ABS Consulting

Feasibility of a Safety Case for ABB Surge Limiters

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Client: Electricity North West

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DOCUMENT SUMMARY

The Is limiter device is a combination of a fast acting switch with high current carrying capability but low switching capacity and a fuse with high breaking capacity, mounted in parallel. When a short circuit is detected a small explosive charge in the main current carrying conductor is detonated. This ruptures the main current carrying path thus diverting the current to the fuse which quenches it. The entire operation takes place within a few milliseconds.

The principal reason for the fitting of an Is limiter is that since it will trip before the first peak of a short circuit current, switchgear and cabling downstream of the Is limiter will not be subject to the full fault current, and can either be of lighter construction, or of increased capacity.

There are, however, some existing concerns which are currently restricting the use of Is limiters. The Distribution Network Operators have a licence obligation to operate their networks in compliance with the Distribution Code, DTI Regulations and Health and Safety Legislation. The Distribution Network Operators have concerns about the use of these current limiting devices. The issues that they are particularly concerned about are:-

- the possibility that a failure of the current limiting device to operate could overstress switchgear.
- any emerging legal liability for damage to equipment or consumers downstream of the Is limiters in the event of their incorrect operation.
- the lack of an associated 'back up' engineered system to prevent faults affecting downstream equipment.
- their intrinsic safety.
- the testing of operation.
- their triggering integrity.

There are some minor administrative issues which would currently prevent the use of Is limiters (an Explosives Certificate, suitable maintenance and training procedures, a risk assessment and training to enable the storage, transportation, fitting and operation of Is limiters), which it is considered would be relatively straightforward to overcome.

However, the principal barrier to the use of an Is limiter within a UK network would appear to be the consequences of the Is limiter failing to operate on demand. It is considered that the only way in which it would be possible to construct an adequate safety case would be to demonstrate that the likelihood of failure to operate on demand has been reduced to an acceptably low level, which in this case would be to demonstrate that there was an incredibility of failure. Existing probabilistic data does not demonstrate this, however, and the studies that exist are not consistent with each other, or with operational data from the manufacturer.

To complete a Safety Assessment, we would recommend:

- HAZOP Study
- FMECA
- Construction of a Fault Tree
- Calculation of a Reliability Assessment.

However, it is accepted that this is a relatively novel approach to take to demonstrate acceptable safety within the electricity distribution industry, therefore it is recommended that prior to conducting any detailed assessment, the prior engagement of relevant Stakeholders be sought.

LIST OF ACRONYMS

ABB	ABB Group
ALARP	As Low As Reasonably Practicable
BERR	Department for Business Enterprise and Regulatory Reform
COER	Control of Explosives Regulations
DNO	Distribution Network Operator
DTI	Department for Trade and Industry (now Department for Business, Innovation and Skills)
EAW	Electricity at Work Regulations 1989
ENW	Electricity North West
ESQCR	Electricity Safety, Quality and Continuity Regulations 2002
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Modes, Effects and Consequence Analysis
HASAW	Health and Safety at Work etc. Act 1974
HAZOP	Hazard and Operability Study
OFGEM	Office of Gas and Electricity Markets

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1 INTRODUCTION

1.1 Brief Description of the Operation of the ABB Is Limiter

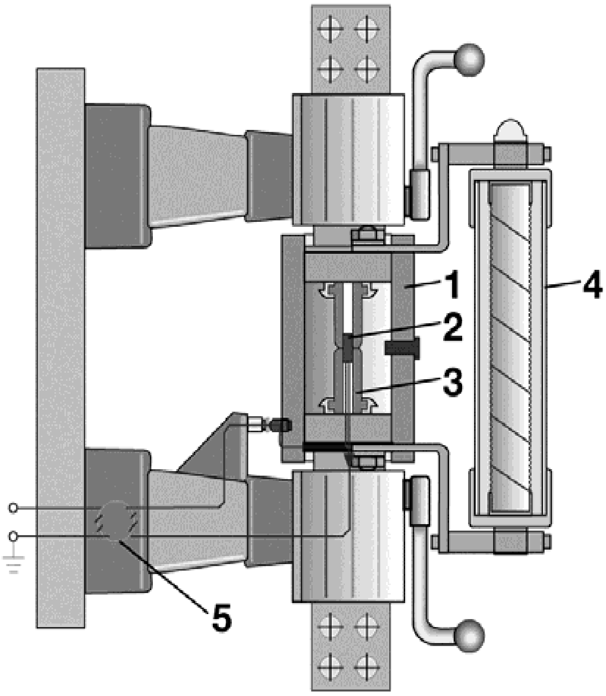

Figure 1 – Insert Holder and Insert

1 Insulating tube
2 Charge
3 Bursting bridge
4 Fuse
5 Insulator with pulse transformer

The Is limiter device is a combination of a fast acting switch with high current carrying capability but low switching capacity and a fuse with high breaking capacity, mounted in parallel. When a short circuit is detected a small explosive charge in the main current carrying conductor is detonated. This ruptures the main current carrying path thus diverting the current to the fuse which quenches it. The entire operation takes place within a few milliseconds.

A small explosive charge is employed to give fast operation of the switch on the main conductor. Once the switch has operated, the current is diverted to flow in the parallel fuse where it is interrupted.

