

An investigation on the effects of feeder outages and non-linear loads on 11kV ring distribution network efficiency

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Abstract

This study investigates the impact of power quality problems on the efficiency of a ring distribution network. The paper focuses on the effects of outage and harmonics on the distribution network efficiency and the practical implications on power system economics and reliability. An 11 kV ring distribution network was modeled and simulated in DigSilent PowerFactory (Demo version) 14.0.512 software package. Five case studies were conducted on the network for normal operation conditions and abnormal conditions (outage and harmonics). A methodology to estimate the technical losses (economic losses) in the distribution system was developed and used as a basis for determining the network efficiency. A load flow based analysis was carried out on the distribution system to determine the voltage and current profiles under normal and abnormal conditions.

It emerged that the loss of feeder cables or lines in the network has an adverse impact on the efficiency of the network. This raises the question on the existence and the need of an optimum supply configuration. It also puts an increased focus on the need of improved reliability engineering in distribution systems as the costs of failures could be high.

The authors conclude that the efficiency of a ring distribution network is affected adversely during contingency (outage and harmonics). The degree to which the efficiency is affected depends on the initial optimal design configuration and the nature of the disturbance or contingency condition. Preventative steps that can be taken to “harden” equipment and systems to PQ problems are also suggested.

Keywords: *harmonics, outages, efficiency, non-linear loads, 11kV ring distribution network, voltage profile, current profile, technical losses, harmonic distortion profile*

Introduction

The ring main distribution network is the name given to distribution feeders which are arranged to form a closed loop having one or several feeding points [Cotton, 1]. This arrangement allows feeders to be fed at both ends thereby approximately halving voltage drops [Chard, 2]. The three main features for which the ring network was initially designed are continuity, flexibility and reliability [Mtetwa, 3]. Energy losses in a power system reduce the efficiency of a power system. Therefore, it is important to know how much energy is being lost in the system in order to take corrective action.

In 2001, a study was carried out on the contingency analysis of an 11kV distribution network which concentrated on developing an algorithm for contingency analysis rather than relying on the instinct of system operators for network analysis [Hawtrey, 5].

In 2004 another study sought to find an efficient approach for contingency ranking based on voltage stability [Bijwe, 6]. It was found that many research papers published on the subject of contingency analysis have only concentrated on overload and voltage deviation [Wildi, 4]. What is of greater anxiety/concern is an environment lacking sufficient generation capacity. To manage such a situation and maintain supply when a contingency occurs, switching plans for the distribution system need to be devised to keep technical energy losses minimal. Literature tends to fall short in taking into consideration the energy losses that occur in distribution networks during a contingency.

The main aim of this investigation is to find out the degree to which the efficiency of the ring distribution network is affected during contingency. In the investigation an 11kV ring distribution network is modeled and is then used for contingency analysis of the network. The *DlgSILENT PowerFactory (Demo Version) 14.0.512* software package was used to simulate different possible contingencies in an 11 kV ring distribution network.

Power system losses can be divided into two categories: technical losses and non-technical losses [Suriyamongkol, 8]. Technical losses are naturally occurring losses (caused by internal actions to the power system) and consist mainly of power dissipation in electrical system components such as transmission and distribution lines/cables, power transformers, measurement systems, etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads. Non-technical losses (NTL), on the other hand, are caused by actions external to

the power system, or are caused by loads and conditions that the technical losses computation failed to take into account [Suriyamongkol, 8].

Because of the unpredictable nature of the failure of the power system components, such as cables, power networks are designed such that the remaining feeder cables should maintain the system by taking up the extra load while still remaining within the cables volt drop limits [IEC, 7]. The NRS 048-2 standard states that busbar voltages should be within a 6 % limit of nominal voltage [NRS, 9]. On cable loading, the SANS 10142-1 states that the voltage drop in cables during normal conditions should not exceed 5%. In a ring network system, the outage of cables results in a change of network impedances, hence causing a change in the energy losses in the network [Mtetwa, 3]. The following formulas are important when evaluating efficiency of an electrical network.

$$P_{\text{losses}} = P_{\text{in}} - P_{\text{out}} \quad (W) \quad (1)$$

Where:

P_{losses} is power lost in the network (W), P_{out} is the electrical output power in the network (W), and P_{in} is the electrical input power in the network (W);

Formula expressing percentage losses:

$$\% \text{Losses} = \frac{P_{\text{in}} - P_{\text{out}}}{P_{\text{in}}} \times 100 \% \quad (2)$$

Formula to calculate the efficiency of a network:

$$\eta \% = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{losses}}} \times 100 \% \quad (3)$$

Formula used to calculate the energy input and the energy lost in the network respectively:

$$E_{\text{in}} = P_{\text{in}} \times t \quad (4)$$

$$E_{\text{losses}} = P_{\text{losses}} \times t \quad (5)$$

Where: E_{in} is energy delivered in the network (J), t is the time taken for energy transfer (s), and E_{losses} is the energy lost in the network (J).

Methodology

The DIgSILENT Power Factory software package was used to simulate different possible contingencies on an 11 kV ring distribution network. A study was undertaken to determine the impact of network configuration changes on energy losses and how energy losses can be minimized to an optimum level. Five case studies were conducted, and for each case study, cable loadings, voltage profile were monitored in accordance with NRS 048-2-2004 standard, so as to ensure quality of supply. The methodology for carrying out contingency analysis for outages on the primary feeders of the ring distribution network was formulated and is as shown in Figure 1 below. Likewise the methodology for determining the efficiency of the network is presented in Figure 2.

