Reduction of Power Losses in Distribution Systems

Y. Al-Mahroqi, I.A. Metwally, A. Al-Hinai, and A. Al-Badi

***Abstract*—**Losses reduction initiatives in distribution systems have been activated due to the increasing cost of supplying electricity, the shortage in fuel with ever-increasing cost to produce more power, and the global warming concerns. These initiatives have been introduced to the utilities in shape of incentives and penalties. Recently, the electricity distribution companies in Oman have been incentivized to reduce the distribution technical and non-technical losses with an equal annual reduction rate for 6 years. In this paper, different techniques for losses reduction in Mazoon Electricity Company (MZEC) are addressed. In this company, high numbers of substation and feeders were found to be non-compliant with the Distribution System Security Standard (DSSS). Therefore, 33 projects have been suggested to bring non-complying 29 substations and 28 feeders to meet the planed criteria and to comply with the DSSS. The largest part of MZEC's network (South Batinah region) was modeled by ETAP software package. The model has been extended to implement the proposed projects and to examine their effects on losses reduction. Simulation results have shown that the implementation of these projects leads to a significant improvement in voltage profile, and reduction in the active and the reactive power losses. Finally, the economical analysis has revealed that the implementation of the proposed projects in MZEC leads to an annual saving of about US$ 5 million.

***Keywords*—**Losses Reduction, Technical Losses, Non-Technical Losses, Cost Analysis

I. INTRODUCTION

AFTER deregulation of the electrical power industry, the distribution business has remained as a regulated monopoly. Because of the deregulation process, distribution utilities are currently facing increased pressures from shareholders and regulatory authorities to improve investment and operational efficiency [1]. The delivery of power from sources to the consumer points is always accompanied with power losses. Power losses occur in distribution networks due to Joule's effect which can account for as much as 13% of the generated energy [1, 2]. Such non-negligible amount of losses has a direct impact on the financial issues and the overall efficiency of distribution utilities. Therefore, methods for losses reductions, that optimally allocate scarce financial resources and maximize firm value, are essential for achieving the financial goals of distribution companies [1].

Y. Al-Mahroqi is with Mazoon Electricity Company, Muscat, Oman (phone: 00968-24557455, fax: 00968-24557474; e-mail: yousuf.almahroqi@mzec.co.om).

I.A. Metwally, A. Al-Hinai and A. Al-Badi are with Department of Electrical & Computer Engineering, College of Engineering, Sultan Qaboos University P.O. 33, Al-Khod, Muscat-123, Sultanate of Oman, (phone: 00968-24142532, fax: 00968- 24413454; e-mails: metwally@squ.edu.om, hinai@squ.edu.om, albadi@squ.edu.om).

Distribution power losses can be divided into two categories technical and non-technical losses [2]. The technical losses area related to the material properties and its resistance to the flow of the electrical current that is dissipated as heat. The most obvious examples are the power dissipated in distribution lines and transformers due to their internal electrical resistance. In addition, technical losses are easy to be simulated and calculated [2]. On the other hand, non-technical losses are caused by clandestine connections, frauds in energy meters, diversity of readings and deficiencies (or losses) in the processes of energy measurement [3].

High rate of technical and non-technical losses might cause [1, 3]:

- Poor quality of service offered to customers.
- High cost due to useless or premature investments.
- Reduction in revenue resulting in cash difficulties with all ensuing economic consequences.

Major losses drive the authorities to subsidize the company, thus increasing the states' financial load. Reducing the losses and reaching an acceptable level will restore the confidence of lenders and private investors to encourage them to participate financially in the development of the power sector. The resulted gains from losses reduction can be classified into economic and financial gains, and institutional benefits [4]. Therefore, the reduction of technical losses leads to a real gain in energy and reduced capital-intensive investments. On the other hand, the reduction of non-technical losses not only improves the financial balance of the company concerned, but also the load curve by subjecting consumption to the tariff regulation [4].

In this paper, different techniques for technical and non-technical losses reduction in MZEC are addressed. Non-complying substations and feeders with the DSSS in the largest part of MZEC's network (South Batinah region) was modeled by ETAP software package with and without 33 proposed projects, where 14 projects were for upgrading existing substations or feeders, and 17 were for constructing new ones, while only 2 were aimed to shift loads among substations. In addition, the model was extended to implement the proposed projects, to examine their effects on losses reduction, and to conduct an economical analysis. These projects were proposed to comply with the current planning criteria called DSSS. The number of these projects was based on the substations which are not currently meeting the DSSS while the distribution of them on 14:17:2 is based on their load forecasting for the coming three years as it can be found in the company's "Distribution System Capability Statement".

International Science Index, Computer and Systems Engineering Vol:6, No:3, 2012 waset.org/Publication/2058

II. Electrical Power System Losses

A. Technical Losses

Technical losses are part of the electric losses in the system, resulting in: losses in drivers, corona effect, iron of the transformers, eddy currents, connectors, and ohmic losses. These losses can still be grouped according to the segment of the electric system where it happens, being subdivided into losses in the transmission system, substation power transformers, primary distribution system, secondary distribution system, connection extensions and measurement systems [2, 3].

Transformer losses can be classified into two components, namely, no-load and load losses. No-load losses occur from the energy required to retain the continuously varying magnetic flux in the core and its invariant with load on the transformer. Load loss mainly arises from resistance losses in the conducting material of the windings and it varies with loading [5]. The cost of losses is the most important factor in selecting a transformer because it is quite possible for the estimated value of future losses to exceed the first cost of a transformer. Therefore, the right balance between the initial expenses and the upcoming loss expenses should be considered when buying a transformer [2, 3].

