

# In Search of Electric Power Reliability in Forested Terrain with Covered Conductors: The ECG Experience

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**Abstract-** A failure condition known as burndown and surface tracking of covered conductor insulating material appears to be restricting the widespread use of covered conductors in Ghana. The paper identifies specific problems militating against the use of covered conductors and reviews international experience on the subject with the aim of developing a performance system specification for covered conductor use in Ghana. The paper also discusses advances in protection methods for detecting downed covered conductors and recommends effective protection scheme that must go with the adoption of covered conductors.

**Keywords:** Covered Conductors, Surface tracking, Carbon black, Vibration fatigue, Burndown

## I. INTRODUCTION

In general, the basic idea for using Covered Conductors (CC) is to make Medium Voltage (MV) overhead distribution network more tolerable to line clashing and prevent supply interruption arising out of trees leaning on the power lines. In some jurisdictions, the use of covered conductors was instigated by governments in consideration of protecting the public from electrical accidents [1]. Others have also used covered conductors in response to public demand to improve supply reliability in power distribution networks.

In Ghana, the use of CC was introduced by the Electricity Company of Ghana (ECG) in the early 2010. The CC were deployed to replace existing bare conductors overhead lines in bamboos and forested terrains with the aim of improving supply reliability in these areas. Barely two years after its installation, monitoring and operational records have shown deterioration in supply reliability in areas where the CC have been installed. A failure condition known as burndown is being reported. Conductor burndown or fusion is said to occur when the conductor burns through or melt and falls to the ground [2][3]. Evidence obtained from actual burndown conductor, see Fig.1, indicates that partial discharges and surface leakage current may be contributing factors in causing the burndown.



Fig.1: Surface tracking of conductor insulation.

The burndown phenomenon appears to be restricting the spread of covered conductors in the country. This paper identifies specific problems hindering the widespread use of covered conductors and reviews international experience on the subject with the aim of developing a performance system specification for covered conductor (CC) use in Ghana.

Inability of protective device to detect live downed conductor was also identified as a major safety concern. The paper discusses advances in protection methods for detecting downed covered conductors and recommends effective protection scheme that must accompany the adoption of CC.

## II. ECG EXPERIENCE

As indicated earlier, ECG opted for covered conductors in search of power reliability in forested areas. So far the company has installed about 120km circuit length of CC in different parts of the country, see Table-1. The CC installed are 120 sqmm aluminum conductor with XLPE and PVC coverings.

Table 1: Circuit length of CC installed

	Kumasi	Central	Eastern	Western
CC circuit length (km)	20	58.7	16	25

Samples of the CC were taken and their respective thickness measured as shown in Fig.2. It was found that the thickness ranged between 2.08 to 2.6mm. The measured values are shown in Table-2. The thickness was found to be in agreement with specification used for procuring them. The specification was mainly based on Australian/New Zealand (AS/NZS 3675) and IEC (IEC 60383) standards which state a minimum insulation thickness of 2mm. According to

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the standards, this thickness is allowed at 33kV. However, modern standards have raised the minimum thickness to 2.3mm for 11kV.

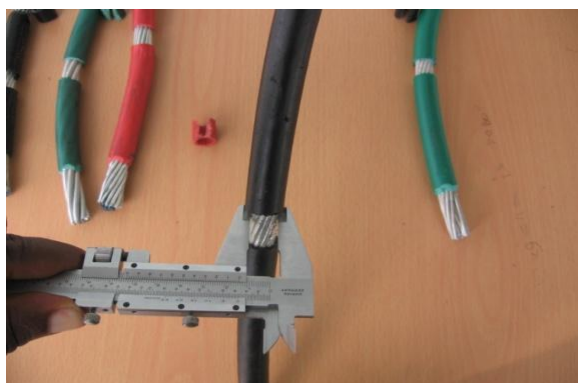


Fig.2: CC samples and measuring of insulating thickness

Table-2: Measured insulating thickness of CC

	Colour of CC		
	Green	Black	Red
At Cape Coast-Insulation thickness in mm	2.25	2.36	-
At Takoradi-Insulation thickness in mm	2.2	2.08	2.6

Although the specification for the procurement called for track resistant and UV stabilized insulating materials, it was not clear from the specification the percentage of carbon black specified for the insulating material. It is important to note that amount of carbon content in the insulation material is critical for the performance of covered conductor. This is discussed later in the paper.

