Creating Failsafe Maintenance Methodologies
In an environment of Diminishing resources

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1. Introduction

A sound maintenance program involves creating a statistical framework with which to understand measure, and maintain the performance of equipment. Electrical networks consist of intricate configurations of electrical equipment working in unison to generate, transmit and distribute electrical supply to the end user. The reliability of the network's electrical equipment will determine the consistency of supply that the consumer will receive at the end of the day. It can thus implicitly be said that '*'reliability is the essence of maintenance.''*

It is important to take cognizance that breakdowns will always occur at the worst times due to the physical exertion of a system, resulting in collateral damage that far exceeds the original problem. An example of this could be, the winter of 2010, when 500 000 soccer enthusiasts enter the shores of South Africa for the Soccer World Cup, and a power failure interrupts the opening ceremony due to peak electrical demand.

Effective maintenance plans need to be in place to protect the electrical networks integrity. Maintenance programs that extend into 5 year,10 year and 20 year maintenance plans, to keep current with the growth of the economy.

The attitude of '' *if ain't broke, don't fix it ''*, has cost companies, incalculable sums of revenue, resulted in licenses been contravened and has meant that the credibility of long, good-standing performance has been ruined. This so called '*'breakdown theory of maintenance''* has to be examined, understood and overcome so that failsafe maintenance methodologies can be implemented.

The result of a methodical approach, once explored will result in the eradication of the undesireable effects due to the presence of a reliable maintenance program.

2. The levels of Maintenance management

Aging electrical equipment needs to be managed against comprehensive maintenance plans and procedures. The goal is to achieve the maximum amount of lifecycle from the equipment to ''sweat the asset'' whilst still effectively protecting the asset.

<u>2a. Reactive maintenance (Level 1 – basic)</u>

A Crisis-styled maintenance approach to asset management, whereby a response is given to equipment malfunction only once it has transpired. This approach involves the highest amount of risk as no forward planning is presented, and can often indicate an inefficient maintenance department or poor management. A lack of maintenance objectives, the absence of historical trends and no weekly, monthly or quarterly schedules in place are what plague this type of maintenance model. This short term maintenance style will result in the steady degradation of our electrical network. The only procedures that are in place with this management style are those that respond to emergencies, creating pressure on production and an imbalanced people dependant system.

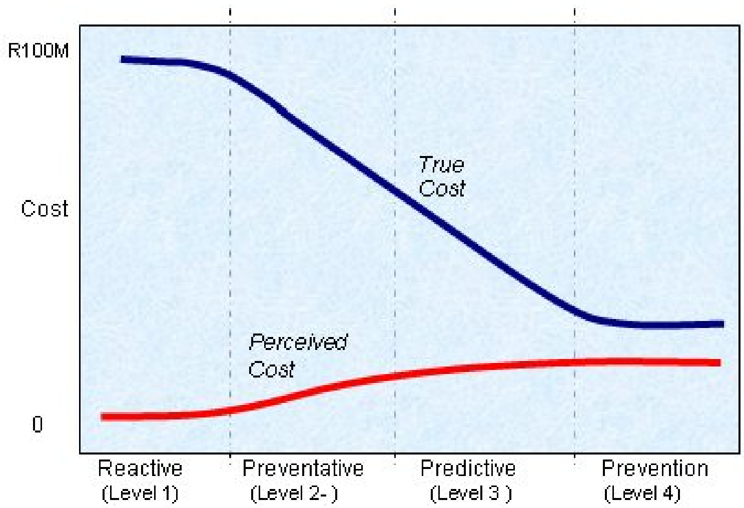
<u>2b. Preventative maintenance (Level 2 – Intermediate)</u>

A more systematic approach to maintenance of our electrical networks would start with periodic checks of the system and adjustments to the desired objective. This would involve replacement of electrical equipment against the dedicated operating life cycles of the product.

The advantage of the preventative model is that the discrepancy of the system is more predictable as management begins to implement maintenance methodologies that are more involved and time based, so the risk is removed. Teams are managed against statistical frameworks, to determine minimum and maximum intervals of time between maintenance schedules.

