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Energy Conservation Techniques to Mitigate the Power Shortage Problem in Pakistan (Case Studies)

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Abstract

The main objective of this research paper is to show benefits of different energy conservation techniques. As a first case study, I performed analysis on University of Gujrat, electrical power system. This case study involves analysis of motors and tube lights installed at the pumping stations and in Engineering Block of UOG respectively, with the help of energy analyzer before and after the installation of required rating capacitors. Power system analysis also done which includes power distribution system losses for example line losses and copper losses of different rating transformers of UOG. Cost and payback period calculation had been done. Second case study is performed on 11 KV Ali Park and Rachna Town feeders to show fruitful results obtained by implementing rehabilitation techniques on the above said feeders. The results showed by adopting energy conservation techniques not only energy is conserved, it also brings other benefits.

1.0 Introduction

As we know Power shortage is a greatest problem in Pakistan due to different reasons; as a result our nation facing the problem of load shedding. So we as a nation come together towards the solution of this problem and immediate solution lies in the conservation of energy. Our highest priority should be to conserve the energy. The specialty of electrical energy is that it is most convenient form of energy, as it can be transmitted, distributed and utilized over a very large area. The major portion of electricity generated is consumed by the industrial and then residential sector. They have to not only pay the high cost of electricity but also compel to purchase the costly equipment to use in the load shedding hours.

These effects altogether provide strong basis for reducing the electricity consumption. The development of technology will take considerable time as it has many basic problems, technical as well as economical. Thus immediate solution lies in the conservation of energy. As per WAPDA statistics cost of complete installation/ generation of a power house generating one KW of energy is approximately comes out to be US $ 4,50,000 and in Pak. Rupees it id Rs. 43,200,000 (W=where 1 US $ = @Rs. 96). From this statistics report it is cleared that investment made in the field of energy conservation yield in net overall saving along with other benefits. [1,2].

Improving energy efficiency in an electrical system has become the major issue. Because in recent years the nature of load has been changed drastically and large portions of electric machinery i.e. mercury lamps, transformers, motors, switchgears are used to run inherently low power factors which means power supply authorities have to generate much more current that is theoretically required So, in order to accommodate this increasing trend of low power factor & every day increasing load the current level on our system is needed to be reduced and every effort should be made to make this system more energy handling with minimum cost involved.

It may involve different techniques such as improving power factor, changing conductor size, substituting cables with conductor etc. this will lead to reduce copper loss as well as damp the heavy currents with out increasing system size in an efficient way [3].

2.0 Energy Analysis of UOG Power System (Case Study-I)

2.1 Analysis of (L.T Side of Transformers)

The calculations were performed by improving the power factor of each transformer installed in the UOG network from 0.7 to 0.95 at full load. Results were observed in the shape of % saving both in terms of KW and KVA. Total KVARs are required to achieve power factor were calculated at the end. Transformers Installed in the UOG Network are as under:-

1. 25 KVA = 01 No.
2. 50 KVA = 01 No.
3. 100KVA = 05 Nos.
4. 200 KVA = 20 Nos.

2.1.1 Saving of Transformer at Full Load (200 KVA) Improving Power Factor From 0.7 to 0.9

2.1.1.1 KVA Saving Calculation (200 KVA Transformer)

$KVA_1 = 200$

$Cos\phi_1 = 0.7$

$P = 200 \times 0.7 = 140$ KW

$KVAR_1 = Sin(Cos^{-1} 0.7) \times 200$
$= Sin(45.57) \times 200$
$= 142.65$ KVAR

Figure 1 shows the improvement in power factor by providing leading reactive power (KVARs). Practically this can be done by installing an adjustable capacitor in parallel with an inductive load. The load can be adjusted in such a way that the leading current to the capacitor is exactly equal in magnitude to the component of the current in the inductive load which in fact is lagging the voltage by 90^0. Thus the resultant current is in phase with the voltage.

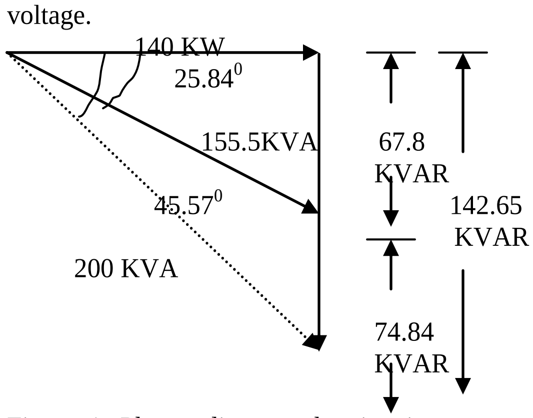

Figure 1**.** Phasor diagram showing improvement of PF by providing leading KVARs [5].

$Cos\phi_2 = 0.9$

$KVA = KW / Cos\phi$

$KVA_2 = 140/ 0.9 = 155.5$

$KVAR_2 = Sin(Cos^{-1} 0.9) \times 155. = 67.80$ KVAR

$$\text{Saving in KVA} = \frac{KVA_1 - KVA_2}{KVA1} \times 100$$

$$= \frac{(200 - 155.5)}{200} \times 100 = 22.2\%$$

2.1.1.2 KW Saving Calculation (200 KVA Transformer)

Figure 2 shows the saving in terms of KW by installing required rating capacitor in parallel with the inductive load. We can save 40 KW by improving power factor from 0.7 to 0.9.

