Developing a remote actuator to address switching concerns on oil-filled switchgear

Authors:

Michael-John Parkin, Electricity Network Asset Manager, Vector Ltd

Jonathan Bishop, Project Manager, Vector Ltd

Presenters:

Michael-John Parkin, Electricity Network Asset Manager, Vector Ltd

Jonathan Bishop, Project Manager, Vector Ltd

“EEA Conference & Exhibition 2014, 18 - 20 June, Auckland”

1. Abstract

We maintain a strong focus on injury prevention which has led Vector to introduce a complete ban on the live operation of Andelect oil-filled switch-units on the distribution network. The switchgear's intrinsic design problem makes oil cleaning and general maintenance very difficult, leading to an unacceptable likelihood of them malfunctioning. This puts the switching operator at risk of a potentially damaging arc-flash, arc-pressure, explosive event.

Vector currently has just under 1050 Andelect switch-units on its network, and while we have started to systematically replace them, this will only be fully achieved over a number of years. The live switching ban was introduced as a prudent means of risk control, but was envisaged as a temporary measure only while a more practical safety solution was sought. (Maintaining such a ban has significant operating and reliability disadvantages.)

To address the issue, Vector, in collaboration with Linak New Zealand Ltd, has developed a portable actuator device. When an Andelect unit is required to be operated, the portable actuator is affixed onto the switchgear. By using this device to do the switching, a time delay is introduced between activating and actual operation of the switch. This allows the operator sufficient time to move away from the switch, to outside the radius where a potential arc flash resulting from malfunction could cause material harm. While the switchgear is generally situated within a concrete enclosure, at times when the equipment is situated in a public area appropriate steps are taken to ensure public access is completely restricted during maintenance. The portable electrical actuator can be installed and removed within 30 seconds and is capable of operating both the isolator and earth switches of all small dimension type switchgear. It has been custom designed to operate all types of small dimension switchgear, Andelect, Astec and ABB series 2 units.

The paper briefly discusses the design issues that eventually led to Vector banning live operation of the Andelect units, and the impact this ban had on our network operations. It provides details of the design and testing process followed in development of the portable actuator, as well as details of the units itself.

Lastly, it discusses the practical application of the units in the field, the benefits this has brought about, and potential future development paths the actuator may take.

2. Background

On the 28th of January 2012, an Andelect SDAF3 ring main unit failed catastrophically shortly after being returned to service. The ensuing arc generated overpressure event forced the fuse access cover hinges to fail, blasting the access cover up and expelling burning oil over the back of the unit and the surrounding substation wall.

Fortunately, the switching operator had moved outside of the enclosed distribution substation in order to confirm operation back to the network control room. He was also wearing appropriate protective clothing that would have minimised the impact of direct exposure to the arc flash. (Incidentally, the very next operation as part of his switching schedule would have seen him go back into the substation.)

Following this incident, an extensive internal and external investigation was launched to ascertain the cause of failure. However, no definitive cause or type specific defect could be identified. Testing of other operational units of similar age and switching history also did not point to any particular deterioration or failure mechanism.

A follow up safety alert was issued to all Vector staff and service providers. In order to manage the unknown risk associated with the potential for similar failures, a switching restriction was issued requiring the immediate suspension of live operation of Andelect switchgear.

3. Context

Oil-filled switchgear offer several beneficial features that have led to widespread use worldwide. However, inherent to the design of such gear, is the bringing together of high voltage electricity with oil in a confined environment. This combination presents the potential for disastrous failure modes that can lead to explosive and potentially fatal consequences. Over the years, the design of such equipment has been refined to minimise and/or mitigate the risk, but it cannot be completely eliminated. However, to put things in context, it is worthwhile to note the following:

- Oil-filled switchgear is used extensively throughout electrical networks around the globe. Experience has demonstrated, that good design, inspection and maintenance practices can control the associated safety risks to tolerably low levels.
- Vector has been successfully using the Andelect switchgear units on its network for an extended period, and has not previously experienced any serious health and safety issue resulting from this.
- During normal continuous operating conditions, the Andelect units pose no greater risk than that faced from any other similar type of oil-filled switchgear. The likelihood of a unit malfunctioning, leading to an explosion under normal operating conditions is negligible.