2c. Level of Maintenance – Perceived versus Actual cost

Fig. 1



2d. Predictive maintenance (Level 3 – advanced)

A defined maintenance program, where periodic measurement of equipment transpires. Equipment is defined by cost and life-cycles whereby, five (5), ten (10) and twenty (20) year maintenance plans are implemented. Strong management policies are set in place for the maintenance department, and the duly authorized personnel are given authority to carry out tasks. Budgets are set in place to cater for the adequate parts and services. Management is involved with total quality management, an ongoing method of improvement. Continuous monitoring of process equipment for any abnormal operating conditions. The movement from people-dependant systems to time-directed methodologies is an important step in the removal of risk from the system.

2e. Prevention Maintenance (Level 4 – Systematic)

This is the most advanced form of maintenance, whereby equipment design (technology) is based on minimal maintenance requirements. This progression of maintenance has moved from people-directed and time-directed maintenance to condition directed maintenance. A close relationship with the suppliers/manufacturers of the electrical equipment is required to continually improve on the electrical equipment. This system creates a framework that relieves pressure on the maintenance department as the maintenance requirements have been minimized and eliminated. Total quality management has advanced to a process of continually improving equipment. Although risk will always be a variable that needs to be considered, it has been effectively minimized, and will be a very reliable system.

2f. Critical (Non-scheduled maintenance plans)

In spite of comprehensive, level 4 maintenance plans, occasions will arise when equipment suddenly fails. This could be for a number of reasons ranging from a deficiency in product quality, unanticipated changes within the electrical network or dramatic weather changes.

A good non-scheduled maintenance plan, provides a system for the uninterrupted deployment of work orders and service requests that can be served on-the spot in accidental and dire needs. In practice, the combination of a dedicated team and the correct equipment replacements should always be available to respond to such occurrences. A duly authorized person would need to deal with this type of crisis so that it would be eliminated as soon as possible, and this person given the priorities and procedures to respond quickly to any unscheduled event.

3. Summary :

Reactive Maintenance *Characteristics :* • *Unpredictable equipment operation.* • *Unplanned maintenance procedures.* • *Short term costs low.* • *Long term costs high.* • *High risk of electrical network*	***Preventative Maintenance*** *Characteristics :* • *People dependant system.* • *Evolvement of teams* • *Periodic system checks.* • *Equipment lifecycle measurements* • *Medium risk to electrical network.*
Predictive Maintenance *Characteristics :* • *Time dependant system.* • *Maintenance department dependant* • *Budgets in place.* • *Total Quality management* • *Low risk to electrical network.*	***Prevention Maintenance*** *Characteristics :* • *Condition directed maintenance.* • *Technology dependant system.* • *Close relationships with manufacturer.* • *Less pressure on department* • *Short term costs high.* • *Long term costs low.*

4. Failsafe maintenance methodologies :

a. Incorporation of new technologies.
b. Maintenance schedules.
c. Maintenance courses and education.
d. Maintenance Audits.
e. Computer software management.
f. Facilities inspection.
g. Provision of spares.
h. Historical records and database development
i. Management's commitment to maintenance.
j. Outsourcing of maintenance activities.

4a. Incorporation of new Technologies.

A failsafe maintenance variable to consider is the process of new technology development within a utility. This is a collaborative effort that is initiated when the utility identifies a problem and can provide the domain, whilst the manufacturing company provides the hardware and software (product platform). Universities are involved to provide the testing facilities.

Technical improvement plans are work practices specifically aimed at making strategic refinements to an electrical distribution network in order to realize such tangible benefits such as :

- Meeting current and future technical capabilities of a system.
- Increasing operational efficiency.
- Keeping current with technological advancements.
- Extending the useful life of a system.
- Adding value to the system. eg. Conservation of energy.
- Reducing losses and excessive costs.

In an environment where forthcoming engineers and operators do not always get the adequate apprenticeships, experience handed down from management or exposure to various system faults, technology development and integration works to compensate for weak areas and to improve on current standards. Technology such as AI (Artificial Intelligence), Mobile Agent software and upgraded hardware can provide a utility with advantages such as:

- Increased productivity.
- Quicker fault clearing & service restoration.
- Improved customer service.
- More powerful design and planning tools.
- The ability to work within smaller margins.