The Green and the black CC were mainly used on the MV distribution network. In order to obtain a fair idea about their electrical performance, samples of the insulating materials were subjected to breakdown voltage and leakage current test. The test was conducted using a variable DC voltage source of a cable test van. The test result is shown in Table-3. It was observed that leakage current drawn from the CC were consistent up to voltage level of 20kV. The ordinary green PVC covering was able to withstand 35kV voltage at leakage current of 22mA. However, to reduce surface tracking, it is recommended that leakage current must be kept below 0.5mA [2]. This is because tracking reduces the lifetime of covered conductors. It can therefore be deduced from the test results in Table-3 that the CC used on MV distribution networks are only suitable for 11kV voltage networks.

From field investigations, it was found that the CC were erected at similar tensions to bare conductors. Effect of tension on the conductor sheath and the reduced level of self-damping in CC were not considered. Protection against wind-induced vibration and lightning-induced stationary power arc were not provided.

Table-3: Insulation breakdown and leakage current test

No.	Voltage Level (kV)	Leakage Current ( $\mu$ A)		
		XLPE Insulation (Black Color)	PVC Insulation (Dirty Green Color)	PVC Insulation (Ordinary Green Color)
1	5	0.006	0.006	0.006
2	10	0.014	0.012	0.014
3	15	0.022	0.022	0.021
4	20	0.034	0.036	0.032
5	25	Insulation Breaks Down	Insulation Breaks Down	0.08
6	30	Insulation Breaks Down	Insulation Breaks Down	4200
7	35	Insulation Breaks Down	Insulation Breaks Down	22000
8	40	Insulation Breaks Down	Insulation Breaks Down	Insulation Breaks Down

### Operational Problems

The incidence of power supply interruption has increased, especially on 33kV feeders where CC has been installed. According to outage statistics obtained from Central Region, the rate of power outage has increased on Assin Fosu feeder by 35% compared with outage statistics when CC was not in use. Most of the interruption were preceded by severe surface tracking on the CC insulation material especially, when in contact with trees or bamboos. In cases where tracking has persisted overtime, conductor fusion or burndown had occurred. A CC line can also suffer burndown due to lightning strikes and vibration fatigue of trees on the line [4].

In some cases where CC had fallen to the ground from conductor fusion, line protective devices were unable to operate. Engineers had to rely on customer complains in relation to service interruption to detect downed conductors. According to [2], leakage current drawn by firm contact with live CC at 11kV under dry and wet conditions are 0.49mA and 0.54mA, respectively. The UK Health, Safety and Environment recommends a safety level of 10mA for human contact. As a result, though the 0.49mA and the 0.54mA leakage current would be noticeable by a person, it would not be life-threatening. The danger is that someone may step or pick up a downed conductor at its end-points. On that basis downed CC is considered a major safety concern.

### III. INTERNATIONAL EXPERIENCE AND STANDARDS

American utilities started replacing bare conductors with covered ones in MV distribution networks in the early 1960s. Utilities in Sweden and Norway soon adopted this system, which has since spread to utilities throughout Europe, Australia, and Japan. There are more than 2200km MV CC installed in Norway, 2800km in Sweden, 3200km in Finland 864km in Slovenia and about 96% of MV distribution overhead lines in South Korea are covered conductors[5]. Initial coverings, generally about 2mm

thickness, of PVC, high-density polyethylene (HDPE) and nylon gave very limited lifetimes, suffered surface degradation and were also subject to failure due to lightning [2]. These failures did not satisfy customer's requirement. As a result, more research and recent work coupled with a developing history of general usage in the field have given very positive results during the last few years. We now look at the specific problems and significant research and development that has made CC more acceptable internationally.

#### A. Covered Conductor Sheaths

Most utility specifications are based on Australia/New Zealand standard AS/NZS 3675-2002. This standard requires that a minimum average sheath thickness should be 2.0 mm for all voltages. To improve performance of CC, European standard considers the sheath thickness of 2.0 mm as inadequate. The European standards organisation CENELEC in their draft standard PrEN 50397-1 of June 2003 has specified a CC sheath thickness of 0.11 times rated voltage in kV with a minimum of 2.3 mm [6]. Consequently, for the distribution voltages, this translates into the following thicknesses for the CC:

