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“ Electricity Supply to Africa and Developing Economies …. Challenges and opportunities.”

Technology solutions and innovations for developing economies.

The use of 3D printing for high voltage applications and non-critical spares.

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Additive manufacturing fabrication techniques using 3D printing technology has grown substantially over the past decade from a high cost technology to implement, to the point where desktop 3D printers are readily available and offer high precision rapid prototyping. The purpose of this paper is to identify key focus areas where 3D printing technology may provide the necessary flexibility in low volume production of innovative and customised solutions that impact on the power distribution network by adding high value.

The paper will begin with a short introduction into fabrication using additive manufacturing techniques implemented by 3D printing technology, it will then proceed to go through dielectric testing of materials, and its application and results for tests conducted on 3D printed samples. The paper will conclude with two practical examples of 3D printed objects that were implemented in a power distribution network. The first object an attachment which allows substation operators to capture photos and videos of equipment from above ground level while in a substation during routine inspections under live conditions. This has been successfully implemented over the past year. The key savings and benefits of this device are discussed as well as the design and prototyping process. The second object is a 3D printed implementation of non-critical spares which can be used on a distribution network. The practical implementation of this has been the design and manufacture of Bucholtz valve handles. The overall benefits of 3D printing technology used for fabrication are presented as well as their drive to promote innovation and forward thinking within organisations.

Additive Manufacturing

Additive manufacturing is an appropriate name to describe the technologies that build 3D objects by adding layer-upon-layer of material.

Common to AM technologies is the use of a computer, 3D modeling software, machine equipment and layering material. The 3D printing method which will investigated further is that of Fused Deposition Modelling (FDM).

Fused Deposition modelling (FDM)

Process oriented involving use of thermoplastic (polymer that changes to a liquid upon the application of heat and solidifies to a solid when cooled) materials injected through indexing nozzles onto a platform. The nozzles trace the cross-section pattern for each particular layer with the thermoplastic material hardening prior to the application of the next layer. The process repeats until the build or model is completed.

There is however a lack of dielectric strength data for commercially available 3D filaments, which limit the applicability and usefulness of 3D printed objects in high voltage environments. [1]

TEST PROCEDURE

Testing of 3D printed material for breakdown voltage has been carried out before [2], These were done according to the ASTM D149-09 (2013).

The procedure used to test the 3D printed samples is based on IEC 60243-1 and BS EN 60243-1. The test procedure used is the one categorised for thermoplastics (FDM 3D printing was used to produce specimens). The tests are conducted on samples specimen of dimensions of 60mm x 60mm x 1mm. The test procedure requires 5 of each specimen to be tested and the average of the outcome to be recorded. The test procedure requirements have been adapted to accommodate for the equipment available. The following tests were required and carried out.

1. Rapid rise test

The test is carried out by increasing the voltage at a uniform rate from zero until breakdown occurs. The rate of rise should be selected so that breakdown occurs between 10 s and 20 s.

2. 20 second step by step test

This test is carried out by starting at 40% of rapid rise breakdown voltage. The voltage is applied for a period of 20 s. If the specimen withstands this voltage, the voltage is increased in incremental steps. Each increased voltage step is applied for 20 s until failure occurs.

3. Slow rate of rise test

This test is carried out by starting at 40% of rapid rise breakdown voltage. The voltage will be increased at a uniform rate so that breakdown occurs between 120 s and 240 s.

4. 60 second step by step test

This test is carried out by starting at 40% of rapid rise breakdown voltage. The voltage is applied for a period of 60 s. If the specimen withstands this voltage, the voltage is increased in incremental steps. Each increased voltage step is applied for 60 s until failure occurs.

5. Very slow rate of rise test

This test is carried out by starting at 40% of rapid rise breakdown voltage. The voltage will be increased at a uniform rate so that breakdown occurs between 300 s and 600 s.

Each test is carried out five times; with each test being carried out on a new specimen. The average of these tests will be regarded as the final result. The final results will be recorded as the breakdown voltage.

TEST SETUP

The test setup is split into two different machines.

The test vessel used can be seen in figure one. The electrodes used are 10mm in diameter as opposed to the required 20mm diameter as required by IEC 60243-1. The distance between the electrodes are 1mm as required. The entire specimen and electrodes are submerged in insulating oil with a breakdown voltage of 70kV/2.5mm. This test setup was used in order to limit the mechanical stress placed on the specimens, as mechanical stresses imposed may affect the breakdown voltage [3].

The first setup is used to obtain a uniform rate of voltage increase. The second is to carry out the step by step test.