The correct idea would be to do routine technology upgrades to a system to avoid having to do major overhauls, major repairs or replacements. The movement away from maintenance intensive and manually structured networks is initially a costly exercise, but once traded-off against decreased maintenance procedure times, less pressure on staff members, and increased commitment to perform the maintenance procedure, the best possible outcome for an electrical network will be realized.

<u>The steps for continuous technology development</u> :

- Identify the maintenance constraint.
- Identify the cause.
- Develop a prototype for improving the system.
- Test the prototype.
- Measure desired results.
- Integrate the new technology.
- Measure the improvement.

<u>Identify the constraint</u>

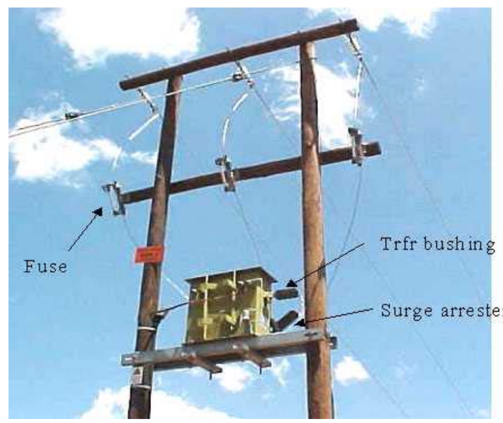
Needs	Challenge
* Identify the cause	Develop prototype
* Measure the results	Test prototype
* Measure improvement	Integrate new technology
Technical department	*R & D Department*

<u>Case Study</u> : <u>Distribution class surge arrestor maintenance in the South African context</u>.

In the early 1990's, DOC Mining Supplies, a manufacturer of low voltage electrical Mining equipment, embarked upon extensive research together with Eskom Distribution, into the excessive downtimes of Distribution networks during summer (rainy) seasons. Eskom's distribution networks range from 3,3kv to 33kv, with the majority of these electrical lines being 11kv and 22kv networks.

Focus was soon directed to pole mounted transformers and excessive downtimes caused by lightning and over-voltage damage. The cause was soon found out to be the lack of effective surge arrestor maintenance and configuration problems.

<u>Fig 2. Eskom's configuration D-DT-1860</u>



It was during this period that an effort was made within Eskom to improve on surge arrestor maintenance mainly on 11kv and 22kv Distribution lines. Pole mounted transformer losses within Eskom distribution was calculated to be approximately four times higher than the average utility and this situation had to be addressed.

The most vulnerable periods for over voltage damage was measured during the rainy months of September through to April each year.

The problems that were identified on these networks with regards to surge arrestors were :

a. Difficulty in the identification of spent surge arrestors, from ground level.
b. The staff's reluctance towards carrying out the maintenance procedure on surge arrestors.
c. The time duration of several hours to carry out maintenance. (outage time)
d. Surge Arrestors often didn't blow clear off the lines causing S.E.F's Sensitive Earth Faults or Earth Faults.
e. Safety of personnel was being compromised during the maintenance in rainy conditions.

Reactive response (level 1 – basic level)

The process of new technology integration began when DOC Mining Supplies researched and developed an overhead phase indicator to reduce surge arrestor maintenance time in configuration D-DT-1860. The phase indicator was developed to provide a visual indication of a downed phase, by using the corona effect of each working phase, at the pole mounted transformer. According to the reactive model of maintenance, this was only a short term effort. It was measured and did reduce fault identification time, but the idea was to provide a more effective maintenance model.

Fig. 3 Phase indicator, connected on a 11kv and 22kv distribution line.

To augment this product, a little black box was placed in the customer's home, to provide a visual indication that one of the phases had gone down. This provided even quicker identification, isolation and rectification of the fault. This was still not the ideal, but a good starting point in the right direction, to improving surge arrestor maintenance on distribution lines.

