ESB's ADOPTION OF SMART NEUTRAL TREATMENTS ON ITS 20 KV SYSTEM

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ABSTRACT

ESB Networks has been upgrading its Medium Voltage Network from 10kV to 20kV over the last 15 years. As a result of the change in voltage level there has also been a change in neutral treatment from isolated to resistance earthed. Operational deficiencies of the 20kV resistance earth system, specifically relating to customer hours lost and customer interruptions have prompted an investigation into alternative neutral treatments. As part of this investigation two different neutral treatments are being explored, namely: Peterson coil coupled with enhanced control, and Faulted Phase Earthing (FPE) through the use of a custom built controller. This unique FPE system has been patented by the ESB [1].

It is hoped that these trial system will deliver enhanced operational performance. In this regard it is planned to gain sufficient experience of both trial systems in order to form future policy with regards to the operation of the 20kV system in Ireland. The research and development of the trial systems over the last 2 years has enabled the building up of new bodies of knowledge around these systems specifically relating to: testing, fault passage indication devices, location of earth faults, applying live faults for test purposes and event recording. This paper details the development of each trial system and the benefits associated with each system.

INTRODUCTION

ESB's 20kV system is at present operated as a resistance earthed system, with 20Ω resistors on the neutrals of the 20kV windings of transformers. The existing system is performing at a fault rate of 14.5 Faults (resulting in an outage) per 100 km of Network per annum. The remaining 10kV (isolated neutral) operated Network is performing to a fault rate of **7.95** Faults (resulting in an outage) per 100 km of Network per annum. The majority of faults are Single Line to Ground (SLG) faults, which are significantly influenced by the neutral treatment of the system.

As a result of penalties for customer hours lost and customer interruptions alternative methods of system operation are being investigated. It is suggested that the best performing systems for earth fault arc quenching would be Compensated, High Impedance and Isolated in that order [2]. It is therefore not difficult to see why a change would be contemplated, as the existing system is low impedance earthed .

The trial systems built by ESB are:

- Neutral Earthing via Peterson Coil complimented with a range of earth fault management facilities.
- Interchangeable resistance earthed/isolated system in conjunction with Faulted Phase Earthing (FPE)

PETERSON COIL TRIAL SYSTEM

Background

Perhaps the most popular form of MV Neutral earth treatment employed in Europe is Arc Suppression. In ESB Arc Suppression has been in use on the 38kV sub-transmission network since 1928. Internal research [3] had suggested that Arc Suppression would be difficult to implement in MV Networks were the level of asymmetry can be as great as 70% as a result of significant lengths of two phase network. Indeed this was the very premise that sponsored the development of the unique FPE solution outlined in this paper. Recent work has suggested the use of a secondary damping resistor as both a solution to asymmetry and an aid to fault hunting [4].

It was proposed in 2008 to implement a trial scheme at 38kV/20kV station feeding a 20kV radial network with approximately 400 km of overhead network. The scheme has been live since July '09. Elements of the scheme are described in detail in [5]. A simplified illustration of the components relating to the system is shown in Figure 1.

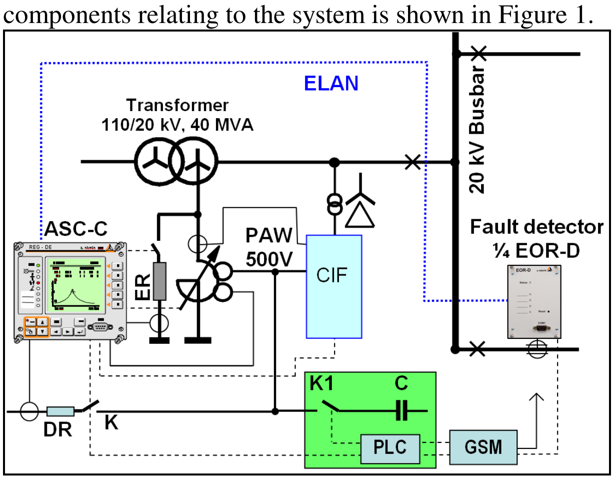

Figure 1. Components of trial ASC system

Where:

