PROTECTION OF ESI EQUIPMENT WHERE PRIVATE GENERATORS ARE CONNECTED TO THE DISTRIBUTION SYSTEM

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SUMMARY

It is now a legal requirement for private generators producing 1 MW of power or more to be able to sell electricity to Regional Electricity Companies (RECs) for their distribution systems. The RECs need to ensure that safety and security of supply are not impaired as a result. Equipment whose rating was adequate before the connection of private generators may therefore require uprating or additional protection. This paper focuses on the additional protection that current limiting fuses can provide for circuit breakers whilst optimising co-ordination. The possible prospective fault currents after the connection of private generators and the times in which they must be disconnected are considered.

1. Introduction

With recent legislation empowering private generators to sell electricity for distribution on Regional Electricity Company systems, consideration must be given to the continued safety and security of supply. ERA, in collaboration with the Electricity Council (now the Electricity Association), has therefore conducted an investigation into some protection aspects of this increasingly important commercial activity. In order to provide the necessary background to the changing situation, discussions were held with representatives of a major electricity board at various stages of the investigation.

The objective of this work is to determine what sort of protection device is most suitable for limiting fault currents on distribution networks at 'medium' voltage (11 kV) in situations where the addition of private generators might cause faults in excess of the breaking capacity of existing protection equipment and of the fault current withstand of other circuit components. At this stage, ERA's study does not include low voltage (415 V) circuits because the connection of small private generators at this voltage rarely causes fault level problems, except occasionally where interconnection between 415 V systems exists. Interconnection increases the fault level and the connection of private generators may then cause the declared fault level to be exceeded. However, in such cases, the relatively low cost, simple solution of removing interconnections can be used to reduce fault levels.

At medium voltage, the characteristics of the combined circuit resulting from the addition of private generators to the distribution system are such that special types or combinations of fuses will probably be necessary to provide full protection, as described below.

2. Normal and Fault Current Levels

2.1 Before the Connection of Private Generators

From discussions with the Electricity Council it is understood that normal full load currents in the systems under consideration are approximately within an order of magnitude of the fault currents.

The fault level on an 11 kV system normally lies in the range 100 MVA to 175 MVA (5.2 kA to 9.2 kA), but the extremes are 50 MVA to 250 MVA (2.6 kA to 13.1 kA)[7]. Usually, a margin of approximately 30 MVA to 40 MVA (1.6 kA to 2.1 kA) exists for the accommodation of the fault level from private generation and induction motors. Existing switchgear can safely disconnect a fault level of 13.1 kA.

The contribution from the motor load on the system is variable, but is typically well within the 30 MVA to 40 MVA margin. However, in some circumstances there may be a much larger contribution; for instance Williams and Corcoran[1] quote up to 35% when induction motors are electrically close to a faulted busbar. In this extreme case, larger margins would be necessary to prevent existing switchgear experiencing fault levels higher than their rating, even before the connection of private generators. However, the presence of large motors or groups of motors would be known to the REC concerned, and allowance made for them. Guistiniani[5] states that the contribution from induction motors decays to a relatively small value after 5 to 10 cycles, ie 0.1 to 0.2 seconds. If a REC circuit breaker takes 0.4 seconds to operate[7] then the contribution from induction motors would be negligible. However, more rapid disconnection is presumably desirable, and could be achieved by fusing.

2.2 After the Connection of Private Generators

The total private generation capacity that could be connected to any one 11 kV system is expected to be in the range 1 MVA to 7.5 MVA[7], with corresponding current levels of 0.05 kA to 0.4 kA. It is expected that the minimum generator size will be 1 MVA because it is unlikely that it will be economic for smaller generators to be connected at 11 kV. The order of fault level contribution from a generator is typically 5 to 6 times its rating for a short circuit, ie at present, a private generator could add 5 to 45 MVA, or 0.3 to 2.4 kA, to the short circuit current. For larger private generators, the fault level margin of the existing system may be insufficient to accommodate their fault level contribution. If several large private generators were connected in parallel without additional fault level reduction measures, then the rating of 13.1 kA switchgear could be significantly exceeded. The contribution from motor loads must also be considered when deciding on fault level reduction measures.
To enable switchgear to be used when fault levels can rise to values significantly above its rating, some back-up device (eg fuse) for interrupting fault currents in approximately a quarter of a cycle, ie 5 ms, is required. Co-ordination would be achieved by disconnection of currents above the switchgear rating by the back-up device, leaving the switchgear to disconnect currents below its maximum breaking capacity.