Methodology for outage

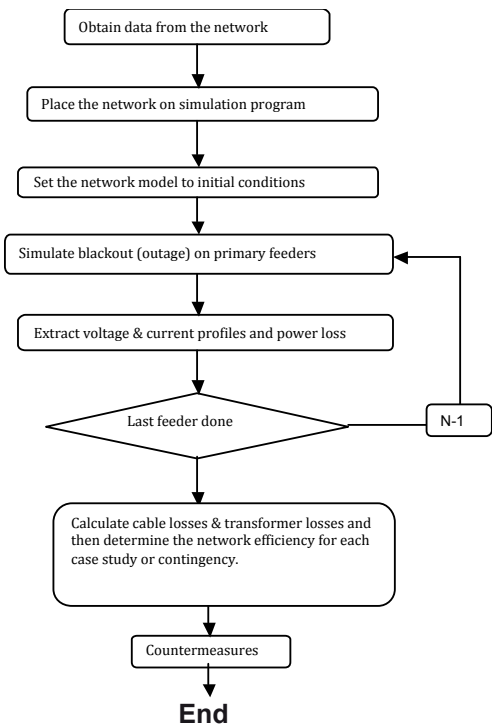


Figure 1: Contingency Analysis work flow diagram

Methodology to determine network efficiency

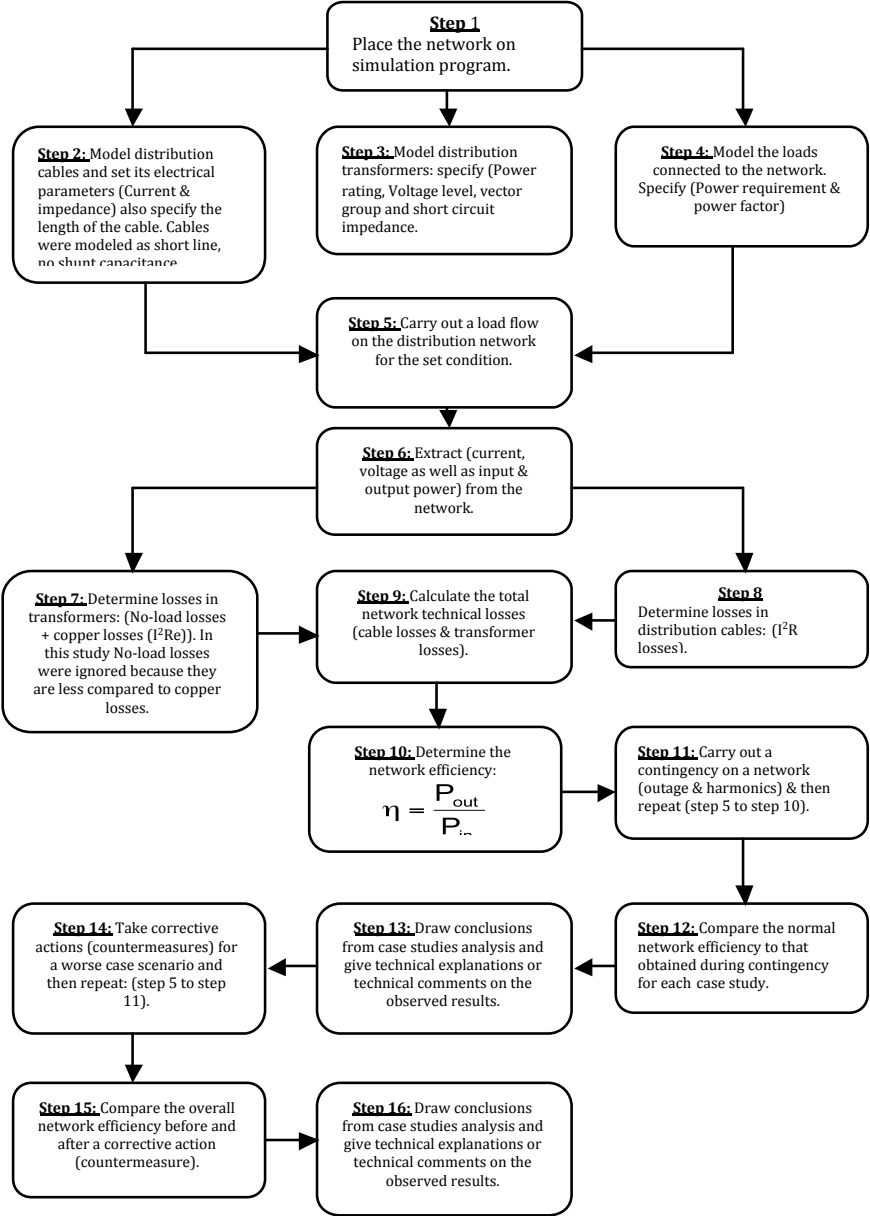


Figure 2: Network efficiency evaluation flow chart

Profile

Voltage Profile

The NRS 048-2-2004 administers the utility to supply voltage to consumers within 6% of the busbar nominal voltage during both normal and abnormal operating conditions in the network. The voltage profile is a verification to check that the voltage is within the 6% limit.

Table 1: Voltage Limits LV busbar

NRS 048 Regulation	Nominal Voltage (V)	Minimum Voltage (V)	Maximum Voltage (V)
6%	400 V	376.00	424.00

Current Profile

According to SANS 10142-1-2004, the voltage drop in cables during normal running conditions should be within 5% of the rated conductor volt-drop. Therefore, it is important to ensure that the primary feeders are not overloaded more than their rated capacity. The current carrying capacities of the feeders that were used are as shown in Table 2 below.