ASC-C	Arc Suppression Coil Controller
PAW	Power Auxiliary Winding
CIF	Current Injection by Frequencies
DR	Damping Resistor
ER	Earth Resistor
PLC	Pulsing Controller
EOR-D	Earth Fault Detection

The trial system has afforded the opportunity to use some smart functionality not currently employed on the older 38kV system.

a) The use of a DR in order to carry out resonance curve shaping and wattmetric detection of faults
b) Pulsing of DR to increase fault detection sensitivity.
c) Current injection by two frequencies (non 50Hz) to enable tuning without coil movement.
d) Individual feeder online capacitive current measurements
e) Rapid control of ASC, tapping to near resonance point during SLG fault conditions to minimize fault current
f) Fast recalculation of resonance point, coupled with tapping of ASC following the switching of a feeder
g) Implementation of 4 parallel fault detection algorithms
h) 3G based telemetry device which allows remote records and log file extraction, online setting, remote firmware upgrades, remote ASC tuning, email and SMS services, to remote desktop

Fault passage indicators and fault hunting

Risk assessment dictates that if an attempt is to be made to sustain an SLG fault then the possible risks associated with this would be mitigated by a precise system of quick fault location. ESB are successfully finding faults on this trial system using a combination of the following actions:

- **Location of faulted section of network**. Stationary Fault Passage Indicators (FPI), coupled with an inbuilt communication system are used to locate the faulted section of Network. This combined system is known as the X-Net and is produced by FMC-Tech. This system will successfully identify between which two nodes the fault has occurred. The hardware installed at each node is shown in Figure 2. The information available to the operators, via web-link using an i-phone is shown in Figure 3. A graphical view of the fault location is shown in Figure 4. This system has proved extremely useful and has preformed well to date. In a number of instances during the testing cross country earth faults developed. In these instances supply was lost to the faulted feeder(s), however the X-Net system was still able to identify the section(s) of faulted network. More details of this system can be found in [6].

- **Location of Fault**. Once the section of network has been identified, a procedure has been developed to locate the fault. Using the components and functionality of the ASC system the DR and/or Capacitor is pulsed. A portable fault passage locator (pathfinder) is then used to 'walk' to the fault.

The number of customer outages as a result of faults has been reduced as a result of the implementation of the trial Peterson coil earthed system, and fault location times have been reduced substantially as a result of the new systems and procedures used for the location of faults.