The current flowing through the device is monitored in an electronic measuring and tripping unit which is responsible for initiating the trip when an abnormally high and fast rising current is detected. Both magnitude and rate of rise of the current are monitored and tripping is initiated only when both quantities are above certain set values. The threshold magnitude and rate of rise of current can be set to suit the individual application.

For three-phase applications, the Is-limiter comprises three single pole holders with replaceable inserts, three tripping current transformers and one electronic measuring and tripping unit.

After operation the devices are isolated and inserts containing the fuses and the ruptured conductors are removed and replaced with spares. A circuit breaker is always required in series with the Is Limiter , in order to perform normal circuit opening and closing duties.

1.2 Reasons for fitting the ABB Is Limiter

The principal reason for the fitting of an Is limiter is that since it will trip before the first peak of a short circuit current, based on the rate of rise of the current flow, switchgear and cabling downstream of the Is limiter could be of lighter construction. Alternatively, the use of Is limiters would allow existing cabling and switchgear to have a potential higher rating, since the peak short circuit current will not be seen.

In these circumstances, conventional circuit-breakers cannot provide protection against high peak short-circuit currents, as they will not trip before the first peak of short circuit current. The Is limiter is capable of detecting and limiting a short-circuit current at the first rise, i.e. in less than 1 ms. The maximum instantaneous current occurring remains well below the level of the peak short-circuit current.

The Is limiter also has uses in transformer or generator feeders, in switchgear sectioning and connected in parallel with reactors.

1.3 Concerns

The Distribution Network Operators (DNOs) have a licence obligation to operate their networks in compliance with the Distribution Code, DTI Regulations and Health and Safety Legislation. The DNOs have concerns about the use of these current limiting devices. The issues that they are particularly concerned about are:-

- the possibility that a failure of the current limiting device to operate could overstress switchgear.
- any emerging legal liability for damage to equipment or consumers downstream of the Is limiters in the event of their incorrect operation.
- the lack of an associated ‘back up’ engineered system to prevent faults affecting downstream equipment.
- their intrinsic safety.
- the testing of operation.
- their triggering integrity.

The Distribution Code of Licensed Distribution Network Operators (Reference 1), also contains rules which could make the use of Is limiters difficult.

DPC 4.4.4 (d) states:

> *Unless the DNO should advise otherwise, it is not acceptable for Users to limit the fault current infeed to the DNO’s Distribution System by the use of Protection and associated Equipment if the failure of that Protection and associated Equipment to operate as intended in the event of a fault, could cause Equipment owned by the DNO to operate outside its short-circuit rating.*

2 REFERENCE INFORMATION

Electricity North West supplied a DTI Report, URN 04/1066, “Development of a safety case for the use of current limiting devices to manage short circuit currents on electrical distribution networks” (Reference 2), which references two different types of Is limiter, one manufactured by ABB, and one by G&W. The two types of current limiters are similar in operation, however, this report will only deal with the ABB Is limiter.

As well as information from the manufacturer of the Is limiter device, there have been searches of the internet for any relevant information. Whilst searching for additional information on Is limiters, a later report was discovered, BERR Report, URN 07/1652 “Application of fault current limiters”. Contract Number DG/DTI/00077/06/REP (Reference 3). A short discussion of both reports is included below.

2.1 DTI Report Number: URN 04/1066.

Reference 1 was published in 2004. The report discusses two similar surge current limiting devices, one manufactured by ABB, and one by G&W. It should be noted that this report deals only with the ABB Is limiter. The conclusion of this report is that the use of Current Limiting Devices would not meet the regulations in force at the time, but it does make some recommendations as to how a safety case could be constructed which might enable the use of Is limiters in UK networks. For clarity, and to illustrate the issues, the conclusions of Reference 2 are quoted below:

> *Installing current limiting devices in order to avoid plant being operated beyond its rating will give some difficulties in complying with UK safety legislation. It should be noted that UK safety legislation is very different from the legislation used elsewhere in Europe. The problems highlighted by the Health and Safety Executive (HSE) are difficult but are possibly surmountable. The problems highlighted by the DTI with the Electricity Supply Quality and Continuity Regulations (ESQCR) could result in dutyholders being in breach of the regulations and open to prosecution.*
>
> *The DTI view is that the dutyholder would be in breach of Regulation 3.1a) and Regulation 6 of the ESQCR if the current limiting device fails to operate. However in this event, if the DTI decided to investigate and/or prosecute, then the key issues would be the consequences of the failure of the current limiting device and the mitigating measures taken by the dutyholder. The decision as to whether there should be an investigation will also depend upon the consequences.*
>
> *A user installing a current limiting device, and other duty holders affected by the installation, could potentially be in breach of the absolute requirements of Regulations 5 and 11 of the Electricity at Work (EAW) Regulations, if there was a failure of the current limiting device, leading to overstressing of other equipment and danger.*
>
> *The possibility of using an exemption process under Regulation 30 needs further exploration. This would require further discussion within the HSE and with the stakeholders. These discussions would need to identify the extent of any exemption, the criteria which would need to be met for an exemption to be granted (for example As Low As Reasonably Practicable (ALARP)) and the process for granting an exemption. All of the dutyholders affected by the installation of the device would need an exemption if the exemption route proved to be feasible*
>
> *The arguments shows that from an ALARP point of view (excluding the consideration of the absolute requirements of the Electricity at Work Regulations) it will not be straight forward to justify the use of current limiting devices This is based on the assumption that current limiting devices present a higher risk than the current good practice relating to protection from excessive fault current (for example the use of adequately rated switchgear).*

The argument for the implementation of current limiting devices is likely to be application specific or for well defined cases. The ALARP assessment would need to address a range of factors, for example the actual increase in risk, those that are affected, the potential benefits associated with the use of current limiting devices, alternative options and control measures. The approach and requirements for such an ALARP assessment, in addition to a 'suitable and sufficient' risk assessment, would need to be explored more fully with the HSE. A common approach and common guidelines to the assessment should be developed.