Table 2: SANS 10142-1-2004 limits for feeders

	Maximum Current (Amps)		
Cable	Ground	Ducts	Air
300 AL	350	292	378

Network description

The ring main distribution network in figure 3 is classed as a four cable feeder group. It is supplied from the distribution substation, a 66kV/11kV Dyn 11 transformer (TRF 1) receives its supply from the AC voltage source that is connected to the reference busbar rated at 66 \pm 0% kV. The network has got 4 primary feeders, cables 1, 2, 3 and 4. Cables 5 to 11 completes the 11kV ring main network. All these cables except cable 6 were 300 AL types with a current carrying capacity of 350 A. Ring main units have distribution transformers which are 11kV/0.4kV and are either Dyn7 or Dyn11. Consumers are supplied via their service cables from the secondary system.

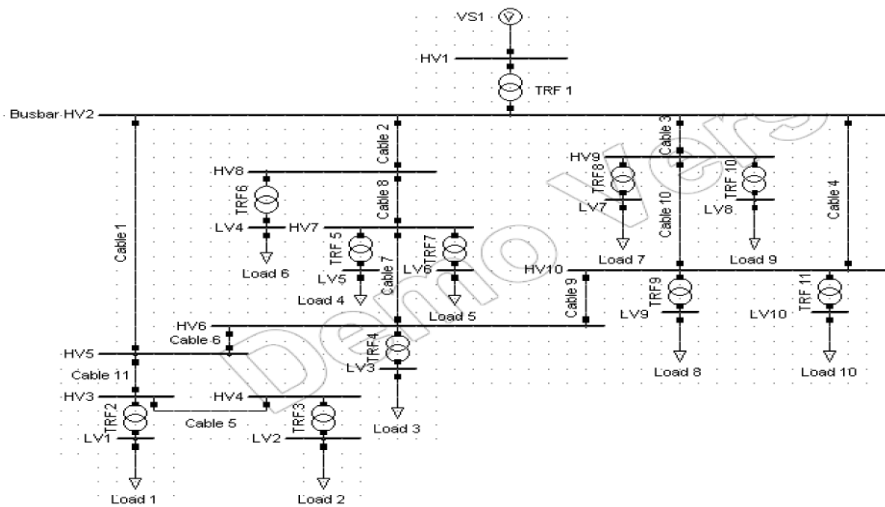


Figure 3: 11kV single-line-diagram ring distribution network

The network components or elements were modeled as presented in the tables below (table 3 to table5). Table 3 shows the loads that were modeled as linear loads. Table 4 depicts distribution transformers while Table 5 presents cable sizes and other cable parameters.

Table 3: Load data

Element	Voltage (kV)	MVA	Power factor
Load 1	0.4	1.2	0.92
Load 2	0.4	1.5	0.95
Load 3	0.4	1.5	0.95
Load 4	0.4	0.6	0.93
Load 5	0.4	1.2	0.93
Load 6	0.4	1.5	0.92
Load 7	0.4	0.75	0.95
Load 8	0.4	0.75	0.95
Load 9	0.4	1.5	0.92
Load 10	0.4	0.6	0.93

Table 4: Distribution transformer data

Element	Voltage (kV)	MVA	R%	X%
TRF 1	66/11	30	0.9217	8.5073
TRF 2	11/0.4	1.6	0.86	4.76
TRF 3	11/0.4	2	0.78	6.03
TRF 4	11/0.4	2	0.78	6.03
TRF 5	11/0.4	0.8	1.04	4.33
TRF 6	11/0.4	1.6	0.86	4.76
TRF 7	11/0.4	2	0.78	6.03
TRF 8	11/0.4	1	0.935	4.678
TRF 9	11/0.4	1	0.935	4.678
TRF 10	11/0.4	2	0.78	6.03
TRF 11	11/0.4	0.8	1.04	4.33

Table 5: Cable/feeder data

Element	Length (km)	Size of Cable(mm) and Conductor Type	+/- Sequence	
			Resistance ohm/ km	
Cable 1	0.946	300 Al	0.1215	0.085
Cable 2	1.831	300 Al	0.1215	0.085
Cable 3	0.578	300 Al	0.1215	0.085
Cable 4	1.563	300 Al	0.1215	0.085
Cable 5	0.807	300 Al	0.1215	0.085
Cable 6	1.502	70 Cu	0.3211	0.0106
Cable 7	0.891	300 Al	0.1215	0.085
Cable 8	0.854	300 Al	0.1215	0.085
Cable 9	1.217	300 Al	0.1215	0.085
Cable 10	0.627	300 Al	0.1215	0.085
Cable 11	0.807	300 Al	0.1215	0.085

CASE STUDIES

Case Studies conducted for outage

The ring network was examined by applying the method above and creating five case studies. Case study 1 (CS 1) was conducted for a normal operational condition while the other three case studies (CS 2, 3 and 4) were conducted for abnormal conditions, regarded as service or fault conditions. Here each

of the primary feeders was removed consecutively. CS is an acronym for Case Study.

- CS1- Operated under normal conditions (Cable 1, 2, 3 and 4 are connected).
- CS2- Cable 1 disconnected, Cable 2, 3 and 4 connected
- CS3- Cable 2 disconnected, Cable 1, 3 and connected
- CS4- Cable 3 disconnected, line 1, 2 and 4 connected
- CS5- Cable 4 disconnected, line 1, 2 and 3 connected

The analysis of results obtained from all case studies focused on voltage profile, current profile, and power/energy losses and network efficiency.

Voltage profile

NRS 048-2-2004 standard on voltage profile limits was used to verify whether voltages are within the 6% limit. Figure 4 depicts the voltage profile at the secondary low voltage (LV) busbar for all case studies (CS1 to CS5). The nominal voltage at the LV side is 400 V or 0.4 per unit.