Two examples of sites being proposed for private generation were considered using the 11 kV system diagrams for the areas supplied by grid supply points called X and Y for the purposes of this paper. 1.5 MVA may be exported from Site A, which is connected to grid supply point X by approximately 6.7 km of cable, and 4 MVA from Site B, which is connected to grid supply point Y by approximately 3.9 km of cable. In the former case there is the complication of home based patients who are presumably noted on the diagram because they are highly dependent on a continuous electricity supply. They are between grid supply point X and generation site A.

In these cases, the highest prospective current would occur if there was a fault close to the grid supply point. There would then be some limitation of the contribution to the fault from the private generator by the intervening cable. A worse case would therefore exist if a private generator was connected close to the grid supply point.

Information from an electricity board[7] gave a range of normal currents of 0 to 400 A flowing either from or to a private generator at its point of connection to the distribution system. A protective device at this point (B in Fig.1) must therefore carry 400 A without deterioration. The maximum current of 400 A into the distribution system could only be provided by a 7.5 MVA private generator, and the maximum current through the protective device feeding into a fault on the distribution system would be approximately 2.4 kA[7], or 6 times the rating of a fuse used for protection at this point. The use of two type K fuses in parallel (discussed in Section 3.4) would give a pre-arcing time of 100 seconds, and would therefore offer no protection from the private generator's output to the electricity board's circuit breakers. This would apply in a similar way for less powerful private generators used in conjunction with correspondingly lower fuse ratings.

If a fuse was placed in series with a private generator (C in Fig.1), but did not carry any current input from the distribution system, it would again have to be rated to carry the maximum power generated. A fault on the distribution system would not cause currents from the generator to the distribution system higher than those described above, and hence disconnection times would be similarly long. This arrangement would also have the disadvantage of disconnecting the private generator from any load it was primarily intended to supply when there was a fault on the main 11 kV system. However, the generator might be tripped whatever the position of the protection because of instabilities on the 11 kV system resulting from the fault and its disconnection. The advantage to the private generator of installing protection at B rather than C is that supply to its load could be resumed without waiting for a fault on the distribution system to be remedied.

This would also apply if there was protection at positions such as A in Fig.1. The prospective fault current would be higher here than at B and C and current sensitive protection devices used to protect the circuit breakers would therefore operate more rapidly. Damage to the circuit breakers from fault currents in the main 11 kV system could be prevented, although current from the private generators could still flow into the local part of the 11 kV system. However, a separate protection system should then rapidly disconnect the private generator from the local system. It would be necessary to ensure that protection at A was co-ordinated correctly with the circuit breakers so that the latter disconnected low fault currents and the former disconnected high fault currents.

3. Methods of Protection with Private Generators Connected to the 11 kV system

In the event of a fault, it is necessary to prevent the combination of main and private generation from damaging REC switchgear. Sometimes, a possible method of accomplishing this is to disconnect private generators from the distribution system to prevent them adding to fault currents whenever running arrangements which give rise to high fault levels are adopted. Alternatively, if the fault is cut off before the current reaches a damaging level, rapid disconnection of the private generators might be unnecessary. Various means of protection are possible and are discussed below.

3.1 The Calor-Emag I_S Limiter

The Calor-Emag I_S limiter[2] is a device intended to provide rapid disconnection of faults. It has a fusible link with an element of considerably lower rating than the normal circuit current in parallel with a tubular conductor, or bursting bridge, which normally carries most of the current. An explosive in the centre of this tube is detonated by an electronic circuit in the event of a fault, diverting all the current through the fusible link. Calor-Emag give a bursting time for the tube of 0.1 ms and a time for limitation of the current by the fusible link of 0.5 ms.