- 11 kV- 2.30 mm
- 22 kV- 2.42 mm
- 33 kV- 3.63 mm

Tracking has been mentioned as a problem with covered conductors with high carbon black contents in the sheath material [5]. Basically, two types of CC are widely used; XLPE or HDPE. The XLPE are designed with carbon content typically of 2.5 to 3%. HDPE commonly has zero carbon content, using Titanium Dioxide (TiO<sub>2</sub>) as the UV inhibitor. HDPE does not have tendency towards tracking. The presence of carbon black tends to make the sheath susceptible to surface tracking and eventual damage. These two results for carbon black confirm the need to specify the correct sheath type for the local environment. High UV areas with no pollution may need high carbon black XLPE sheaths but, in polluted areas, the use of carbon black is not beneficial. There are several ways to reduce tracking problems. Using reduced or zero carbon content sheath materials is one of the effective methods of reducing tracking.

#### B. Aeolian (Wind-Induced) Vibration

Wind induced (aeolian) vibrations of conductors and overhead shield wires of transmission and distribution lines has been identified to cause fatigue failures and impact negatively on the reliability of these lines. Fatigue failures are the direct result of bending a material back and forth over a sufficient number of cycles. All materials have a certain "endurance limit" related to fatigue. In the case of CC lines being subjected to aeolian vibration, the maximum bending stresses occur at locations where the CC lines is being restrained from movement. The level of restraint, and therefore the level of bending stresses, is generally highest at the supporting structures. When the bending stresses in CC due to aeolian vibration exceed the endurance limit, fatigue failures will occur.

The first CC lines suffered from wind induced (aeolian) vibration damage due to inadequate damping. It was suggested that the everyday stress (EDS) be limited to 18% of the conductor rated breaking strength (RBS) to assure

safe operation with regard to Aeolian vibration [7]. In Finland it is recommended not to use higher EDS (every day stress) tension than 35 N/mm<sup>2</sup> [2] for CC. UK specified tension limits of 35 and 30N/mm<sup>2</sup> EDS but this was later modified to 28N/mm<sup>2</sup> after problems in operation. The most up-to-date and comprehensive industry specification for aeolian vibration dampers is IEC 61897:1998.

#### C. Burndown due to Arc Generation from Lightning Strike

It is known that direct strikes usually do not cause permanent damages to lines with bare conductors provided the fault duration is limited by a short-circuit protection device [8]. However, in the case of covered conductors, it has been found that the coating prevents the footprint of the power frequency arcing current from moving along the line, and therefore a flashover between phases for such lines may cause conductor fusion or burndown [8]. In order to prevent CC burndown, lightning protection device has been developed. The device is intended to initiate arc deliberately at purpose-designed electrodes and not on the conductor. Several methods of lightning protection devices are currently in use [9-11]. The Power Arc Device (PAD) and Arc Protection Device (APD) are commonly use. These have operated successfully in Scandinavia and the UK for many years. Indeed, the advent of PAD and APD has significantly reduced CC burndown. Nowadays, cases of burndown are generally due to incorrect installation of the conductor or fittings. This can be reduced by the training of linesmen [2].

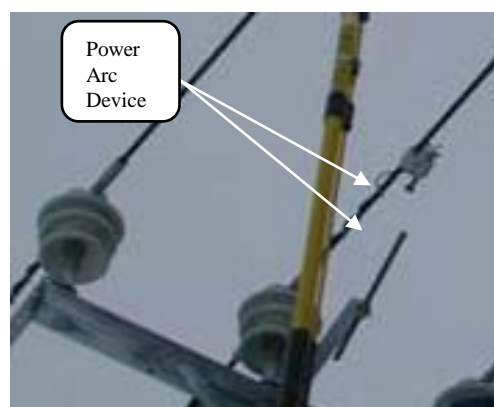


Fig.3: Power Arc Device

It is recommended that one lightning protection device should be installed on each pole and alternate among the phases of the power line (as shown in Fig.3), or three be installed on every third pole.

#### D. Choice of Insulator and tie for CC lines

As discussed above, partial discharges and surface leakage currents at high electric-field points in insulator/tie region may be contributing factors to burndown.



Fig.4: Insulator/tie region

To determine which insulator and tie is most effective in preventing burndown, K. Nakamura et al [3] investigated the lightning impulse characteristics of eight different insulator and tie assemblies. The following were found:

1. Semi-conductive tie proved effective in preventing burndown.
2. Polymeric insulators, especially high-density polyethylene-based compound, reduce high electric field in the insulator/tie region.