The risk associated with an oil-filled switch unit malfunctioning is elevated during switching operations or shortly thereafter, when residue in the oil-tank can be disturbed and lead to tracking or flashover. In addition, making or breaking currents is also when the risk of flash-over or arc-flash most prominent. Vector's decision to suspend live switching of the Andelect units therefore ensured that any operational risk was minimised.

Switching or maintaining the Andelect units only in a de-energised state therefore avoided any material public or operator risk. However, this also meant that larger parts of the network had to be de-energised when working on or around Andelect units than would otherwise have been the case, adding to the operational workloads, requiring more field crews, and extending both the extent and duration of planned outages. The suspension of live operation could therefore only be a temporary solution. In addition, given the large number of Andelect units on the Vector network, replacing these in a short time frame is impractical.

4. Vector's experience with the Andelect switch-units

Vector continues to manage and operate a significant fleet of Andelect small dimension oil filled switchgear. The range of operating variants cover SD, SDF, SDAF, SD2, SD2TN, SD3, SDF3, SDAF3 and P-type units (6.6/11 kV double operating springs). The operating environment and situational use of the Andelect switchgear and quantity of units in operation are as follows:

- 525 units enclosed within various forms of pad mounted substation canopies
- 150 units located within fully enclosed stand-alone substation buildings

- 100 units situated within the confines of third party buildings
- 275 units of a free standing nature, generally located within the road berm.

Andelect small dimension switchgear was widely adopted by both Auckland Electric Power Board and Waitemata Electric Power Board and embedded in both networks across the wider Auckland area. The SD range was designed by Frank Wilde and produced and released locally by S Gordon Anderson Ltd during the 1980's.

The average unit age is approaching 30 years. Given Vector's maintenance regime, there has been no need for a material population renewal over that time and unit failure rates were similar to that of other oil-filled switchgear used on the Vector network, for example ABB series 2 SD switch-units (3050 units), and Long and Crawford switch-units (2000 units).

The number of successful switching operations performed over the lifetime of this population has not been deliberately recorded, however it is estimated to be at an order of magnitude of around 100 thousand (on all 1050 units). Incident recording accuracy and content has improved dramatically in recent years, but an accurate statement of the number of safety incidents involving Andelect switchgear over the earlier part of the lifetime of the population is not available. Based on anecdotal evidence and recollection of long-serving staff, it is estimated to be in the order of 5 to 10 incidents over the 30 year period (again on all 1050 units).

4.1 Common Andelect Switchgear Failure Modes

Based on the limited number of switch-unit failures experienced by Vector, together with collective industry observations and specialist experience[1], the following potential common modes of failure have been identified for Andelect units:

- Swarf retained in the units from initial production along with other debris can be stirred up by the switching action, leading to potential flashover. Particulates are very difficult to remove due to the design of the switchgear.
- Conductive sludge caused by moisture, ingress of dust, or decomposition of the contained oil due to switching by-products (e.g. carbon), can lead to flashover during switching. Sludge deposits within the switch-units are also very difficult to remove due to the design of the switchgear.
- Heat Shrink Cable termination failures, through workmanship or in some cases long term discharges due to vegetation or rodent related flashover.
- Bus-Bar Coupling chambers experience partial discharge effects due to condensation, primarily an installation issue.
- Introduction of foreign body contaminants during maintenance and testing activities, test prods etc., leading to potential flashover.
- Water ingress into the main tank, due to hosing down or waterblasting the switchgear or possibly conducting maintenance during rainy conditions.

None of these causes were confirmed to have led to the switch-unit failure Vector experienced that gave rise to the live operations ban, but all represent possible causes.

[1] Vector enlisted the aid of UK and Australian based experts in its analysis of potential fault-causes on the Andelect units.

5. Implications of the Live Switching Ban

As noted above, following the incident in question, Vector imposed a restriction on live operation, to prevent possible operator risk. The switching restriction required remote isolation of Andelect units, with the flow-on effect being additional switching steps and in many cases wider area outages, especially where Andelect units bordered other Andelect units.

Due to the significant numbers of Andelect switchgear within the Vector network the cessation of live operation of Andelect switchgear, has resulted in the following impacts;

- Remote isolation from neighbouring switchgear has increased the overall volume of switching operations.
- Field validation and data acquisition incurred significant costs, GIS and SCADA systems were rapidly updated to ensure all Andelect sites were accurately identified.
- Shutdown planning and the consideration of wider area impacts has become more complex, resulting in significantly increased volumes of customer notifications, additional mail-drops and corresponding costs.
- In situations where Andelect units are embedded electrically side by side in a chain of Andelect units, the remote isolation required a short but potentially wide area outage incurring additional planned SAIDI/SAIFI.