Fig. 4 The Black box Phase indicator, connected inside the customer's home.

After two seasons of implementation and measurement it was noted that this reactive response to maintenance was only achieving minimal improvements and was not viable as a long term consideration.

It was thus decided that another approach was needed for management to gain the co-operation of field staff's attitude towards effective surge arrestor maintenance on 11kv and 22kv distribution lines.

Preventative maintenance (level 2 – intermediate)

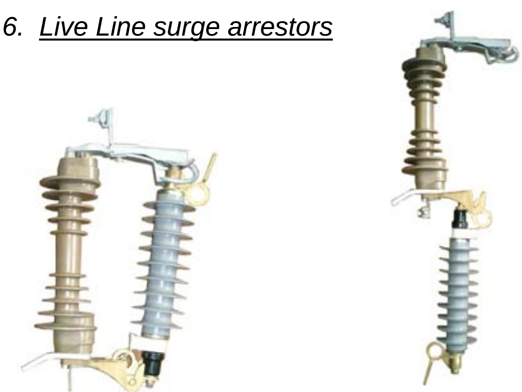
A more concerted effort was needed to ensure that field staff wouldn't only properly identify the spent surge arrestor but would also be more co-operative in the replacement of these units.

Thus, DOC Mining supplies set out to design a surge arrestor that could be maintained live line without the need of an outage. After just one year of implementation, the results were measured once again and the results were astounding. The return on investment was realized in the first season of their implementation.

Fig.5 Conventional surge arrestors

Healthy unit *Spent units require 3hr maintenance operation.*

Fig 6. Live Line surge arrestors



Healthy unit *Maintenance simplified.*

Predictive maintenance (level 3 - advanced)

Because the research on transformer losses and surge arrestor replacements was a continuous study and a continuous process of improvement, the measurement of the system was consistently carried out so that improvements could be brought about.

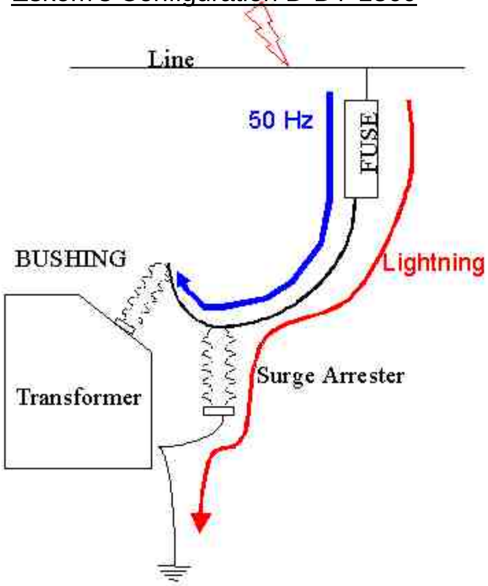
It was thus identified, that the excessive pole mounted transformer losses could be further reduced further by improving on Eskom's configuration at pole mounted transformers.

Engineers working on this project were seeking to remove the reactive and preventative component from their development plans. It was soon realized that by focusing on the root cause of problem, a solution would be found, directly relating to the excessive transformers losses and bringing them closer to a prevention maintenance model.

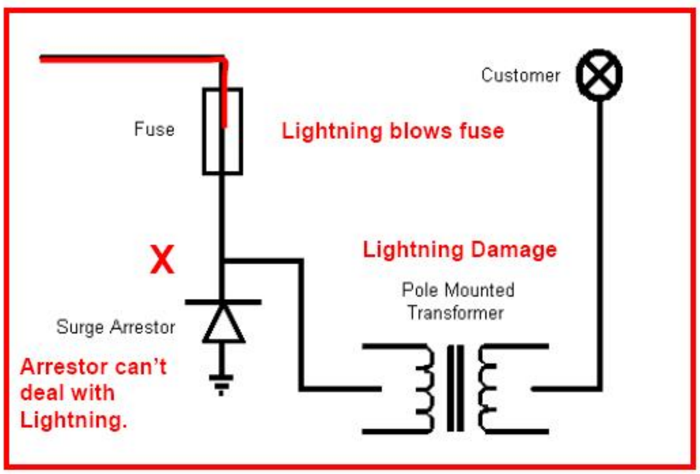
A mathematical model was soon implemented to analyze the properties of the fuse and surge separately and in their fuse-arrestor configuration. It was not long after these steps were taken that it was discovered that the surge arrestor could withstand greater amperages than the fuse over their individual time durations.