In the case of porcelain and glass insulators, it was found that the electric field strength around the insulator/tie region presents high voltages on the conductor sheath surface which is believed to result in surface tracking.

Accordingly, semi-conductive tie and polymeric insulators are strongly recommended for CC lines.

#### IV. PERFORMANCE SPECIFICATION FOR CC USE IN GHANA

It should be noted that the widespread of CC in developed countries shows that CC is no longer a problem but could prove significant advantages in terms of safety, reliability and security to MV distribution network. It is evident from the above review that major developments in the application of CC have been made since its introduction in the 1960s. The review addresses issues that are restricting the spread of CC in ECG operational areas and provide a guide to developing a CC performance specification. To specifically address ECG's operational problems, the following solutions are proposed:

For adoption in CC specification:

1. Since ECG MV distribution networks are mainly of 11 and 33kV voltage levels, the following sheath thickness are recommended for use:  
11 kV- 2.30 mm  
33 kV- 3.63 mm
2. High Density Polyethylene (HDPE) should be specified as the sheath material with zero carbon content. Titanium Dioxide (TiO<sub>2</sub>) should be used for UV stabilization or
3. Use XLPE and specify 0.5% carbon black sheaths with tracking resistant materials such as hindered amine light stabilisers (HALS)

For adoption in CC construction manual:

1. Semi-conductive tie and polymeric insulators should be used.
2. Every Day Stress (EDS) of the CC should be limited to 28N/mm<sup>2</sup>
3. CC line should be constructed with lightning protection device. Either the Power Arc Device (PAD) or the Arc Protection Device (APD) should be used.
4. Since erection of CC lines require a specialized skill it is important that linesmen are given special training on CC erection.

#### A. Protection of downed CC

The challenge faced by electric utilities using CC system in overhead distribution networks is how to detect downed CC lines or falling trees on CC lines. Sensitive Earth Fault (SEF) protection schemes have been used with varying degree of success [2]. It works by measuring the residual current across the three phases in a system. This is done using a Core Balance Current Transformer (CBCT). In the ideal condition, the residual current will be zero as all the currents flow through the three wires and their magnetic fields cancel each other out. In the event of a fault, the residual current over the three phases will not be equal to zero as the current from the faulted phase flows through the earth. It can sense currents as low as 0.2% of the CT secondary current [12]. This protection scheme has been found ineffective especially, where a downed CC line is very long way from a relay. If the imbalance is below 10% of the nominal relay current, then the system will fail to detect the fault condition. The use of zero sequence earth voltage relays has been recommended. This is based on a principle that in an event of a downed one phase CC line, the neutral voltage will rise. However this is useful in detecting high impedance faults up to 100 kΩ. It is important to note that a fault impedance of 2.1 to 3.2MΩ have been measured in CC distribution system [5]. As a result, detecting a downed conductor is still a subject of research. Using a Rogowski coil in monitoring partial discharges in CC line appears to be effective method. The method was investigated by G. M. Hashmi [5] and is briefly described below.

A CC line in contact with the ground or a tree produces partial discharges (PD). Rogowski coils are used as a sensor to detect PD activities in CC line. The captured PD data is then processed to obtain PD characteristics. Time Domain Reflectometry (TDR) is used to extract the frequency component of PD which is related to the wave propagation characteristics of CC overhead distribution lines. The wave propagation characteristics, derived from PD activities, are modelled and used to detect and localize downed CC lines.

Considering the various protection schemes discussed, the Rogowski coil technique looks very promising. However, this is a new method that is yet to be commercialized. Meanwhile, most utilities consider the SEF sufficient to meet the relevant safety requirement.

#### V. CONCLUSION

This paper has presented ECG's experience in the use of covered conductors in Ghana. Problems affecting their

operational performance have been identified. Research and development in the area has significantly addressed initial problems that were associated with CC utilization. To specifically address ECG operational problems, proposal in relation to CC performance specification and constructional standard has been presented.

Protection of downed CC lines was also identified as a major problem. Various protection schemes for CC system have been discussed. Even though the Rogowski coil detection technique was identified as a potentially effective method of detecting downed CC lines, it is yet to be commercially available. The use of Sensitive Earth Fault Relay is an alternative. For now, the use of the SEF is considered adequate to meet the relevant safety standard.

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