How do Victoria's REFCLs deliver more fire-risk reduction than simple theory and experience elsewhere say they should?

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Tony Marxsen

Chairman, Grid Innovation Hub at Monash University

Theory says there are clear limits to REFCL fire-risk benefits: REFCLs don't prevent fires from some types of powerline, nor from some types of powerline faults, and they are associated with events called cross-country faults that can potentially undermine their effectiveness. Some countries seem to have had bad experiences with REFCLs, installing them and then later taking them out of service. One could think REFCLs offer limited benefit to powerline fire-risk and are perhaps not worth the cost of installing them.

Victoria's ignition research programs and actual experience indicates REFCLs being deployed in Victoria, are in fact very effective in preventing powerline fires. Ten years of ground-breaking ignition research following Black Saturday provided the hard evidence for this assessment, prompting Victoria to rollout REFCLs to cut fire-risk on forty-five of its highest fire-consequence networks. Victoria is now three years into the seven-year rollout and experience so far continues to indicate REFCLs are effective in prevention of fires from powerlines.

So how come REFCLs in Victoria perform better than theory and experience elsewhere seem to say they should? This article outlines how this happens. It sets out my own personal observations and analysis based on experience of Victoria's ten years of ignition research and its REFCL rollout. It has no official status beyond this.

To summarise the conclusions in just five points:

1. REFCLs stop fires from the most common type of fire-starting powerline fault (a single wire pushing electric current into the earth either near dry grass or via a tree branch) that occurs on the most common types of high-voltage powerlines in rural Victoria (two-wire and three-wire 22,000-volt powerlines). This is where most of REFCLs' fire-risk benefits come from;
2. REFCLs cannot stop fires from faults on single-wire SWER powerlines. However, these faults contribute a minority (perhaps ten to twenty per cent) of total powerline fire risk in Victoria. Fire-risk from SWER powerlines is being reduced by other (non-REFCL) technologies;
3. REFCLs reduce fire-risk from many types of complex powerline faults. Their extreme sensitivity allows them to 'see' faults that other powerline protection systems cannot and they disconnect the power in about ten seconds. The only faults they cannot respond to are those with no electrical current into the earth at all. Two types of these cause fires: flying debris across the wires and wires clashing (hitting together in the

wind). In Victoria, these are less common and are being reduced even further by best practice design standards, selective use of insulated conductors and new line surveillance technologies such as LIDAR;

4. Experience so far suggests that consequential faults (faults triggered by other faults) such as cross-country faults are rare on Victoria’s REFCL-protected networks and those that do occur often don’t create fire-risk - their effect on REFCL fire-risk benefits is insignificant; and
5. REFCLs being installed in Victoria are far more advanced than those in use in other countries; the installation process is different here; they are operated differently; and, Victoria’s powerline networks are different, so experience elsewhere is not of much use in predicting REFCL fire-risk benefits here.

Detailed estimation and modelling show Victoria’s REFCLs will cut powerline fire-risk to a much greater degree than simple theory or experience elsewhere might predict – in fact, by seventy to seventy-five per cent on average. Early experience supports this estimate.

REFCLs are not a panacea or a ‘silver bullet’ by themselves. They are a key element of a multi-faceted approach Victoria has adopted to reduce the risk of catastrophic fires from rural powerlines. Powerline fires will still happen in Victoria, but there should be many fewer than in the past.

Details of each of the above points follow. It’s a long read, but recommended if you are seeking to understand the basis of Victoria’s commitment to REFCLs.

Different powerline types – REFCLs make some fire-safe, but do little for others.

Between my house and the distant electricity generators that supply me are many different types of powerlines operating at many different voltages ranging from 240 volts to 500,000 volts. The following sections focus on just those rural powerlines that are prone to causing serious fires. Victoria has two powerline types that have a history of causing by far the most serious fires: single-wire ones that operate at 12,700 volts and multi-wire (polyphase) ones that operate at 22,000 volts.