6. Moving Forward

With prudent safety mitigation in place, attention turned toward a more comprehensive risk assessment and associated optioneering. Additional control measures had to be instituted if live switching was to be reinstated. The main control options that were considered focussed on operator safety:

- Enhanced protective clothing - was considered but not recommended as it made practical operations very difficult.
- Extension Handles - to place the operator slightly further away from the switch-unit, was considered but not recommended, as it would not provide sufficient distance and was not practical in many installations
- Operating Lanyard - a rope and pulley system again to put some distance between the operator and the switchgear. This has been successfully implemented at other utilities, but was not practical in many cases (depending on the enclosure) and our service providers also sited valid public image concerns.
- Electric Actuator – placing a device on the units that would accomplish switching while the operator could stand well away. This was Vector and our service providers' preferred solution.

7. Portable Actuator Development

Vector commenced working with Linak New Zealand in Feb 2012 to design and manufacture an electric actuator that would allow remote switching of Andelect units.

Vector had previously worked with Linak on retrofitted automation solutions[2] and we were aware of their wide experience with magnetic actuator devices, including their use on distribution networks. They were therefore selected as the design partner for developing the portable actuator.

The portable actuator was discussed with Linak at a concept level, and subsequently the design specifications were developed and delivered to them. The design requirements encompassed the following:

A motorized kit was required that could operate the Andelect units, include the following features;

- Light weight (Target approx. 5 - 8kgs)
- Simple design and easy to install and use
- Robust design, as it will be portable and carried inside service vans
- 5 metre control cable
- Current sensing protection in case of jammed situation
- Operated by a 12V DC battery with ability to charge from van 12V socket using an inverter (as the battery doesn't allow DC to DC charging) or AC port with 12V charger
- Handset with forward and reverse dead man button control & resettable emergency stop
- Keep overall size of the kit to a minimum for ease of installation and ability to store within a service van
- Operation by continuous (Deadman type switches) push buttons on hand pendent

The process involved conceptual designs of the device, followed by prototyping. This initial work was completed by Linak with assistance from Wilson's transformers in Australia. Once the conceptual design was approved, testing and refinement was completed between Vector and Linak. Prototypes were handed to Vector's service providers after a couple of iterations and associated refinements.

As per the design specifications the device had to be easily installed and removed. It also needed to be fixed to the switch, anchored well enough to support the torque required to operate the switches, including the double spring P-type switches.

An example of an early prototype unit is shown below. This design would not have worked on switches within canopies and any switch with a cover on it. It worked by getting the leverage required for operation by being anchored to the back of the switch and had the actuator in the vertical position.

[2] Vector was working with Linak with their Netline range of products. These are remote switching devices permanent fitted to the switchgear, operable from our SCADA system.

Figure 1 Early Concept Mock-up

8. Final Concept

The final and accepted concept design was presented to Vector, by Linak and Wilson Transformers in the prototype form illustrated below.

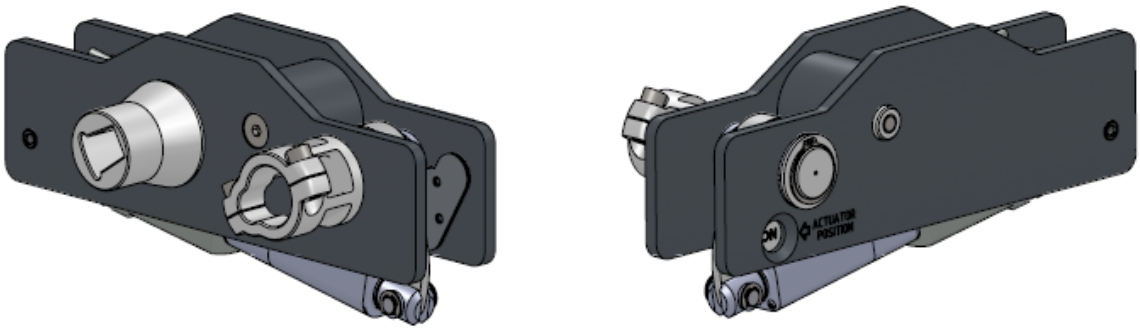

Figure 2 Final Concept Design

This resolved the canopy issues and using the earth switch to anchor the device provided a solid enough platform to deliver the torque required to operate even the double spring type switches. Vector and Linak decided to take this conceptual design through to final refinement.

