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How Can Corona Cameras Minimize Losses

The formation of corona on transmission lines is associated with loss of power. This loss is governed by environmental factors and by the power line properties. There are two major sources of losses in high voltage AC transmission lines: resistive loss and corona loss. Resistive loss occurs because of the non-zero resistance found wire's metal. Corona loss occurs when the electric fields around a conductor exceed a specific value leading to ionization of the air.

The total power loss on transmission lines is described by the following equation

$$T_L = RI^2 + 242\frac{(f+25)}{\delta}.\sqrt[4]{\frac{r}{d}}(V - V_c)^2.(10)^{-5}\ kW \quad (1)$$

where ***f*** represents the frequency of transmission, **δ** denotes the air density factor, ***r*** is the radius of the conductor, ***d*** represents the space between the transmission lines, **V** is the operating voltage and $\mathbf{V_c}$ denotes the disruptive voltage.

In correlation with the above equation, some of the means to reduce corona loss on conductors include:

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- The use of bundle conductors reduce corona loss
- Spacing between conductors is selected so that corona is tolerable
- Since the shape of conductors affect corona loss, cylindrical shape conductors have uniform field that reduces corona loss than any other shape
- The voltage stress and electric field gradient should be minimized which can be accomplished by using good high voltage design practices. Using conductors with large radii reduce corona loss
- Void free solid conductors and insulators should be used
- Corona formation can be suppressed, if the terminals on high voltage equipment are designed with smooth round diameter rounded shapes like balls and the addition of corona rings to insulators of high voltage transmission lines

According to the USA Department of Energy, California lost about 19.7 x 10^9 kWh of electrical energy through transmission/distribution in 2008 (2). This amount of energy loss was equal to 6.8% of total amount of electricity used in the state throughout that year. At the 2008 average retail price of $0.1248/kWh, this amounts to a loss of about $2.4B worth of electricity in California, and a $24B loss nationally. It is commonly accepted among electrical utilities that resistive loss ranges between 1.9% and 2.8% over 1000km. These losses are fixed and depend on wiring configuration. Corona losses range between 0.083% - 3.66% depending on power line properties & environmental factors (3).

Corona losses as calculated by the above equation sum up to considerable figures, and yet these are only the tip of the iceberg. Corona is an indicator of existing electrical failures and an active ageing factor that accelerates electrical deterioration processes. As such, detecting corona and arcing discharges is included in the list of predictive maintenance recommended practices.

Failures found by Ofil's corona cameras

Electrical losses due to corona discharge and to corona related failures can be reduced to minimum through a planned maintenance scheme that combines predictive, preventive, reactive and proactive mix. Maintenance activities at facilities typically run about 80%–85% reactive (service requests, trouble calls, repairs), 15% preventive, 1% predictive, and 1% proactive. It is claimed that by changing the mix to equal shares of 30-35% reactive preventive and predictive and 10% for proactive it is possible to reduce maintenance costs drastically and refrain from lethal unexpected shutdown consequences.

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Reactive maintenance is typically unplanned and it involves repair or replacement in response to failures and breakdown. The philosophy behind reactive maintenance assumes that failure is equally likely to occur in any part, component, or system. Yet, in such a case there is a risk of not having available replacement parts resulting in delays hence running a large inventory of replacement parts is impractical and costly in particular for major expensive components. Failures tend to occur usually at the most inopportune time resulting in premium payments for urgent attention, an inefficient use of the workforce. But, reactive maintenance is acceptable for components that pose only little risk to operations and the costs of maintenance outweighs the items replacement cost.

Preventive maintenance is typically planned, based upon time and not on the actual condition of the components. Regularly prescheduled activities such as: inspection, adjustments, cleaning, lubrication, parts replacement, and repair of components are usually predefined by the manufacturers, who may have a protective self-interest at stake and a lesser regard for costs to the plant. Being arbitrary, these time-based activities can result in unnecessary even damaging maintenance. Preventive maintenance induces failures and is considered to be costly as for example is the case of overhauling a properly functioning motor generator set based on a manufacturer recommended timetable.

Predictive maintenance is based upon the actual condition of components and uses nonintrusive non-destructive testing techniques. Predictive maintenance is based upon analyzed performance data that is has been collected during visual inspections. With predictive maintenance there is no need for arbitrarily scheduled maintenance and the risk of unplanned failure is very much reduced. A major role in this kind of maintenance plays trending analysis, because it is used for planning and to establish schedules. Electrical condition monitoring techniques should be applied to electrical distribution cabling, panels, and connections; switchgear and controllers; transformers; electric motors; and generators. Obviously, it not applicable to all types of equipment or failure modes, and therefore it should it is most effective when used in conjunction with a preventive program.