SWER powerlines in Victoria

Single-wire powerlines are called SWER (Single Wire Earth Return) because the electric current goes out across the network to the customer on a single wire and returns to the source substation through the earth. SWER powerlines are used at the edge of the grid to supply farmhouses, pumping stations, shearing sheds and all manner of loads out in the bush. SWER powerlines are cheap and reliable - which is why Victoria has about 30,000 kilometres of them. REFCLs cannot do anything to cut fire-risk from faults on SWER powerlines. Other new technologies as well as selective use of some traditional ones such as undergrounding or insulation, are being used to do that.

Polyphase powerlines in Victoria

The most common type of high-voltage powerline in rural Victoria is a type called polyphase because it has multiple wires – either two or three of them. The three-wire ones are the backbone powerlines that do the heavy lifting of supplying towns and areas where there are a lot of customers. Victoria has about 50,000 kilometres of rural two- and three-wire polyphase powerlines, nearly all of them operating at 22,000 volts. REFCLs can protect two and three-wire polyphase powerlines to prevent fires when many common types of powerline faults happen.

Powerline types elsewhere in the world

In other parts of the world, the powerline mix can be very different to what we have here. For example, in California it is unlawful to construct a SWER powerline and all powerlines are polyphase, having two, three, or even four wires. Four-wire high-voltage powerlines are not used in Australia but make up the majority of powerlines in some areas of the USA, including California. REFCLs cannot do anything to cut fire-risk from faults on high-voltage four-wire powerlines so it’s a good thing they are not used here, nor ever likely to be.

Fire-risk contributions of different powerlines

Because REFCLs are limited to reducing fire-risk on just the polyphase powerlines, then at best they can address fire-risk from only 50,000 kilometres of powerlines, i.e. only five-eighths of Victoria’s 80,000 kilometres of rural powerlines, which is a little over sixty per cent. But this isn’t the full story when it comes to fire-risk. SWER powerlines are widely thought to have, on a per-kilometre basis, a lower risk of causing ignition than polyphase lines – this has been a frequent observation over many decades in all Australian states that use them. The difference is thought to be due to SWER powerlines’ very simple construction which means fewer point of potential failure. There appears to be no definitive study published that provides the exact ratio of fire-risk, but industry surveys indicate the number of SWER powerline faults per year per kilometre may be as low as one-sixth the rate of faults on polyphase lines.

If we assume fire-risk is proportional to the number of faults and do the sums, this would mean Victoria’s 30,000 kilometres of SWER powerlines contribute only around one-tenth of Victoria’s total powerline fire-risk, even though SWER powerlines make up nearly four-tenths of all rural powerlines. REFCLs which cut fire-risk from polyphase powerlines very effectively, would then address about ninety per cent of Victoria’s total fire-risk even though such lines are only about sixty per cent of the State’s total rural powerline length.

REFCL benefits by powerline type

The assumption that fire-risk varies as the number of faults per kilometre per year is reasonable, being based on the best available data, but it’s never been rigorously proven. To be conservative, if the polyphase/SWER fire-risk ratio was assumed to be only two-to-one instead of six-to-one, i.e. SWER powerlines have half the fire-risk per kilometre of polyphase lines, that would mean SWER powerlines produce around twenty per cent of Victoria’s total fire-risk and polyphase powerlines would create the remaining eighty per cent of it. Either way, by addressing fire-risk from polyphase powerlines, REFCLs are addressing the major part (eighty to ninety per cent) of Victoria’s total powerline fire-risk. The remainder created by SWER powerlines, is being addressed by other means.

Cutting fire-risk from SWER powerlines

It is a tragic fact that some of the most catastrophic fires on Black Saturday were started by failures of SWER powerlines including the worst of them, the Kilmore East fire. Victoria's powerline bushfire safety program is rolling out non-REFCL technologies to reduce fire-risk from SWER powerlines. These include fast smart Automatic Circuit Reclosers (ACRs) and Early Fault Detection (EFD) systems. Research is also underway into new methods of detecting falling SWER powerlines in time to disconnect them before they hit the ground. Conventional means of cutting fire-risk are also being selectively employed such as underground cables or insulated wires. However, all these programs are separate from the REFCL focus of this article.