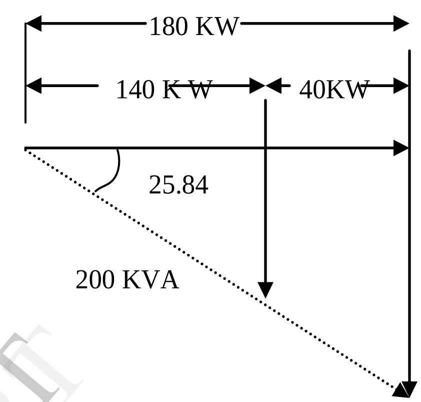

Figure 2. Phasor diagram showing saving in KW by installing capacitors of required rating [5].

For Active Power (KW)

$KW = KVA\ Cos\phi$

$P_I = 200 \times Cos\phi_2$
$= 200 \times Cos\phi_2$
$= 200 \times 0.9$
$= 180$ KW

Saving in KW $= 180 - 140$
$= 40$KW

$$\%\text{Age saving} = \frac{180 - 140}{140} \times 100 = 28.57\%$$

Similarly calculations were done to improve the power factor from 0.9 to 0.95. As WAPDA is planning to impose low power factor penalty charges on 0.95 power factor instead of 0.9.

2.1.1.3 Total KVAR required

KVAR required improving PF from 0.7 to 0.9= 74.84
KVAR for improving PF from 0.9 to 0.95 = 27.84
Total KVAR required for 20 Nos. Transformer =102.69x20=2053.8 KVAR

At present there are 20 Nos. of 200 KVA transformers in the UOG network. So for twenty 200KVA transformers in UOG distribution system KVARS required are 2053.8.

2.1.2 Cost of Power Factor Improvement Capacitors

The cost calculation is done for the installation of capacitors required in improving the power factor to desired level to avoid low power factor penalty charges. Table 1 & 2 shows the market price of both automatic and static capacitors available in different ratings [4].

Table 1. Market Price of Static Capacitors

Sr #	KVAR	440 VAC
1	5 KVAR Capacitor	Rs. 8000/-
2	7.5 KVAR Capacitor	Rs. 10,000/-
3	10 KVAR Capacitor	Rs. 16,000/-
4	12.5 KVAR Capacitor	Rs. 19,500/-
5	25 KVAR Capacitor	Rs. 32,000/-
6	50 KVAR Capacitor	Rs. 50,000/-
7	100 KVAR Capacitor	Rs. 90,000/-

Table 2. Market Price of Automatic Capacitors

Sr #	KVAR	440 VAC
1	25 KVAR Capacitor	Rs. 51,080/-
2	50 KVAR Capacitor	Rs. 91,200/-
3	100 KVAR Capacitor	Rs. 149,680/-

2.1.2.1 Cost of Capacitors Required for (200 KVA) Transformers at Full Load

Required KVARS for 1 # 200 KVA Transformer
= 103 KVAR
Total KVARS for twenty #200 KVA Transformers
= 2060 KVAR
Whereas
Cost for 100 KVARS 440 VAC Static Capacitor
= 90,000 Rs/-
Total cost of static capacitors for 20 Nos. transformers is: = Rs. 20x 90,000
= Rs. 1,800,000/-

Whereas
Cost for 100KVAR 440VAC Automatic Capacitor
= 149,680 Rs/-
Total cost of automatic capacitors for 20 Nos. transformers is: = 20 x 149,680
= Rs. 2,993,600 /-

2.1.2.2 Cost of Capacitors Required for (100 KVA) Transformers at Full Load

Required KVARS for 01# 100 KVA Transformer
= 51 KVAR
Total KVARS for 05 # 100 KVA Transformers
= 255 KVAR
Whereas
Cost for 50 KVAR 440 VAC Static Capacitor
= Rs. 50,000/-
Total cost of static capacitors for 05 Nos. transformers is: = 05 x 50,000 = Rs. 250,000/-
Whereas
Cost for 50 KVAR 440 VAC Automatic Capacitor
=Rs. 91,280
Total cost of automatic capacitors for 05 Nos. transformers are: = 05 x 91.28 = Rs. 456,400/-
= Rs. 2,993,600 /-
Similarly calculations were done for 50 and 25 KVA Transformers respectively.

Hence Total Cost for all the Static Capacitors:
1. 01 x 25 KVA Transformer =Rs. 19,500/-
2. 01 x 50 KVA Transformer=Rs. 32,000/-
3. 05x100 KVA Transformers=Rs. 250,000/-
4. 20x200KVATransformers=Rs. 1,800,000/-

Grand Total = Rs. 2,101,500/-

Hence Total Cost for all the Automatic Capacitors:
1. 01 x 50 KVA Transformer = Rs. 50,070/-
2. 05x100 KVA Transformers=Rs. 456,400/-
3. 20x 200 KVA Transformers = Rs. 2,993,600/-

Grand Total = Rs. 3,500,070/-

2.2 Energy Analysis of Motors

For the comprehensive and complete analysis of motors installed at the pumping stations of the UOG, energy analyzer equipment was used. In the analysis procedure energy analyzer was attached with the motor installed while keeping the load on the motor ON and complete set of data was obtained showing the frequency, current in each phase, line current, line voltage in each phase, power factor, active power, apparent power, reactive power, distortion factor, KWH, KVARH etc. This analysis was done to calculate what ratings of capacitors are required for the power factor improvement in addition to other outputs.