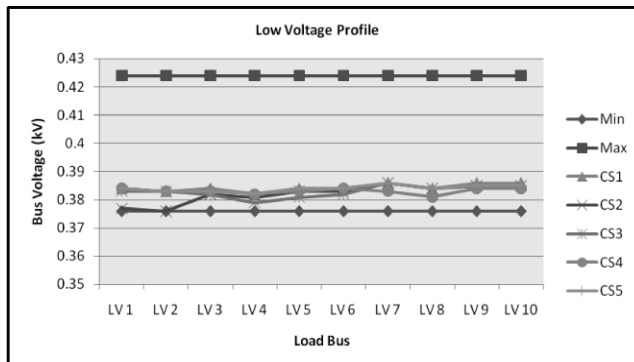


Figure 4: Secondary LV busbar voltage profile

Under normal operation conditions (CS1) all bus voltages are within the limit of 6% as stipulated by NRS 048-2-2004. Likewise, on average, the bus voltages (CS2 to CS5) have voltage deviations less than 6%, except LV2 in CS2 which is at 6%. Thus, there are no voltage violations encountered in the network as a result of loss of primary feeders compared to the allowable limits.

Current profile

Figure 5 below shows the cables loading. This profile is to verify overloading.

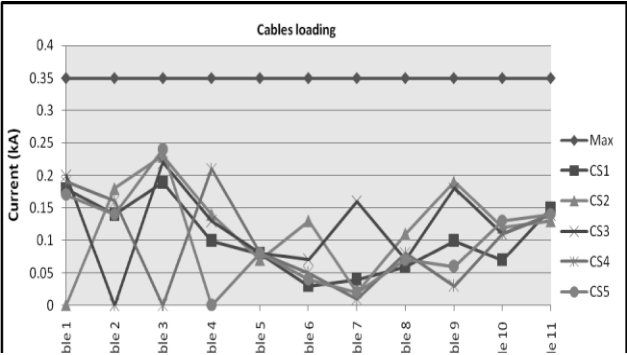


Figure 5: Current profile (cable loading)

Network efficiency

Table 6 shows the powers obtained during each case study conducted. The Table shows the input power, power losses, output power and efficiency in each of the case study conducted. The total technical losses in all case studies conducted are as a result of cable and transformer losses. The total technical losses for the normal operating conditions (CS1) were 145 kW. Therefore the technical losses contributed as a result of a contingency in the network (CS2 to CS5) are expressed as losses increase.

Table 6: Powers obtained for all case studies

Network	Units	CS1	CS2	CS3	CS4	CS5
P in	MW	9.7	9.64	9.67	9.67	9.69
Pout	MW	9.56	9.45	9.5	9.51	9.54
Cable losses	kW	54.76	98.2	75.86	71.304	56.545
	kW	90.2	89.49	89.81	89.49	90.14
Total losses	kW	145	187.69			
losses increase	%	0	29.44	14.26	10.89	1.16
Efficiency	%	98.56	98	98.2	98.3	98.45

The power losses obtained from CS3 and CS4 increased normal operating

condition (CS1) power losses by 14.26 % and 10.26% respectively. The highest power losses in the system were experienced in CS2. In this case, the system technical losses increased by 29.44%. It can be seen in table 6 above that the technical power losses in the cables for CS2 to CS5 are higher. In comparison to normal operation (CS1) cables power losses, the cables power losses for CS2 to CS5 are 79%, 38.54%, 30.22% and 3.3% in the respective cases, with CS2 giving the highest percentage of cable power losses. The focus is therefore, placed on the power losses occurring in cables. These losses increase in cables during contingency as a result of increase in current simply because the remaining cables in the network have to take the extra load current from the lost feeder. When a feeder is lost from the network, the network configuration changes and so the network efficiency also changes.

Overall network efficiency

Figure 6 below shows the efficiency of the network for various case studies conducted.

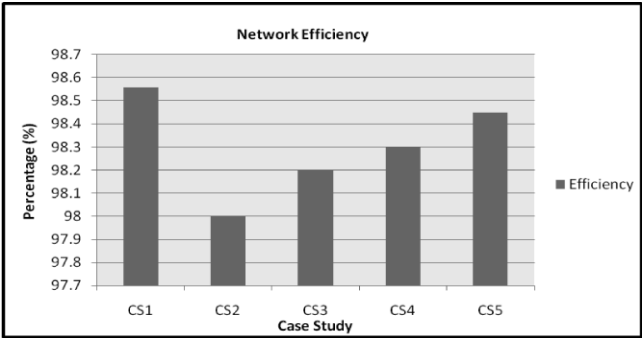


Figure 6: Efficiency of network obtained in case studies

From figure 6, the efficiency of the network is heavily affected by the removal of feeders. The case study number 2 (CS2) was considered to be the worst case for network efficiency reduction. Therefore for this worst case scenario (CS2), countermeasures were considered in order to reduce the power losses to an optimum level.

Energy losses

Figure 7 below shows the network energy losses for the worst case scenario (CS2) with cable 1 disconnected. The energy losses were calculated over

an estimate of power transferred in 1day (24 hours) recorded at an interval of two hours.

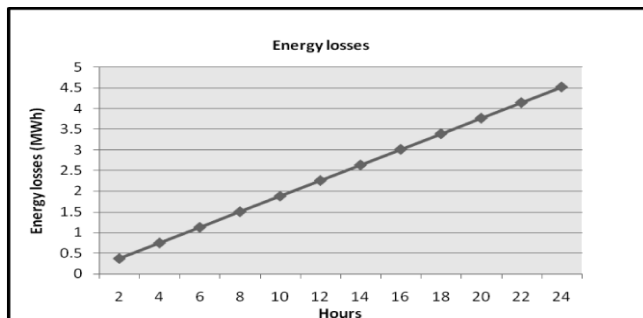


Figure 7: Energy losses obtained in CS2

The network energy losses will increase linearly with time, with the assumption that the loads are constant power loads for the duration of the investigation. This graph demonstrates that the longer (time) cable 1 is out-of-service, the more the energy losses are experienced in the network. This shows that the loading of cable 1 during normal operating condition is high compared to other feeders. It is for that reason that the energy losses increases much more when cable 1 is out of service. More input energy to the network will be required than normal, hence enhance the risk of load shedding and reducing system reliability.

