearing at transformer windings in "kWh" and "10^3 kWh" respectively. V_{EQ} is the equivalent voltage which is taken equal to the normal voltage of system $V_{norm.}$ R_{EQ} is the equal resistance of winding in ohms, and $k_f$is the form factor of load.

Sometimes form factor of load and its reactive energy consumption may not be declared. In such cases, the following (5) [1] is used to calculate energy consumption of load.

$$\Delta E_L = 1.63\left(\frac{E_P^2}{V_{norm} \times T}\right) R_{EQ} \quad \text{kWh} \qquad (5)$$

The correspondent resistance of system line which is actually a feeder line can be calculated by (6) [1]

$$R_{EQ} = \frac{r_0 \times l}{1000} \quad \text{ohms} \qquad (6)$$

Where r_0 is the specific resistance of power line in ohms/ Km and l is length of power line in meters.

Estimated and real power loss reduction by means of balancing the system (Unequal load distribution on various phases), can be calculated by (7) [6]

$$\partial E = \Delta E(K_{j1} - K_{j2}) \quad \text{kWh} \qquad (7)$$

Where ΔE is the power loss in 11 kV feeder circuit with balanced phase loads estimated by using (4) and K_{j1} & K_{j2} are the imbalance parameters before and after balancing of network, which can be determined by (8) [6]

$$K_j = [3\times(\frac{I_A^2 + I_B^2 + I_C^2}{I_A + I_B + I_C})]\times(l + 1.5\times\frac{R_0}{R_{PH}}) - (1.5\times\frac{R_0}{R_{PH}}) \qquad (8)$$

Where R_0/R_{PH} is the correspondence between the zero sequence and line phase resistances respectively and I_A, I_B, I_C are currents of three individual phases. Since the imbalance load data for various intervals can be obtained by installing smart meters at the distribution transformers.

When the values for load currents are missing, the following standard assumptions are used [15]

For lines with $\frac{R_0}{R_{PH}} = 1$ $K_j = 1.13$

For lines with $\frac{R_0}{R_{PH}} = 2$ $K_j = 1.2$

When the system is imbalanced, averaging current needs to be focused, so as to distribute the balance equally among all three phases and the average current for three phase currents can be calculated by (9) [1]

$$I_{avg} = \frac{(I_A + I_B + I_C)}{3} \qquad (9)$$

In order to visualize the imbalance, difference in the currents needs to be measured as in (10) [2]

$$I_D = \begin{vmatrix} I_A - I_{avg} \\ I_B - I_{avg} \\ I_C - I_{avg} \end{vmatrix} \qquad (10)$$

Therefore the percentage imbalance can be calculated by (11) [2]

$$\%I_{imbal} = \frac{\max(I_D)\times 100}{I_{avg}} \qquad (11)$$

The results calculated before and after balancing are shown in Table-2. It can be realized fromTable-2 that by using balancing method a major part of power can be saved, that proves to be economical for both customers and the producer.

TABLE 2. Power Loss Calculation Forum Balanced and Balanced Loadings On 11 KV Dhari feeder, Sepco Network

TRANSFOMER		**POWER LOSS (kW)**			
Serial No.	**KVA Rating**	**$\%I_{imbal}$**	K_{j1}	K_{j2}	K_{j1}-K_{j2}
1	100	36.8%	2.32	1.81	0.51
2	200	25.1%	12.35	11.17	1.18
3	200	49.5%	7.85	7.11	0.74
4	100	8.2%	5.26	3.67	1.59
5	50	26.3%	17.31	15.23	2.08

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6	50	29.3%	5.85	3.22	2.63
7	100	8.7%	11.47	9.68	1.79
8	150	23.1%	19.57	15.77	3.8
9	150	14.2%	11.48	9.87	1.61
10	150	21.8%	7.64	2.67	4.97
11	300	4.8%	15.64	13.91	1.73
12	150	33.2%	16.3	13.7	2.6
13	50	19.7%	3.4	1.8	1.6
14	100	42.8%	5.7	3.8	1.9
15	200	12.2%	8.87	6.14	2.73
16	150	17.3%	6.78	2.54	4.24
17	150	26.2%	13.98	11.23	2.75
18	50	33.6%	3.56	2.78	0.78
19	50	17.8%	1.23	1.02	0.21
20	200	25.5%	4.65	3.32	1.33
21	300	28.6%	13.67	11.51	2.16
22	300	31.6%	19.56	15.45	4.11
23	150	15.7%	8.57	5.64	2.93
24	150	41.2%	6.37	3.73	2.64
25	50	22.4%	0.87	0.34	0.53
26	500	27.6%	23.47	20.78	2.69
27	100	6.8%	8.72	6.83	1.89
28	500	11.7%	21.45	17.57	3.88
	Total		283.89	222.29	61.6

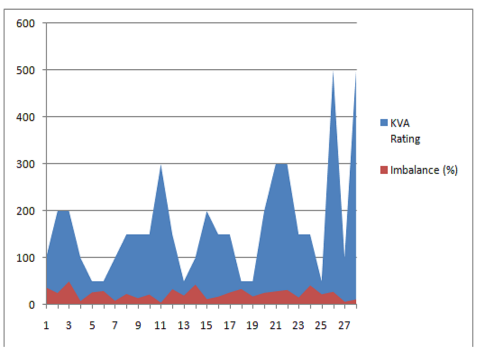

Fig. 3 Transformers' ratings and their unbalance loading

Fig. 3 depicts the respective unbalancing loading of different transformer against their rating installed over Dhari feeder.