In order to obtain a uniform rate of voltage increase, a Megger OTS80AF is used with a modified operating standard. The vessel of the Megger OTS80AF is filled with insulating transformer oil and the specimen is place in-between the two electrodes. The machine is able to produce a uniform rate of voltage increase and automatically detects when breakdown occurs and records the value. The limitation of this machine is that the lowest voltage rise achievable is 500 V/s. Which is above the voltage rise required for slow rate of rise and very slow rate of rise test.

In order to carry out the step by step test, the same test vessel and insulating oil is used, but the vessel is connected to a High Voltage VLF Hipot AC test machine. This machine is able to maintain the specified voltages for the required time period. The voltage is control manually via a control panel. The machine automatically detects breakdown but does not automatically record the value. The machine also provides a leakage current value to the operator and has an adjustable timer built in. This machine was also used to carry out the slow and very slow rate of rise tests.

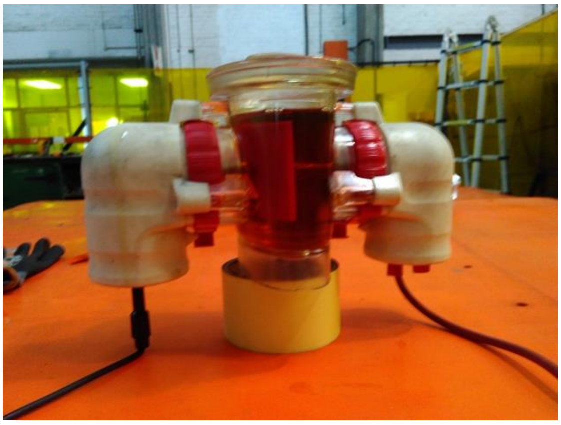

Figure 1:Test vessel filled with insulating transformer oil, 10mm diameter electrodes and a 3D printed specimen. Test leads are from the High Voltage Hipot machine

Figure 2: High Voltage Hipot Transformer and lead connections.

Figure 3: High Voltage Hipot control panel. The manual voltage control can be seen on the right hand side. The top centre display indicates the current voltage level in kV, the lower centre display indicates leakage current in micro amperes. The module on left hand side with display is a timer module.

Specimens

The standard sample required by IEC and BS requires a 60mm x 60mm x 1mm specimen to be tested according to the test procedure. A total of 25 specimens was printed. Five specimens were used per test. The objects were printed with the following parameters.

Printer	Zortrax M200
Material	Z-ABS
Length (Designed)	60mm
Width (Designed)	60mm
Height (Designed)	1mm
Length (Actual)	60mm±0.05mm
Width (Actual)	60mm±0.05mm
Height (Actual)	1mm±0.05mm
Layer Thickness (mm)	0.09
Speed	Normal
Infill	Max
Support	20
Print Coding	Auto
Filament Usage (m)	3.38
Filament Usage (g)	8
Print Time (min)	35

Table 1: 3D printing parameters used for specimens

Test Results

A summary of the test results can be seen in table 2 below:

kV	Ave	Test 1	Test 2	Test 3	Test 4	Test 5
Rapid Rise	27.88	25.7	26.3	28.2	30.1	29.1
20s Step	23.22	18.4	22.5	34.2	20	21
60s Step	27.04	30	37	21.2	22	25
120s Rise	21.88	22	21.4	21.2	20.8	24
300s Rise	20.22	20	19.8	20.3	20	21
Average of test averages				24.048 kV		
Standard Deviation				2.02796		

Table 2: Results of testing per IEC 60243-1

The results indicate that we have a mean breakdown voltage of 24kV/mm. Five rapid rise test was also carried on 1mm thick oil impregnated transformer board, resulting with an average of 25kV.

3D Printed	24kV
Oil Impregnated paper*	25kV

**Not tested according to full IEC60243-1*

Table 3: Comparison of breakdown voltage between 3D printed and oil impreganted paper.

Delimitations of Testing

The following delimitations were self imposed due to constraints in availability of test equipment and time. However these factors were noted and could be investigated in future research.

- The specimens under test were not preconditioned for temperature and humidity and their interrelationship with dielectric strength of the material.
- Ambient environment testing conditions were also not considered to be influencing the test results.
- Homogeneity of test samples were not accounted for.
- The influence of printing direction of test specimen was not accounted for.
- The influence on specimen thickness.

FUTURE CONSIDERATIONS

Materials with high electric strength will not necessarily resist long-term degradation processes such as heat, erosion or chemical deterioration by partial discharges, or electrochemical deterioration in the presence of moisture, all of which may cause failure in service at much lower stress none of these factors where considered.

Future testing will take into account the delimitations identified within this test case. It will allow for more accurate results to be determine by identifying dominant factors.

CASE STUDIES

As the breakdown voltage of these 3D printed components was previously unknown, its use in the high voltage environment was limited to non-direct contact with high voltage.