The complete set of analysis, which was done with the energy analyzer of all the motors installed in the pumping station, has been shown below in the tabular form. The final analysis after the installation of the required capacitors was done again to check the power factor improvement and what effects does this procedure has on the improvement of power factor. It was observe that power factor of the motors has been increased remarkably moreover other factor like voltage increase, current drawn decreases, decrease of KVA rating etc. Results of the analysis before and after the installation of capacitors have been shown below in Table 3.

Comparison of Different Parameters of Water Supply Motors before and after the Installation of Capacitors by Computerized Energy Analysis

1. Water Supply Motors

P = 40 HP, V = 415 Volts, I = 60 Amps.

Table 3. Showing Energy Analysis of Water Supply Motor

Phase	Current (Amps)		Voltage (Volts)		Power Factor	
	Before	After	Before	After	Before	After
L1	59.3	49.9	380.2	385.8	0.843	0.971
L2	57.6	48.1	378.7	384.0	0.841	0.981
L3	60.2	50.5	377.5	382.7	0.846	0.984
Mean	59.03	49.50	378.8	384.1	0.843	0.979

Phase	Active Power (KW)		Reactive Power (KVAR)		Apparent Power (KVA)	
	Before	After	Before	After	Before	After
L1	10.97	10.79	7.06	2.66	13.02	11.12
L2	10.95	10.46	6.83	2.55	12.59	10.67
L3	11.10	10.98	7.11	2.67	13.12	11.16
Total	32.67	32.24	20.99	7.87	38.73	32.94

Calculations:

Step -I

P.F before the installation of capacitor = 0.843

P.F after the installation of 20 KVAR capacitor = 0.979

So net % age increase of power factor $= \frac{PF1 - PF2}{PF1} \times 100$

$$= \frac{0.843 - 0.979}{0.843} \times 100$$

= 16.13 %

Step –II

Current before the installation of capacitor = 59.03 A

Current after the installation of 20 KVAR capacitor = 49.50A

So net % age difference in current decrease.

$$= \frac{I1 - I2}{I2} \times 100$$

$$= \frac{59.03 - 49.50}{49.50} \times 100 = 16.14\ \%$$

Step –III

Voltage before the installation of capacitor = 378.8V

Voltage after the installation of 20 KVAR capacitor =384.18V

So net % age difference in voltage increase

$$= \frac{V1 - V2}{V1} \times 100$$

$$= \frac{378.80 - 384.18}{378.80} \times 100 = 1.42\%$$

Step –IV

KVA before the installation of capacitor = 38.73 KVA

KVA after the installation of 20 KVAR capacitor = 32.94 KVA

So net % age difference in KVA decrease

$$= \frac{KVA1 - KVA2}{KVA1} \times 100$$

$$= \frac{38.73 - 32.94}{38.73} \times 100 = 14.94\%$$

There are three 40 HP water supply motors in University of Gujrat. Preceding analysis describes the energy analysis of one 40 HP motor. Other two 40 HP motors have the same energy analysis.

2.3 Energy Analysis of Different Loads Installed in Engineering Block Building of UOG

In order to implement the power factor improvement technique, analysis was made on the engineering block building with the help of energy analyzer after putting the entire load in ON condition at different time intervals.

Although building and effects were calculated with the help of energy analyzer. analysis is quite tricky because of variety of electrical equipment (different loads) has been installed in the engineering block building moreover due to large usage, load conditions vary from time to time. As an exercise, analysis was also made of the tube lights (inductive loads) installed in the engineering

Observations were taken after the installation of 4.5uF capacitor. As a sample case capacitor was installed on tube-lights at three to four different locations in the engineering block building. These observations were taken individually on each floor and effects were examined individually on each tube-light. It was observed that tube-lights fitted with 4.5uF shows improvement in power factor. If this procedure is repeated on all the installed tube lights in the engineering block building, it will bring a worth value improvement in the system capacity. The results taken have been placed in the tabular form below. It was observed that power factor of the total system has been increased, other factors like voltage increase, decrease of KVA rating etc. Results of the analysis before and the installation of capacitors have been shown in the table 4 below.