The Calor-Emag I_S limiter[2] is already in use for disconnecting fault currents at some sites where private generators feed power into area board systems. However, the limiter is not a failsafe device, and is understood to have failed. Problems may arise in the circuits which initiate operation of the limiter or in the detonation of the bursting bridge connection. There is no system to indicate the presence of a malfunction before the limiter is required to operate.

If a fuse with a rating appropriate to the normal current and voltage of the circuit was connected in series with the I_S limiter, then the combined system would fail to safety if the bridge failed to burst. The breaking capacity of the fuse would be sufficient to disconnect safely the maximum fault current if the I_S limiter failed to operate correctly for whatever reason. This would add to the cost of protection and it would be simpler and cheaper to use a single fuse system which would disconnect faults sufficiently rapidly (see Section 3.4). However, the back-up function could be performed using present designs of fuse, which are not fast enough to provide complete protection. The switchgear would not be fully protected by such a system, but it would be safer than with an I_S limiter alone.

Also, the connection of such a series fuse would not have prevented the type of limiter failure reported to the Electricity Council[7] in which the bridge was burst but the fault current was insufficient to be cleared by the parallel fusible link. The link then overheated and a flashover occurred. Calor-Emag do not use a sealed cartridge fuselink in their limiter, but replace the element and quenching material in the same barrel after operation. The performance in this respect could probably be improved by the use of a general purpose fuselink conforming to BS 2692 Part 1. Such a fuselink would have to be replaced in its entirety after operation of the limiter.

The Calor-Emag is the oldest device of its type, and is in use in various locations, but other companies such as the G & W Electric Co and the S & C Electric Co produce similar devices. They may have advantages, but this would have to be ascertained by comparative testing.

3.2 Uprating Switchgear

An alternative solution to the problem of increased fault current levels is uprating the switchgear whose rating may be exceeded. According to GEC[1], economical switchgear ratings are now available at ratings higher than 250 MVA, eg 475 MVA and 600 MVA. The smaller of these ratings would be sufficient to disconnect the present maximum fault levels, allowing for significant contributions from induction motors (87 MVA) (see Section 2.1) and the anticipated contribution to a fault from a large private generator (45 MVA) (see Section 2.2), whilst still allowing for some future increase in generating capacity.

When a private generator wishes to be connected to the distribution system, the fault levels after connection should be carefully calculated, taking into account the distance of the generator from any switchgear. The Electricity at Work Act does not permit switchgear ratings to be exceeded, so if this is found to be possible, then the uprating of switchgear may be necessary if a private generator is to be connected. The effect of the rate of rise of the increased fault current, which may adversely affect the switchgear even if the current is cut-off before rated values are reached, should also be considered, and switchgear manufacturers consulted.

Even if switchgear with ratings of the order of 475 MVA is now more economical than before, it is unlikely that the RECs would want to go to the expense of uprating switchgear unless it becomes due for replacement. However, this could be a solution if the private generating company met all or some of the cost of necessary uprating of the protection to accommodate the addition of their supply. Such additional costs may make the connection of some private generators uneconomic, and other protection methods should then be considered.

3.3 GEC's Short-Circuit Limiting Coupling

In the same paper[1], the authors suggest the use of a 'short-circuit limiting coupling' (SLC) developed by GEC. The device consists of a reactor in series with a capacitor, and the combination resonates at power frequency thus adding a low impedance to the circuit. An iron-cored reactor in parallel with the capacitor saturates if the voltage drop across the capacitor increases due to an excessive current. The tuning of the circuit is then changed, producing a high impedance. This device appears to give rapid limitation of fault currents, but has the disadvantages of being bulky and expensive. Also, it may be possible for it to fail to operate, for instance in the case of a fault in the capacitor. However, it is more likely to be reliable than a device incorporating explosives.

3.4 Conventional Fusing

The use of fusing is an alternative to the protection options described above. Fuses are failsafe devices when used within their specification, they have very high breaking capacity and are compact and economical. They are most economical if a device from normal production can be used, rather than a specially made one. Electricity boards and the Electricity Council have examined the characteristics of fuselinks produced by various manufacturers, including GEC's standard, type K, high voltage, high breaking capacity fuselinks[3], which are rated at 12 kV. However, the maximum current rating available in a single fuselink is 350 A and the application under consideration was a private generator with a total load current of 410 A (slightly higher than the usual range[7]).