Although there is no obligation under the ESQCR for the duty holders to disclose information to consumers, there is an obligation under the Management of Health & Safety at Work Regulations. It will be essential for the industry to have a common approach and a common set of guidelines for the installation of current limiting devices and the exchange of information. As a first step in developing the process and guidelines the legal, commercial and safety duties of all parties will need to be clarified and set out. This will require all parties to take legal advice.

The operational information provided by the manufacturers is not sufficient to carry out a suitable reliability assessment. The information on the reliability of the current limiting device is critical for any future safety assessment. Ideally this should be based on historical data, and it is recommended that the manufacturers should critically review their operational data and consider the collection of additional data to support any future safety assessment. This will also be critical to the successful demonstration of compliance with the IEC 61508 design requirements for dealing with systematic failure causes and for providing evidence that the devices meet the safety integrity level requirements.

Using a risk assessment approach, rather than relying on good engineering practice will represent an important shift in some parts of the electricity industry. New competences and extensive training in risk assessment will be required. Training in the maintenance activities associated with current limiting devices will also be required. The costs associated with using current limiting devices will therefore not be trivial. Ofgem's key concern is that the use of the devices should be an efficient solution. A full cost benefit analysis will be required to establish that the use of current limiting devices is an efficient solution.

The Boards of the DNO's should be made aware of the business implications of the adoption of current limiting devices, including the legal issues, the costs and benefits, the competences and training required for the move from a good practice to a risk assessment approach and the increased DNO role in coordination and information exchange with other parties.

Reference 2 provides a valuable benchmark to be able to conduct a gap analysis as to the actions that would be required to be able to satisfy current legislation.

Reference 2 also contains a Hazard and Operability Study (HAZOP), for the surge current limiters, and a Failure Modes, Effects and Consequence Analysis (FMECA) for the G&W surge current limiter. These studies conclude that the principal hazard with the surge current limiting devices is their failure to operate on demand.

Reference 2 also includes a suggested predictive reliability assessment. However, this dates from 1980, and the probability of failure to operate on demand, which was estimated at 1.75×10^{-3}, would appear to be pessimistic, when compared with actual operating experience of the device.

2.2 Report DG/DTI/00077/06/REP

Whilst searching for additional information on Is limiters, a later report was discovered, BERR Report, URN 07/1652 (Reference 3). Reference 3 does reference the earlier report (Reference 2), but it only discusses Is limiters briefly, and appears sceptical as to their utility in UK networks. This was published in 2006.

Paragraph 2.2.1 of Reference 3 states:

> *Use of these devices has not been identified within the UK utility sector, but a previous report (PB Power, 2004) indicated limited industrial use of I_S Limiter technology. There are manufacturers with commercially available current limiting devices, for use at service voltages ranging from 450V to 38kV.*
>
> *These devices are not considered to be failsafe and require servicing after each operation.*
> *A DTI commissioned report issued in 2004 (PB Power, 2004) concluded that the installation of I_S Limiters would lead to:*
>
> - *difficulties related to compliance with UK Health and Safety Executive (HSE) safety legislation*
> - *duty holders bound by The Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR) being in breach of their license conditions and therefore open to prosecution*
> - *potentially being in breach of the absolute requirements of Regulations 5 and 11 of the Electricity at Work Regulations*
>
> *Their suitability for higher voltage applications is also limited and, with the current legislative and regulatory environment in the UK unlikely to change in the near-term, it is unlikely that these devices will offer a practical solution to electrical networks with high fault level problems.*

As can be seen from this later report, Reference 3 does not endorse the use of Is limiters, neither does it suggest any solutions which might lead to the use of Is limiters. Given that the two reports were written by the same company, and only two years apart, it seem surprising that the conclusions for use of Is limiters has gone from ‘possible’ to ‘unlikely’.

3 REVIEW OF DTI REPORT NUMBER: URN 04/1066

Reference 2 conducted a review of relevant safety legislation, and makes reference as to where the use of surge current limiters may be in breach of this legislation. Where appropriate, the report has sought guidance from relevant regulatory authorities.

The specific legislation reviewed in Reference 2 was:

- The Health and Safety at Work etc. Act 1974.
- Management of Health and Safety at Work Regulations 1999.
- Electricity at Work Regulations 1989.
- The Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR).
- Explosive Regulations (Explosives Act 1875, , Control of Explosives Regulations 1991(as amended), Carriage of Explosives by Road Regulations 1996, Classification and Labelling of Explosives Regulations 1983). The Manufacture and Storage of Explosives Regulations 2005 (http://www.hse.gov.uk/explosives/licensing/storage/).

The legislation above has been confirmed as extant and at the latest revision at the date of this report.

3.1 The Health and Safety at Work etc. Act 1974

3.1.1 Commentary from DTI Report No: URN 04/1066

The Health and Safety at Work etc. Act 1974 is an enabling act, which paves the way for other, more specific pieces of legislation. However, it does contain a number of general duties that an employer must adhere to, both to those in your employ, and to those not in your employ.