9. Testing and Refinement

Initial testing of the prototype device was undertaken by both Linak and Wilson Transformers on old switchgear that had been provided by Vector for the purposes of the project. The aim of the testing and refinement was to get the device to a stage it could be presented to the service providers and perform as required. The target was to demonstrate a 95% reliable isolator operation across all types of small dimension switchgear including the P-type (double spring), Andelect, Astec, and ABB units.

As discovered during the initial testing phase, a small number of problems were encountered as follows;

- Manufacturing tolerances. The operating bosses varied in size from switch to switch. Also noted significant variance in the distance horizontally and vertically between earth and isolator bosses. Both issues caused "play" in the bosses where the first 10-15 degrees of actuator rotation wouldn't carry through to the switch boss rotation.
- Andelect and ABB switchgear operate at different points of rotation. The ABB switchgear travels through 60 degrees before operating while the Andelect can travel between 60 to 90 degrees before operating.

To remedy these issues the following changes were made to the device:

- Actuator fixed and rotating bosses were shaped and machined out to accommodate tolerances, and grub screws added to reduce play.
- Actuator changed from an 85mm stroke to 100mm stroke.
- Pivot arm lengthened to provider greater rotation.
- Front and back plates reinforced with additional bridge between them to reduce the plates twisting.

Figure 3 Final Concept Prototype

This stage of testing and refinement succeeded in the 95%+ reliability target on the switch types specified.

10. Field Testing and Design Changes

The next stage in the portable actuators evolution was consultation with the main stakeholders, both of Vector's service providers (Northpower and Electrix), and a chance to field/stress test. This stage involved issuing the prototype devices constructed during the initial refinement stage to both service providers for a few weeks. The main aim was to socialise the devices, have the service providers practice operations, stress test them by operating them on as many different types of switchgear, with as many staff as possible, recording operating performance and any improvement suggestions. The culmination of field testing was to complete a live operation, which Northpower were successful in achieving.

The changes suggested during the field testing resulted in the following design changes:

- Activation of the portable actuator was changed from an infra-red remote to a switch on the battery pack.
- Stop switch changed to more user friendly type.
- Battery status/indicator added.
- Operation of the earth switch was added to allow the device to operate both the earth and isolator on all switches.
- Outside plate coloured yellow (for isolator use) and black (for earth use) to line up with the switches boss colours.

11. Operation of the Portable Actuator

Having made the suggested design changes, a production run of twelve units was delivered and issued to Vector's service providers. The following points and images provide a brief summary of the portable actuator operation;

- Assumed context, at the correct switchgear, front cover off, familiar with operating instructions.

Figure 4 Site Preparation for Application of Portable Actuator

- Remove the following items from the carry case: Portable actuator with umbilical cord socket, Control box with Battery unit, T handle Allen key.