Harmonic Analysis

Actual voltages and currents in electrical power systems deviate from ideal sinusoidal waveforms. These distortions can be caused either by saturating devices like transformers or by thyristor controlled devices, particularly AC/DC converters [DIgSilent,10]. The injection of harmonic current or voltages into the power system leads to voltage distortions and additional losses.

In power systems, harmonics appear only as integer multiples of the fundamental frequency as long as they are generated by saturation effects or by line-commutated converters. However in the case of modulated converters (e.g. PWM converters), non-integer harmonics (*inter-harmonics*) can also be found. Symmetrical waveforms are free of even harmonics. Therefore, the appearance of even harmonics in power systems is usually weak. They occur most commonly in the supply current of transformers with DC-components on their load side. [DIgSilent, 11]

Network Description

The ring main distribution network in figure 8 is classed as a four cable feeder group. It is supplied from the distribution substation, a 66kV/11kV Dyn11 transformer (TRF 1) receives its supply from the AC voltage source that is connected to the reference busbar rated at 66□0^o kV.

The network has got 4 primary feeders, cables 1, 2, 3 and 4. Cables 5 to 11 complete the 11kV ring main network. All these cables except cable 6, were 300 AL types with a current carrying capacity of 350 A. The primary system supplied the secondary system via a ring main unit. Ring main units have distribution transformers which are 11kV/0.4kV and are either Dyn7 or Dyn11. Consumers are supplied through the service cables from the secondary of the load transformers. The non-linear loads (HSource 1 & HSource) connected at the bus LV 1 (PCC bus) has the harmonic spectrum shown in Table 7. It is a 100kVA Variable Speed Drive with a displacement power factor of 0.766.

Table 7: VSD Harmonic Spectrum

Harmonic Order	Harmonic Current (%)	Spectrum Angle (°)
5 th	63.9	-23
7 th	40.8	-76
11 th	1.1	26
13 th	7.1	22
17 th	3.6	29
19 th	0.70	23

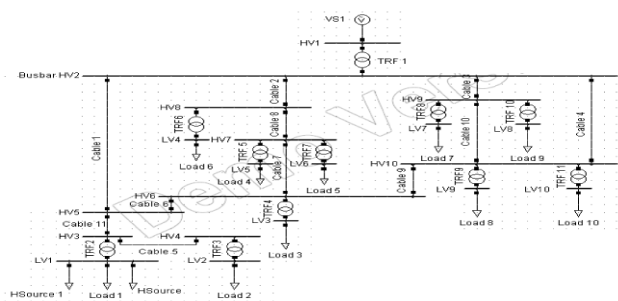


Figure 8: 11kV ring distribution network

Case studies on the impact of harmonic sources

Two case studies were conducted on the distribution network shown in figure 8 where the acronym CS represents Case Study.

The acronym CS represents Case Study

- CS 1- Operated under normal conditions (Harmonic loads disconnected).
- CS 2- Harmonic loads (HSource 1 & HSource) at LV1 (PCC bus) connected.

Plans for reducing energy losses to an optimum level and countermeasures were implemented based on the analysis of the results.

These case studies focused on evaluating the effects of harmonics on the efficiency of the network with respect to:

- Voltage limit violations;
- Overload conditions and volt drop violations and;
- The network's power and energy losses.
- Total Harmonic Distortion profile

Although the main focus of this paper is to investigate technical losses during abnormal conditions and find possible ways of reducing these losses to an optimum level, factors such as cable loading and voltage violations have to be studied first to ensure that the network can handle outages without cables being overloaded or any voltage violation happening, hence ensuring quality of supply. This makes it easier to find areas for improvement.

Voltage Profile

The NRS 048-2-2004 administers the utility to supply voltage to consumers within 6% of the busbar nominal voltage during both normal and abnormal operating conditions in the network. The voltage profile is a verification to check that the voltage is within the 6% limit. Figure 9 below depicts the voltage variation from the nominal voltage (400 V) at the LV busbars for normal and abnormal conditions. The acronym LV represents low voltage busbars.

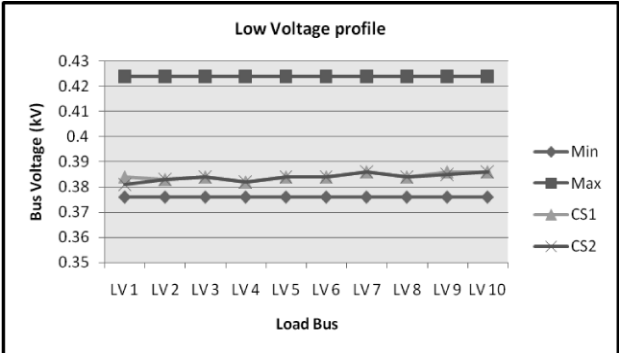


Figure 9: LV busbar voltage profile

During normal operation conditions (CS1) and abnormal conditions (CS2) all bus voltages are within the limit of 6% as stipulated by NRS 048-2-2004. Thus there are no voltage violations encountered in the network as a result of non-linear loads as compared to the allowable limits of standard.

Current Profile

Figure 10 below shows the cables loading. This profile is to verify overloading. No overloads were encountered. This verification was to investigate any overloading and voltage drop violations. The simulated cables in this network had a maximum carrying capacity of 350A (0.35kA).