A decision was thus taken to correct this configuration, to ensure that the fuse would not continually take the surge arrestor out of circuit during electrical storms. It was thus concluded, that the fuse's position needed to be corrected in this configuration.

Fig. 7 Eskom's Configuration D-DT-1860



This configuration performed satisfactory under normal 50hz conditions but when it was exposed to over voltage occurrences such as lightning, the vulnerabilities exposed itself in excessive fuse blows and pole mounted transformer losses.



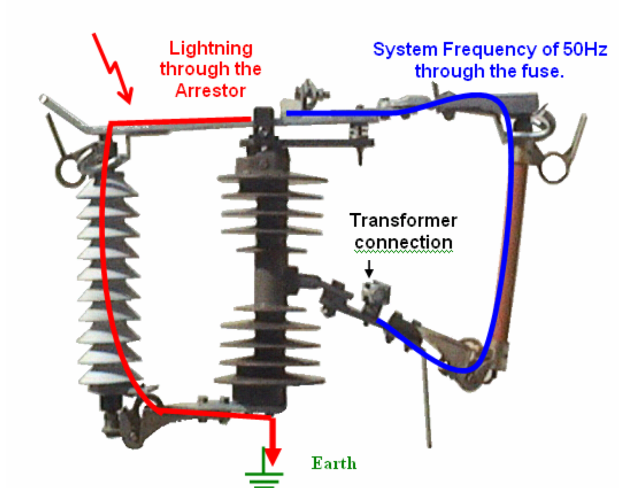
Prevention maintenance - The final solution

A unit was finally designed to ensure that the arrestor-fuse configuration at pole mounted transformers was corrected. The Transformer Combi unit ensured that the surge arrestor was placed in parallel to the fuse and no longer in a series connection.

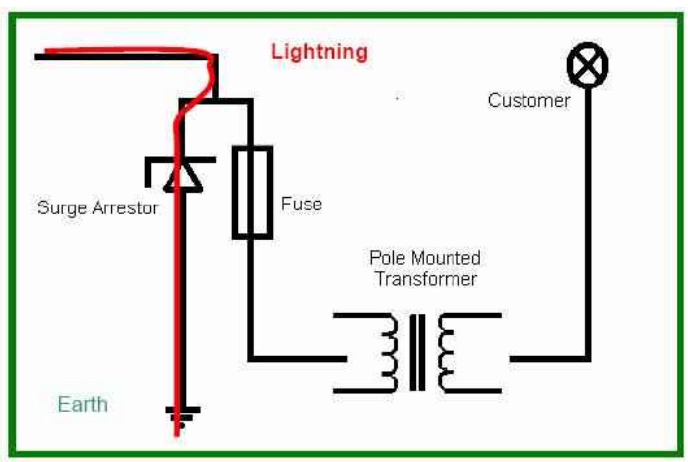
This final design not only corrected the fuse and surge arrestor into the correct position, but also ensured that a healthy surge arrestor was also present at all times. Live line capabilities was a requirement, as well as unique arrestor alert, which was an automatic indication that the surge arrestor was spent.

The conclusion to the maintenance program was that the surge arrestor could now, effectively deal with the over voltage problems at the pole mounted transformer effectively bringing about a prevention maintenance approach.

Fig. 8 The Transformer Combi Unit.



This configuration performed better under normal 50hz conditions and when exposed to over voltage occurrences such as lightning the surge arrestor could now affectively deal with the over voltage occurrences. No more nuisance fuse blows or transformer losses.



4b. Maintenance schedules

The product life cycle of the various equipment within an electrical utility will differ considerably according to the type and use. The maintenance schedule will have to be systematically setup and accurately recorded into a maintenance database.