Different powerline fault types – REFCLs work well for some, less so for others.

With rare exceptions, a powerline fault is simply any situation in which high-voltage electric current goes where it shouldn't, often into the local environment where it can start fires. Powerline faults are as unique as fingerprints – no two are exactly the same and many can be very complex. There are so many variants that it is best to consider them in broad groups to work out where REFCLs can offer reduced fire-risk in this complex diversity of fault types.

The most useful grouping is to group fault types by how many (one or more) wires are involved and by whether there is electric current into the earth or not. The benefits offered by a REFCL across the range of fault types varies from almost complete fire safety to no benefit at all.

Pure earth faults – one wire injects current into the earth

In a 'pure' earth fault only one wire is involved and the current goes from that wire into the earth. This simplest 'pure' form of fault is called 'single-phase-to-earth'. This type of fault is the most common fire-starter in Victoria. It was studied intensively in Victoria's ignition research program to produce reliable estimates of the fire-risk reduction that different technologies, including REFCLs, can deliver for this type of fault.

REFCLs deliver a lot of fire safety benefits for pure phase-to-earth faults.

Examples of this 'pure' earth fault type would be a live wire fallen on ground covered in dry grass or onto a metal fence or roadside safety rail surrounded by dry grass, or a tree branch touching a live wire, or a live wire come loose from an insulator and fallen onto the crossarm or swinging in the wind against the pole or a tree. Powerline faults even in this simplest group take many, many forms.

In these faults, a REFCL can see there is a fault and knows exactly what to do about it to stop a fire – and does it very quickly. REFCLs cut fire-risk from this type of fault dramatically – up to one hundred per cent. Given this is the most common type of fault that occurs on high-fire risk days (in fact, it's the most common type on most days), a REFCL's compelling fire-risk benefits in this type of fault constitute the foundation of any business case for REFCL investment.

Transient and permanent faults

Many instances of this type of fault are transient rather than permanent. Victoria's REFCLs are unique in that they can test whether the fault is still there and identify which powerline it is on, all without starting a fire in doing so. Other methods of testing for a permanent fault create enough current into the earth that they can start a fire, regardless of whether a fire was started by the original fault event itself. With conventional (non-REFCL) protection systems this test is often simply to reconnect the power after five to eight seconds and see what happens!

Undetected faults

The extreme sensitivity of REFCLs on high fire-risk days means they detect faults that conventional (non-REFCL) protection systems cannot 'see'. Many of these are transient faults, so the proportion of transient faults compared to permanent faults on REFCL-protected networks can be as high as ninety per cent, whereas traditionally it is around seventy per cent.

It is not known how many of these previously-undetected faults create fire-risk, but Victoria's research program showed that electric current at less than one-tenth of the lowest levels detected by non-REFCL systems is enough to start a fire. What it showed was that REFCLs reliably detect and respond to these previously-undetected faults and reduce any fire-risk they may create.

Faults that start simple and become complex

Often powerline faults start out as pure phase-to-earth faults but the energy release at the fault site is so high they rapidly develop into more complex types as more wires become involved. Field inspection reports can be misleading because the field crew can only see the final form of the fault. They can report a fault as complex, even though it only became complex because it was not disconnected fast enough to prevent it developing from a pure earth fault to a complex one.

REFCLs can disconnect the power in time to prevent this development (from simple to complex). On a REFCL-protected network one expects to see a higher proportion of pure earth faults than on non-REFCL networks.

Back-fed faults

One particular type of pure earth fault is called a 'back-fed' earth fault because the current from the fallen wire into the earth/fence/barrier has already been through customer loads and is on its way back to the substation when the wire carrying it falls. The break in the wire is on the upstream end of the fallen section which remains supplied with power from the downstream end, i.e. backwards compared to the normal direction of current flow.