Reference 2 highlighted the following sections of the Health and Safety at Work etc. Act 1974:

Duties to those in your employ

> Section 2 (1) – There is a general duty on all employers to ensure, so far as is reasonably practicable, the health, safety and welfare at work.
>
> Section 2 (2)a – So far as is reasonably practicable, employers must provide machinery, equipment and other plant that is safe and without risk to health and must maintain them in that condition. Safe systems of work should be used.
>
> Section 2 (2)b – Manufacturers should ensure, so far as is reasonably practicable, that materials supplied for use at work are safe and without risk to health, and they should supply users with information about its use and any associated hazards.
>
> Section 2 (2) – Employers must provide employees with suitable instruction, training and supervision.

Duties to those not in your employ

> Sections 3 (1) & 3 (2) – Employers should ensure, so far as reasonably practicable, that they do not expose people who are not in their employ to risks to their health and safety. This duty applies to people who may be inside the workplace such as visitors, contractors and another employer's workers visiting their premises.

There is also a duty to ensure the safety and health of those people who have accessed the premises without authorisation.

Reference 2 invited HSE comment on the relevance to the Health and Safety at Work etc. Act 1974. The HSE view was that:

'The HSW Act 1974 is relevant and would not, in principle, prevent the use of Is Limiters'.

3.1.2 Conclusion and recommendations

The Health and Safety at Work etc. Act places a number of duties on an employer, the relevant parts of which are, quite correctly, pointed out in Reference 2. It should be noted that these duties are not absolute, they are all 'so far as is reasonably practicable'.

Reference 2 does make the point that there are implications from the requirement to protect those not in your employ, which could be interpreted as having an impact on the wider electrical network, should current limiting devices be fitted. However, it is considered that other legislation contains more onerous restrictions, so any work which would satisfy other requirements would also make a case that was compliant with the Health and Safety at Work etc. Act 1974. Therefore, it is considered that there would be no specific further work required to satisfy the requirements of the Health and Safety at Work etc. Act 1974.

3.2 Management of Health and Safety at Work Regulations 1999

3.2.1 Commentary from DTI Report No: URN 04/1066

Regulation 3 of the Management of Health and Safety at Work Regulations states that:

Every employer shall make a suitable and sufficient assessment of-

> *The risks to health and safety of his employees to which they are exposed whilst they are at work; and the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his undertaking.*

The contents of Reference 2 provide material for the risk assessment, however each user will be required to undertake an application specific risk assessment of the current limiting devices as installed. Equally, any other employers whose network is affected by the installation of the current limiting devices will need to carry out a risk assessment, or revise their existing risk assessment. The complexity of the interaction required should not be underestimated.

The HSE were invited to comment. Their response was:

> *The Management of Health and Safety at Work Regulations 1992 are relevant. Regulation 3 (1.b) is particularly relevant and would have important implications for duty holders involved in electrical generation and distribution network operations together with users of electricity.*

The implication from Reference 2 was that whoever installs a fault current limiting device will need to look beyond their own network when examining the effect that the device could have, including the consequences of the device failing to operate when required. Where the Is limiter is installed, there will be an obligation to provide all necessary information to other duty holders who are affected, so that those duty holders can assess the effect on their networks and the risks resulting.

3.2.2 Conclusion and recommendations

Anyone installing an Is limiter will be required to undertake a risk assessment of the current limiting devices as installed, including any implications for equipment downstream of the Is limiter, which could be potentially overstressed should the limiter fail to operate. Equally, any other employers whose network is affected by the installation of the current limiting devices will need to carry out a risk assessment.

It will be for the network operator to demonstrate that this risk assessment is suitable and robust enough, particularly in the case where the Is limiter fails to operate on demand.

3.3 Electricity at Work Regulations 1989

3.3.1 Commentary from DTI Report No: URN 04/1066

There are a number of regulations within The Electricity at Work (EAW) Regulations 1989 which are particularly relevant to the use and application of Is limiting devices. The relevant regulations include:

Regulation 4(1) which requires that 'All systems shall at all times be of such construction as to prevent, so far as is reasonably practicable, danger.'

Regulation 5 states 'No electrical equipment shall be put into use where its strength and capability may be exceeded in such a way as may give rise to danger.'

Regulation 11 states that 'Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger.'

Reference 2 also states that:

> *There is no part of The Electricity at Work Regulations 1989 which would prevent the use of current limiting devices, provided that:-*
>
> - *they operate successfully on demand without dangerous effects, and*
> - *they are used and applied correctly within a network such that they meet regulations 4, 5 and 11.*

In addition, there are 2 regulations which provide a degree of mitigation to Regulations 5 and 11. Regulation 29 provides a defence clause in any proceedings for an offence consisting of a breach of a number of the regulations, including regulations 5 and 11. It states that 'it shall be a defence for any person to prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that defence'.

Regulation 30 gives the HSE the power to issue general or special exemptions to the regulations, these are only granted if 'it is satisfied that the health and safety of persons who are likely to be affected by the exemption will not be prejudiced in consequence of it.'