One of the main sources of losses in the distribution system is the copper losses in power overhead lines and cables. Since these losses are a function of current flow through the line [6]. Furthermore, unbalanced loading is another factor that can contribute to the line losses, where if one of the phases has more load than the other two, the losses will be larger than that if these phases are balanced [6].

Temperature rise introduces significant increase of power consumption, where the power loading can increase by 3.75 % for 1 °C temperature rise [7]. For the rainy day with higher humidity and lower temperature, a negative correlation among the power consumption was also found [6, 7]. On the other hand, the temperature change has less effect to feeder power losses because transformer losses dramatically contribute more in the power losses [7].

B. Sources of Non-Technical Losses

Non-technical losses include defective/incorrect metering, human error on installation, administrative processes, and non-metered authorized customers, especially, theft. In several cases, when total power losses of the system are large, it becomes evident that part of non-technical losses (net company revenue loss) is serious because theoretically the technical losses typically vary between 3 % and 6 % [3, 8]. This depends on the length of line, age of the system, voltage level and other factors [3, 8]. The estimated energy theft in some of the third-world countries is staggeringly high in the range of 10 % to 40 %, contrary to the developed countries where it reaches up to 3 % [8].

In some regions, the electrical energy usually is illegally taking from the nearest network; direct theft of energy. This type of losses can be produced by [9]: direct theft, manipulation of the measurement equipment so that they do not register the total consumption, deterioration of the measuring instruments causing incomplete consumed energy registry, and human errors during taking the meter readings. The problem not only resides in the consumer who robs but also in the inefficiency of the energy distributors to replace the measurers on time.

III. Losses Reduction Techniques

The most efficient losses reduction techniques in distribution systems are: feeder reconfiguration [1, 10-11], distributed generation (DG) [12, 13], VAR compensation [14], and installation of smart metering for non-technical losses [8].

Minimization of power losses and maximization of the load balance are the two most common criteria that used to reconfigure networks [10]. Feeder reconfiguration is a very important function of automated distribution systems to reduce distribution feeder losses, load balancing and improve system security. Loads can be transferred from feeder to feeder by changing the open and close status of the feeder high-speed switches [11]. The optimal reconfiguration model responds to changes in the network topology by switching the automatic breakers installed in the network [1].

Applying small amounts of distributed generation (DG) results in decreasing the power losses until they reach a minimum level. Once this minimum level is reached, if DG penetration level still increases, then losses begin to increase marginally [12, 13]. If DG penetration levels increase further, then losses can be even higher than those without DG connected (more than 5 times in extreme cases) [12].

Controllable capacitors can also be used to reduce active power losses and to improve voltage profiles [14]. To do so, network reconfiguration achieves this goal by optimizing active power flow in the system, while capacitor control achieves this goal by reducing reactive power flow in the system [10, 14].Establishing an online system for continuous assessment of the non-technical losses in distribution systems is not only imperative but also a strategic necessity for distribution companies. The surveillance and vigilance of revenue protection is inadequately addressed [8]. All these factors largely justify the implementation of a Distribution Management System (DMS) including a corporate of IT-based platform to feed data from the Geographical Information System (GIS) [8].

IV. Action Taken to Reduce Losses at MZEC

Technical and non-technical losses accounted for 18.9% of total units generated in Oman in 2009. Therefore, MZEC has started a focused approach to reduce the total losses and formed a team to monitor and to investigate the techniques of reducing both types of losses.

It has been found that non-technical losses can easily be reduced or even eliminated by applying the following actions:

- Perform regular inspection to randomly selected and any suspected customers.

- Install new meters at the primary substation to measure the internal consumption and invoice the company to avoid considering substation consumption as losses.
- Survey and identify the defective meters to replace them, and replace meter seals with new tamper-proof ones.
- Conduct regular campaign to increase the customers' awareness with the efficient use of electricity.

On the other hand, technical losses can be reduced by taking the following actions:

- Install capacitor banks.
- Re-conductoring overloaded lines with bigger conductors.
- Avoid any overloading of system and monitor the progress in losses reduction.
- Disconnect unloaded transformers to avoid no-load losses.
- Balance the transformer loading to reduce the neutral current and power losses.
- Upgrade transformers to match the load and the installed capacity, and to replace old/degraded ones.
- Ensure that all industrial customers are meeting the requirement of 0.9 PF.
- Perform regular preventive maintenance.
- Ensure the frequent live-line washing to reduce the leakage current.

V. Results and Discussion

A. *Implementing losses reduction projects*

One of main useful techniques to reduce the losses is to establish a working team to manage a strategic project for losses reduction, which can be broken down into three major phases [4]:

1. Diagnosis of the existing situation, identification of losses and their main causes.
2. Recommendations with the writing of an action plan to reduce the detected losses.
3. Implementation of the action plan and measurement of the results obtained.

High numbers of substations and feeders have not been found compliant with the Distribution System Security Standard (DSSS). Hence, it is not technically feasible how to study the effect of optimal loading of the lines and substations. 33 projects have been suggested to bring non-complying 29 substations and 28 feeders to meet the planned criteria and to comply with the DSSS. In addition, these projects were modeled in ETAP [15] and the simulation results for reducing the technical distribution losses are presented in Section V(B). 14 projects are for upgrading existing substations or feeders and 17 are for constructing new ones, while only 2 are aimed to shift load among substations.