GEC suggest the use of two identical fuses in parallel to achieve higher current ratings, which are less than the sum of the two ratings used. The characteristics of such a pair of fuses were supplied to ERA by GEC. An appropriate fuse with a rating of 450 A can be produced by connecting two 250 A fuselinks in parallel. Combining two fuselinks in parallel also has the advantage that the combination's time/current characteristic is steeper than that of a single fuselink, giving faster operation at high fault currents.

Similar characteristics were provided by Hawker Fusegear[4]. To save space, the following examples are taken from the GEC data, but other manufacturers' products could be used in a similar manner.

The characteristics for this combination show that prospective fault currents (symmetric rms) above 10.2 kA are cut off, and at this current, the pre-arcing time is 50 ms, or between 2 and 3 cycles. At the maximum fault current without private generators, 13.1 kA, the pre-arcing time would be 25 ms (1 to 2 cycles) and with the addition of a 7.5 MVA private generator, the maximum fault current of 15.5 kA would give a pre-arcing time of 12 ms (0.5 to 1 cycle). Switchgear would therefore be exposed to a current exceeding its rating for part of this time, and for part of the arcing time. Thus although this combination fuse operates much more rapidly than the circuit breakers normally in use, it does not provide sufficient protection. At such fault currents, the pre-arcing I^2t would be close to its minimum value of 1200 x 10^3 A^2s.

However, it may be possible to achieve the required protection by taking the process of combination further, ie connecting more fuselinks in parallel. For example, GEC gives characteristics for two 125 A fuselinks in parallel for which the combined rating is 225 A. Thus GEC derate the sum of the ratings combined in parallel by 10%. Combining two such pairs of fuselinks in parallel would therefore presumably give a fuselink with a rating of 405 A. Fuses are derated because of the effects of heating by adjacent fuses and because there will be some uncertainty about the exact distribution of current in parallel fuses, whose resistances may be slightly different. Less derating may therefore be required if the fuselinks are spaced to allow better heat dissipation. Also, when more than two fuses of the same rating are connected in parallel, it is statistically more likely for there to be a more even current distribution.

Four 125 A fuselinks in parallel would provide suitable protection for the case of the maximum normal current of 400 A expected by some electricity boards (Section 2.2), and possibly when there is a slightly higher current of 410 A[7] as in some applications. The time/current characteristics would be steeper than for a pair of fuselinks and it is possible that fault currents exceeding the switchgear rating could be disconnected sufficiently rapidly. However, it would be necessary to determine characteristics for such a combination experimentally to establish its suitability for the application. The use of more than four fuselinks in parallel may be necessary if this method of protection is to be used.

The rating of approximately 405 A may be too small for some applications, but combining four 160 A fuselinks, the next rating above 125 A provided by GEC, should give a rating of approximately 520 A. This would probably be too high to provide sufficient protection, and the manufacture of fuselinks with a rating between 125 A and 160 A may be necessary. Alternatively, it may be possible to used mixed ratings in parallel if the difference between ratings is produced by variations in the number of parallel elements of the same design. The current distribution would have to be checked to ensure that the current through each fuse was proportional to the rating. However, this is a departure from existing practice and careful investigation and testing would be required before this concept could be accepted by fuse manufacturers and users. Such a combination of fuses should then only be used as recommended by the manufacturer, and this could be accomplished by connecting the fuses in a single unit which could only be fitted to a specially modified fuse holder.

At B or C in Fig.1, the fault current flowing to or from the private generator should be much less than the values of 10 to 15 kA for which operating times are given above, giving longer operating times and greater values of pre-arcing I^2t. The use of such a fuse system at these positions would therefore provide the required protection. The combination fuselink must therefore be connected at positions such as A where current from the grid and the private generator flows. Fuses with ratings of the order of magnitude described above would only be appropriate in branches of the 11 kV system supplying currents of approximately 400 to 500 A. Fuses with higher ratings will be required closer to grid supply points, and can be produced with fast characteristics using the principles described above.