Important variables that are taken into account are the following ; the manufacturer's recommendations to the maximum lifecycle of the product in service, the relative importance of the product (primary versus secondary equipment) and the exposure to extreme conditions.

An example of the different equipment schedules :

Secondary equipment (5 year schedule)

- *Overhead conductors.*
- *Surge arrestors.*
- *Insulators.*

Primary equipment (20 year schedule)

- *Transformer replacement (transmission transformer).*
- *Pole structures and support.*
- *Turbine replacements. (Generation)*

Specialised equipment (10 year schedule)

- *Auto-reclosers.*
- *Circuit breakers.*

4c.Maintenance courses and education.

It is important for managers to show their commitment to an effective maintenance program and for this to extend to the every staff member in the maintenance department. This will be achieved when provisions are made in terms of education in maintenance programs and courses. New technology and computer software is constantly being developed to improve on existing systems often rendering certain systems redundant. Management needs to allocate parts of their budget towards the education of every staff member in this department.

Courses and education could be provided by outside contractors, suppliers, trade associations, conferences and publications.

4d Maintenance Audits

An audit is the barometer of success for the maintenance program. An audit will show the real success in terms of continued operation, reduced maintenance costs, reduced downtimes and increased production. Without measurement it is impossible to rate the condition of the equipment and the measure of the system's improvement.

4e. Computer software management

It has become increasingly advantageous for electrical utilities to utilise computing software to manage their infrastructure. Computer software is often capable of acting reasonably on behalf of the user.

It can also provide greater knowledge exchange, flexibility, communication and adaptability. System software engineered for electrical utilities such as mobile agent software used in circuit breaker maintenance uses a set of high-level abstractions to represent systems and can be manipulated to portray cause-effect impacts. Different strategies for the most effective application can also be revealed with this type of software.

Information about the spare parts required, test procedures, historical records and instruction manuals can all be accessed from the enterprise maintenance system. Work orders initiated by computer software management indicates when and where to perform and what kind of maintenance on what devices.

4f. Facilities Inspection

A thorough facility and asset inspection periodically is a key element in the maintenance program. This inspection lists the various life safety equipment, line equipment, generation parts, transmission (sub-stations) and distribution sectors. These inspections should be documented by the duly authorized staff member and summaries should be brought to monthly maintenance meetings. After the initial facilities inspection for positive identification, it is then the responsibility of top management representatives to take periodic tours to certain facilities and make the right maintenance decisions.

4g. Provision of spares.

The maintenance department needs to be in constant collaboration with the logistics manager to ensure that spare parts are always available. Adequate budgets need to be in place to provide the necessary spare parts and services to make maintenance methodologies work. A budget process should be established and adequate resources directed at maintenance. The maintenance department must be actively involved during the budgeting process, so that the provision of spares can be achieved. If this is overlooked it often becomes extremely difficult to finance random maintenance efforts or the needed services from current operating funds.

An example, of not having the adequate spares was the Cape Provinces' experience of outages during November 2005 to February 2006 due to not having the adequate spares for one of the main components of the turbines in their power station.

4h. Historical records and database development.

It is thus imperative to keep accurate records of product lifecycles, information on the aging of areas and assets within an electrical network and keeping diagrams/maps of the current network so that a utility can undergo effective maintenance plans. Maintenance software programs available today provide manager's with the opportunity to equip their staff with the best tools to maintain sound maintenance programs. Gathering data and keeping historical records enables the creation of statistical analysis which is explicit information and the movement towards prevention maintenance.

4i. Management's commitment

A strong management policy establishing leadership and support for the maintenance program is a primary part in establishing an effective maintenance program. Management must communicate its sincere support through an aggressive communication of the policy and procedure to all employees.

Maintenance programs should never be seen as a service cost to any organization, but rather an investment to ensure the protection of assets. Asset management of an entire electrical network comprises of many different electrical parts equivalent hundreds of millions of rands.

