METHODS OF ELIMINATING EXCESSIVE FAULT LEVELS WHEN INTRODUCING MODULAR STATIONS IN THE AZERBAIJAN POWER SUPPLY SYSTEM

AKHUNDOV B.S.

Azerbaijan Research and Design Institution of Power Engineering

Abstract: Introduction of Distributed Generation principle based on modular stations into the Azerbaijan grid has a number of issues to be resolved effectively before connecting generation units to the grid. Amongst others, increased fault levels in the connection nodes (substations) is one of the major risks that requires in-depth review in terms of assessing capability of installed distribution boards and other HV/MV equipment to withstand raise in faults. The paper outlines a number of methods which are proposed for consideration when connecting modular stations to the Azerbaijan power grid.

Introduction and Scope

Distributed generation from both synchronous and asynchronous machines makes a contribution to fault levels. Thus, the connection of distributed generation to the network could cause a distribution network, which happens to be close to its fault level limit, to exceed it. The risks when fault levels are exceeded are of damage and failure of the plant, with consequent risk of injury to personnel and interruption to supplies. The paper outlines the various solutions available to minimize fault levels, giving an indication of the implications for each of the major stakeholders. The following solutions are reviewed and assessed within the framework of the present paper:

1. Uprating Network Components
2. Increasing Impedance of Components
3. Inserting Impedance Devices
4. Network Reconfiguration

1. Uprating network components

Where fault levels are close to existing limits, the most immediate issue raised by the addition of distributed generation to he network is that circuit breaker ratings are likely to be exceeded. Circuit breakers associated with the connection may then have to be uprated. Whilst it is sometimes possible to uprate the capability of existing equipment to increase the fault level capability of the network, it is more normal that network equipment has to be replaced with equipment having a higher design rating. The need for uprating can be even more extensive of cable networks and switchgear relatively close to the connection point are affected (a particular issue for meshed networks) and/or where there are existing customers, connected to the same network, whose plant may also need uprating. The cost of these network upgrades can seriously affect the commercial viability of a distribution generation scheme if all the costs are passed onto the generator in the form of a “deep” connection charge. This is seen as particularly unfair if the resultant network upgrade creates additional fault level headroom on the network which is subsequently used by their distributed generators connecting to the network. In other situations, the switchgear may already have been uprated and therefore cannot be uprated further. Hence increasing the capability of the network would require replacement of equipment. The timing of asset replacement can take place either when plant ratings are about to be exceeded (i.e. when a request for connection is received) or as a part of longer term asset replacement programmes. It may be difficult to assess the feasibility of uprating equipment or the following reasons:

- the fault current capability of installed older equipment (including cables and transformers) may not be ascertainable.
- the manufacturers of installed older equipment (including circuit breakers, cables and transformers) may no longer be in business, or unable (or unwilling) to advise on the feasibility of uprating or to confirm the actual capability of the equipment.

These factors may make larger scale replacement the only uprating method. The solution of uprating network components has been evaluated for a mid-scale power supply system similar to the Azerbaijan's and the following implications have been identified:

Implications for customers

The upgrading of network equipment may facilitate the connection of generator capacity to a level that will lead to short circuit levels exceeding the capacity of customer equipment. The increase of fault level imposed on customer plant may require the customer to change primary equipment, protective devices or settings if the increase is material.

Customers may experience disruption to supplies or an increase in risk of supply failure during implementation of network upgrades. It may be possible to minimize these risks by coordinating works with particular customers or by implementing network upgrades during the period of lower power consumption.

- The solution could discriminate against existing connected customers because they are more likely to have plant and equipment that requires replacement or modification.
- The solution increases the potential for increased fault damage from the passage of short circuit currents. Appropriate re-engineering of customer protection equipment should mitigate this risk.
- The solution facilitates the installation of additional generation capacity, but with increased connection cost.
- The solution may require an interaction with other distributed generators, particularly where there is a requirement for enhancements of distributed generators' plant.
- The solution increases the potential for increased fault damage from the passage of short circuit currents. Appropriate re-engineering of generator protection equipment should mitigate this risk.

Implications for distribution network operators

The solution would require the distribution network operation (Azerenergy) to change equipment, protective devices or settings.

The solution may involve some disruption to customers during implementation and therefore will affect network operator performance indices.

There are regulatory risks associated with the interpretation of existing connection agreements in relation to the funding of customer plant replacement.

Discussion will be required with other distributed generators and customers.

Asset replacement could result in equipment that is not that old (i.e. recently replaced) being changed well before its end of life.