IV. ECONOMIC EFFECTS

In order to increase the efficiency of distribution network and to meet the economical requirements of power, it is required to calculate the losses on high tension and low tension sides of system.

While referring equations (1-10) and Table-2, losses can be calculated on low tension (L.T) side by (12) [1] as under.

$$P_{LT} = \sum K_{j1} - \sum K_{j2} \quad (12)$$

$P_{LT} = (283.89\text{-}222.29) = 61.6$ kW

In order to calculate losses on high tension (H.T) side of distribution system equation (13) [6] is used.

$$P_{HT} = I^2 \times \left(\frac{\rho \times l}{A}\right) = 5.89 \text{ kW} \quad (13)$$

Equation (13) [6] calculates Ohmic losses on high voltage side of distribution system, which are actually winding resistance losses. Where ρ is the resistivity of winding wire, which on average is taken as 0.1 ohms / m

$$W = P_{LT} + P_{HT} \quad (14)$$

W = 61.6 + 5.89 = 67.49 kW

Equation (13) provides the overall losses on the Dhari distribution feeder.

TABLE 3. Economic effect outcome with cost recovery period for different Transformer bays

Transformer (KVA)	Same Rated Transformers Quantity	Cumulative Consumers	Reduction of power loss after implementing proposed method in (kW)	Saving after implementing balancing proposed method in (Million Rs.)	Expenditure for Implementing method in (Million Rs.)	Time for total cost recovery (Months)
50	6	69	7.83	0.3341	0.1013	4
100	5	113	7.68	0.3277	0.0993	4
150	8	218	25.54	1.0889	0.3301	4
200	4	137	5.98	0.2552	0.0773	4
300	3	189	8	0.3414	0.1035	4
500	2	195	6.57	0.2803	0.0849	4

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The financial saving of implementing the above discussed solution annually will be approximately Rs. 2.88 Millions as shown in Tabl-2 and the cost may be recovered in around 4 months as shown in Table-3, for implementing proposed techniques in SEPCO feeders. Table-1 presents the full hand capacity information of all 28 transformers, installed over 11 kV Dhari feeder. Table-2 concisely illustrates the percentage of imbalance at all 28 transformers and loss accumulation after implementing the balancing method. Table-3 shows the life span recovery for implementing such balancing method at different rated transformers.

V. CONCLUSIONS

On the basis of executed calculations, it is concluded that, the amount of technical losses occurring in 11 kV Dhari feeder, of 132 kV grid station Larkana in SEPCO distribution network is due to imbalanced load distribution before implementation of the proposed research. This data confirms that there was a big amount of electricity loss experienced in 11 kV Dhari feeder. By implementing the proposed research, it is proved that the losses could be reduced from 283.89 kW to 222.29 kW on the Low tension side of and a reduction of 5.89 kW in power loss could be achieved on High tension of one of SEPCO distribution network in the considered work area.

Application of load balancing reduces the methodological power losses in the small span of time with minimum expenditure. It is also worth noticing that all the distribution companies in Pakistan do not pay much attention to the power loss in distribution network, and greater revenue of distribution is lost due to that. In the conducted research on 11 kV Dhari feeder, which supplies electricity to 28 transformers, the maximum recorded percentage imbalance observed was on 200-kVA transformer that was 49.5%. The reason for this high imbalance was the implication of a B-16 wire size [13] of major overhead line. Over to this section of line, it is suggested that it must be replaced by a B-25 wire size [13]. With this change, the imbalance could be reduced from 49.5% to 32%. Finally it was also concluded that by load balancing, energy efficiency can be increased by load shifting and balanced planning by experienced personnel.

VI. FUTURE RECOMMENDATIONS

It is recommended that a validated imbalanced three phase power flow program may be used to determine the percentage imbalance in voltage and current throughout the circuit. The optimal voltage regulation method that produced the least voltage spread uses the Load Tap changing transformer, step regulators, capacitors and distributed generators. It is however recommended that these devices may be located at midpoint of the circuit to produce the best overall improvements in voltage regulation, loss reduction and released capacity. It is also recommended that the size of conductors used for feeder should be such that it should not heat up when distribution line has more than 3% voltage imbalance or more than 10% current imbalance.

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