Link Stick Attachment

A problem found within distribution network is that operators are not able to easily obtain an above ground view of primary plant equipment. This is due to safety regulations around energised substations and equipment. One method to obtain above ground level information is to employ close proximity or live work methods. Both of these require specialised personnel to be present and may involve the use of specialised equipment such as live-work trucks. These methods are not always practical and their expense may not justify the extra information.

In order to overcome this problem, the development of an attachment for a link-stick/hot-stick begun. The envisioned outcome is a simple device that can be operated by almost any personnel within a power utility. The 3D printer was chosen as it would allow for rapid prototyping of models at minimal cost.

The result from this development can be seen in figure 4 below. The unit can be printed with minimal cost and requires minimal training to operate.

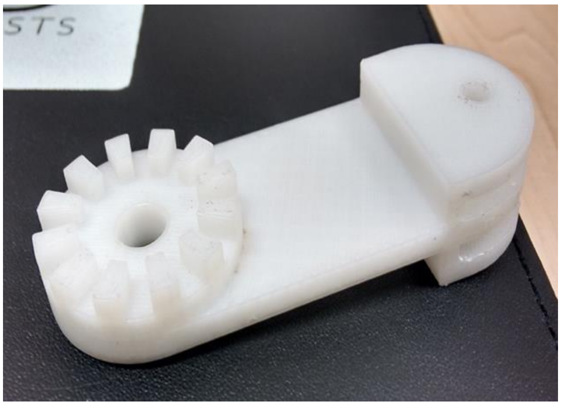

Figure 4: Figure of completed link stick attachment

Figure 5: Completed link stick attachment with camera attached

Figure 6: Image captured under live conditions

Non-Critical Spares

The practical implementation of this has been the design and manufacture of Bucholtz valve handles where the different OEM's have a number of different permutations. These items were designed in-house with available skills and are now kept as a stock item by us.

The spares printable are currently limited to non-critical due to vast number of unknown factors such as breakdown voltage for 3D printed objects within high voltage environments.

DISCUSSION

To maintain a distribution network requires vast inventories of non-critical spares, 3D printing spares with material that have comparable electric strength properties to insulating materials that the non-critical spares are made from provides excellent flexibility for on-demand printing of these non-critical spares. This promotes spare optimisation and a reduction of non-critical spares to be kept for repair work.

The practical implementation of this has been the design and manufacture of Bucholtz valve handles where the different OEM's have a number of different permutations and keeping all permutations as non- critical spares would be costly as well as slow spare turn-over. Having the ability to print these handles on demand has not only realised cost savings but other effects like storage requirements around non-critical spares, space allocation for spares, monthly stock taking etc.

Manufacturers of high voltage equipment would no longer need to keep copious amounts of spares, instead they would be able to store all spares in digital format, and with a fleet of 3D printers, be able to provide rapid, customised production of spares.

Operators and maintenance personnel would also benefit. New equipment should be delivered with a digital copy of all spares printable. So should they require a spare, it could be printed anywhere in the organisation. It will also allow for historically scarce parts to be efficiently and rapid manufactured.

Being able to fabricate objects that have desired dielectric properties provide a great deal of flexibly within an operational environment. Further testing and manipulation of the 3D process for specific high voltage applications should come forth. One aspect which is of vital importance for further investigation is the possibility of creating insulating oil impregnated 3D printed object. Which could mimic the currently used oil impregnated paper and board, but would allow for a higher degree of complexity to be added to objects with possible reduction in manufacturing cost.

CONCLUSION

Previously, one of the main constraints on designing new solutions was the limitations of the manufacturing process. A considerable portion of the design of many components is determined by the restrictions of the manufacturing process. AM opens up new design possibilities. Simply because we are designing specifically for Additive Manufacturing, it automatically creates more innovation.

The most interesting effect is the ability that the technology can drive to promote innovation and forward thinking within organisations. This 3D printer has had a direct effect on the innovation within the department. While no formal plan for innovation was developed, the environment created by adopting new technology allows personnel to explore ideas and develop creative solutions.

These conceptual solutions would not be previously investigated due to high prototyping costs.

This paper is the culmination of the innovation process running within the constraints of our developing economy. We were forced to find new solutions to problems. In having 3D printing technology easily accessible it drove innovation within our organisation. Engineers and technicians gained a new appreciation of innovative thinking. This was due to the addition of additive manufacturing solution to their problem solving skills. It allows them to expand their solutions to those which were previously not technically and financially feasible with historical subtractive manufacturing processes.

The use of 3D printing within high voltage environment has not gained the same traction that 3D printing has in other environments, but it has many applications which could shape the future of the high voltage industry.

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