The HSE were invited to comment. They have stated that in their view, Regulation 5 of The Electricity at Work Regulations 1989 is particularly relevant since it places an absolute requirement on duty holders. For example, Regulation 5 would apply to a duty holder, downstream of the Is Limiter, who has under his control a circuit break being 'protected' by the Is Limiter. In the event of a fault, (e.g. a cable fault) arising downstream of the circuit breaker and subsequent failure of the Is Limiter causing the circuit breaker to become over-stressed and fail catastrophically, it could be argued there was a breach of Regulation 5.

However, the HSE did comment that that Regulation 29 could provide a basis of a defence for the relevant duty holder providing the duty holder was able to demonstrate he had taken "all reasonable steps and exercised all due diligence". However, Reference 2 does have concerns, and concludes that this could become a matter for the courts to decide.

Reference 2 also comments on the provision of an exemption, under Regulation 30 of the EAW Regulations 1989, relating to the application of Regulation 5, but admits that this would be only a stop-gap measure.

3.3.2 Conclusions and recommendations

Regulation 5 is an absolute requirement, as opposed to being qualified by a 'reasonably practicable' statement. Electrical equipment should be used within the manufacturer's rating and in accordance with any instructions supplied with the equipment. The selection of equipment should take into account the fault levels and characteristics of the electrical protection provided to interrupt or reduce fault current. One of the reasons for the selection of an Is limiter is that since it will trip before the first peak of a short circuit current, switchgear and cabling downstream of the Is limiter could be of lighter construction. Alternatively, the use of Is limiters would allow existing cabling and switchgear to have a potential higher rating, since the peak short circuit current will not be seen.

Regulation 11 states that ‘Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger.’

The most likely challenge to compliance with the EAW Regulations 1989 is the situation where if the device fails to operate on demand then equipment is likely be overstressed, depending upon the type and location of the fault. The particular circuit breakers which are overstressed, their ownership, and the degree of overstressing will also depend on the particular application.

Whilst there can never be an absolute guarantee that the Is limiter will work on demand, there is data from the manufacturer to suggest that the Is limiter has a high degree of reliability. It is considered that this data should be reassessed, to see if a sufficiently robust argument can be made that the failure of the Is limiter to operate is of such a low probability as to be incredible (see Section 3.6 below).

It is not recommended that any form of exemption or waiver be sought.

3.4 The Electricity Safety, Quality and Continuity Regulations 2002

3.4.1 Commentary from DTI Report No: URN 04/1066

There are a number of regulations within The Electricity Safety, Quality and Continuity Regulations 2002 which are particularly relevant to the use and application of current limiting devices.

Regulation 3.1’General adequacy of electrical equipment’ which states that:-

Generators, distributors and meter operators shall ensure that their equipment is -

(a) sufficient for the purposes for and the circumstances in which it is used; and

(b) so constructed, installed, protected (both electrically and mechanically), used and maintained as to prevent danger, interference with or interruption of supply, so far as is reasonably practicable.

Regulation 3.1(a) is an absolute requirement, Regulation 3.1(b) uses the ALARP principle. It does not preclude the use of a Is limiter, because if designed and specified properly, it should be “sufficient for purpose”. The Is limiter will prevent existing switchgear seeing fault levels above duty. The premise here is that the Is limiter will work in all circumstances. If the Is device fails, it is clear that any circuit breaker unit that fails subsequently to clear (due to inadequate duty) would not be "sufficient for purpose". In this circumstance, the duty holder would have to demonstrate that he/she had anticipated the consequences of a possible failure of the Is device and any mitigation measures required to keep within a tolerable risk level the duty holder would need to justify.

It should be noted that this would not be an issue if the current limiting device was being used with equipment that would still be operating within its rating without the device.

Regulation 4 ‘Duty of co-operation’, requires that generators, distributors, suppliers and meter operators should disclose such information to each other as might reasonably be required and otherwise co-operate amongst themselves so far as is necessary in order to ensure compliance with the ESQCR.

Also, Regulation 28 lists the information which a DNO must provide to interested parties for consumer’s installations connected to his network.

The main issues here are as to which fault levels will be assumed between networks and as to what would be communicated between duty holders. If there is a chance of adjacent networks becoming overstressed this should be communicated. The duty holders concerned can then decide how they wish to comply with the relevant regulations and the level of risk they take for insurance/safety of employees/public. The important thing is that the possibility of risk is communicated clearly and the consequences are spelt out between parties.

There is an expectation that consumers to be informed of the effect on his/her network due to the adoption of Is limiters on the duty holder's network. This would allow the consumer to decide what level of risk he/she wishes to take at his premises

Under Regulation 28 there is no obligation on the duty holder to provide information on the network unless requested by the consumer connected to the network.

However, in line with the comments on Regulation 4 above, a code of practice would need to be developed so it was clear that under Regulation 28 when fault level data was supplied to connectees, fault levels should be stated for correct device operation and for the situation if it failed to operate. The connectee could then decide how much risk he/she wanted to take.

Regulation 6 'Electrical protection', states that:-

A generator or distributor shall be responsible for the application of such protective devices to his network as will, so far as is reasonably practicable, prevent any current, including any leakage to earth, from flowing in any part of his network for such a period that that part of his network can no longer carry that current without danger. Again, this mirrors the requirements within The Electricity at Work Regulations 1989.

If the device is considered as an "intelligent fuse" and therefore an electrical protection device, and it operates correctly, then there would be no breach of this regulation.

If it fails to operate there is no other protection that will clear the fault, no grading being possible because the disconnection devices (i.e. circuit breakers) remaining will be inadequate.