The traditional solution of uprating the network provides a "benchmark" against which other solutions can be assessed. The key issue is the high cost of replacing the switchgear and other network equipment, especially when switchgear at several substations is affected.

2. Increase impedance of components

It is possible to specify a higher impedance for certain network and generator components (e.g. substation transformers, generator impedance). This will reduce the fault level and is a low cost solution for new installations, but is more costly or impracticable as a retrofit option. New components such as fault limiting reactors can also be introduced into the network to increase network impedances. The addition of series reactors to link bus sections uses established technology. Their insertion can allow a reassessment of the engineering compromises involved between fault level, power quality, system losses, source impedance and security. Reactors may also be used at other network locations, either to limit infeed from a single source (generator or network transformer) or to add impedance to the interconnectors between network areas. These three approaches are examined in more detail below.

Increasing generator impedance

The majority of megawatt-scale generators are designed to have a low source impedance since they are primarily intended for stand-alone (i.e. non grid-connected) applications. This is to ensure, amongst other things, that adequate current can be supplied for the starting of induction motor loads. Therefore, there is some scope to increase the generator impedance at the design stage for grid-connected generator applications. There are costs associated with using non-standard generator designs, but over time the standard generator impedances could increase towards a higher limit. There are, however, technical constraints, primarily associated with losses and stability criteria, which limit the fault level reduction from distributed generators to approximately 10 to 20%, depending on generator size.

Increasing transformer impedance

Increasing network transformer impedances is normally done by swapping out grid and primary transformers for higher impedance units. The impedance of transformers currently used on the network represent a balance of factors including maintaining certain fault levels, network losses, tap changer capability, voltage step changes and the performance of protection schemes. A number of these factors provide technical limits to increasing the impedance of network transformers. It should be stated that if transformers were replaced with high impedance units before the generation plant was connected, networks would then be sub-optimal for load customers. In addition, until there was a sufficiently diverse portfolio of generators connected to maintain fault levels at an acceptable level, networks would be sub-optimal at any time when the generators are inactive. It is obvious that whilst increasing transformer impedances may mitigate fault level problems, it exacerbates the voltage control problem, losses and distributed generator stability problems.

Inserting impedance devices

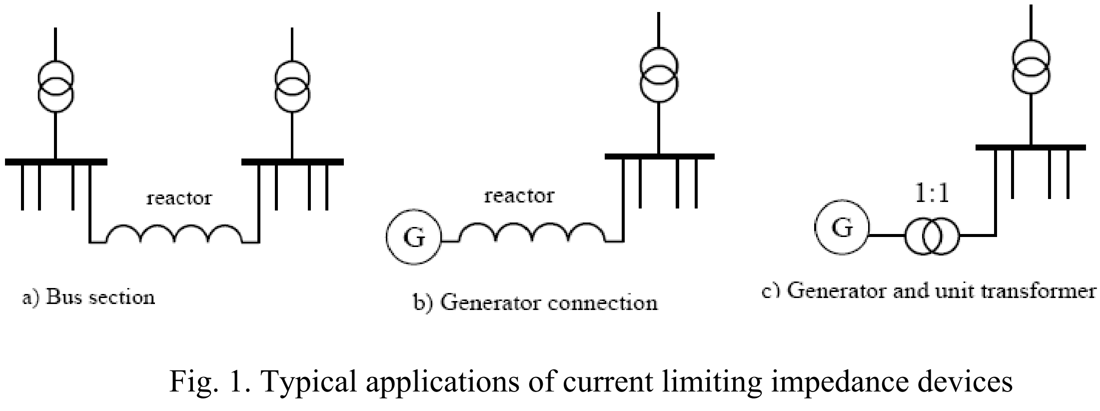

Fig. 1. Typical applications of current limiting impedance devices

As an alternative to traditional methods of introducing network impedance, it is possible to install new impedances into various locations in distribution networks. There are a limited number of examples of this being done in Azerbaijan.

Three typical examples of possible locations for inserting impedance devices into networks are shown in Figure 1. Figure 1(a) shows a reactor used to connect two busbar sections together, Figure 1(b) shows a reactor used in series with a generator and Figure 1(c) shows a unit transformer-connected generator. The main disadvantage of the impedance device is the presence of high reactive impedance in normal operation. This could increase the voltage variations delivered to customers under fluctuating load conditions and also influence the effective operation of tap-changing transformers. Step voltage changes under fault conditions could also increase. The reactors are also physically quite large and so there may be some difficulties in accommodating them within typical substations.