4j. Outsourcing of maintenance activities

It often so occurs that there are large scale losses of experienced engineers and operators due to retirement or as we have seen in South Africa of late, a brain and skills drain to the countries of Australia and New Zealand. New engineers are not always exposed to the intricacies of new systems and therefore lack the expertise that a utility may require. In these cases it may then be worthwhile to employ a private party to install, commission and maintain certain specialized equipment to ensure that operation is as intended by the manufacturer.

Outsourcing activities allows electrical utilities to maximize their productivity by exploiting the expertise of the private sector. Service level agreements may also allow a higher standard of service quality standards and commitments.

5. Effects of Poor Maintenance :

a. Downtime – factories.
b. Degradation of the network.
c. Damage to equipment.
d. Loss of life. (human life)
e. Poor customer service.

5a Downtimes

Reactive styled crisis maintenance plans are the cause of excessive downtimes and most certainly cause the most destruction to the end user. Factories, mining operations and production facilities are the hardest hit areas of collateral damage. Downtimes are usually brought about due to the following causes :

- Basic conditions that are neglected.
- Inadequate skills of staff.
- Operating standards are not followed.
- Deterioration of equipment.
- Quality of equipment compromised.

5b Degradation of the network

Certain equipment requires periodic maintenance and upgrading otherwise it can be exposed to extreme working conditions or obsolescence. If this is not carried out, then this equipment could start to relay this stress onto other equipment.

Once, a system is exposed to excessive stress, then a chain reaction of degradation can set into a system.

5c. Damage to equipment

By not maintaining the electrical equipment against the standards set in the maintenance program, will mean that it will be exposed to conditions outside their scope of design, and this can result in the product becoming damaged. The replacement cost of a product, outweighs the periodic maintenance that should be carried out in a disciplined manner.

5d Loss of human life

By failing to do maintenance operations at their designated times, may expose our employees or colleagues to very dangerous circumstances at a later stage.

Electrical power is a willing slave, but an unforgivable master, and neglect in the maintenance duties of our equipment should never result in the death of an employee or colleague.

5e. Poor customer service

The degraded condition of an electrical network, will continue to wreak havoc on customer service levels as a system is only designed to operate for a designated number of years before efficiency levels off.

It is thus imperative that we don't falter in our main objective to keep our customer service levels high, especially when South Africa intends on hosting a world famous event, like that of the Soccer World Cup in the year 2010.

6. Conclusion

Sound maintenance methodology involves continuous examination, inspection and assessment of an electrical network and the associated risks as a result of deviation from the standard.

An effective maintenance program will identify the undesirable effects of a deviation from standard. Management needs to keep current with the status quo of an electrical network, so that the identified problems can be highlighted, treated and eradicated. The objective is to maintain the standard and the reliability of the system, as well as to keep current with the latest technological developments.

Important constraints of a maintenance plan ;

1. *The strategic importance of the equipment.*
2. *Cost constraints and consideration of budgets.*
3. *The lifecycle of the equipment.*
4. *The skills required to implement the type of equipment being maintained.*
5. *Duration or time interval required.*

A level four maintenance program can be achieved by implementing statistical frameworks, so the strategic importance of each individual line in the distribution network can be mapped, categorized according to a time-based model describing the operating lifecycle of each piece of equipment.

A sound maintenance programs involves strong leadership of management and commitment to creating a statistical framework. It is Management's responsibility to implement the necessary time-based maintenance methodologies, against the fixed set of constraints mentioned above.

Relying on human abilities and not considering a controlled system will only result in failure.

Manager's need to communicate this proactive attitude to all staff members and need to ensure that all the necessary financial and human resources in are made available to the maintenance program

All maintenance programs need to receive the priority they deserve. The movement away from reactive maintenance programs, that are crisis styled and unorganized towards preventative methods that are statistical and condition directed removes the element of risk in the system.

Practical maintenance methodologies are the incorporation of new technologies, developing maintenance schedules, taking part in maintenance courses and education, performing maintenance audits, incorporation of computer software management, effective facilities inspection, the adequate provision of spares, historical records and database development, management's commitment to maintenance and lastly the outsourcing of maintenance activities.

It is within this framework that the reliability of a system is enhanced and the assets of a utility effectively protected.

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