Bearing this in mind, it would be difficult to demonstrate compliance with Regulation 6 if the device failed. However, this would also be the case for conventional relays where it was set incorrectly or failed to operate.

Regulation 23 'Precautions against supply failure' will affect how the current limiting devices are applied and set in order to avoid spurious tripping. The regulation requires distributors to arrange their networks and provide fuses or automatic switching devices, located and set, as to limit, so far as is reasonably practicable, the number of consumers affected by any fault in his network.

Under Regulation 23 the duty holder must show that the device is set to operate at a correct level to restrict, so far as is reasonably practicable, the numbers of consumers affected by any fault and also that all reasonably practicable steps have been taken to avoid interruptions of supply resulting from his own acts.

As this cannot be demonstrated without destruction of the device, there would be no way of practically demonstrating correct setting other than by the demonstration of the detection circuit function and correct trip signal. This is no different to the case with a conventional fuse except that a back-up arrangement (from a larger fuse) is available with a conventionally fused circuit arrangement. It will be essential that the current limiting devices are set correctly and tested regularly.

3.4.2 Conclusions and Recommendations

In summary, the regulations allow for technical developments, as long as it can be shown that all risk and hazards have been reduce to a minimum in so far as is reasonably practical. The use of an Is limiter as providing a single point of protection for a circuit can only be by the provision of either an analysis that would demonstrate an incredibility of failure on demand, or by the inclusion of a back up device.

3.5 Explosive Regulations

3.5.1 Commentary from DTI Report No: URN 04/1066

The Is limiter employs an explosive charge. The mass of the charge is under 2g. The type of explosive is as follows:

Classification	UN Class 1
Hazard Division	1.1B
UN No	0030

Explosives can normally be stored only in a place registered or licensed under the Explosives Act 1875. The Act requires the explosives to be stored in an appropriate category of storage. The amount of explosive within the spare inserts likely to be stored by users would require the premises to be registered with the Local Authority. The Local Authority may decide to relax some of these requirements for the users of fault current limiting devices because of the small amount of explosive involved.

The Control of Explosives Regulations 1991 (COER) addresses the security of explosives. The type of explosives used in the Is limiter is not exempted by the COER, so the use of these devices would come under these regulations. One of the main requirements of the COER is an Explosives Certificate, supplied by the police.

The transport of explosive is controlled by the Carriage of Explosives by Road Regulations 1996. Explosives must be transported in a vehicle suitable for the safety and security of the explosives being carried. It is considered that for current limiting devices the amount of explosive will be small and most vehicles would be suitable. However it is recommended that the driver is separated from the load. The driver should be provided with appropriate information, instruction and training. Depending on the type of explosive being transported the Carriage of Dangerous Goods by Road (Driver Training) Regulations 1996 may place additional responsibilities on the employer. The consignor of any explosive by road needs to ensure that it is transported in the packaging in which it was classified and labelled in accordance with Classification and Labelling of Explosives Regulations 1983. In addition, the package is required to comply with the requirements of the Packaging of Explosive for Carriage Regulations 1991.

3.5.2 Conclusions and Recommendations

The pyrotechnic device used in the Is limiter falls under the United Nations Hazard Class 1, which refers to the UN recommended system of nine classes for identifying dangerous goods. Class 1 identifies explosives. The pyrotechnic device is given a Hazard Classification code of 1.1B, and a UN Serial Number of 0030, which places the pyrotechnic device in the category as a **Detonator, Electric (for blasting).**

Given the classification of the pyrotechnic device, it is considered that an Explosives Certificate would be required. Given the nature of the explosive device involved and the very small amount of explosive material per limiting device, it is not thought that obtaining an Explosives Certificate, and providing a safe method of storage would prove to be an onerous task. For example, as the explosive charge is classified as a detonator, the requirement for separation distances in Paragraph 5 of the Manufacture and Storage of Explosives Regulations 2005 does not apply.

The transportation of the Is limiters would also need to comply with the legislation, but given that the number of inserts in transit at any one time would be limited, again, it is considered that this would be relatively straightforward to comply with.

It is expected that, just as ENW would provide the relevant training and proper risk assessments for any of its staff involved with any new equipment or operation, the transport, storage and maintenance of the Is limiters would be addressed in the same way.

The Is limiters contain only very small amounts of explosives. When in service, they will be fitted along with other electrical switchgear, which is operating at high voltages. The Electricity at Work Regulations, and the Electricity Safety, Quality and Continuity Regulations 2002 place duties on the network operators to ensure that both their staff and other persons are protected from the Hazards associated with high voltage electricity. It is considered that the precautions which are already in place to cope with these hazards should be adequate to protect from any potential hazard that the Is limiter could generate, should it operate.

It is recommended that the relevant local authority is consulted prior to making arrangements to store Is limiter inserts.

Note: A direct comparison can be made with the detonators carried on board trains as warning devices which are attached to the track in the event of a train breakdown. These detonators have a similar classification, and have a greater quantity of explosive within them. These are carried and stored on board a train (in close proximity to the general public) with no particular difficulties.

3.6 Hazard Studies

3.6.1 Commentary from DTI Report No: URN 04/1066

Reference 2 also contains a HAZOP study for the surge current limiters, and an FMECA for the G&W surge current limiter. These studies conclude that the principal hazard with the surge current limiting devices is their failure to operate on demand.