Total no of tube lights in engineering block = 247
The detail is as under:
Ground Floor: Total no of tube lights = 89
First Floor: Total no of tube lights = 89
Second Floor: Total no of tube lights = 89

2.3.1. Computerized Energy Analysis & Comparison of Engineering Block Building Before and After the Installation of Capacitors

1. First Floor Analysis

P = 40 x 247 = 7.88 KW, Vp = 221.63 Volts
I = 74.1 Amps (0.3 Amps each)

Table 4. Showing Energy Analysis of First Floor of Engineering Block Building

Phase	Current (Amps)		Voltage (Volts)		Power Factor	
	Before	After	Before	After	Before	After
L1	85.2	75.8	368.5	374.1	0.795	0.974
L2	70.3	60.8	395.1	400.4	0.825	0.987
L3	100.2	90.5	376.3	381.5	0.811	0.951
Mean	85.23	75.70	379.9	385.4	0.810	0.971

Phase	Active Power (KW)		Reactive Power (KVAR)		Apparent Power (KVA)	
	Before	After	Before	After	Before	After
L1	14.41	15.59	13.02	3.70	18.13	16.37
L2	13.23	13.87	12.59	2.25	16.04	14.06
L3	17.76	18.96	13.12	6.16	21.77	19.93
Total	45.30	48.78	38.73	12.11	55.93	50.36

Calculations:

Step –I
P.F before the installation of capacitor = 0.810
P.F after the installation of 35 KVARs capacitor = 0.971

So net % age increase of power factor

$$= \frac{PF1-PF2}{PF1} \times 100$$

$$= \frac{0.810-0.971}{0.810} \times 100 = 19.87\ \%$$

Step –II
Current before the installation of capacitor = 85.23 A
Current after the installation of 35 KVAR Capacitors = 75.70 A

So net % age difference in current decrease.

$$= \frac{I1-I2}{I2} \times 100$$

$$= \frac{85.23-75.70}{75.70} \times 100 = 12.58\ \%$$

Step –III
Voltage before the installation of capacitor = 379.9V
Voltage after the installation of 35 KVAR capacitors =385.35V

So net % age difference in voltage increase

$$= \frac{V1-V2}{V1} \times 100$$

$$= \frac{379.97-385.53}{385.35} \times 100 = 1.40\%$$

Step –IV
KVA before the installation of capacitor = 55.93
KVA after the installation of 35 KVAR capacitors = 50.36 KVA

So net % age difference in KVA decrease

$$= \frac{KVA1-KVA2}{KVA1} \times 100$$

$$= \frac{55.93-50.36}{55.93} \times 100 = 9.95\%$$

Similarly analysis was done for tube lights installed in 2nd and third floor. For above analysis we can see that improvement in PF has been done just after installing the 4.5uF capacitor on each tube light but it is difficult to analyze the total load

3.0 Energy Analysis Calculations of U.O.G Power System

Low power factor results in the form of penalty by the WAPDA. Investments in the power factor improvement are made to avoid the low factor penalty charges. However, in WAPDA and KESCO where the electric utilities have a penalty based rate structure, power factor correction capacitor and systems can generate a one-year or less payback.

3.1 Analysis of U.O.G Power System

Due to the power factor UOG pays huge amount as penalty charges to WAPDA. By proper adopting a technique for power factor improvement, penalty charges can be avoided. WAPDA has fixed 0.90 power factor for the consumers and any consumer having power factor less than the prescribed value has to pay the penalty and WAPDA is planning to increase its power factor to 0.95. As per WAPDA tariff structure is concerned, UOG electricity load falls in the C2 (A) type, (Tariff 28) category whose formula for finding the low power factor LPF is as under.

Penalty = Energy Charges * (0.9 - Power Factor)
Energy Charges = KWh Units * Unit Rate
(Rs. 8.65 from Tariff Table)

Hence the penalty along with the cost of capacitors to avoid penalty charges is calculated. Then the tentative recovery payback period is also calculated. For energy analysis of U.O.G distribution system detail drawing showing all electrical equipment like transformers, motors etc with ratings along with their respective distances from the source were drawn that will facilitate in the calculation work. Results like current drawn, KVAR required to achieve this power factor and saving in KVA and saving in terms of cost due to power factor penalty will be calculated at the end.

3.2 Analysis of U.O.G Electricity Bills

For calculating the reduction / saving in the bills of UOG, complete energy analysis of UOG distribution system was essential and for this purpose electricity bills of UOG for the twelve months from July, 2010 to June, 2011 were analyzed. Table 5 shows the detail of data available from electricity bill of UOG for the year (2010/11).

Table 5. Showing various Units Consumed / Year (2010/11)

Month / Year	KW	KWH	KVARH	$P.F_1$
31.07. 10	640	175040	113066	0.84
31.08. 10	640	162560	105000	0.84
30.09. 10	640	133360	103499	0.79
30.10. 10	640	134880	111765	0.77
30.11. 10	480	110560	109657	0.71
30.12. 10	480	130480	111582	0.76
27.01. 11	480	140960	124315	0.75
26.02. 11	640	110080	65318	0.86
28.03. 10	2400	125200	80871	0.84
27.04. 10	160	120560	109580	0.74
27.05. 10	640	176800	95427	0.88
25.06. 10	16352	197280	158274	0.78