The selection between upgrading, new construction and load shifting is mainly driven by the future loading of the substation, where the upgrading was proposed in the case of lower-capacity substation with reasonable load growth and no nearby substations. While new construction was proposed when either the substation is with higher capacity and no upgrading is anticipated or the growth is very high and even upgrading will not solve the problem in medium to long terms. Finally, the substation with low load or low load growth and is located in urban area with other substation nearby, it is more economical to shift load through short length 11-kV feeders rather than investing in new substations.

The most important six substations were taken for further analysis and study of the effect of the proposed solutions on power losses and voltage profiles. Table I presents a summary of the proposed changes. Fig. 1shows the percentage reduction of the actual and targeted power losses, where there is a significant reduction in both the actual (technical and non-technical) and targeted power losses due to the projects' implementation.

It is worth mentioning that the conductor and the ambient temperatures were respectively kept at 75 °C and 40 °C for the whole simulations in this work. Figs. 2 and 3 were taken as snapshots of the modeled distribution network and represent the network configuration in 2010 and the post changes that reflect the recommended projects for Wadi Mistal and Widam Sahel substations, respectively. Active and reactive power flow, and voltage are shown for these two substations. It is worth mentioning that 80 % of the simulated loads are motors, i.e. voltage-dependent load. Therefore, any reduction in the voltage results in an increase of the drawn power.

TABLE I
SUMMARY OF THE PROPOSED CHANGES IN THE SIX SELECTED SUBSTATIONS

Substation Name	Proposed changes in the substations
Hufri	Construction of Al Hufri (2×20 MVA) with 2×5 MVAr and two circuits of 7.5 km UGC
Al Hadheib	Construction of Subikhi 3×20 MVA with 3×5 MVAr with two fresh circuits 12 km OHL and 4.5 km UGC and shift load between substations
M P Farm	Additional transformer of 6 MVA and capacitor of 1 MVAr were added
Nakhal and Afi	Upgrading Afi (2×6 MVA) to (2×20 MVA) with (2×5 MVAr) capacitor bank and two circuits from Nakhal Grid 8 km OHL
Wadi Mistal	Additional transformer of 6 MVA and capacitor of 1 MVAr were added
Widam Sahel	2×10 MVA transformers were replaced by 2×20 MVA

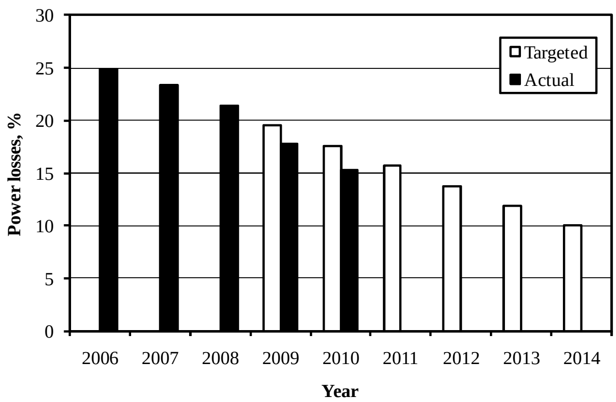
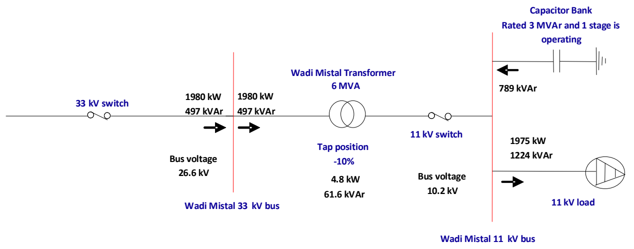
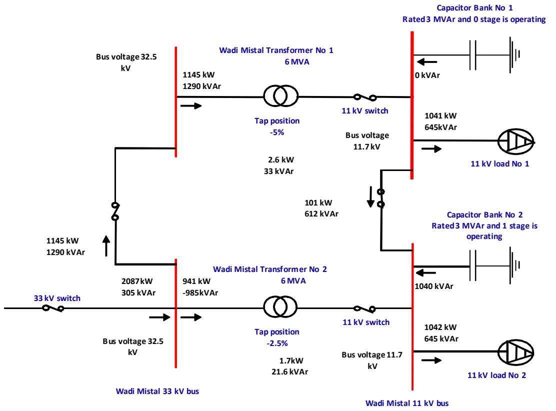


Fig. 1 Reduction of the actual and targeted power losses



(a) Before upgrading.



(b) After upgrading.

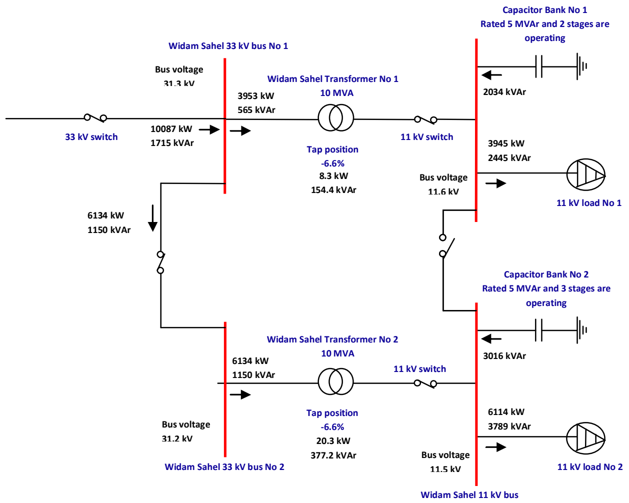
Fig. 2 Single-line diagram of Wadi Mistal substation before and after the proposed changes (transformers upgraded from 1×6 MVA to 2×6 MVA and capacitor banks upgraded from 1×3 MVAr to 2×3 MVAr).

