Evaluation of HVDC Impact on AC Network Protection

The National HVDC Centre

Purpose

This document is a summary of the questions, answers and discussions from the webcast co-hosted with the University of Strathclyde on Tuesday 27th April 2021.

Reference Document:

Presentation slides used the presenters are available at:
https://www.hvdccentre.com/innovation/dc_with_ac_protection/

If you have any further questions, please email us at info@hvdccentre.com

Questions and Answers

Q1: Are there any options to solve the problem without using a synch comp. These have traditionally been costly, unreliable & need significant ongoing maintenance.

A1: We can minimise the distance protection issues by designing the control algorithm embedded in the HVDC systems and/or addressing the settings or approach of the protection algorithm embedded within the relays deployed. As discussed in the slide, the under-reach/over-reach issues are related with the angle difference of the local and remote infeed, therefore, we can adaptively change the current angle from HVDC system to cater for the fault current from remote end, which can be realised by changing the control algorithm of HVDC system- or alternatively address the relay algorithms' approach towards polarisation, detection criteria and reach.

From the analysis we conducted, the issues with distance protection's over/under reach are caused by the angle difference of the currents injected from the two ends of the line and the fault resistance. The angle difference of the fault current determines the nature of whether it is over or under reach. This could be largely mitigated if alternative control is deployed at the HVDC system, i.e. it is possible to minimise the reactance measurement error via the HVDC control; but this may have other consequence to the HVDC system performance operationally that would require further investigation. However, the severity of the impedance issue is relating to the magnitude of the fault resistance and the ratio of the magnitudes of fault currents contributing from both ends. Since HVDC has limited fault current capacity, the capability to mitigate the severity of the impedance measurement error is limited. Therefore, assuming the HVDC is equipped with a control that fully eliminated the angle difference between the fault current, there will still be a measurement error in the resistance, which is proportional to the fault resistance and the fault current magnitudes ratio. This can be beyond the distance protection resistance reach if there is significant difference in the fault levels at two connected buses during resistive faults.

In addition to impedance measurement issue, there could also be issues in other elements of the relay, e.g. faulty phase selection. This is mainly caused by the relay algorithm being developed based on the assumption that the fault characteristics are dominated by voltage sources. This could potentially be addressed with control via deploying grid forming converters and this is actively being investigated.

Some IEDs do have the ability to estimate the actual fault current angle resulting from the pre-fault loading. This estimated fault current angle is used to create a dynamically change top line to the quad characteristic that alleviates the risk of under- or over-reach. Further testing would be required to see if/how this was affected by the unconventional input from the HVDC system. These and other potential solutions may be investigated further within the follow-on NIA project that was mentioned within the webinar, which is focussed on the evaluation and testing of new protection solutions.

Q2: As shown in slide No. 23, the fault resistance that has been modelled was 2 ohms. Have you got a chance to increase the fault resistance to 100ohms in this study?

A2: The fault with 2 ohms is used as the example in the slide and we have not tested the high impedance fault as you mentioned (100 ohms). The reason for a selecting relatively low fault impedance is we were mainly focusing on the sensitivity of the relay and from the analysis, the larger of the fault impedance, the greater challenge the relay will face in detecting the fault. Therefore, if the relay fails to detect a fault with small resistance, it will be even more difficult for it to detect faults with high impedance. However, as mentioned in Q1, the magnitude of fault resistance plays a major role in the impedance measurement error. When the fault currents' angle difference lead to system to have under reach issue, it will be interesting to investigate whether a zone 2 fault just beyond the remote bus with high resistance will cause maloperation in zone 1 – this could potentially cause severe protection security issue. We can include this in our future research and testing. Furthermore, the model developed from the project can be set up to be a sandbox, allowing a variety of fault impedances, fault locations and convertor injection strategies to be considered.

Q3: Have you used grid-following control for HVDC converter in all models and tests?

A3: In this project, the HVDC converter is equipped with the grid-following control, which is typically used in the industry. It can realise the various control strategies (e.g., balanced current, constant active and reactive power modes) and inject different levels of negative sequence current during faults. As discussed in Q2, the use of grid forming control at the HVDC converter can potentially introduce voltage source behaviour to the converter, thus can potentially act as a promising solution. However, this has not been investigated in this project and we will look into this in the next phase of the project which is being scoped.