There are many examples where a reactor has been used at the generator site to reduce the fault level. In some cases, this has caused an excessive voltage drop on-site. This problem can be mitigated by the use of automatic switching capacitor banks and careful management of reactive power flows across the reactor.

The solution of increasing component impedances has been evaluated for a mid-scale power supply system similar to the Azerbaijan's and the following implications have been identified:

Implications for customers

- If the modification is to the network, customers may experience disruption to supplies or an increase in risk of supply failure during implementation of network upgrades. It may be possible to minimize these risks by coordinating works with particular customers. Modifications at generator sites only do not affect customers.
- Increasing network impedance can require the customer to review his protection arrangements, or in some cases to replace protection equipment.
- Increasing impedance of components generally decreases the power quality experienced by customers.
- The solution may lead to less fault damage resulting from a change of short circuit current provided that the protection operating time does not significantly increase.

Implications for distributed generators

- The solution involves disruption to supplies during implementation if the solution takes place at the generator site.
- The solution results in an increase in network impedance which will increase background voltage fluctuations.
- Increasing the impedance of the generator connection could affect internal losses within the distributed generators system and cause voltage control problems, depending on where the increase in impedance is located.
- Increasing the impedance within the network and connection is also likely to introduce issues for generator stability.

Implications for distribution network operators

- The solution may require the distributor to change equipment, probably protective devices or settings in some situations.
- The solution may affect the voltage profile on circuits.
- The solution results in an increase in background voltage fluctuation.
- The solution may lead to an increase in network losses for which the distributor may experience a financial penalty under the current regulatory framework.

In summary, inserting additional series impedances is a logical solution to counteract the effects on network fault levels of increasing the number of current sources within the network. Increasing component impedances is most cost-effective when applied at the design stage rather than as a retrofit option. Fault limiting reactors currently appear to be more widely used on private co-generation sites rather than on public distribution networks.

Greater consideration should be given to applying this solution on networks operated by the network operator although its suitability will be dependent on local circumstances.

3. Network reconfiguration

Distribution networks are designed to allow their connectivity to be altered, either in response to a fault or to allow a section of network to be isolated for maintenance purposes. Thus, distribution networks contain switchgear which is either used to provide additional connectivity (a normally-open switch) or isolation (a normally-closed switch).

Normally open switches are often found at the furthest point of an open ring or at a point where two feeders could interconnect adjacent substations.

Distribution networks are designed to allow their connectivity to be altered, either in response to a fault or to allow a section of network to be isolated for maintenance purposes. Thus, distribution networks contain switchgear which is either used to provide additional connectivity (a normally-open switch) or isolation (a normally-closed switch). Normally open switches are often found at the furthest point of an open ring or at a point where two feeders could interconnect adjacent substations. As detailed below two possible solutions can be considered in this case.

a) Reconfiguring networks

Reconfiguration of the network can reduce fault levels by either changing the fault current paths or reducing the number of network feeds through parallel paths. One of the simplest ways to change the fault current path is to simply move the normally-open point (i.e. close the normally-open point and open an associated normally-closed switch). In this way, the generator may electrically become farther away from the substation and therefore the fault infeed to the switchgear becomes less. Alternatively moving the normally-open points could be used as part of a network connection design to connect a generator to part of an adjacent network where fault levels were not an issue. These are established normal practices within network operators. Alternatively, the number of parallel paths can be reduced in networks comprising radial transformer feeder arrangements (rather than interconnected meshes) , without physical network change, using network splitting configurations. These are generally referred to as:

- operating with the bus section circuit breaker open
- operating a transformer circuit breaker in open standby In both cases, an auto-close scheme would be needed to close the breaker for upstream faults.

b) Network Splitting

Network splitting can significantly reduce the fault level at a busbar. However, this action will also increase system losses, harmonic voltage levels, voltage dips and flicker and will reduce power quality in general because of the increased source impedance. Also, the risk of supply failure would increase, as would the number of transient interruptions seen by customers. It is important to note that once a number of generator connections have been permitted following the permanent opening of the bus section, the options for restoring the substation configuration, should the resulting power quality prove to be unacceptable, could be expensive.

Another issue to be considered with this solution is that the busbar sections have to be coupled prior to a transformer being switched out for maintenance. This usually requires generation to be constrained off for this period. The solution of reconfiguring networks either by changing the relative positions of existing normally open or normally closed switched or ‘splitting’ normally closed parts of the network has been evaluated for a mid-scale power supply system similar to the Azerbaijan’s and the following implications have been identified:

Implications for customers

- Network splitting increases the network source impedance and therefore has an adverse effect on power quality. Although the number of voltage dips due to network disturbances is generally reduced, their magnitude increases, increasing the likelihood that sensitive electrical equipment will trip.
- Network splitting may lead to an increase in customer interruptions, customer minutes lost and short term/transient interruptions.