Fig. 2 shows that Wadi Mistal substation feeds a 2-MW load and as per the newly established DSSS, the allowable time for interruption is only 3 hours. As this is a remote area, it is not feasible to link existing feeders to provide feedback. Adding a second transformer, to share the load and supply full load in case of one transformer is failed, will comply with the DSSS and result in a significant improvement in the busbar voltage (within the allowable tolerance) as shown in Fig 2 and later in Fig. 5.

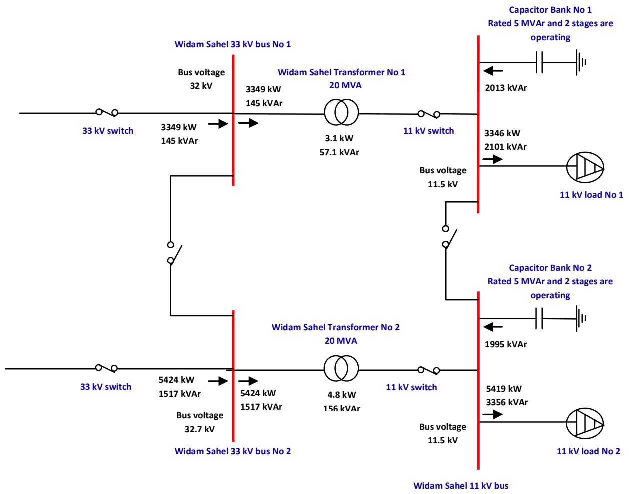
Outage of one transformer in Widam Sahel substation (shown in Fig. 3) results in inability of the other transformers to supply the full load. This substation is classified as Class C in the DSSS and immediately the load should be restored. Full redundancy should exist to comply with the DSSS requirements and the current loading of the substation is more than 100%. Additional transformer will reduce the losses by 60% as it will be presented later in Fig. 6.

B. Active and Reactive Power Consumption

Figs. 4(a) and 4(b) illustrate the active and the reactive power consumption for the most important 6 substations, respectively. Fig. 4(a) shows that the proposed projects cause a little decrease in the active power since the substation capacity is increased by upgrading the transformers (lower active and reactive power losses) while the customer loads remain unchanged. This is also attributed to fact that 80 % of the simulated loads are motors, i.e. voltage-dependent load.



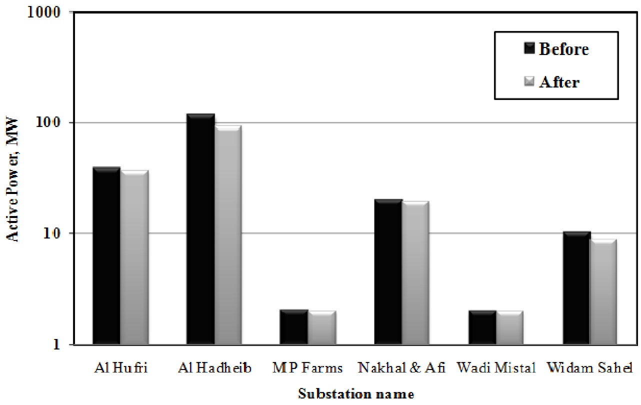
(a) Before upgrading.



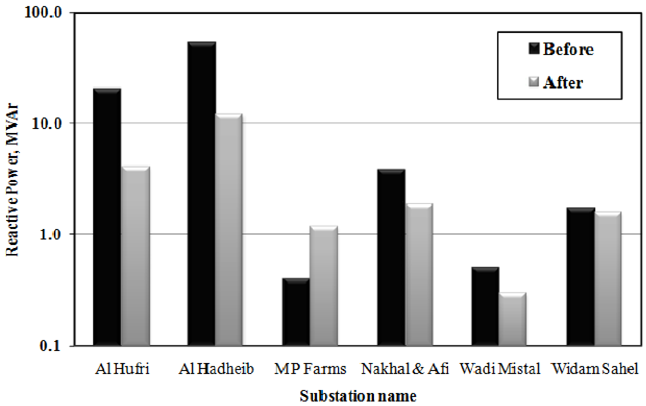
(b) After upgrading.

Fig. 3 Single-line diagram of Widam Sahel substation before and after the proposed changes (transformers upgraded from 2×10 MVA to 2×20 MVA and constructed a second circuit).

Therefore, improvement of the voltage in the 6 substations leads to a little reduction in the active power. In contrast, a major decrease in the reactive power for most of substations can been observed in Fig. 4(b) because of the newly installed capacitor banks at the substations (e.g., additional 1×3 MVAr at Wadi Mistal as shown in Fig. 2). It is worth mentioning that the MP Farms substation is fed by a single, 33-kV long OHL and the voltage profile before the implementation of the projects was very low. To increase the voltage to be within the allowable limit, a large quantity of reactive power has to be injected at this substation. Fig. 4(b) also illustrates that Al Hufri, Al Hadheib and the associated substations gained a reduction of the reactive power by almost 80 %. While other substations gained a reduction between 10 % to 50 %. There is an increase of the reactive power at Wadi Mistal substation due to excessive low voltage (–12 % from nominal value 33 kV), which is improved to –2 % to be about 32.4 kV as it will be explained later.