Reference 2 also includes a suggested predictive reliability assessment. However, this dates from 1980, and the probability of failure to operate on demand, which was estimated at $1.75x10^{-3}$, would appear to be pessimistic, when compared with actual operating experience of the device.

ABB have conducted a Failure Mode and Effect Analysis (FMEA) to estimate the reliability of their current limiting device. Under ideal conditions, assuming a proof test interval of once per year, the FMEA predicted the probability of failure to operate on demand as $1.75x10^{-3}$.

ABB collected some information on the failure data and device operation. This information has been used to provide an approximate estimate of the current limiting device reliability. The probability of failure to operate on demand, based on this operational data, is estimated as $8.3x10^{-5}$. However, this estimate is based on a number of assumptions.

3.6.2 Conclusions and Recommendations

Reference 2 concludes that there is significant uncertainty as to the completeness of the data for reliability assessment. There is a difference between the reliability estimated from the predictive assessment and that estimated from operational data, which is of the order of a factor of 20 difference. Given that Reference 2 is 10 years old, and there have been no recorded instances of the Is limiter failing to operate on demand, it is considered that the gap between the predicted failure rates and data from operational experience will have widened.

The failure to operate on demand remains the principal hazard for the Is limiter. For the Is limiter to be considered acceptable for use, it will be required to demonstrate that the probability of failure to operate on demand has been reduced to an acceptable level.

4 DISCUSSION

There is one significant issue identified with the proposed adoption of Is Limiters in the UK. This relates to the consequences of its failure on demand. Other issues are of an administrative nature.

4.1 Failure on Demand

Some of the regulations discussed earlier place absolute requirements on the network operators, rather than requirements which are to be complied with ‘so far as is reasonably practicable’. One of these absolute requirements is that the equipment used in the network must be fit for purpose, ie it must sufficiently robust to be able to withstand a potential short circuit current. Surge limiters offer the advantage that since they are designed to operate before the first peak of any short circuit, the network will not see those peak current, so that there is the potential to utilise cabling and switchgear of a lesser capacity. This of course offers a potential to make substantial cost savings, but cost saving alone cannot be used as a justification for changes to a network. It is generally understood that for cost saving to be a factor, the overall risk should not be significantly greater than it was before.

To complicate matters, there is no way to actually test the tripping mechanism. It is possible to test the triggering circuitry, and the manufacturers have a maintenance procedure for this, but the operation of the actual tripping device (ie the pyrotechnic charge) cannot be tested. This is not an unusual situation, mechanical systems that use Bursting Discs to release pressure have a similar disadvantage, as do Airbag ignition in cars – there is no way to be absolutely certain that the device will operate when it is required.

4.2 Current Mitigation

There are several current mitigating factors.

- Operational experience.
- Redundancy.
- Existing safety studies.
- Trip units taken out of service.

These are discussed below. However, it is not considered that, at the moment, these mitigations are robust enough.

4.2.1 Operational Experience

There is considerable operational experience in the use of Is limiters world-wide. The Is limiter has been in service since 1961. Reference 2 indicates in excess of 120,000 device years of operation. In that time, ABB have no record of the Is-limiter device failing to operate on demand.

There have been five cases of spurious trips. Investigation showed that all five cases were related to a change in the network by the operators, who had installed capacitor banks without checking the settings of the existing Is-limiters. The charging and discharging of these capacitor banks, and the resulting high rate of rise, high peak currents had caused the Is-limiter to trip. ABB have no record of injury to people arising from hazardous incidents associated with the transport, storage, operation, maintenance and disposal of the Is-limiter units.

4.2.2 *Redundancy*

The system is 3 phase. By definition, a short circuit will involve a minimum of two phases. For the protection to fail, both surge limiters would need to fail to operate. For a 3 phase short circuit, 2 out of three would need to fail to operate.

4.2.3 *Existing Safety Studies*

ABB commissioned TŰV Rheinland to conduct an assessment of the safety related reliability of the Is Limiter. TŰV Rheinland published a Report – Report Number 968/EL 444.00/07 Report on the determination of the safety related reliability of the Is limiter type BA 323/04 E, dated 2007-01-03 (Reference 4).

The scope of the report was to conduct a Failure Mode and Effects Analysis (FMEA) on the components of the Is limiter, and to calculate the safety parameters according to IEC 61508 (Reference 5).

The outcome of the study was that the average probability of failure on demand (per year) was calculated as:

One Phase System – $4.9x10^{-5}$

Three Phase system – $1.02x10^{-4}$

These results once more differ from those in Reference 2, and, given the available operational data, would also seem to be somewhat pessimistic.

4.2.4 *Trip Units taken out of Service*

The tripping inserts have a recommended in service life – either 8 years in service, or 12 years if they have not been connected. This service life is dictated by the bursting charge component.

The inserts are returned to the manufacturer, where they are then tripped, to check their correct operation. Information from ABB indicates that they refurbish between 450 and 600 of these inserts per year. ABB do not keep data from individual tests, but they report that this is because they have had no instances of the inserts failing to operate when destructively tested in this fashion.

4.3 Outline of a Safety Case

A safety case refers to the totality of a Duty Holder's documentation to demonstrate safety. It should consist of documentation to justify safety during the design, construction, manufacture, commissioning, operation and decommissioning phases of the installed equipment. A safety case should present the following information:

A hazard identification technique appropriate to the complexity of the installation, the stage of the installation in its lifecycle and the scale and nature of the hazards on the installation, eg:

Hazard Identification (HAZID)

Hazard and operability study (HAZOP),

Failure Modes and Effects Analysis (FMEA),

Safety reviews,

Industry standard or bespoke checklists,

Job safety analysis.