1. Data Available (From Electricity Bill) of January, 2011.

Year/Month = 1 / 2011
KW = 480
KWH = 140960
KVARH = 125600
Load factor = KWH / (730 x KW)
= 140960 / (730 x 480)
= 0.40
$P.F_1$ = $\text{Cos}(\text{Tan}^{-1}(\text{KVARH/KWH})$
= $\text{Cos}(\text{Tan}^{-1}(125600/140960)$
= 0.75
KVA Load = KW / $P.F_1$
= 480 / 0.75
= 640
PF_2 = 0.95
$KVAR_1$ = $\text{KW}(\text{Tan}(\text{Cos}^{-1}0.75))$
= $480(\text{Tan}(\text{Cos}^{-1}0.75))$
= 423.32
$KVAR_2$ = $\text{KW}(\text{Tan}(\text{Cos}^{-1}0.95))$
= $480(\text{Tan}(\text{Cos}^{-1}\ 0.95))$
= 157.77
KVAR required = $KVAR_1$ - $KVAR_2$
= 423.32 - 157.77
= 265.55
KVA Saving = $\mathbf{KW(1/P.F_1 - 1 / P.F_2)}$
= 480 (1/ 0.75 - 1 / 0.95)
= 134.74

WAPDA imposes penalty on the consumer having power factor less than 0.9 and for that WAPDA has divided its tariff as per load type and UOG tariff type C2 (A) 28 of which unit rate penalty is 8.65.

Penalty Charges = Total Energy charges x P.F [7].

Whereas
Penalty Charges=KWH Units x8.65 x (0.9 - P.F)
= 140960 x 8.65 x (0.9 - 0.84)
= Rs. 182,895.60/-

Similarly all the Calculation were made for different monthly data obtained from Bill.
Total Penalty=Rs1,461,151.08/-(for 12-months)

3.3 Cost and Payback Period Calculations

Maximum KVARs were observed in March, 2011 = 761.41
Static Capacitors required to Provide 761.41 KVARS = 7x100 KVARs +1x50 KVAR +1x25 KVAR.
Cost of 100 KVAR Static Capacitor=Rs.90,000/-
Cost of 50 KVAR Static Capacitor= Rs.50,000/-
Cost of 12.5 KVAR Static Capacitor= Rs.9,500/-
Total Cost = 630,000 + 50,000 + 19,500
= Rs. 699,500/-
Pay Back Period for the Static Capacitors are five months.

3.3.2 Automatic Capacitors Requirement and Pay Back Period Calculation

Automatic Capacitors required to Provide 761.41 KVARS = 7x100 KVARs + 1x 50 KVAR + 1x 25 KVAR.
Cost of 100 KVAR Automatic Capacitor
= Rs 149,680/-
Cost of 50 KVAR Automatic Capacitor
=Rs. 91,280/-
Cost of 25 KVAR Automatic Capacitor
=Rs. 50, 070/-
Total Cost = 149,680 + 91,280+ 50,070
=Rs. 1,189,110/-
Pay Back Period for the Automatic Capacitors are eight months.

4.0 Power Distribution System Losses of University of Gujrat

For calculating HT line losses in the distribution system of UOG, exact length of the HT line from the source to the transformer is measured from the electrical design map of the UOG.

4.1 Overall Reduction H.T Line losses Connected to 200 KVA Transformers

Length of HT Cable from the source

TF1 = 82M TF2 = 123M TF3 =139M
TF4 = 172M TF5 = 140M TF6 = 201M
TF7 = 157M TF8= 050M TF9=091M
TF10= 44M TF11 = 52M TF12 = 151M
TF13= 038M TF14= 93M TF15=425M
TF16 = 302M TF17= 261M TF18 = 389M
TF19 = 265M TF20 = 94M

Resistivity of dog conductor=0.000391 Ω / Meter

4.1.1 Reduction in HT line losses Connected to TF1 (200 KVA)

Power losses at $P.F_1$ (0.7) = $(I_1)^2$ xR x Length
$=(10.497)^2$x0.000391x 82
= 3.533 Watts
Power losses at $P.F_2$ (0.95)= $(I_2)^2$ x R x Length
= $(7.735)^2$ x 0.000391x 82
= 1.918 Watts
Reduction in HT line losses= 3.533 - 1.918
= 1.615 Watts
% Age Reduction in HT Line Losses = $\frac{(3.533-1.918)}{1.746}$
= 45.69%

Similarly Calculation were done for all 200, 100, 50 and 25 KVA Transformers.

5.0 Transformer Copper Losses

Distribution transformers generally have two types of losses

1. Copper losses (I^2.R Losses)
2. Iron losses (Fixed losses)

Copper losses are proportional to the square of the load currents [6].

Standard Distribution Transformer losses at different loading are given in the table 6 below.

Table 6. Standard Distribution Transformer Losses at Different Loading

T/F Capacity (KVA)	Max Current (Amps)	%Age Load vs. Losses in Watts					
		25%	50%	75%	100%	125 %	150%
25	36	130	234	425	71	1001	1403
50	72	248	468	833	1345	2003	2807
100	144	436	815	1346	2330	3466	4855
200	288	708	1320	2413	3905	5823	8167

5.1 Reduction is Copper losses of 200 KVA Transformer

KVA before P.F improvement at 0.75 = 200 KVA
KVA after P.F improvement at 0.95=157.89 KVA
Reduction in KVA after improvement = $\frac{(200 - 157)}{47}$

= 26.3 %

Standard losses at 100% load =3905 Watts (From table)
Standard losses at 75% load =2413Watts
Reduction in copper losses = (3905 – 2413)
= 1492Watts

%Age reduction = $\frac{(3905 - 2413)}{3905} \times 100$
= 38.2%

Total reduction for 20 x 200 KVA transformers = 20 x 1492 = 29840 Watts.