(a) Active power



(b) Reactive Power

Fig. 4 Power consumption before and after implementing the projects

C. Voltage Profile and Losses

The injected MVAr by the newly installed capacitor banks has resulted in a decrease in the flow of the reactive power from the grid substations (132/33 kV) to the distribution substations in this study. This leads to a reduction in the reactive power and improvement of voltage profile in the substations as shown in Figs. 4(b) and 5, respectively.

Out of these 6 substations, there were four which previously had voltages outside the allowable tolerance (± 6 %). The simulation results reveal that implementing the projects will improve the voltage profile to a nominal value of about 33 kV. Whilst the voltage at the remaining 2 substations was in the allowable tolerance and it has been improved to the nominal value. Furthermore, none of the substations after implementing the projects exceeds the maximum allowable voltage level. In particular, Widam Sahel substation has nearly no change in the reactive power consumption and the voltage maintains at the nominal level as shown in Figs. 4(b) and 5, respectively. This is attributed to the fact that the transformers of Widam Sahel substation were upgraded without installing any capacitor banks as given in Table I. The relation between the increase in the voltage and the installed capacitor banks is clearly observed from Figs. 4(b) and 5, respectively.

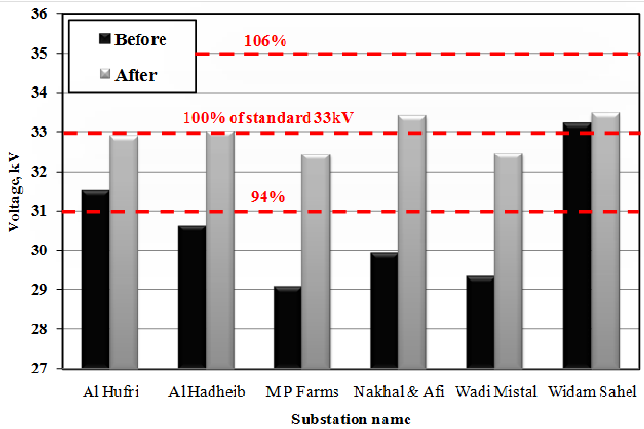


Fig. 5 Voltage profile before and after implementing the projects

The aim of the study is to reduce the distribution losses in MZEC network. While positive effects of the proposed projects are clearly noted in the voltage profile,the reactive power consumption, and with a major impact on the technical losses. Fig. 6 shows that the active power losses are reduced by at least of 40 % for all substations, where the losses of 3 out of 6 substations have been reduced by more than 60%. The total losses of these 6 substations were reduced from more than 1000 kW to 400 kW. Percentage change in the power losses (ΔP_{loss}) can be defined by:

$$\Delta P_{loss} = \frac{P_{LA} - P_{LB}}{P_{LB}} \times 100 \tag{1}$$

where P_{LA} and P_{LB} are the power loss after and before implementing the projects, respectively.

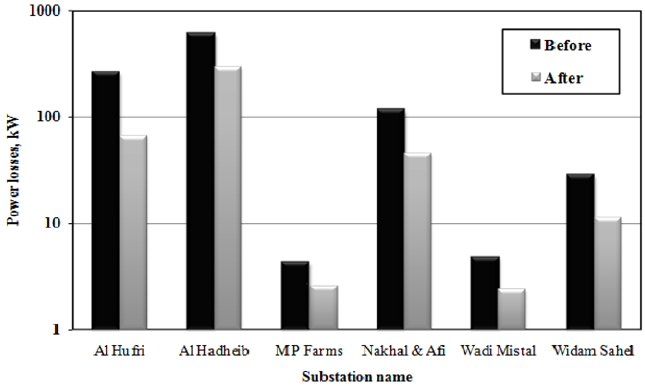
A 60% reduction in the technical losses will result in major saving in the generated energy, thus reduce greenhouse gases emissions. In addition, reduction in loses will delay/minimize the need for more installed generation capacity and transmission and distribution assets expansion. Section VI will discuss the cost of the technical losses before and after implementing the projects. In addition, it will highlight the needed investment and expected returns from the saving of the losses reduction and from compliance with the statutory obligations.

VI. Economical Analysis

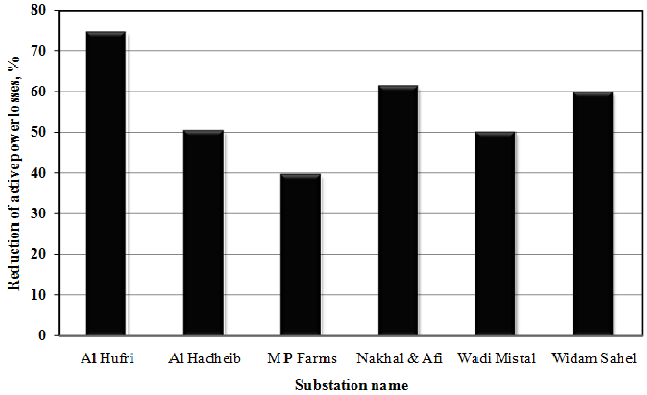
It is important to check the validity of the project solution by determining its total cost and comparing it with the total financial benefit to be obtained after the implementation. In this section, the cost of power losses for the company as well as the cost of the recommended projects will be determined. Finally, a cost benefit analysis will be carried out.

A. Cost of Power Losses

The results for analyzing the cost of losses are based on the peak time calculation. However, the peak time can be considered in the summer period only (April to August). It is worth mentioning that the obtained results are no longer valid for the rest of the year.



(a) Actual power losses.



(b) Percentage reduction of active power losses.

Fig. 6 Reduction of the power losses resulted from implementing the projects.