Figure 2 X-Net FPIs Hardware at each Node

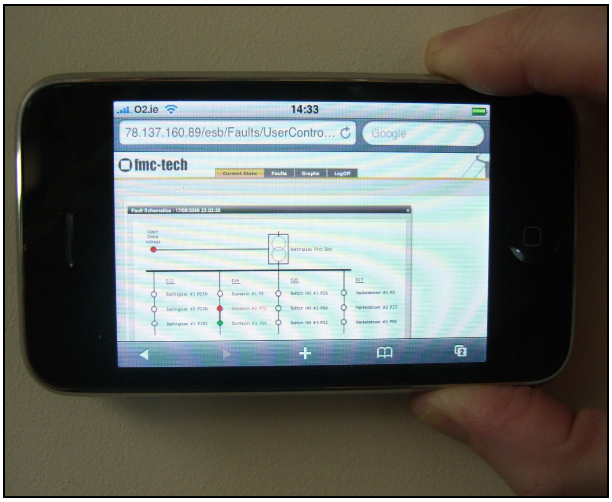

Figure 3. Information Available to Operator

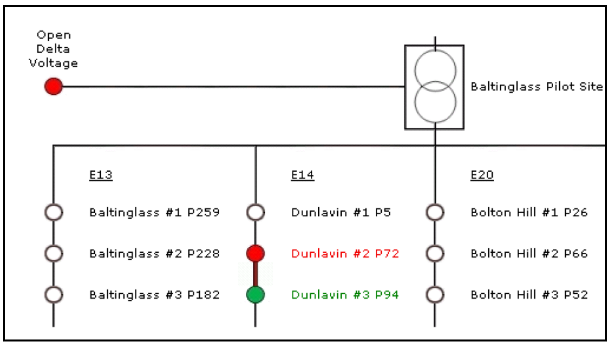

Figure 4 Graphical View of Fault Location

FPE TRIAL SYSTEM

Background

The proposed system will operate as an interchangeable high resistance earthed/isolated system in conjunction with FPE, by the use of a custom designed Earth Fault Controller (EFC). The system uses a 300Ω Neutral Earth Resistor (NER), which is switched out during sustained faults. This NER is required to restrict switching over-voltages. During a single line to ground fault, the faulted phase will be earthed and transformer neutral will be isolated, as shown in Figures 5 and 6. As the phase to phase voltage is unchanged with the FPE applied, and load is connected via delta windings, the supply voltage to customers is maintained. This system has been patented by the ESB [1].

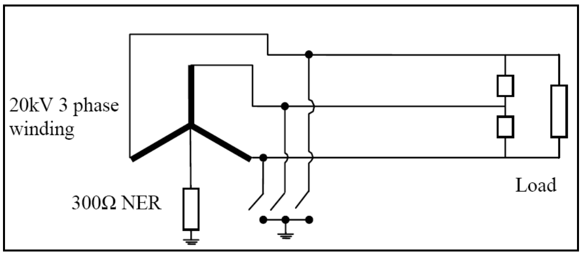

Figure 5. System under normal operation

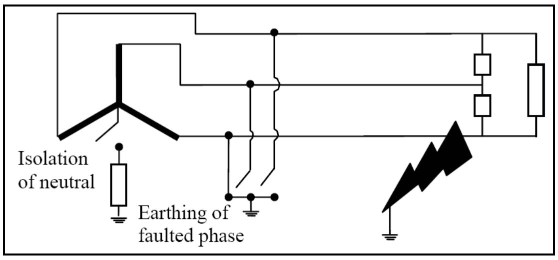

Figure 6. Operation under single phase fault

The operation of this particular FPE system is enabled by the use of a custom built EFC that has the ability to detect high impedance faults of up to 12kΩ. The EFC can also successfully identify single pole switching events, which have at times caused the mal-operation of existing protection. As FPE involves the earthing of a faulted phase during an SLG fault, it is ensured that the fault site is made safer and that no customers are interrupted during the fault. Pervious work details the algorithms associated with the EFC [7], and testing of the new FPE system [8], which will be discussed briefly in this publication.

Earth Fault Controller

The controller provides a robust method of detecting SLG faults of up to 12kΩ, and can distinguish between high resistance faults and single pole switching events. This is an improvement on the existing system which has the ability to detect single line to ground faults of not more than 3kΩ. The controller algorithms are designed using Labview® graphical programming language, which is produced by National Instruments. All the hardware associated with the controller is also supplied by National Instruments. The program was developed on a conventional PC and installed on a stand alone industrial computer which has real time capability. An illustration of the system hardware is shown in Figure 7. All I/O functions are channelled through a signal processing unit. The EFC performs each of the following:

- Measures individual phase currents on three feeders as well as the neutral current, three phase voltages,
- Operates digital outputs to control four switches within the substation compound on the neural and three phases.
- Signals a number of alarms, which identify the nature of the fault, which are connected to the SCADA system.