5.1.1 Overall Reduction in Copper Losses

(i) Total reduction of Copper Losses for 1 x 25 KVA transformer = 1x285 Watts.

(i) Total reduction of Copper Losses for 1 x 50 KVA transformer = 1 x 512 Watts.

(ii) Total reduction of Copper Losses for 5 x 100 KVA transformer = 5x984=4920 Watts.

(iii) Total reduction of Copper Losses for 20 x 200KVA transformer=20x1492= 29840 W.

Total saving in Copper losses of all transformers = 285+512+4920+29840 = 35,557Watts
Units saving per day = (35.55 x24)
= 853.6 KWH
Units saving per month = (35.55 x 24 x 30)
= 25,601.04 KWH
Units saving per year = 311,479.32 KWH

6.0 Total Saving Analysis of Transformers

Following are the overall results of the above mentioned calculations. Table 7 shows the saving in terms of kW and kVA by improving power factor.

1. 25 KVA Transformer = 01 No.
2. 50 KVA transformers = 01 Nos
3. 100 KVA transformers = 5 Nos
4. 200 KVA transformers = 20 Nos

Table 7. Saving in terms of kW & kVA by power factor improvement.

KVA		Power (KW)		Power Factor (Cosϕ)		KVAR Required at 0.95 PF
Before	After	Before	After	Before	After	
25	19.74	18.75	23.75	0.75	0.95	13
50	39.47	37.5	47.50	0.75	0.95	25
100	78.95	75	95	0.75	0.95	50
200	157.89	150	190	0.75	0.95	100

Total KW before power factor improvement (0.75 P.F) = 2401.7

Total KW After power factor improvement (0.95 P.F) =3259. 45

Total savings =(3259–2401) =857 KW

Total Saving in KW(%age) = $\frac{(3259 - 2401)}{2401} \times 100$
= 35.7 %

Total cost of installation /generation of power house =US Dollars 450/KW
So Total cost for generation of 857KW of energy = 857x 450 = US $ 405,000 = Rs. 96 x 405,000
Total saving in terms of Pak Rupee
= Rs.38,800,000/-

Total KVA before power factor improvement (0.75 P.F) = 3431

Total KVA after power factor improvement (0.95 P.F) = 2528

Total Saving in KVA = $\frac{(3431 - 2528) \times 100}{3431}$
= 26.3%

Total HT line losses of all transformers at 0.75 $P.F_1$= 175.90 Watts.

Total HT line losses of all transformers at 0.95 PF_2 = 95.39 Watts.

Reduction in HT line losses = 175.90 – 95.39
= 80.509 Watts.

%Age reduction = $\frac{(175.90 - 95.39) \times 100}{175.90}$
= 45.76%

6 .1 Overall saving Analysis by Power Factor improvement on L.T Side of Transformers

Case I: (As Per General Analysis)

(i) Unit saving/year due to transmission line losses = 705.2 KWH
(ii) Units saving/year due to transformers copper losses = 9,344,380 KWH

Total saving/year in units due to power factor improvement =9,345,085 KWH.
Whereas rate/unit = Rs.8.69/-
Total saving/year = 9,345,085x8.69
= Rs. 81,208,790.39

Case II (As per Actual Consumption During Year 2010-2011)

Total penalty charges due to low power factor for 12 months = Rs. 1,461,151.08/-

7.0 Energy Loss Reduction and Cost Benefit Analysis by Implementation of Rehabilitation Technique (Case-II)

This part of paper includes the area planning and bifurcation of 11KV Ali Park and 11 KV Rachna town feeder emanating from 132 KV Shamkey Grid Station. The main purpose of this case study is to give relief to the subject feeders by implementing rehabilitation techniques which may not withstand the heavy load in the summer season. This case study shows that by implementing rehabilitation techniques how much energy can be conserved by reducing power losses. The strategy is to minimize technical losses which in turn minimize total losses in an electrical distribution network.

Increasing energy costs and environmentalists actions to protect the natural resources force energy supply companies to conserve and reduce energy usage. Therefore the study focused on the reduction of electrical energy losses in distribution networks. Reducing these losses ensure that the cost of electricity to customers will be reduced and in turn improve the efficiency of the distribution network.

7.1 Data Collection

The data collected to carry out the analysis for the project is taken from the distribution facility (LESCO). This data covers the High Tension (HT) Line information of 11 KV Ali Park and Rachna Town Feeders which is required for generating single line diagram. HT Line information includes:

1. Node to node distance in meter
2. Conductor Type (PANTHER, DOG, RABBIT etc.)
3. Transformer Rating in KVA
4. Capacitor Rating in KVAR

7.2 Silent Features/ Technical Parameters

The case study involves following 11 KV feeders for rehabilitation.

7.2.1 11 KV Ali Park Feeder

It's a mixed load feeder having small industrial, commercial and agricultural / rural load on it. The length of the feeder is 30.5 Km having 400 amps load on it.

7.2.2 11 KV Rachna Town Feeder

It's a mixed load feeder having small industries and city load on it. The length of the feeder is 13.3 Km having 330 amps load on it.