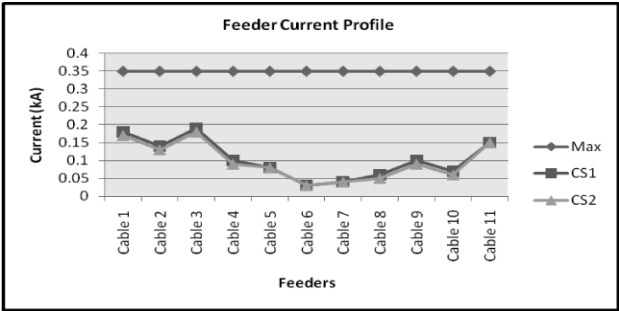


Figure 10: Cable Loading

Total Harmonic Distortion Profile

The voltage total harmonic distortion limit for distribution networks is 8% according to the NRS 048-02:2004 standard. This profile was evaluated at all the LV busbars to determine the effect of harmonics on the other consumers

connected to the PCC bus and the rest of the network LV consumer busbars. Figure 11 shows the VTHD recorded at all the LV busbars in the network.

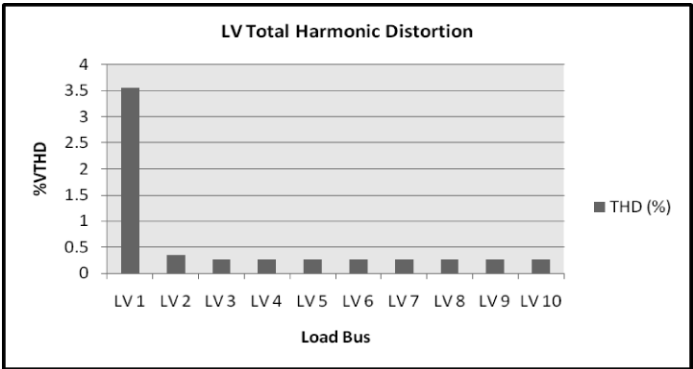


Figure 11: Total Harmonic Distortion

The highest THD (3.55%) was measured at the PCC bus (LV1). All the recorded total harmonic distortions in the network are within the NRS 048-02:2004 standard. It can be seen that although the harmonic loads are connected at LV1, the THD were seen at other LV busbars (consumers) in the network.

Harmonic Distortion Profile

Figure 12 shows the VHD recorded at the PCC bus LV1 busbar as a result of individual harmonic order. This profile was evaluated at the PCC (point of common coupling) LV1 bus to determine the effect of harmonics on the other consumers connected to the PCC. Figure 13 shows the injected harmonic current being injected at LV1 (PCC) busbar by the non-linear load. This is an appreciation that non-linear load injects distorted currents in the network.

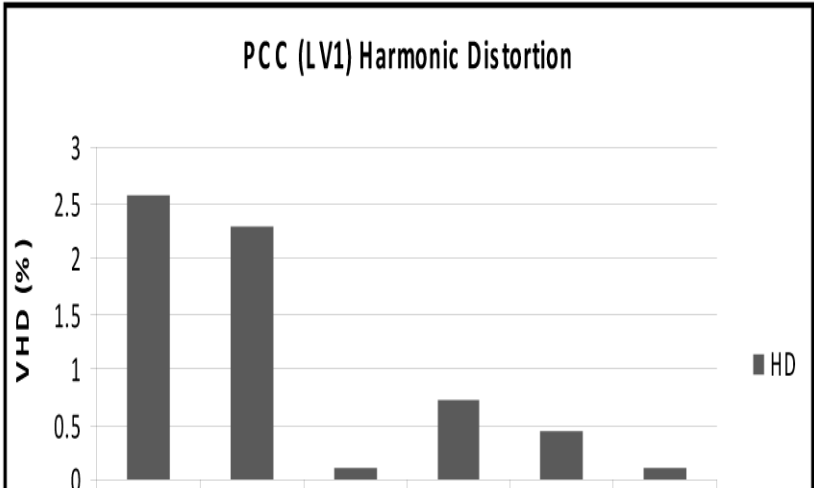


Figure 12: Harmonic Distortion at LV1

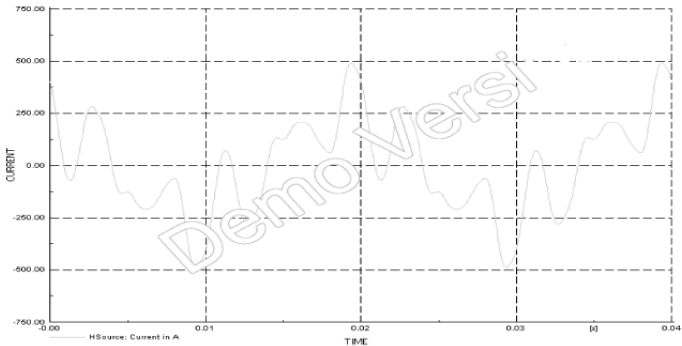


Figure 13: Non-linear load current

Efficiency of the network

Table 8 shows the powers obtained during each case study conducted. The Table shows the input power, power losses, output power and efficiency in each of the case study conducted. The total technical losses in all case studies conducted are as a result of cable and transformer losses. The total technical losses for the normal operating conditions (CS1) were 145 kW. Therefore, the technical losses contributed as a result of a contingency in the network, (e.g. CS2), are expressed as an increase in losses. Table 8 shows powers obtained in the case studies conducted.

Table 8: Powers obtained for all case studies

Network Parameters	Units	CS1 (No Harmonics)	CS2 (With Harmonics)
P in	MW	9.7	9.86
Pout	MW	9.56	9.7
Cable losses	kW	54.77	48.414
Transformer losses	kW	90.2	104.83
Total losses	kW	145	153.244
losses increase	%	0	5.69
Efficiency	%	98.56	98.4

The power losses obtained from CS2 increased normal operating condition (CS1) power losses by 5.69 %. It can be seen in table 8 above that the technical power losses in the transformers for CS2 are higher as a result of harmonic current. However, cable power losses have decreased showing that the transformers are prone to harmonics hence contributes to technical losses.