The peak load losses will be liberalized but introducing approximation method using the average load of the system. First, the load factor (F_{LD}), which is the ratio of the average load over a designated period of time to the peak load occurring in that period, can be calculated using the following formula [6, 16]:

$$F_{LD} = \text{(Average Load)/(Peak Load)} \quad (2)$$

Using actual data for South Batinah region starting from 1 January 2009 to 31 December 2009, the peak and the average loads were 565 MW and 270 MW, respectively. These data resulted in a load factor of 0.478. Looking to the South Batinah particularly, the sampled network can be classified as rural one. Then, the loss factor (F_{LS}), which is derived from the load factor, can be calculated as the following [6]:

$$F_{LS} = 0.84\, F_{LD}^2 + 0.16\, F_{LD} \quad (3)$$

This results in a loss factor of 0.27. The average loss is the product of F_{LS} times the peak loss [6]. The peak power losses were obtained by running the load flow using ETAP software package, e.g. before complying with the DSSS, they were found to be 38.3 MW and 10.3 MW, respectively, which gave an annual energy losses of 89,610 MWh.

The above calculation will then be utilized to find out the cost of the technical losses for the company during 2010. It is fair to say that the annual cost of power losses is the annual power losses multiplied by the economical cost of each MWh. The latter is almost 72.28 US$/MWh [6]. Finally, this annual energy loss is multiplied by unit losses to find the cost of losses before and after complying with DSSS as it is presented in Table II. It can be noted from Table II that around –78% of the technical losses can be reduced by complying with the DSSS with the saving of US$ 5,074,045 in 2010.

B. Cost of Complying with DSSS

The annual saving from complying with the DSSS is US$ 5,074,045, which will annually increase by 7 %. This increase was estimated based on the increased profile of demand supplied from 2005 to 2009, which showed an average annual increase of around 10 % [17]. However, this percentage has been pushed upwards by the sharp increase of unit supplied in the last two years and the sensible average over the study period which cannot increase more than 7 %. As a result, the annual units supplied over 4 years were estimated and the annual power losses were increased by 7 % with the increase of the units supplied for the coming 4 years. Power losses before and after complying with DSSS were calculated for both cases. The net saving over 4 years, discounted to equivalent monetary value of 2010, was also estimated. The above saving will need about US$ 116,707,225 in 2010 to be invested in implementing the proposed projects to achieve compliance with DSSS.

C. Cost Benefit Analysis

In order to compare between this two streams of cash flow, projects investments and return from loss reduction saving, two methods will be used to determine the viability of these proposed projects economically, namely, the present value and the annuity. Since the average lifetime of the installed assets is in range of 30 to 40 years, a middle value of 35 years will be used as the study period [17] although the losses saving will be taken from only 4 years.

Present value (*PV*) is the current worth of a future sum of money or stream of cash flow given a specified rate of return. Future cash flow is discounted at the discount rate, where the higher the discount rate, the lower is the present value of the future cash flow.

TABLE II
COMPARISON OF COST OF POWER LOSSES BEFORE AND AFTER COMPLYING WITH DSSS

	Cost of losses	
Complying with DSSS	Before	After
Average load (MW)	270	270
Peak load (MW)	565	565
Load factor	0.478	0.478
Loss factor	0.27	0.27
Average power loss (MW)	10.23	2.27
Peak power loss (MW)	38.3	8.5
Annual energy loss (MWh)	89,610	19,887
Cost of annual power loss (US$)	6,521,370	1,447,324
	Reduction in power losses	-78%
	Saving from loss reduction (US$)	5,074,045

Determining the appropriate discount rate is a key for a proper evaluation of future cash flow. Equation (4) presents the calculation of the present value and the net present value, which has to be added to the resultant present value with the actual cost in that year [6].

$$PV = \sum_1^n \frac{C_i}{(1+r)^i} \tag{4}$$

where C_i is the cash flow in the i^{th} year and r is the interest rate (7.55% in the electricity sector).

An annuity is a series of equal payments or receipts that occurs at evenly spaced intervals, e.g. leases and rental payments. The payments or receipts occur at the end of each period for an ordinary annuity, while they occur at the beginning of each period for an annuity due [6]. The net present value (NPV) is calculated based on the difference between the present value of the cost cash flow and the present value of the return cash flow as follows [6]:

$$NPV = \sum_1^n \frac{C_i}{(1+r)^i} - \sum_1^n \frac{P_i}{(1+r)^i} \tag{5}$$

where P_i is the payment flow in the i^{th} year.

Table III gives the present value of losses reduction saving (for 4 years only) in 2010 prices as US$ 21 million. In addition to this saving around US$ 125 million return on investment calculated by the regulator compared to US$117 million is needed to be invested to comply with DSSS. This results in a net present value of around US$ 29 million. Moreover, the simple payback period for these investments will occur after 10 years (i.e., by the end of 2019 from the start of the investment in 2010) and the discounted payback period will occur after 17 years (i.e., by the end of 2026). The positive net present value and the discounted payback period that is far lower than the asset life, which clearly demonstrates the benefit from these investments and their financial viability.

Fig. 7 shows the undiscounted cost of power losses in the coming 4 years with and without the proposed investments. With the ever-increase in energy, the cost of losses also increases and the difference in cost between the two cases increases linearly from less than US$ 6 million in 2010 to little more than US$ 6 million at the end of year 2013. Although there will be an investment cost in addition to the proposed projects but the return and saving will guarantee the net profit out of these investments.