Conventional powerline protection systems have great difficulty detecting back-fed faults and they can be very dangerous as sometimes a wire can remain live on the ground for a long period until customers call to report it. Back-fed earth faults are known fire-starters and pose obvious risks of electrocution to people and animals nearby. REFCLs detect these faults with much greater sensitivity than conventional protection systems and will disconnect the power within ten seconds, quickly eliminating both fire risk and electrocution risk.

Complex earth faults – multiple wires involved plus electric current into the earth

We've all seen news photos of a tangle of wires and tree branches on the ground, sometimes in the company of other objects such as parked (or crashed) vehicles. In these cases, there is always some electric current into the earth and usually two or three wires are involved. In these complex faults as well as current into the earth, there is also current from each wire to each of the others - through for example, branches entangled in the wires. Sometimes the current from one wire to another is by direct contact where two wires have been pushed together by a fallen tree. In this case the current can be thousands of amps (i.e. a lot) and a conventional (non-REFCL) protection system will very quickly disconnect the powerline.

REFCLs and conventional powerline protection systems work together

In Victoria's REFCL-protected networks, conventional protection systems have not been removed – they continue to operate in parallel with the REFCL. In complex faults, the currents that flow from wire to wire can be enough to trigger these systems to quickly disconnect the powerline. On very high-risk days, it will not be automatically reconnected. If the current is not that strong, then the REFCL's response when it detects the current into the earth may determine the outcome. Alternatively, the wire-to-wire current may start low and progressively increase as branches char, until a flashover (a short-circuiting arc between the wires) occurs that greatly increases the current and triggers conventional protection to disconnect the power. It is not just the initial form of the fault that can exhibit diversity, it is also how it develops during the first minute or so.

Both the initial form of the fault and its development determine the respective roles of the REFCL and conventional protection systems dealing with a complex fault. Putting it very simply, if the electric currents that flow in the fault are large, then conventional protection systems will normally beat the REFCL to disconnect the power. If the currents are low, the REFCL may beat the conventional protection systems to disconnect the power – this depends on settings in both systems. If the currents are very low, the REFCL may be the only protection system that can 'see' and respond to the fault. The issue is made more complex because the conventional protection system may be a pole-mounted ACR or set of fuses located out in the powerline network, while the REFCL is (so far) always located at the source substation.

Network owners have put a lot of thought into making sure the two types of powerline protection support each other in the best way possible to ensure maximum community safety when these complex faults occur. It is yet early days and entirely possible that improved methods that deliver even greater benefits may be identified over time.

Applying ignition research results to complex faults

Victoria's REFCL ignition research results can be used with the exercise of a little logic to work out whether REFCLs cut fire-risk in these more complex faults – and it turns out that in many cases they do. REFCLs cannot completely cancel the current flow into the earth as they do in phase-to-earth faults, but they can detect the complex fault, confirm it is permanent not transient, and disconnect the power fast enough to reduce fire-risk.

If a complex fault involves any electrical current at all into the earth, the REFCL can ‘see’ there is a fault, even if it cannot work out exactly what the fault is, i.e. which wire is passing current into the earth. In high fire-risk conditions, just seeing the fault can be enough as REFCL settings on such days mean if the fault is permanent, the REFCL will disconnect the powerline. It normally takes four to ten seconds for the REFCL to determine the fault is permanent - as many complex faults are. Ignition research results show disconnection in this timeframe will cut fire-risk and reduce the chance the fault will develop into a much higher energy form with all the public safety risk that that implies.

How does disconnection in five to ten seconds cut fire-risk? Usually, we expect powerline protection systems to work much faster – within a second or two. The answer is provided by Victoria’s vegetation ignition research done at Springvale South in 2015. The feature of faults caused when trees bring powerlines down is that usually the branches involved or the tree trunk are quite substantial. The 2015 tests showed the highest fire-risk comes from thin branches that are typically less than 25mm in diameter. These don’t draw much current (and so are hard to detect quickly) and before they are detected, they have time to produce and drop embers that can ignite the grass below. Thicker branches take a lot more current so they are detected almost immediately and they take longer to produce embers, so fire-risk from larger branches is less than from thin ones.