Overall efficiency

Figure 14 below shows the efficiency of the network for the case studies conducted

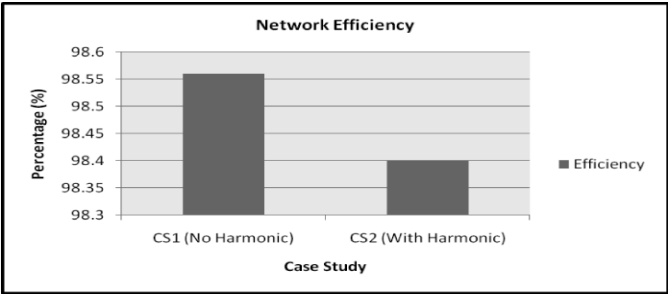


Figure 14: Efficiency of network obtained in case studies

From figure 14, the efficiency of the network is affected by the non linear load that draws harmonic currents. The case study number 2 (CS2) is considered to be the worst case scenario for network efficiency reduction. The efficiency reduced as result of increase on the RMS current due to harmonics. Therefore for this worst case scenario (CS2), countermeasures were considered in order to reduce the power losses to an optimum level. The results are discussed in the next section.

Countermeasures

There are a range of countermeasure techniques that can lead to energy-efficient network and inherently have additional benefits of, improving the reliability and quality of supply of the power network as well as reducing system losses. Improving energy efficiency presents a mutually beneficial situation for all sectors within energy supply, delivery and utilization systems.

Network reconfiguration for outage

To decrease energy losses in a ring distribution network, one method which is commonly used is to reduce current flow through conductors by adding an additional cable to the network so as to provide an alternative path to the load. For this network a cable was added in turn to all the various areas within the network. Simulations were conducted in an experimental way to find the best area giving a reduction in losses less than the worst case scenario (CS2). Areas with percentage voltage deviation close to the limit were highly considered especially LV1, LV2 and LV4 for CS2 with 5.8%, 6% and 4.8%. The appropriate cable for power losses reduction was chosen based on the percentage total losses increase (see table 6) for worse case scenario (CS2) and maximum current for feeder cable 1. The appropriate cable size (120 AL) was chosen based on calculations shown below.

Percentage total losses increase =29.44%

Feeder maximum current=350A

Power= I^2R

For argument sake it is logically clear that if you reduce the current by 2 then we inherently reduce the power loss by 4.

New cable current requirement = Feeder maximum current x square root of total losses increase.

$$\therefore I = 350 \times \sqrt{\frac{29.44}{100}}$$

$$= \underline{\underline{190A}}$$

Therefore a cable such as 120 mm² AL, rated current 210 Amps was chosen. It was found that adding a cable between busbars HV2 and HV6 that supply the aforesaid LV busbars resulted in a dramatic reduction in the energy losses. Figure 14 below depicts the reconfigured ring network.

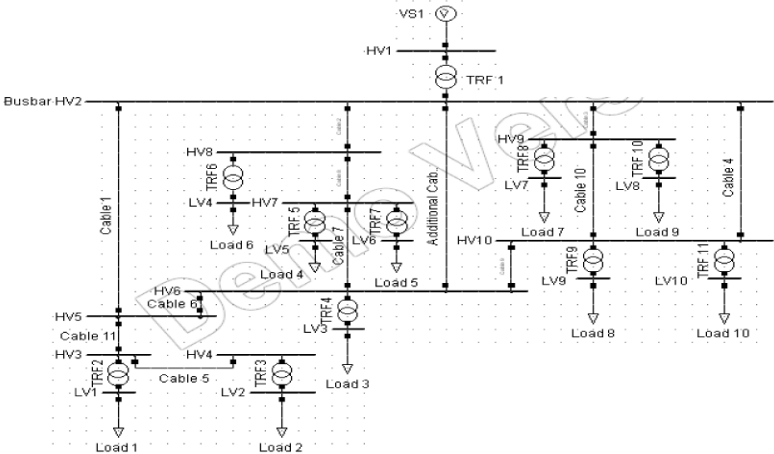


Figure 15: Reconfigured 11kV ring distribution network

Table 9 shows the technical power losses acquired from the network after and before network reconfiguration. These losses (before and after reconfiguration power losses) were compared to show the significance of carrying out contingency analysis in the network.

Table 9: Comparisons of power losses

Case study	CS1	CS2	CS3	CS4	CS5
Total losses before (kW)	145	187.69	165.67	160.794	146.685
Total losses after (kW)	142.02	161.5	156.75	156.758	143.73

Table 9 that the total network technical power losses have decreased as a result of network reconfiguration especially in CS2. This shows that the method of adding an extra cable will work effectively. Figure 16 depicts how the efficiency of the network has increased as a result of network reconfiguration.