Q4: How to integrate with possible competition directed from regulators for one type of solution, say Synchronous Condensers?

A4: This is a very good question and is certainly critical for ultimate implementation of any solutions to be rolled out in the system. However, it is a topic more relating to the system planning and design of ancillary service, which has not been a focus of this project. The objective of the project is to have a full understanding the protection issue and the causes, and then suggest potential solutions. This is expected to support the system planning and introduction of potential ancillary services to make sure the system condition will not fall into the region where it could bring risk to protection operation.

The ESO is separately operating a number of stages of stability pathfinder that is exploring these commercial points by optimising a range of solutions against overall need. The analysis and platform for it which we have identified, enables more effective identification of protection related needs and solutions which provide further tools for one specific aspect of stability management and hopefully more insights into the ranges of solution then available

Q5: Have you investigated possible false trips for external faults taking place in the adjacent AC lines?

A5: As part of this project, focus has been mainly placed on the protection sensitive to fault in primary protection zone. Initial research has been conducted at Strathclyde to look at mal-operation risk of zone 1 for external faults. From the initial results we saw, it does seem to have such risks but systematic testing and analysis are still on-going.

Q6: Did you test travelling wave protection?

A6: We have not tested the travelling wave-based methods so far as the objective of this project is investigating the HVDC impact on protection, particularly focussed on distance protection performance. But we will consider the possible solutions (e.g., travelling wave as suggested) in the forthcoming follow on NIA project, along with other relevant and available protection solutions. It's not clear ahead of the testing what other methods are beneficial, but we need to think about whether older techniques e.g. phase comparison schemes (using PLC), directional comparison schemes, are also relevant/useful and other new technologies/algorithms that can look at small changes in network operation to give good sensitivity but cope with potentially un-conventional waveforms too. It is important we evaluate a range of solutions for their reliability within a future protection system incorporating various approaches forming a layered effectiveness across the future circuits operating in a low SCL, convertor dominated environment.

Q7: **Agreed and as mentioned care is needed with the Syncons solutions in such weak systems, since not all Inverter Based Resources do necessarily provide damping support and fewer Synchronous Generators would lead to reduced system damping as well. This in combination with large power transfers in the system (especially over long distances) may cause inter-area oscillations and also angular separation in which Synchronous condensers may be prone to (e.g. in Texas) or even adversely contribute developing oscillatory responses. Such testing might be considered at scale to also clarify stability issues and interaction among devices that based on different technologies (?) as Synchronous Machine stability would need to be applied in Synchronous condensers (?)**

A7: Absolutely some parts of the solution for protection may introduce issues of their own. This is in the same way that some of the control modes for the convertors are great solutions for particular stability issues but, as shown here, introduce issues for the traditional protection systems. A whole system approach is required to find the optimal balance between the different requirements and this will require extensive testing.

Notes from Interactive Discussions

1. **The calculation of impedance within a Distance relay assumes a near ideal voltage source is deriving that fault impedance - rather than a convertor which during a fault is attempting to reconstruct an aligned voltage source with a disturbed system voltage angle and low voltage measurement-challenging the principles of its operation**

2. Multiple testing automation is important for what is an EMT investigation across a range of points on the voltage waveform across which faults are initiated and cleared, across a range of locations of fault within a circuit, against a range of fault impedances. This mirrors the robustness of testing conventionally undertaken by an assumed signal injection to a protection relay in an environment where the network is dominated with conventional synchronous sources.

3. **The protection system is there to serve the network rather than the network being there to serve the protection. Therefore, protection should be adapted to meet the changing requirements of the network rather than forcing the new technology to serve the protection. In saying that there is a balance to be struck where different control options can have clear benefits for the operation of the protection.**

4. Currently the protection is expected to still operate as expected. Although realistic fault levels have been used, they are predicted future values.

5. **The algorithms currently used in distance relays have been developed many years, learning from experience of issues along the way. Therefore, as the underpinning assumptions behind the algorithms change so too could and should the relays. Although it may not be possible to engineer out all the issues a future generation of distance relay could perform better than observed during the project.**

6. To completely change the protection across the [UK] network would be a project of >10 years and many millions of pounds of investment.

7. **Any solution reliant on communications would be met with the issue of being able to realise a dual redundant path of adequate speed and bandwidth. This can be especially problematic in more remote areas of the network.**

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