A demonstration of sound engineering practice, eg:

Derivation of operating limits,

Examination, inspection, maintenance and testing regimes,

Commissioning and trials information.

Optimisation of protection and balanced plant design

Engineering Justification, eg:

Inherent and passive safety,

Codes and Standards,

Redundancy and Diversity; Single Failure Criterion,

High Integrity Design (with numerical targets),

Consideration of Ageing and Degradation,

Material Control,

Purpose and Limitations of Commissioning.

Design Basis Analysis.

Design for Safety.

Consistency with function,

Safety Systems,

Monitoring and Control,

Role and Training of Operators.

It is considered that most of the information to establish a Safety Case already exists, or can be obtained without a substantial amount of additional work.

A full Hazard Identification has not been carried out for the Is limiter.

In the Engineering Justification, the Codes and Standards that are applied to the Is limiter are European, rather than UK specific ones, and the demonstration of a High Integrity Design, particularly the numerical targets, is not consistent.

4.4 Recommendations

The potential advantage of an Is limiter is that because it interrupts the surge current from a short circuit before it reaches its peak, the downstream circuitry never sees the full surge current, therefore it need not be of such a high capacity.

The principal issue with the Is limiter is one of being able to demonstrate reliability. Should the Is limiter operate as designed, then there is no reason that would prevent their use in a network in the UK. However, Reference 2 is quite clear that should the Is limiter fail to operate, **and equipment downstream was overstressed**, the network operator would be in breach of current legislation. It should be noted that this would only apply if the Is limiter was fitted in conjunction with cabling and switchgear that could be overstressed.

To satisfy an absolute requirement of any of the legislation, the integrity levels as they currently stand would not be suitably robust enough to provide an argument that the probability of failure on demand is not credible. There is also some ambiguity between the available operational data and the reliability figures published in Reference 2 and Reference 4. This report's author is not aware of the standard required to demonstrate incredibility of failure, but for the nuclear industry, a probability of failure on demand of the order of $1x10^{-6}$ would be required.

5 FINDINGS/CONCLUSIONS

As can be seen from the comments in previous sections, there are a few issues to be resolved before a Safety Case in Reference 2 which would, in the opinion of its authors, require to be addressed in order to permit use of Is limiters in a UK network. In resolving these issues, the concerns raised in Reference 3 would no longer be valid. There are 5 issues which require to be addressed so that an Is limiter could be used within a network.

1. An Explosives Certificate (one required for each Local Authority in whose area one of these Is limiters is installed).
2. Suitable maintenance procedures. Those developed by the manufactures should if compliant with EU directives be suitable for use after a review. Maintenance procedures should also include procedures to inspect for damage in the event of a suspected failure on demand, ie overstress of down-stream components.
3. A suitable risk assessment and training to enable the storage, transportation, fitting and operation of Is limiters.
4. Involvement of relevant industry Stakeholders, including Ofgem and the HSE.
5. An assessment that the Is limiter has the required reliability. In particular, that the probability of failure on demand is reduced to an acceptable level.

It is considered that numbers 1 to 3 above are relatively straightforward, and whilst they might take some time to complete, it is not anticipated that any of those would prove to be insurmountable barriers to the use of an Is limiter. The principal barrier to the use of an Is limiter within a UK network would appear to be number 5 above, the consequences of the Is limiter failing to operate on demand. It is considered that it would be possible to construct a safety case to demonstrate that the likelihood of failure has been reduced to an acceptably low level. However, it is accepted that this is a relatively novel approach to take to demonstrate acceptable safety within the electricity distribution industry, therefore it is recommended that prior to conducting any detailed assessment, the prior engagement of relevant Stakeholders be sought.

6 RECOMMENDATIONS

It is considered that develop a safety case to achieve regulatory approval, by Ofgem and HSE, for use of the Is limiters in the UK is realistic. The adoption of Is limiters will allow lower capacity installation to be specified thereby saving costs. The risks are that in the failure to operate on demand, the down-stream equiment may be damaged. Loss of life associated with this is unlikely as the down-stream equipment will be in its normal operating state with all protective features in place.

To achieve this it is recommended that:

1. Hold a workshop with HSE, Ofgem and other industry bodies as appropriate. This will include a discussion outlining the proposal and its shortcomings with a view to establishing approval in principle, and discussion of legislative changes required, if any.
2. Draft a Safety Case based on the information held at present. To complete a Safety Assessment, we would recommend:
   - HAZOP Study
   - FMECA
   - Construction of a Fault Tree
   - Calculation of a Reliability Assessment.

7 REFERENCES

1. The Distribution Code of Licensed Distribution Network Operators of Great Britain: Issue 22: February 2014.
2. DTI Report Number: URN 04/1066 Development of a safety case for the use of current limiting devices to manage short circuit currents on electrical distribution networks. Contract Number DG/CG/00022/00/00.
3. BERR Report, URN 07/1652 Application of fault current limiters. Contract Number DG/DTI/00077/06/REP.
4. TŰV Rheinland Report Number 968/EL 444.00/07 Report on the determination of the safety related reliability of the Is limiter type BA 323/04 E, dated 2007-01-03.
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