Quick detection and early disconnection by a REFCL will prevent fires in many complex tree faults. Victoria’s research into vegetation ignition in powerline faults showed that disconnection within five to ten seconds greatly reduces the fire risk even in thin branches – by sixty to ninety per cent. Unlike wire-down faults, tree faults don’t start fires quickly – the research revealed it often took many tens of seconds, often more than a minute, for a fire to be ignited in the dry grass below the fault.

The REFCL doesn’t replace conventional protection systems, it simply reduces fire-risk from these more complex faults to a level lower than conventional systems alone can achieve.

In summary, REFCLs in Victoria are set to disconnect the powerline whenever they detect current into the earth in a complex fault. If the current is high, the conventional protection systems will disconnect the power extremely quickly. If the current is low, the REFCL ensures it happens in five to ten seconds at most. This means REFCLs reduce fire-risk from these more complex faults. REFCLs can’t eliminate the fire-risk completely but the reduction they deliver is of material consequence.

Pure phase-to-phase faults – multiple wires involved with no current into the earth

At the extreme, there are some types of powerline faults in which no current flows into the earth at all. These are called ‘phase-to-phase’ faults because the only current flow is from wire to wire. REFCLs cannot ‘see’ these faults - to a REFCL, the fault looks like a new customer load has suddenly appeared - so REFCLs cannot prevent fires from them. There are three groups of faults that fall into this category, each very different from the others. They are faults due to flying debris, internal equipment failures and conductor clashes.

Flying debris faults

In high fire-risk weather with strong winds, flying debris (usually tree branches) can land on a powerline and create a wire-to-wire fault. The electric current through the branch between the wires will usually progressively char the branch until the flame extends all the way from one wire to another. Flame conducts electricity and this creates a flashover (an arc through the flame) which carries enough current to exceed the threshold of conventional (non-REFCL) protection systems which then quickly disconnect the line. Alternatively, the debris may get blown off the line again to continue its wind-borne journey. The 2015 Springvale South tests revealed that dry branches do not carry current in hot dry conditions, so the main fire-risk from flying debris faults is green branches torn off trees by strong winds.

Victoria's vegetation ignition research showed that if flashover occurs within about 15 to 20 seconds, fire-risk from one of these faults was less than fifty per cent, but if it took longer for a flashover to occur, fire-risk was higher. It rose to near-certainty of a fire if the flashover took one minute to occur. Thinner wind-blown branches are higher risk than thicker ones as they take longer to develop into a flashover. On the other hand, thin branches have a propensity to get blown off the powerline again. They also soften as they heat up due to the electric current flowing through them to the extent they can fall through the wires. The range of outcomes – and the associated fire-risk – is very broad.

Flying debris faults cause fires and there is not much a REFCL can do to stop it happening. There is little reliable data on the rate of occurrence of fires from 'detached branch' faults though many powerline workers report they see evidence of these faults after days of very strong wind. A review of the records of powerline fires on very high fire-risk days gives the impression they are not as common as trees falling onto powerlines or wires falling to the ground but the exact number is usually not clear.

Internal equipment faults

Many wire-to-wire faults do not create fire risk because the current is contained inside equipment, not out in the open. For example, phase-to-phase flashovers inside metal enclosed switchgear or in-tank transformer winding faults. Many of these generate only low fire risk though some can start fires if there is a loss of containment. The occurrence of internal equipment faults is also not usually correlated with fire-risk weather - they occur throughout the year, which in effect reduces the chance of having one on a high-risk day. Their occurrence on high-risk days is a random coincidence and infrequent.