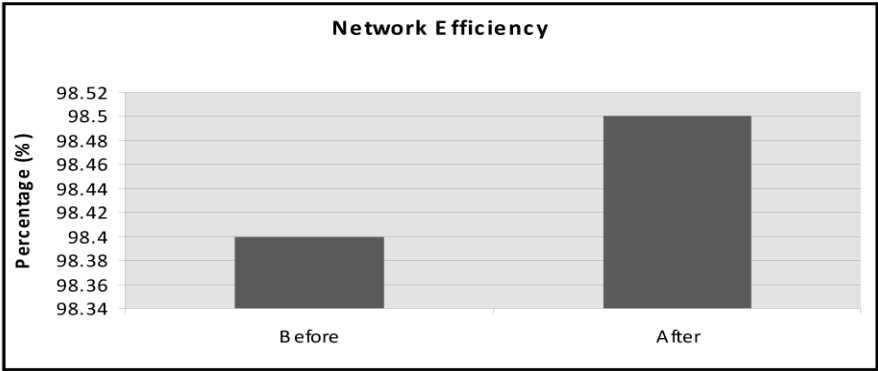


Figure 16: Efficiency comparison before and after the reconfiguration

The efficiency of the network has improved significantly, especially for CS2. This shows that reconfiguring the network was the most effective way in this network to lessen power losses during an outage. The reduction in losses was a result of reduction in current in the remaining feeders due to reconfiguration of feeders during an outage.

Installation of Power Factor Correction Capacitors (for correction and harmonic mitigation)

Capacitor installation is used to improve the power factor and voltage regulation of the network, thus improving voltage profile. Since the power factor is improved the current will be reduced just as the technical energy losses (I^2Rt) are reduced, hence improving the network efficiency. The power factor capacitor is placed at the LV1 bus to improve the power factor from 0.766 to 0.95 for the non-linear load. The capacitor rating requirement for power factor correction was determined as follows.

Non-linear load ratings:

$$S = 100kVA$$

$$P = 76.6kW$$

$$Q = 64.27kVar$$

$$PF = 0.766$$

$$Q_{New} = P \tan 18.2$$

$$= 76.6 \tan 18.2$$

$$= \underline{\underline{25.2kVar}}$$

$$Q_{Required} = Q_{Old} - Q_{New}$$

$$= 64.27 - 25.2$$

$$= \underline{\underline{39.1kVar}}$$

Since there are two non-linear loads, the capacitor rating will be doubled. Therefore the total kVar rating for the capacitor will be. The capacitor is placed at the PCC busbar (LV1) where the non-linear loads are connected and is as shown in figure 17 below.

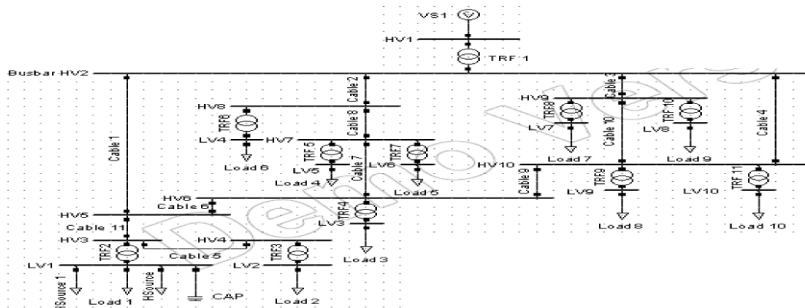


Figure 17: Improved PF 11kV ring distribution network

Figure 18 shows how the efficiency of this network was improved as a result of the network power factor correction at LV1 busbar. The losses (before and after power factor correction) were compared to show the significance of carrying out contingency analysis in the network focusing on harmonic mitigation.

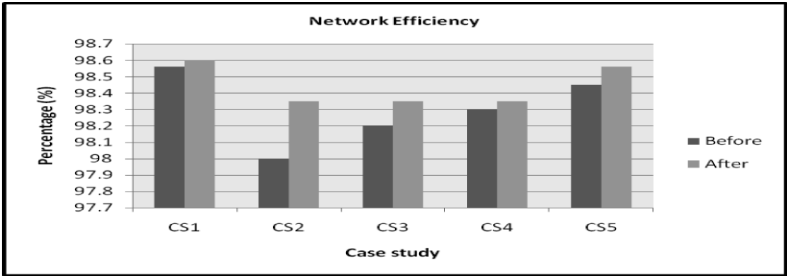


Figure 18: Efficiency comparison before and after the PF correction

The overall efficiency of the network was improved when the power factor correction equipment was installed. This shows that installation of power factor correction capacitor and harmonic filters is an effective way of lessening power losses due to harmonics in power distribution systems.

Network reconfiguration significance

Traditionally, contingency plans are temporary back-up plans for power system networks, to ensure continuity of supply during outages. The consideration of efficiency in power networks has made contingency plans a permanent feature. Although this method might have high initial cost, it reduces costs in a long run due to reduced maintenance requirements. Also the supply power requirement for distribution will be reduced owing to a reduction in the energy losses of the power system networks.

Conclusions

The research concludes with the following remarks:
In most cases, energy losses and efficiency of the entire system are usually ignored during contingency analysis studies. However the results from the case studies conducted showed that the energy losses increased during the outage. This is because there is a change in network configuration and

remaining feeders are taking extra load current from the lost feeder therefore increasing technical losses.

Harmonics in the network contributes to the technical losses in a ring distribution of the network simply because the RMS line current of the network increases with the increase or presence of harmonic current hence causing an increase in power losses.

It is very important to carry out contingency analysis in a distribution network so as to predict the network behaviour and take corrective actions. This investigation was done to consider technical losses (and efficiency) during contingencies.

The investigation concludes by noting that the efficiency of a ring distribution network is adversely affected during contingency conditions. The degree to which it is affected depends on the design and the nature of disturbance, hence affecting the reliability and flexibility of the network.

The treatment of T&D losses, including PQ losses, in emerging competitive energy markets needs to be analysed, benchmarked and to apportion the responsibility and accountability between network operators and consumers. The development of distributed generation systems against a background of energy shortage within the regional energy trading block, Southern African Power Pool, may need an assessment on the impact this will have on network efficiency. The relation between network losses and distributed generation needs to be investigated with a view to determine how regulation can be used as a substitute to competition [Chatterton, 15], so as to promote the development of competitive electricity markets in traditionally monopolistic energy supply environments.

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