The above mentioned feeders have also have deteriorated / off size conductors.

7.3 Benefit/ Cost Calculation

For Reconductoring, Bifurcation and Area Planning proposals B/C >= 2 [8,9].

7.3.1 B/C Calculation for Area Planning and Bifurcation of 11 KV Ali Park and Rachna Town Feeder

<u>Without Growth</u>

Saving in Losses due to Bifurcation of Load,S_1 = 335.800 KW
Saving in Losses due to Fixed Capacitor Banks S_2 = 0 KW
Saving in Losses due to Switched Capacitor Banks,S_3=0 KW
Saving in Losses due to Reconductoring, S_4 =0 KW

Total Saving in Losses without Growth S_5 =335.800 KW

<u>With Growth</u>

Saving in Losses with Growth:
$[(((S_1+S_4)x F)+(S_2+S_3))]$, S_6 = 401.6168 KW
Where, F = Growth Factor = 1.196 @ 5% growth for 5 years.
Value of benefits with growth:
$VFxS_6$,S_7 = 5714622.8

Where, VF = Valuation Factor = Losefactorx8760xelectricity purchase rate = Rs.14229.0432 kW/Annum
New facility Cost, NFC = Rs. 10070711
Replaced Facility Cost, RFC = Rs. 299151

Benefit Cost Ratio

B/C Ratio = $\frac{57 - 0.04\,(NFC) - 0.0858\,(RFC)}{0.143\,(NFC)}$

Benefit Cost Ratio = 3.7
So the proposal is technical and economical [8,9].

7.4 Proposed 11 KV Industrial Feeder

A new feeder namely 11 kV industrial (P) feeder is proposed from 132 kV Shamkey Grid Station which will cater 3.13 km & 4500 connected kVA of 11 kV Ali Park Feeder and 4.54 km & 3320 connected kVA of 11 kV Rachna Town Feeder.

The new proposed feeder will be mix load feeder with mostly small industries like flour mills, marriage hall etc. the rural / agricultural load of 11 kV Ali Park feeder is proposed to be separated from the industrial load by shifting the later on new proposed 11 kV industrial feeder. Table below describes the technical parameters detail containing existing, existing modified and proposed position of feeders and overall savings / improvement

7.5 Existing Position of Feeders

Table 8 shows technical parameter detail of 11 kV Ali Park and Rachna Town feeders before applying rehabilitation technique.

Table 8. Existing position of 11 KV Ali Park and Rachna Town Feeder

Feeder	Grid Station	Length	Connected	Peak Load	Voltage Drop
		(KM)	(KVA)	(A)	(%)
Ali Park (Ext)	132 kV Shamkey	30.539	15465	400	10.8%
Rachna Town (Ext)	132 kV Shamkey	13.326	9325	330	8.2%
Total		43.865	24790	730	

Feeder	Grid Station	Power Loss	Annual Energy Loss	Loss	Loss
		(%)	(%)	(KW)	(KWH)
Ali Park (Ext)	132 kV Shamkey	5.8	4.2	376.3	1424091
Rachna Town (Ext)	132 kV Shamkey	3.8	2.7	201.7	763358
Total				578	2187449

7.6 Proposed Position of Feeders

Table 9 shows the position of feeders after proposing new feeder namely Industrial Feeder emanating from 132 kV Shamkey Grid Station which will cater 4500 & 3320 connected kVA of 11 kV Ali Park & Rachna Town feeders respectively. The table shows technical parameter detail and overall saving or improvements

Table 9. Proposed positions of 11 KV Ali Park, Rachna Town and Industrial Feeder

Feeder	Grid Station	Line / Load / Connected KVA Shifted From			
		Feeder	Length (KM)	Connected (KVA)	Load (A)
Ali Park (Ext)	132 kV Shamkey	Ali Park	27.41	10965	226
		New Line	2.16		
		S/Total	29.57	10965	226
Rachna Town (Ext)	132 kV Shamkey	Rachna Town	8.79	6005	213
		S/Total	8.79	6005	213
Industrial (P)	132 kV Shamkey	Ali Park	3.13	4500	93
		Rachna Town	4.54	3320	117
		New Line	6.66		
		Idle Line	0.22		
		S/Total	14.55	7820	210
Total		Total	43.865	24790	730

Feeder	Grid Station	Voltage Drop	Power Loss	Annual Energy Loss	Loss	Loss
		%	%	%	KW	KWh
Ali Park (Ext)	132 kV Shamkey	5.4	2.57	1.85	94.1	356065
Rachna Town (Ext)	132 kV Shamkey	2.7	1.66	1.20	57.4	217140
Industrial (P)	132 kV Shamkey	4	2.67	1.92	90.7	343140
Total			2.30	1.66	242	916345

7.6 Analysis of 11 KV Ali Park Feeder

7.6.1 At Actual (400 A) Load Existing Position

The technical losses at this actual load on the feeder are calculated as:

i. Technical losses at this load without bifurcation, re-conductoring and capacitor bank installed are 376.1 kW.

