New Implosive Connector Technology for High Voltage Conductors

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Abstract

A new method of splicing high voltage conductors has been making its way into the electrical utility industry, displacing the conventional method at an ever-increasing pace. While conventional technology uses a hydraulic compression process, this new method uses implosive energy to make the splice. This paper describes the basic principals behind this new technology and compares the implosive method with the hydraulic method. Reference is made to case examples, test results and some of the practical aspects of working with the technology.

1 Introduction

The conventional method for splicing high voltage conductors uses a hydraulic press to form a compression joint that connects the two ends of a conductor. There are two types of hydraulic compression fittings typically used. The single sleeve type is used for copper, copper clad, aluminium or aluminium clad conductors. The double sleeve type is used for ACSR conductors. The hydraulic compression method has been in use for many decades as the standard industry practice for splicing conductors and cables. Requiring a hydraulic press and a source of power, this method is well practiced and has been widely used, but it can be cumbersome, time consuming and costly. Since this method requires heavy equipment, the splicing operation can be unavoidably more difficult to apply in certain environments. Moreover, since this type of connector has been in use a long time, many are beginning to show signs of age. In one informal survey of twenty-one utilities in North America, it was estimated that an average of 3.6 failures per year has occurred over the past ten years [9]. As line loads continue to increase, this points to the need for a more reliable joining alternative for the future.

The new method of splicing needs no equipment. This method takes advantage of the energy contained in explosives to make the splice. Compression is achieved by explosive force, obviating the need for any equipment and making the splice easier and faster to apply. Moreover, the splice produced by this method is mechanically and electrically superior to the conventional hydraulically formed splice. This joining method is referred to as “implosive splicing”.

The implosive splicing process is easier to work with than the hydraulic compression process and it produces a better quality connection. The technology may well become the way of the future for most, if not all, conductor joining and repair in the electrical utility industry.

2 Implosive Splicing Technology

In the 1950’s, it was discovered that metals could be welded with explosives. Early studies found that a permanent metallurgical bond could be produced between two metal surfaces by selectively and carefully controlling the energy contained in the explosive. Later studies taught that the strength and ductility of the metals, the velocity of the explosive, and the geometry of the interface were important variables in the bonding phenomenology.

Conventional explosives were found to be suitable for this purpose and by controlling the explosive loading and other parameters associated with the bonding surfaces, it was possible to produce a permanent high quality bond in a variety of welding applications, without the use of heat. This process was particularly notable in its effectiveness in bonding dissimilar metal combinations.

Field trials in Norway soon led to the development of implosive sleeve technology for making compression fittings for the joining of high voltage conductors. Before long, in 1968, implosive joining technology was adopted by the electrical utility industry in Scandinavia, which faced particular geographical challenges, and it has been in industrial use in that part of the world ever since.

Further experimentation by CIL, and more recently through research and development by Implo, implosive splicing technology has now been refined to a very high level of consistency. It has evolved into a highly reliable process that is becoming increasingly popular with a growing number of utilities throughout the world, thanks to many years of research and practical experience.

One of the barriers to acceptance of implosive splicing in its early years was the widely held view that the handling of explosives required special training whose complexity was not cost-justified. With increasing experience and education, this view is becoming largely dispelled, as an increasing number of users are finding that the special handling required is no more complex than any other industrial safety discipline. Once the initial training is acquired, work crews are thereupon qualified to work with implosive joining technology and find that the process is easier than the hydraulic compression process and is, in many ways, safer.

Another worry was the noise and disruption that the process might cause to nearby neighbourhoods. A number of methods have been explored in an attempt to reduce blast overpressures, with good success [4], but a more immediate solution has been to simply avoid using implosive sleeves in built-up areas. This could well change in future, as communities begin to accept the temporary noise impact as a trade-off for faster completion of the project going through their community. Project managers are becoming satisfied that, when properly applied, no danger is presented to nearby property by the use of implosive sleeves [2].

Installed properly, an implosive sleeve produces a permanent high-quality splice with perfect reproducibility. This type of joining technology can be used in many specialized joining requirements for high voltage transmission lines and substations in stringing and maintenance. Steel wires such as guywires and skywires can also be joined with implosive splicing technology. Special requirements may arise in many field situations where a high strength connection might be required, such as the joining of a steel cable to the stub of a steel rod (Fig. 1). In such cases, implosive joining technology can provide a simple and safe connecting alternative.