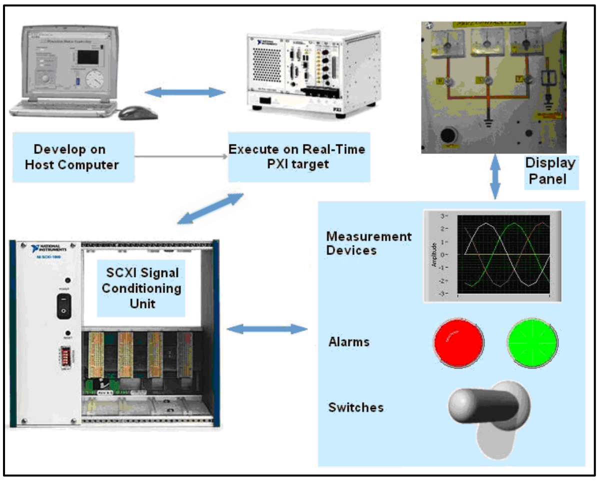

Figure 7. System Interface of EFC

The EFC works by closing the appropriate FPE switch as a result of a significant change in neutral current. The EFC then computes the change in the phasor values of voltages and currents before during and after the FPE cycle. During this analysis the controller specifically looks at the change in zero sequence current to determine if there is an earth fault on the system, further details may be found in [7].

Testing of this system has been carried out in a number of ways: firstly by injecting of simulated currents and voltages at the primaries of measurement current and voltage transformers, and secondly by applying earth faults to the system, and carrying out single pole switching operations. The controller has preformed well using both methods, further details may be found in [8].

CONCLUSIONS

The ESB sought to investigate alternatives to the exiting method of neutral earthing and system operation of the 20kV distribution network Two different methods have been identified and successfully implemented at trial sites in Ireland. The trial systems are:

- Neutral Earthing via Peterson Coil complimented with a range of earth fault management facilities.
- Interchangeable resistance earthed/isolated system in conjunction with Faulted Phase Earthing (FPE)

Conclusions will be drawn separately for each system

Peterson Coil Trial System

The trial system using the person coil is operational since July 2009. Operational experience gained from this system suggests that there are less outages due to faults than the 20kV resistance earthed system. Fault location times have been reduced substantially as a result of the new systems and new procedures used to locate faults. The benefits of this system include:

Improved Sensitivity: The ASC will treat all faults irrespective of Ohmic value. Signalling of an EF is triggered by Neutral Voltage Displacement of 30%.

Selectivity: Existing SEF protection may mal-operate due to MV single pole switching on a long two phase spur. The Peterson Coil system removes this restriction.

Fault Location: With the system, SLG have been tracked down successfully within the 3 hour time limit.

Supply Continuity: From a technical standpoint no customers need be interrupted during a single line to ground fault. Risk assessment would dictate that for urban networks safety risk can be mitigated via a tripping strategy. The first eight months of operation have shown the Network to be operating at a rate of 4 faults per 100KM of network per annum.

Fault Site Safety: The system normally operates at 5% over-suppressed. For the purpose of fault site voltage management the coil retunes to a net 2A away from resonance within 5 seconds of permanent fault inception.

FPE Trial System

The trial system has been built and is still under test. It is hoped that this system will become operational during 2010. Experience gained shows that the system works, however it is more onerous on the system insulation than the Peterson coil solution. Work previously carried out suggests that it will provide a greater level of fault site safety than the Peterson coil solution [3]. The benefits of this system include:

Improved Sensitivity: Existing protection on the 20kV system can identify a fault of about 3kΩ (~4A) while the EFC can identify a High Impedance Faults (HIF) of up to 12kΩ (~1A) and even up to 16kΩ.

Selectivity: Existing SEF protection may mal-operate due to MV single pole switching on a long two phase spur. The controller using FPE can identify this event as not being a fault

Fault Location: With the existing system, network technicians may have no indication of the phase or feeder on which a fault has occurred. The EFC will identify the faulted feeder and phase thus saving time in fault location.

Supply Continuity: With the use of FPE on the 20kV system no customers need be interrupted during a single line to ground fault, until the fault is found and an adequate plan is formulated how to remove the fault, which may involve temporarily switching out customers.

Fault Site Safety: Previous work carried out by Tobin et al [3] has shown that fault site GPR using the FPE is generally lower than a similar fault on a system with a neutral earthed via a Peterson coil.

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