TABLE III
COST BENEFIT ANALYSIS AT 2010 PRICES

Total saving (million US$)	21
Total return on investment (million US$)	125
Total return and saving (million US$)	146
Total investment needed (million US$)	117
Net present value (million US$)	29
Simple payback period (Years)	10
Discounted payback period (Years)	17

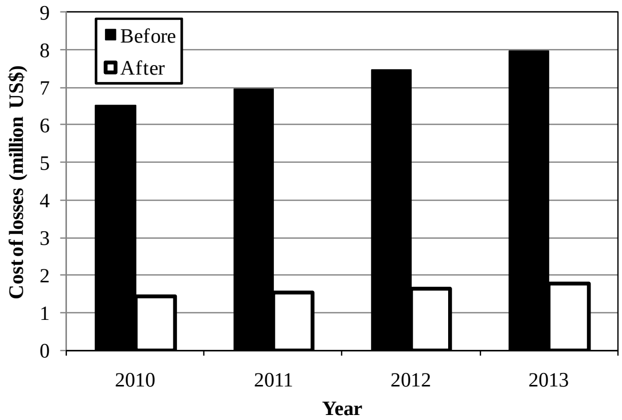


Fig. 7 Cost of power losses before and after implementing the proposed projects

VII. CONCLUSIONS

Technical and non-technical power losses were studied and different reduction techniques were described in details. MZEC has started focusing on reducing the total losses and formed a team to monitor and to investigate the techniques for reducing both types of power losses.

MZEC has been found that non-technical losses can easily be reduced or even eliminated by: (a) performing regular inspection to randomly selected and any suspected customers, (b) installing new meters, (c) surveying and identifying the defective meters to replace them with new tamper-proof ones, and (d) conducting regular campaign to increase the awareness of the customers with the efficient use of electricity.

Reduction of the technical losses was studied using ETAP software package. The largest distribution network of MZEC (South Batinah region) was modeled before and after implementing 33 projects to reduce the loading of lines and substations. The following projects were examined: (a) installing parallel feeders for overloaded feeders according to the approved security standard, (b) introducing transformer(s) for overloaded substation, (c) installing more capacitor banks at the primary feeder which will help in boosting the voltage and improving the power factor as well as reducing the reactive power losses, and (d) introducing more links between the feeders to facilitate load sharing. Results reveal that there was a little decrease in the active power but the reactive power decreases considerably. On the other hand, the losses were dramatically reduced and voltage profiles were improved to be within the standard tolerance (±6 %).

The above measures were modeled and the resultant peak losses were obtained for the network before and after implementing the proposed 33 projects. Using the load factor of MZEC's network, the average losses were estimated for the full year and then the cost of losses in both scenarios was calculated. Thereafter, the saving from the losses reduction was estimated for the coming 4 years with the aim of studying the cost benefit of the proposed projects. Around US$ 29 million as net present value was estimated to be gained from the proposed projects, which will pay for itself within only 17 years. Finally, the economical analysis has revealed that the implementation of the proposed projects in MZEC leads to an annual saving of about US$ 5 million.

Work is in progress to investigate the effect of using distributed generation (DG) on losses reduction before and after implementing the aforementioned projects.

REFERENCES

[1] D. P. Bernardon, V. J. Garcia, A. S. Quintela and L. N. Canha, “Multicriteria Distribution Network Reconfiguration Considering Subtransmission Analysis,” IEEE Trans. on Power Delivery, Vol. 25, No. 4, pp. 2684-2691, Oct. 2010.

[2] M.S. Dalila, M.N. Khalid and M. Shah, “Distribution Transformer Losses Evaluation under Non-Linear Load,” Australasian Universities Power Engineering Conference, Adelaide, SA, pp. 1-6, 27-30 Sept. 2009.

[3] C. M. P. dos Sanyos, “Determination of Electrical Power Losses in Distribution System,” IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela, pp. 1-5, 2006.

[4] E. S. Ibrahim, “Management of Loss Reduction Project for Power Distribution Systems,” Electric Power Systems Research, Vol. 55, pp. 49-56, 2000.

[5] T. D. Kefalas, and A. G. Kladas “Harmonic Impact on Distribution Transformer No-Load Loss,” IEEE Trans. on Industrial Electronics, Vol. 57, No. 1, pp. 193-200, Jan. 2010.

[6] Hadi Saadat, “Power System Analysis”, 2nd Edition, McGraw-Hill Primis Custom Publishing, 2002.

[7] C. S. Chen, M. S. Kang. J. C. Hwang and C. W. Huang, “Temperature Effect to Distribution System Load Profiles and Feeder Losses,” IEEE Trans. on Power Systems, Vol. 16, No. 4, pp. 916-921, Nov. 2001.

[8] A. ILo, J. Koppensteiner, M. Reischbock, P.Parra, H, Socorro, L. Rodriguez, T. Romero and R. Cespedes, “On-line Estimation and Location of Non-Technical Losses in a Distribution System,” C I R E D 17th International Conference on Electricity Distribution, Barcelona, Spain, Paper No. 39, pp. 1-5, 12-15 May 2003.

[9] R. Alves, P. Casanova, E. Quirogas, O. Tavelo and W. Gimenez, “Reduction of Non-Technical Losses by Modernization and Updating of Measurement System,” IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela, pp. 1-5, 2006.

[10] H.M Khodr, Z. A. Vale and C. Ramos, “Optimal Cost-Benefit for Location of Capacitors in Radial Distribution System ,” IEEE Trans. on Power Delivery, Vol. 24, No. 2, pp. 787-796, April 2009.