Fig. 1: Implosive sleeve connecting guy grip to steel anchor rod

3 Description of an Implosive Sleeve

Implosive splicing technology is basically very simple. A layer of explosive is placed around an aluminium sleeve. A protective layer of plastic is wrapped around the explosive to keep the entire assembly clean and dry. The layer of explosive is designed with the right properties of detonation velocity, pressure and geometry so that it will create the required compression. High quality explosives are produced to very high standards, which provides a valuable tool for this type of "energetic" application where the need for perfectly reliable and consistent results are critical. Although explosive energy is extremely high, it can be controlled to a high degree of accuracy. In the case of implosive connectors, explosive energy is harnessed in a precisely engineered manner to produce a carefully controlled compression of the sleeve around the conductor.

The sleeve itself is also produced to high standards. The sleeve is designed to accommodate a specific type of conductor. There are many conductor types, and each sleeve is unique to a specific conductor type. The many conductor types are easily accommodated by small variations in sleeve design, so that each specific conductor application is perfectly addressed by the implosive sleeve designed for that particular conductor.

The sleeve consists of a few simple components, each designed to perform a specific duty. The combined result is a high quality splice that is adaptable to all requirements and dimensions. The sleeve is designed to fit over the conductor in such a way that a small space remains between the conductor and the sleeve (Fig. 2). This space provides the gap necessary between the two surfaces for bonding angles to form and compression to take place.

Fig. 2: Implosive splice ready for detonation

During the installation process, the installer first marks the conductor so that the sleeve can be centered properly. The components of the sleeve are placed onto the conductor, and a detonator is placed in direct contact with the explosive wrap. The detonator is the non-electric type, which can only be initiated by means of a special initiator designed only for this purpose. This makes for a very safe process. Upon detonation, the sleeve implodes and a permanent compression of the sleeve and conductor is produced (Fig. 3). The protective layer evaporates, and no flying debris is produced. The result is a fully compressed, permanent, smooth connection. The conductor and the sleeve become one solid mass that appears as if it had been cold welded. Compression of the splice is 100% and the interface between the conductor and the splice, and the spaces between the conductor strands, cannot be detected.

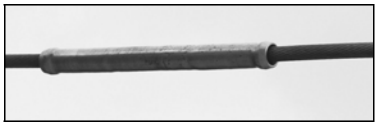

Fig. 3: Finished implosive sleeve

The work procedure for installing implosive sleeves is very efficient. The work crew prepares the conductors and sets up a convenient number of sleeves that will be detonated simultaneously. After the sleeves are placed into position, the work crew retreats to a safe distance of about 100 feet from the splicing area. Following a signal of three horn blasts, the foreman fires the detonator (Fig. 4). After the detonation, the foreman issues a single blast of the horn to indicate the all-clear signal, and the work crew is then free to return to the splicing work area. Each splice is complete and no further finishing work is required on them.

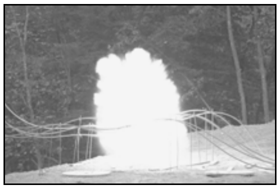

Fig. 4: Six simultaneous implosive sleeve detonations

Implosive splicing can be carried out at ground level (Fig. 5) or in air (Fig. 6), whichever is more convenient for the stringing crew and for the project at hand. If the splicing is carried out at ground level, a mat can be placed directly beneath the detonation zone to prevent small stones from being thrown by the blast pressure.

Fig. 5: Splicing crew preparing six implosive splices for simultaneous detonation

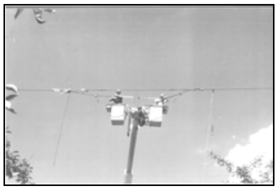

Fig. 6: Crew working from a bucket truck

Implosive sleeve connectors can be used for many types of joints. Full tension joints or mid-span joints, jumper terminals and t-taps are examples of the types of joints that are routinely made with this technology. Dead-end connectors consist of a hollow sleeve and an oval or flat eye end connector. For ACSR and SD conductors, an additional sleeve with an aluminium alloy filler tube is used and a 15° NEMA pad is welded to the main sleeve. End connectors are usually supplied already attached to the aluminium sleeve. This type of connector is free to rotate to the resting position relative to the pad prior to installation to remove all torsion stresses.

4 Implosive vs. Hydraulic Compression

Implosive sleeve technology offers a number of advantages over conventional hydraulic methods of joining conductors. Connection quality is better, the splice is easier to install, overall cost is reduced and project completion time is shortened [5]. Moreover, connection quality is not only high, it is consistently high.

An implosive sleeve connection is perfectly void-free. All interstices between the sleeve and the conductor and between the strands of the conductor are filled. Upon examination, no gaps are visible (Fig. 7). Compression is at an optimum, with only radial deformation taking place. No elongation of the sleeve occurs.