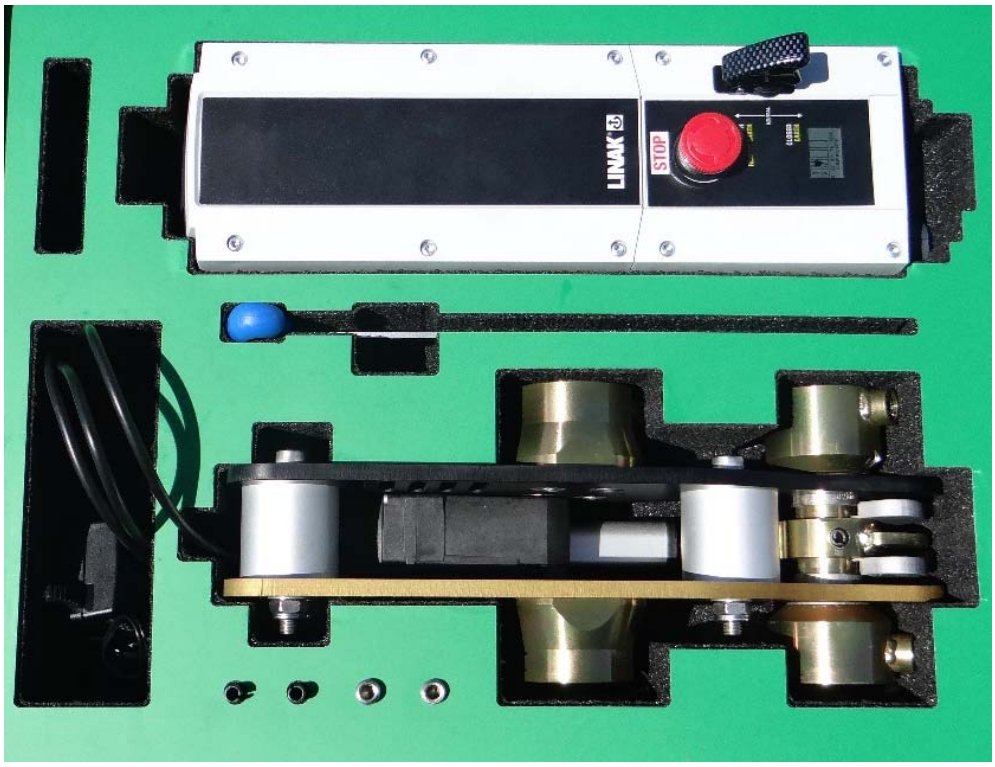

Figure 5 Portable Actuator as supplied by Linak NZ Ltd

- If performing an isolation operation, gently push and slide both of the actuators isolator and earth bosses onto the corresponding switchgear bosses, the yellow plated side of the actuator will face the switchgear, the black plated side will face the operator.

Figure 6 Portable Actuator ready to operate the Isolator switch

- Tighten the grub screw onto the earth boss (this is used as the anchor point)
- Tighten the grub screw onto the isolator boss
- Plug the actuator umbilical cord into the Control box with Battery unit.

Figure 7 Portable Actuator plugged in to the Control and Battery Unit

- Place the control box at the base of the switch unit.
- Ensure everyone on site is back beyond established control barriers (each lines business and service provider will have their own procedures for switching and site control)
- Depending on operation set the switch on the control box to open or close, then extract back beyond established control barriers.
- The actuator will take around 30 seconds to complete its rotation travel to the point of spring release within the switchgear.
- When the switch operation is complete, wait five minutes before removing the actuator in the reverse order to installation
- If performing an earthing operation, gently push and slide both of the actuators isolator and earth bosses onto the corresponding switchgear bosses, the black plated side of the actuator will face the switchgear, the yellow plated side will face the operator.

Figure 8 Portable Actuator ready to operate the Earth switch

A further refinement of the actuator is under development to address a problem encountered in some instances. When the switchgear is within a canopy, the device cannot be placed on the outside earth on the left side, or the outside isolator on the right side. While this issue can be worked around in the field, it is not ideal. The next version of the actuator, that addresses this issue has already been developed in prototype, and is expected to be in operation later in 2014.

12. Operational Outcomes

Following the successful introduction of the portable actuator, the following operational guidelines have now been implemented on the Vector network (for Andelect switches):

- The ban on operation of live Andelect Series 1 isolator switches was removed. Andelect Series 1 isolator switches shall only be operated live using a Linak portable actuator.
- The minimum distance between the operator of the actuator and a switch shall be five metres at the time of switching.
- The minimum time between operation of an isolator or earth switch from the actuator location and returning to the switch shall be five minutes.
- The minimum time between completing invasive maintenance on a ring main unit or switch and livening the equipment shall be fifteen minutes.
- A check for electrical and acoustic discharge on the switchgear shall be made prior to and after switching using a portable emission detector. It is suggested that an UltraTEV detector is used. Switching should not be carried out if an LED indication other than green is obtained.

13. Future Development

The future development of the portable actuator will be undertaken will likely head in two directions. As noted above, further refinement of the current device is underway to allow for operation on switches within all canopies.

The second development will be to create similar devices that can operate other types of switchgear on the Vector network, notably the Long and Crawford units.

Acknowledgements

The authors gratefully acknowledge the many people who have contributed and supported the development and implementation of the portable actuator. At its inception the development of the actuator was all about enhanced operator safety, thank you all for helping achieve that. We specifically wish to acknowledge the following contributors;

- David Johns, Linak New Zealand
- Brett Tracy-Inglis, Vector
- Todd Wilkinson, Northpower
- Henry Lotter, Electrix
- Terry Cochrane, Opus
- Paul Blackmore, EA Technology
- Ian Naylor, EA Technology
- Peter Ebenwaldner, Linak Australia
- Wilsons Transformers