It is estimated that 95% of all electrical problems are due to insulation deficiencies, connections (loose, corroded, under-sized, and over tightened), unbalanced load, inductive heating, spiral heating in multi-strands wires, contamination and design errors. Condition monitoring detects abnormal electrical discharges, temperature, voltage, current, resistance, complex impedance, insulation integrity, phase imbalance, mechanical binding, and the presence of arcing. The most common predictive tests are: Ultraviolet corona cameras - to detect arcing, corona and surface partial discharge; Infrared thermography - to detect overheating of circuits; Insulation power factor—measures power loss through insulation to Insulation; Oil analysis—detects transformer, switch, breaker insulation oil condition, and contamination; Dissolved gas analysis—trends the amount of nine gases in transformer oil formed by transformer age and stress ; Megohmmeter testing—measures insulation resistance phase to phase or phase to ground ; High-potential (hi-pot) testing—

go/no-go test of the insulation; Airborne ultraviolet inspection — detects electrical arcing and corona discharges; Battery impedance—checks impedance between terminals and compares the same battery against previous readings ; Surge testing—go/no-go test of winding insulation; Motor circuit analysis (MCA)—measures motor circuit resistance, capacitance, imbalance, and rotor influence; Motor current signature analysis (MCSA)—provides signatures of motor current variations.

The manifested use of proactive maintenance is to implement the trend analysis collected through predictive and preventive maintenance in order to improve the design, installation and workmanship so that the whole system performs better and longer and maximize maintenance effectiveness.

An optimized maintenance mix will have a sizeable impact on the cost of maintenance: breakdowns and repairs typically cost about $17–18 per installed horsepower (hp)/year, preventive costs about $11–13 per installed hp/year, and predictive maintenance costs about $7–9 per installed hp/year.

Unplanned emergency maintenance takes 25% to infinity longer to do than planned and is normally done on overtime rates. The part costs and their shipping rates are higher. The waiting time for replacement parts to arrive, the contractor's urgent labor fees, specialty equipment to arrive on site; wasted hours due to the staging of parts and equipment in an emergency or unplanned work situation; overtime hours involved with the emergency work; extra procurement and shipping costs for emergency parts, etc. all add up to huge costs.

ABB calculated that for each 1$ invested in condition based maintenance they save 3$ of catastrophic failures. An engine can be left running until it fails completely risking the possibility of crankshaft or the block to get damaged. Repairing an engine is estimated to cost much less and involves only the cost of the overhaul kit. With planned activities, ABB can coordinate with production the repair time reduce notably the downtime of the equipment; allow production to take the necessary precautions.

There is a wide variety of cost ratios between planned and unplanned work. This is due to the various types of operations. In linear processes, where any piece of equipment can shut down the whole process, unplanned breakdown cost will be relatively high. In non-linear processes, a breakdown affects a limited amount of processes.

> ***"The primary purpose behind condition based maintenance (CBM) is early detection/early correction. Running to failure costs downtime, revenue and profit loss. Don't' think of CBM as saving money but as one choice for an appropriate asset management"*** *Christopher Williamson, Director Maintenance and operations t Jacobs Engineering [Jacobs, with 2013 revenues of nearly $12 billion, is one of the world's largest and most diverse providers of technical, professional, and construction services].*

"Almost 80% of power outages experienced by all Power utilities are due to external insulation problems. After 25 years in extensive work focused on HV system performance in polluted conditions in Northern Africa where combined marine salt spray & desert sand blowing by dominated winds were the main cause" *R.Z HV Systems Consulting. INMR Contributor at INMR Journal.*

The reliability of today's generation of composite insulators (NCI), manufactured in accordance with the latest technology, can only be reached, if the correct corona protection of the composite insulator is set. For a comprehensive evaluation of NCI a combination of UV method and other tools is needed. The UV method is particularly efficient in detecting conductive/semi-conductive defects that have developed on insulators (4)

Productivity and monetary loss

Reactive maintenance, as mentioned above, can cause unexpected shutdowns. In such cases, the losses from a power failure can be extensive and of great consequence. For a business, the recovery time is significant. The costs are high. Financially, power outages can mean substantial losses for the company affected. According to the US Department of Energy, when a power failure disrupts IT systems:

· 33 percent of companies lose $20,000–$500,000

· 20 percent lose $500,000 to $2 million

· 15 percent lose more than $2 million

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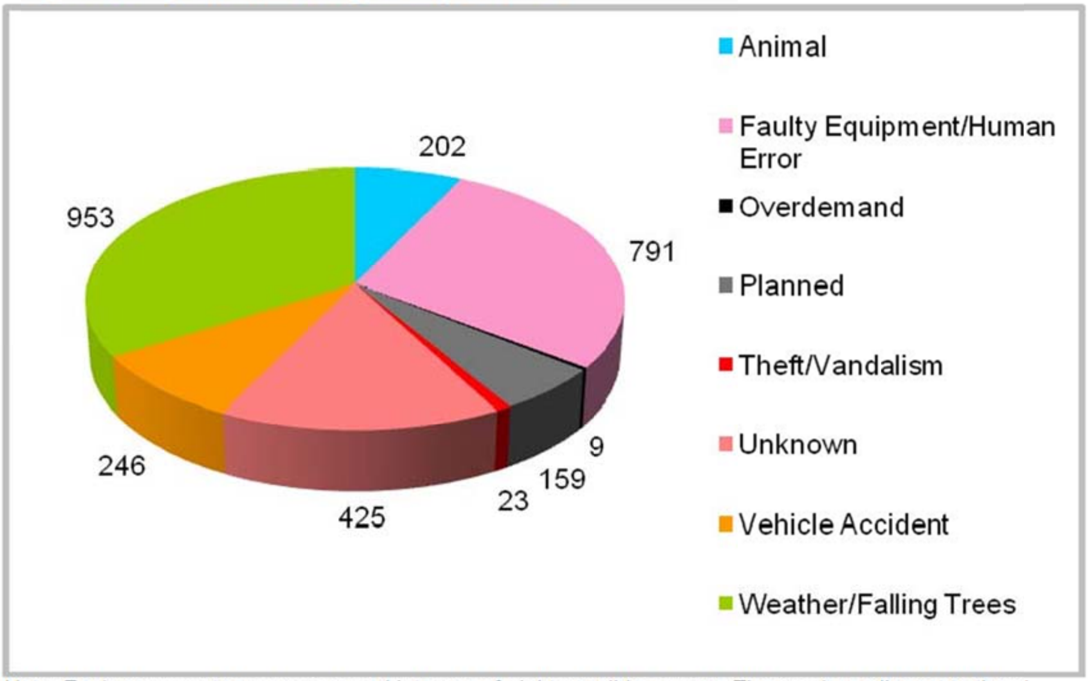
Reported power outages by cause