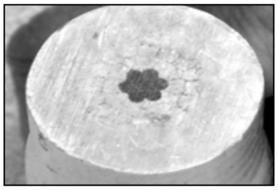

Fig. 7: Cross-section of an implosive sleeve

The implosive sleeve connection is free of corona. Conventional hydraulic joints are known to produce a corona if they are not cleaned after compression. This causes hotspots on the transmission line, and can lead to breakdown of the connection over time. The implosive sleeve does not produce a corona, and hotspots along the line are avoided.

The implosive splice is free of corrosion. This type of joint is completely sealed, with no interstices or spaces for moisture or contaminants to enter the splice. In the case of the hydraulic splice, the spaces between the strands are not completely sealed, which requires that they be injected with grease prior to the compression stage. Where the grease is lacking, it is possible for moisture to accumulate within the splice. Over time, this can become the root cause of ultimate catastrophic failure.

The implosive splice needs no mechanical equipment for installation. All the compression work is done by the explosive. This is not the case with a hydraulic connection, which requires a hydraulic press and a source of power to be hauled to the splicing worksite. This gives the implosive sleeve a considerable advantage, allowing it to be installed almost anywhere. This type of connection can be installed in any terrain, in remote locations, and in almost any weather conditions.

The implosive sleeve has better compression strength than a hydraulic sleeve and compression quality is always consistent. The holding power of an implosive splice exceeds 100% of the rated tensile strength of the conductor itself [10].

The implosive connector is uniformly smooth. No preparation is required before compression, and no sanding or filling is required afterwards. No inhibitor is required. Once installed, the implosive sleeve connector is completely maintenance free.

A properly installed splice will have a resistance lower than an equivalent length of continuous conductor. In the case of an implosive splice, the resistance is typically one-half that of the conductor. In the case of a hydraulic compression splice, resistance is generally higher, and can be as much as 95%. As the connection deteriorates, this ratio exceeds 1.0, and higher operating temperatures ensue. This becomes a vicious cycle as increasing temperatures accelerate deterioration. Ultimately connection failure may result.

One of the most common causes of connection failure over time is high temperature. Recent initiatives propose to undertake more detailed studies of connector behaviour under conditions of elevated temperature [3]. Field experience points to a growing risk of potential failures as connections age and loads increase [9].

Implosive connectors are contoured at the ends, allowing them to be pulled through stringing blocks without damaging the conductor, the connectors, or the blocks (Fig. 8). This enables faster, more efficient line installation, and makes it possible to pull a number of spools in a single run. Pulling stations and tensioner stations can be situated in convenient locations, not just in locations dictated by the length of the spool. This way, the project manager has more control in siting workstations and avoiding environmentally sensitive areas. By pulling mid-span joints through the stringing blocks, the need for a separate sleeving crew can be avoided and the stringing operation can be greatly expedited. These advantages empower the project manager with better control in managing project deadlines.

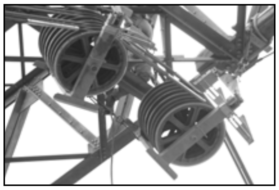

Fig. 8: Implosive splices traveling through stringing blocks

With implosive connectors, project managers find that smaller crews are required, and installation time is a fraction of that required if the same job were to be carried out using conventional compression fittings. A recent study found that the dead-ending of a tower required 40% less labour using implosive connectors, compared with using conventional hydraulic connectors [5].

5 Applications

In a recent case, American Electric Power was facing a particularly difficult challenge with the construction of a new six bundle 765 kV transmission line through one of the most environmentally sensitive areas in North America – the Jefferson and George Washington National Forests [1]. This line required the best of available technologies to mitigate environmental impacts to the highest possible degree. One of the technologies selected was the implosive sleeve. This method of splicing made the stringing operation capable of pulling all six conductors simultaneously through greater distances, in a single run. This made is possible to situate pulling stations at selected locations where impacts could be better controlled. It also reduced the time required for the stringing operation. Moreover, in this particular installation, the challenge of extreme pulling angles truly put the implosive sleeve to the test. In the case of one particular tower, the implosive sleeve successfully and easily negotiated a pulling angle of 41° through the stringing blocks.

More generally, implosive sleeves have been used on a wide range of conductors from 266 MCM to 3360 MCM, and from 5/16" HS sky-wire to 1.5" rebar, including all the sizes of guy-wires and alumoweld / copperweld wires. Conductors serving a voltage range from 138 kV to 765 kV have been joined using implosive sleeves. Hydro One in Ontario has used implosive sleeves on conductors ranging from 240 kV to 500 kV. Quebec Hydro has used them on 735 kV lines. Throughout the world to date, more than one million implosive connections have been installed in various forms for new installations, substations, repair, and live line work.

6 Testing and Qualification

A considerable amount of testing has been carried out on implosive sleeves over the years. The following briefly describes examples of some of the testing that has been carried out on implosive sleeves, and the results obtained.