Implications for distributed generators

- Network splitting results in lower firm capacity for generation, and may lead to increased short term interruptions that compromise operating arrangements with existing distributed generators.
- The stability of distributed generators could be affected due to reduced system short circuit levels by network splitting.

Implications for distribution network operators

- Network splitting requires the distributor to change equipment and protective devices used for the operation of reconfiguration. There could be risks from auto-switching failure.
- Power quality generally will become worse due to increased system impedance.
- The distributor may be exposed to increased liability for additional disruption against which claims for damage and loss of business may result.
- Moving the open point on a radial network will have implications for voltage control and would tend to increase losses if open points were moved to suboptimal network locations.
- Moving the open point within a network also may have power quality implications on those customers who are moved further from the substation (due to increased impedance).

Conversely, customers who are closer to the substation from moving the network open points may benefit. The network splitting configurations provide significant reductions in network fault level, but raise many additional issues which will need to be considered and addressed before these solutions can be taken forward. Specific attention should be given to the methods of mitigating the impacts of splitting low voltage systems, particularly in preventing or minimizing supply interruptability, and in quantifying the fault level benefit versus the cost and performance impact for network splitting.

Splitting the network represents a major change to the way in which networks are designed and operated. There are a number of ways in which a network can be split each of which will have different reductions in fault level and impact on customers.

Conclusion

The methods considered in the paper, although well known to the engineering community, are presented in the present paper from a slightly different perspective. In particular, differentiation in the both supplier's and consumer's standpoints and implications for them are analyzed. In addition, there are technical options that could be used to mitigate any adverse impact yet still deliver a reduced fault level. A key aspect of any future study would be to identify these options and assess the potential they have for reducing any adverse impact of network splitting. The ultimate aim of such the study would be an analysis of the options for striking a balance between fault level reduction, impact on customers and the cost of reasonable mitigation measures.

References

1. *R. C. Dugan, T. E. McDermott.* "Operating conflicts for distributed generation on distribution systems," Proceedings of the Rural Electric Power Conference, pp. A3/1-A3/6, 2001

2. *M. Hird, N. Jenkins, Ph. Taylor*. CIRED, 17th International Conference on Electricity Distribution, Barcelona, 12-15 May 2003.
3. *P. M. Anderson*. “Analysis of faulted power systems,” IEEE, PRESS Power System Engineering Series, New York, 1995.

MODUL STANSİYALARININ AZƏRBAYCAN ELEKTRİK ŞƏBƏKƏSİNƏ DAXİL EDİLDİKDƏ QISA QAPANMA ZAMANİ ARTIQ CƏRƏYANININ MƏHDUDLAŞDIRİLMASI METODLARI

AXUNDOV B.S.

Sinxron və ya asinxron maşinlardan qurulmuş paylaşdırılmış generasiya qurğuları elektrik şəbəkəsinə qoşulduqda qəsa qapanma cəriyanına onun artmasə kimi məsir göstərir.
Məgalədə MS-nin Azərbaycan elektrik şəbəkəsinə qoşulması zamani qısa qapanma cərəyanının məhdudlaşdırılması metodları qiymətləndirilir və bu metodların qısa xarakteristikaları verilir, həmçinin bu metodların verici operatorlara və MS-na yaxın qoşulmuş istehlakçılara təsirinin texniki və iqtisadi göstəriciləri açıqlanmışdıır.

МЕТОДЫ ОГРАНИЧЕНИЯ ИЗБЫТОЧНЫХ ТОКОВ К.З. ПРИ ВНЕДРЕНИИ МОДУЛЬНЫХ СТАНЦИЙ В ЭНЕРГОСИСТЕМУ АЗЕРБАЙДЖАНА

АХУНДОВ Б.С.

Устройства распределенной генерации, основанные как на синхронных, так и на асинхронных машинах, при подключении к распределительным сетям влияют на мощность короткого замыкания в сторону её увеличения. В статье оцениваются методы ограничения токов к.з. при вводе модульных станций в энергосистему Азербайджана. Дается краткая характеристика этих методов, а также рассматривается влияние методов на технические и экономические показатели работы как оператора передающей сети, так и потребителя электроэнергии, подключенного вблизи узлов соединения модульных станций.