Fire-risk from this class of fault is limited by conventional (non-REFCL) powerline protection systems that quickly disconnect powerlines when very high currents flow. In Victoria, these protection systems are set to act more quickly than normal on high fire-risk days and on extreme-risk days the power is not reconnected automatically to test if the fault is still there as it is on other days. The settings used on such days further reduces the fire-risk from these faults.

Conductor clashing faults

Sometimes wires clash (hit each other) as they move in strong wind, causing high currents to flow between them and particles of molten incandescent metal to fall to the ground and ignite fires. Action taken in Victoria after Ash Wednesday in 1983 and after the 1977 fires, means clashing due to wind is now pretty rare on Victoria's powerlines. However, wind-induced clashes can still occur (and start fires) if a power pole is leaning or wires have been made asymmetric by some earlier trauma and there have been instances of this as recently as earlier in 2019. Many utilities are now investing in LIDAR (Light Detection and Ranging – a sort of high-precision, light-based radar) to scan their powerlines and detect these risks in advance.

REFCLs cannot reduce fire-risk from conductor clashing. The adoption of low fire-risk settings for conventional protection systems on high fire risk days, especially not automatically reconnecting power once it has been disconnected, reduces fire-risk from this type of fault.

Non-wind causes of conductor clashing are vehicles that collide with poles and large birds that fly into (or during nesting season drop debris onto) powerlines. Both of these are infrequent and their occurrence does not increase at times of high fire risk weather. Conductor clashing is now most commonly caused by high currents flowing in a fault on the powerline, i.e. it is a symptom rather than a cause (see next section on consequential faults).

Consequential faults - cross-country faults, conductor clashing and burned joints

Some types of powerline faults are caused by other powerline faults, which is why they are called consequential. They include: cross country faults, conductor clashes and burned conductor joints. Again, the fire-risk benefits of REFCLs vary widely across this diversity of fault types.

Cross-country faults

Cross-country faults have received recent media attention in Victoria despite their rarity here. Cross-country faults are consequential faults that happen when a deteriorated item of electrical equipment fails during REFCL operation, triggered by the voltage disturbance the original fault has produced. The sequence is: a phase-to-earth powerline fault occurs, it increases the voltage on the two wires that do not have a fault on them, this voltage disturbance triggers failure of a deteriorated item of equipment elsewhere on the same powerline network, causing a second fault. This can happen on non-REFCL networks, but happens more readily on those fitted with a REFCL because the REFCL makes it easier for the first fault to disturb the voltage on the other two wires. These faults are called cross-country faults because the consequential fault may be a long way from the original fault.

Some media stories have implied that REFCLs cause cross-country faults – that cross-country faults occur when "REFCLs go wrong". The reality is that three things come together for a cross-country fault to happen: an initial powerline fault with some current into the earth; the disturbance caused to network voltages caused by that fault; and, the failure of a deteriorated piece of equipment stressed by the voltage disturbance. Where the REFCL comes into this picture is that depending on the nature of the original fault, a REFCL can increase the level of the voltage disturbance and depending on settings, it can increase its duration. Did the original fault cause the second one? Or was it the deterioration in the failed equipment that caused it? Or did the REFCL cause it? We all have a free choice in this rather academic debate.

Some commentators have asserted that cross-country faults elsewhere are relatively common. However, Victoria's experience continues to indicate they are quite rare here. This experience now includes about one thousand ignition tests in the 2014 and 2015 research test programs. These thousand faults produced just a single cross-country fault – Test 217 at Frankston South in 2014, with its spectacular video. Since Victoria's REFCL rollout started, there have been about a further five thousand phase-to-earth faults applied to REFCL-protected networks during REFCL commissioning and regulatory compliance tests, triggering only a handful of cross-country faults involving fire-risk. A rough estimate is that perhaps there is one cross-country fault that creates fire-risk for every one thousand faults that elicit a REFCL response. This would be consistent with the 2017 analysis of ten years' experience with the REFCL at Frankston South.