Heat Cycling

Testing consists of repeated heating cycles at elevated temperature rises at the connector. Implosively formed full tension joints, jumper terminals and deadends for ACSR conductor Grackle 54/19 (per CSA standard C57-1966, ANSI C119.4-1976) were tested for 500 heat cycles at 100°C rises [6]. Results showed a resistance increase of less than 10% between the 25th and the last cycle, while conductor temperature was at 50-60°C, or a maximum of 60% of the temperature of the conductor. This was well within accepted limits.

Tensile Strength

A pull test applies tensile force to the connector, until failure occurs. In a pull test of a full tension joint on ACSR Falcon 1590 MCM [8], with a conductor having a breaking strength of 242 KN, load was gradually increased until failure occurred. No displacement was measured up to 100% of the ultimate breaking limit. The conductor ultimately failed at 254 KN, which is 105% of the rated strength of the conductor. Breakage occurred in the aluminium strands, while the steel strands and connector remained intact. This result is typical of the implosive connector.

Electrical Resistance

By measuring the difference between the resistance of the connector and the resistance of the connector and conductor together, the resistance of the contact surface between the connector and the conductor is found and can be attributed to connection resistance. A typical test, carried out by SensorNote in Quebec, on an implosive full tension joint connector measured a resistance of 8μΩ at the connector and 8–9μΩ between the conductor and the connector. This was compared to a typical hydraulically crimped connection, which measured a resistance of 8μΩ at the connector and 17-20μΩ between the connector and the conductor. Expressed as a ratio, the implosive sleeve measured 0.94, while the hydraulically crimped sleeve measured 0.43, half that of the implosive sleeve. A ratio of 1.0 would represent equal conductivity of the connection and the conductor. This test is typical, showing that implosive splices are more conductive than the hydraulic splice.

Vibration

The splice is subjected to a vibration of known frequency and known amplitude after passing through stringing blocks. A pull test then determines breaking strength. One of the early tests carried out by the Norwegian Power Board tested an implosive full tension joint on 1192.5 kcmil 54/7 Grackle by pulling it through a distance of 7.5km through 21 towers. After pulling, two such joints were subjected to a vibration test at 14.13 Hz to an amplitude of 54mm. The splice was positioned within the testing apparatus such that maximum bending stresses occurred at the mouth of the joint, and 70^7cycles were performed. After the vibration, each splice was pull tested to failure, which occurred at 104% and 109% respectively of ultimate breaking strength. Failure was clean tensile failure, occurring outside the zone influenced by the bending stresses of the pulling operation, indicating not only a pass, but also indicating failure mode as being normal within the conductor.

Visual Corona

In a visual corona test on a full tension joint 585 kcmil 26/7, positive corona was first observed at 198kV rms –24.7 kV/cm – 5200 μV riv, which was well in excess of the requirement of 151.7 kV rms, per OH spec A-6M-79 [7].

7 Conclusion

The technology of implosive splicing has been known for many years, but only recently has it become increasingly recognized as a viable alternative for the joining of conductors and cables. This method of splicing offers many advantages over conventional hydraulic splicing practices that could well advance it as the emerging standard for splicing throughout the whole of the electrical utility industry. Easier installation, better connection quality, lower labour requirements, faster stringing, and the fact that no compression equipment is required are compelling advantages that promote this technology as a viable alternative to conventional compression splicing practice.

References

[1] American Electric Power, Jackson-Ferry to Wyoming 6 bundle 765 kV project, West Virginia (2005).

[2] Bonneville Power Administration, Grand Coulee-Bell 500-kV Transmission Line Project, Eastern Washington Reinforcement (2004).

[3] J. Chan, "Performance of Single-Stage and Implosive Compression Fittings at Elevated Temperatures", project proposal, EPRI (2005/2006).

[4] E. Contestabile, C. Thomas, "Suppression of Blast Pressure and Noise From Implosive Type Connectors", CANMET, Ottawa, ISEE (2000).

[5] K. MacMillan. "Labour Analysis – Compression vs. Implosive Dead-Ends" Canadian Lineworks Inc. (2005).

[6] Norwegian Research Institute of Electricity Supply, Laboratory Report 1525, H. Jensvold, (1985).

[7] Ontario Hydro, "Visual Corona Tests on Modified Full Tension Joint Assembly for 585.0 kcmil 26/7.", CIL (1985).

[8] Russel Drummond, L. Lamare, Quebec, Implo (1993).

[9] J. Snell, J. Renowden. "Improving results of thermographic inspections of electrical transmission and distribution lines", SPEI (2003).

[10] Unirope Ltd., "Tensile Test of AACSR WASKAG, 272-A4/S1-23/7", Hydro Quebec, (2005).