Note: Each power outage was grouped into one of eight possible causes. The number adjacent to the pie piece is the number of outages attributable to that cause.

According Eaton Corporation's Blackout Tracker Annual Report for 2012

Top states for outages caused by faulty equipment/human error

2012 (791 total outages)	**2011** (767 total outages)	**2010** (895 total outages)	**2009** (834 total outages)
1. California (197)	1. California (141)	1. California (171)	1. California (143)
2. Michigan (41)	2. New York (39)	2. Texas (43)	2. Ohio (42)
3. Texas (40)	3. Texas (38)	3. Florida (35)	3. Texas (40)
4. Massachusetts (38)	4. New Jersey (35)	3. Illinois (35)	4. Washington (39)
5. New Jersey (34)	5. Pennsylvania (28)	3. Michigan (35)	5. Michigan (33)
6. New York (30)	6. Michigan (26)	6. Ohio (34)	5. New York (33)
7. Ohio (28)	7. Ohio (25)	7. New Jersey (32)	7. Florida (32)
8. Pennsylvania (26)	8. Connecticut (24)	8. Washington (30)	8. Massachusetts (29)
9. Washington (25)	8. Illinois (24)	9. Pennsylvania (24)	9. Pennsylvania (24)
10. Wisconsin (21)	8. Massachusetts (24)	10. Virginia (29)	10. Illinois (21)
			10. Wisconsin (21)

Almost 30% of the reported power outages were caused by faulty equipment and human error. This is the category where corona issues belong to. Corona cameras are dedicated to predictive and condition based maintenance. Their greatest advantage is in the combination time-quality, meaning the time it takes corona cameras to process raw data into meaningful information and the quality of that information. Once the camera is powered it immediately captures and shows existing failures. If even a small discharge exists, Ofil's corona cameras will show it. The accuracy of showing the discharge is top level so that the emitting sources

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are recognized and displayed. Corona cameras show in real time the decaying processes with a qualitative indication of the discharge intensity.

Ofil's corona cameras have the following characteristics:

- Low entrance cost
- Detector life time - no degradation
- Output information – visual, natural language
- Information availability – online, immediate
- Information quality – excellent accuracy
- Information relevancy – very high
- Information exclusivity – supplied only by UV
- Category – NDT
- Pre Requisites – NONE, use and benefit
- Can be used by any maintenance team member
- Basic instructions are needed
- Pinpointed info – reduced search time cost
- Use results to assess the present condition
- Combine results with other tools to get a comprehension view of the condition
- Generate trends to schedule activities
- Get information that no other tool can provide

To summarize, it can be concluded that to get to the desirable Reliability Centered Maintenance that combines the strengths of reactive, preventive, predictive & proactive it is necessary to use a combination of testing technologies that act synergistically. Each technology contributes its unique added value and unique information. Overlapping redundant information will have to be revaluated so that the most efficient equipment prevails. The trend towards using testing tools, such as Ofil's corona cameras, that provide immediate clear information goes in tandem with the developing technologies and smart tools. Because, when revenue is at stakes, the best practice should prevail.

Resources:

(1) Predictive models of current, voltage and power losses on electric transmission lines O. M. Bamigbola_, M. M. Aliyand K. O. Awodele z Department of Mathematics, University of Ilorin, Ilorin, Nigeria, School of Computational and Applied Mathematics, Faculty of Science, and TCSE, Faculty of Engineering and the Built Environment, University of the Witwatersrand, South Africa, Department of Electrical Engineering, University of Cape Town, Cape Town, South Africa

(2) M. Bowles, " State Electricity Profiles 2008," US Energy Information Administration, DOE/EIA 0348(01)/2, March 2010

(3) Paul Gill, *Electrical Power Equipment Maintenance And Testing,* Second Edition, CRC Press2009 by Taylor & Francis Group, LLC

(4) Assessment Of Composite Insulators By Means Of Online Diagnosis , WG B2.21,2012