3.5 Special Fuse Types

It may be possible to achieve the required protection using a device similar to that being developed by General Electric[6]. It is based on a conventional fuse element, but has chemical charges attached to it. It is hoped that it will be possible to use a microprocessor monitoring system to blow the charges and hence disconnect the current. This device might give operating times of the order of those claimed for the Calor-Emag I_s limiter (Section 3.1). However, there is no evidence that General Electric have yet produced a successful prototype.

The General Electric Device could presumably be set to operate at any current level required. It would have a great advantage over the Calor-Emag I_s limiter because the fuse element could operate in the normal way if the charges or their triggering circuits failed. The General Electric element has an M-effect blob to dissolve the element and operate the fuse at low overcurrents, and a series of constrictions at which multiple arcs would be created by a high overcurrent. These features would presumably be designed in the same way as in a conventional fuse of similar rating, making the device failsafe if similarly filled and enclosed. However, the article[6] does not make clear how the device was to be enclosed such that products of the explosion did not create a hazard.

Also, the reliability of the operation of the explosive is not assessed and there could be other hazards associated with its presence. Its stability in its working environment would have to be proved. Explosive devices have historically been less reliable than required when used in protection applications. For instance, explosive indicators were removed from British low voltage fuses because of unreliability, occasional spurious operation, possible association with the initiating of arcing faults and the known failure record of the Calor-Emag I_s limiter. In contrast, conventional fuses (Section 3.4) have extremely high reliability and repeatability.

4. Conclusions

At present, it appears that combining fuselinks in parallel (Section 3.4) offers the most reliable, safe and economical method of protecting existing switchgear. However, the number of fuselinks required to give sufficiently rapid operation is excessive. If fuse manufacturers can develop a fuselink that operates more rapidly than existing designs, then complete protection against increased fault levels caused by the connection of private generators could be provided. It is also possible that in future, a reliable fusible element combined with an explosive charge (Section 3.5) could give more rapid protection. Such a device would have to be thoroughly tested to ensure reliability and safety.

If funds were available, a straightforward method of preventing problems due to the contribution of fault currents by private generators would be to replace existing circuit breakers with new ones of higher breaker capacity.

5. References

[1] Williams W.P. and Corcoran J.C.W., Progress in design of industrial power networks, 1987, GEC Review, Vol.3, No.3.

[2] Calor Emag, Technical/Advertising Leaflet No.1357/6E on I_S limiters.

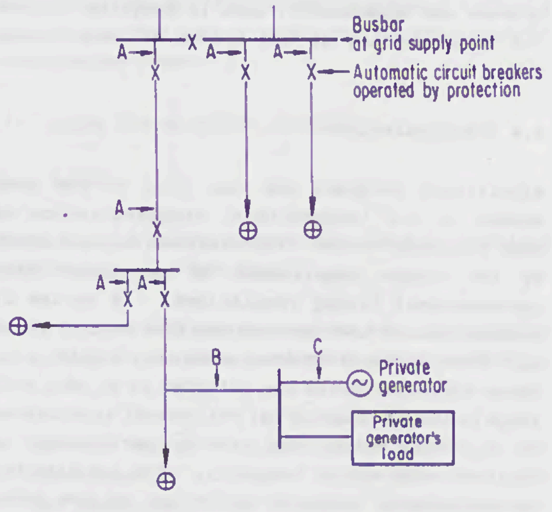
[3] GEC Alsthom catalogue for fuselinks to BS 2692.

[4] Hawker Fusegear catalogue for fuselinks to BS 2692.

[5] Guistiniani D., Presentation on the operation of private generating plant in parallel with the grid distribution system, Ref.7R/53/7, East Midland Electricity Board.

[6] Martin D., Smart fuses enter with a small bang, 1960, Electrical Review, p7.

[7] ERA investigation into the possible use of HV fuses for restriction of generator fault current contribution; information requested at meeting arranged with an Electricity Board by the Electricity Council (27 Sept 1989). (Not available except with the permission of the electricity board concerned.)



⊕ To normal domestic and commercial loads

Fig. 1 Schematic distribution network with private generator