7.6.2 At Proposed (226 A) Load Existing Modified Position

The technical losses at this proposed load on the feeder are calculated as:

i. Technical losses at this load without re-conductoring and capacitor bank installed are 124.1 kW

ii. Technical losses at this load with re-conductoring at N-38 & N-115 and with a capacitor bank of 450kVAr installed at N–75, N-125 & N–148 are 94.0 kW.

7.6.3 Analysis of 11 kV Rachna Town Feeder

7.6.3.1 At Actual (330 A) Load Existing Position

The technical losses at this actual load on the feeder are calculated as:

i. Technical losses at this load without bifurcation, re-conductoring and capacitor bank installed are 201.6 kW.

7.6.3.2 At Proposed (213 A) Load Existing Modified Position

The technical losses at this proposed load on the feeder are calculated as:

i. Technical losses at this load without capacitor bank installed are 71.0 kW

ii. Technical losses at this load with a capacitor bank of 450kVAr installed at N–54 & N-128 are 57.3 kW.

7.6.4 Analysis of 11 kV Industrial Feeder Proposed

7.6.4.1 At Proposed (210 A) Load

The technical losses at this proposed load on the feeder are calculated as:

i. Technical losses at this load without re-conductoring and capacitor bank installed are 139.4 kW.

ii. Technical losses at this load with re-conductoring at N-1.0, N-176, N-177, N-178, N-180, N-181, N-183, N-188, N-189, N-211 & N-229-231 and with a capacitor bank of 450kVAr installed at N–208, N-229 & N–234 are 89.4 kW.

7.6.5 Reduction in the Technical Losses (11 KV Ali Park Feeder)

Reduction in the technical losses due to re-conductoring and installation of capacitor banks are described as under:

7.6.5.1 At Proposed (226 A) Load

i. Loss without re-conductoring and without any capacitor bank installed is 124.1 kW.

ii. Loss with re-conductoring and a capacitor banks of 450kVAr installed are 94.0 kW. Reduction in losses is:

$$124.1\text{KW} - 94.0\text{ kW} = 30.1\text{ kW} = \frac{30.1\text{ kW}}{124.1\text{ kW}} \times 100$$

7.6.6 Reduction in the Technical Losses (11 KV Rachna Town Feeder)

Reduction in the technical losses due to installation of capacitor banks are described as under:

7.6.6.1 At Proposed (213 A) Load

i. Loss without any capacitor bank installed is 71.0 KW.

ii. Loss with a capacitor banks of 450kVAr installed are 57.3 kW, Reduction in losses is:

$$71.0\text{ kW} - 57.3\text{ kW} = 13.7\text{ kW} = \frac{13.7\text{ kW}}{71.0\text{kW}} \times 100 = 19.26\%$$

7.6.8 Reduction in the Technical Losses (11 KV Industrial Feeder Proposed)

Reduction in the technical losses due to installation of capacitor banks are described as under:

7.6.8.2 At Proposed (210 A) Load

i. Loss without re-conductoring and any capacitor bank installed are 139.4 KW.

ii. Loss with re-conductoring and capacitor banks of 450 kVAr installed are 89.4 kW.

Reduction in losses is:

$$139.4\text{ kW} - 89.4\text{ kW} = 50\text{ kW} = \frac{50.0\text{ kW}}{139.4\text{ kW}} \times 100 = 35.86\%$$

8.0 Conclusion

From the preceding analysis (first case study) one can conclude that by adopting P.F improvement technique on the L.T side of the transformer not only relieved the UOG power system from the lower power factor penalty charges imposed by WAPDA but can brings the following advantages:

(i) Reduction in KVA demand (27.48%)

(ii) Reduction in energy losses of transmission lines (45.70%)

(iii) Total saving in KW (27.46%)

(iv) Saving is terms of Units (KWH) is 9,345,085 KWH

The best technique to conserve energy in UOG power system is by power factor improvement. Implementation of Rehabilitation Techniques is not necessary because voltage drop across H.T Line is within WAPDA's standard up to 3%.

Second case study shows the best technique to conserve energy in LESCO system is by implementation of rehabilitation techniques.
By applying rehabilitation techniques (second case study) on 11 kV Ali Park and Rachna Town feeders gives a healthy benefit cost ratio 3.7.

LESCO can save 336 kW active power and 1,271,104 KWH energy units annually. Voltage drop, power losses and annual energy loss reduces from 10.8% to 5%, 3.5% to 2.3% and 4.9% to 1.6% respectively.

Hence power factor improvement and rehabilitation techniques are both useful to conserve the energy depending on the power system requirement.

Recommendations

Work related to this thesis can be preceded, if the software were further enhanced in the direction to make it more dynamic. Graphical representation of power losses, current, voltage, power factor and cable network can be incorporated moreover it could be intelligent enough to show at which point analysis has been done.

11 KV Ali Park and Rachna Town Feeders, emanating from 12 kV Shamkey Grid Station are not capable to withstand the heavy load in summer. Therefore a new feeder namely, 11kV Industrial feeder is proposed to shift load from 11 kV Ali Park and Rachna Town Feeders.

It is also recommended that all DISCOS may rehabilitate its existing system to achieve fruitful results and there is also need to identify and promote the policies that can motivate and create awareness of energy conservation policies on sustainable basis.

9.0 References

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