[11] Y. K. Wu, C. Y. Lee, L. Liu and S. H. Tsai, “Study of Reconfiguration for the Distribution System With Distributed Generators,” IEEE Trans. on Power Delivery, Vol. 25, No. 3, pp. 1678-1685, July 2010.

[12] V. H. M. Quezada, J. R. Abbad, and T. G. S. Román, “Assessment of Energy Distribution Losses for Increasing Penetration of Distributed Generation,” IEEE Trans on Power Systems, Vol. 21, No. 2, pp. 533-540, May 2006.

[13] Y. M. Atwa, E. F. El-Saadany, M. M. A Salama and R. Seethapathy, “Optimal Renewable Resources Mix of Distribution System Energy Loss Minimization,” IEEE Trans. on Power Systems, Vol. 25, No. 1, pp. 360-370, Feb. 2010.

[14] D. Zhang, Z. Fu and L. Zhagn, “Joint Optimization for Power Loss Reduction in Distribution System,” IEEE Trans. on Power Systems, Vol. 23, No. 1, pp. 161-169, Feb. 2008.

[15] ETAP Enterprise Solution for Electrical Power Systems. Available on: http://www.etap.com

[16] C.W. Huang, “MGE Dual Zig-Zag Harmonic Reduction Transformers,” IEEE Trans. on Power Systems, Vol. 16, No. 4, pp. 916-921, Nov. 2001.

[17] Technical Reports, Mazoon Electricity Company, Muscat, Oman, Vol. 1, May 2010.

Yousuf M. Al Mahroqi was born in 1981. He received the B.Eng. degree in electrical engineering (Hons.), preparing for the M.Eng. degree in Distribution System Planning from Sultan Qaboos University, Muscat, Oman, in 2005 and 2011, respectively. Currently, he is a Professional Engineer with Mazoon Electricity Company, Oman. He is a M. Sc. student at the Department of Electrical & Computer Engineering, Sultan Qaboos University, Muscat, Oman.

Ibrahim A. Metwally (IEEE M’93–SM’04) was born in 1963. He received the B.Eng. degree in electrical engineering (Hons.), the M.Eng. degree in high-voltage engineering, and the Ph.D. degree in high-voltage engineering from Mansoura University, Mansoura, Egypt, in 1986, 1990, and 1994, respectively. The Ph.D. degree was received in collaboration with Cardiff University, Cardiff, U.K.Currently, he is a Professor with the Department of Electrical Engineering, Mansoura University, Mansoura, Egypt. He worked as a Visiting Professor with the University of the Federal Armed Forces, Munich, and Darmstadt University of Technology, Germany from 2000 to 2002 and in the summers of 2003-2007, and in summer 2009, respectively. He has also been on leave as a Professor with the Department of Electrical and Computer Engineering, College of Engineering, Sultan Qaboos University, Muscat, Oman since August 2002. His areas of research include high-voltage engineering, computational electromagnetics and power systems.Prof. Metwally is a Fellow of the Alexander von Humboldt (AvH) Foundation, Bonn, Germany, a Senior Member in the Institute of Electrical and Electronics Engineers (IEEE) and a Member of the International Electrotechnical Commission (IEC). He has published 125 papers, of which 69 papers have appeared in highly reputed international journals. He has completed 17 industrial projects in UK, Egypt, Germany and Oman, and 16 support services (consultancies) in Oman. He has completed 17 industrial projects in UK, Egypt, Germany and Oman, and 16 support services (consultancies) in Oman. He was awarded both the First Rank of the National Prize in Engineering Sciences in 1998 and 2004, and the Late Prof. Dr.-Ing. M. Khalifa’s Prize in Electrical Engineering in 1999 and 2005 from the Egyptian Academy of Scientific Research and Technology. He has been a regular peer reviewer for many IEEE Transactions, IET Proceedings and other electrical-power related journals. His biographical profile was published in Who’s Who in Science and Engineering in 2001.

Amer S. Al-Hinai received a B.Sc. in Electrical Engineering from Sultan Qaboos University, Muscat, Oman in 1997 and joined the University as a Demonstrator in 1998. He received his M.Sc. and Ph.D in Electrical Engineering from West Virginia University, Morgantown, USA in December 2000 and May 2005, respectively. Currently, he is an Assistant Professor in the Electrical & Computer Engineering Department at Sultan Qaboos University. His areas of interest are Power Systems: Control and Operation, Multi-Agent Systems: Application to Control of Power Systems, Optimization Techniques and Applications to Power Systems. Dr. Amer carried out more than 25 research projects related to energy savings, power system analysis, load flow analysis, short circuit analysis, power system protection, load shedding, power system quality and transient stability of power systems. He has published over 30 research papers in international journals and conferences. Beside his research activities, Dr. Amer conducted several training/short course sessions in the field of Electrical Power System. He is a member of the Institute of Electrical Engineering and Electronics, IEEE, USA.

Abdullah H. Al-Badi (IEEE M’94–SM’08) was born in 1969 in Oman. obtained the degree of B.Sc. in Electrical Engineering from Sultan Qaboos University, Oman, in 1991. He received the degree of M.Sc. and Ph.D from UMIST, UK, in 1993 and 1998, respectively. In September 1991, he joined Sultan Qaboos University as Demonstrator and in 2008, he became an Associate Professor. He has published over 70 papers in international journals and conferences, in the fields of electrical machines, drives, renewable energy, interference and high voltage. He has completed 19 industrial projects and 9 grants. He is a Senior Member of the Institute of Electrical Engineering and Electronics, IEEE, USA.