The important qualification here is 'cross-country fault *that creates fire-risk*'. Many cross-country faults do not create fire-risk. Common equipment items that fail in these events include surge diverters and underground cable joints as well as the occasional in-tank transformer failure. These internal equipment failures produce much less fire-risk (if any) than 'wire down' or 'tree touch' faults. These failures are not made more likely by fire-risk weather, so operating REFCLs all year flushes them out in the low risk period of the year.

Theory says a cross-country fault will create fire-risk at the site of the original fault as well as the consequential fault. However, experience has shown this does not always (or even often) happen. The initial fault that produces the voltage disturbance is most commonly transient and has often disappeared before the second fault happens, so there is never a time when the two faults are both present. In this situation, the REFCL has prevented a fire from the first fault and remains very effective at preventing a fire from the second fault as well.

Why are cross-country faults so rare in Victoria? Perhaps it's because Victorian utilities are carefully hardening their networks prior to REFCL installation – replacing known weak equipment, testing all cables and replacing those that don't pass, 'soak' testing networks at higher than normal voltage to flush out hidden weaknesses so they can be fixed, and running REFCLs all year to increase the chance any remaining weakness will reveal itself during low fire-risk conditions, rather than on a Code Red day. While this approach has increased the cost of the REFCL rollout, a side benefit of all this work is improved overall safety and supply reliability as a lot of old defective network equipment is being replaced in the rollout.

A second reason for the difference is likely to be the duration of the voltage disturbance caused by the first fault. On non-REFCL networks the voltage disturbance caused by a fault can last a second or two. In Victoria's REFCL-protected networks, the duration of the voltage disturbance is still kept short, especially on high risk days: about ten seconds - just long enough for the REFCL to determine if the fault is permanent. In some other countries there are reports of voltages allowed to remain disturbed for hours after a fault, but that is not the practice here. A short disturbance is much less likely to trigger failure of a defective piece of equipment than a prolonged one would.

Overall, the effect of cross-country faults on REFCL fire-risk reduction benefits in Victoria is insignificant.

Conductor clashing and burned conductor joints

Consequential faults also appear in non-REFCL networks caused by the heavy currents that can flow when faults occur and a REFCL is not present. These currents can be large enough to cause conductor clashing or to burn out defective conductor joints. Both of these faults can release lots of incandescent metal droplets and a joint failure can possibly drop a wire on the ground. Neither of these faults are as rare as cross-country faults. Both can create fire-risk but do not always do so.

If there is a REFCL on the network, consequential clashing that previously would have been caused by high currents in phase-to-earth faults is now unlikely because the currents in such faults are no longer enough to create the strong electromagnetic forces required to bring wires together. Clashing can still occur if the high current causing the clashing is from a wire-to-wire fault. However, these are less common than phase-to-earth faults on high fire-risk days. Similarly, REFCLs reduce the chances of a burned conductor joint. The current in phase-to-earth powerline faults without a REFCL can be one thousand amps or more, whereas with a REFCL the current is likely to be just a few amps. This is not enough to cause a defective conductor joint to burn.

So REFCLs provide an indirect fire-risk benefit in at least partially reducing the occurrence of consequential clashing and destruction of conductor joints due to high fault currents.

Bringing it all together – the overall fire-risk reduction due to a REFCL

The overall fire risk reduction depends on the mix of fault-types, the rate of occurrence of each fault-type on high fire-risk days, and the fire-risk reduction delivered by a REFCL for each fault-type, which can vary from nearly one hundred per cent to zero. Historical data shows about 70% of powerline faults are of the ‘pure’ phase-to-earth fault type. The majority of the remainder are of the more complex type but still with some current into the earth. A small minority are faults with no current into the earth. Experience to date on REFCL-protected high-voltage powerlines indicates transient faults make up about ninety per cent of all faults.

Plugging the best available estimates for all this data into the network asset risk optimisation model developed by CSIRO for the Victorian Government, the bottom line is that REFCLs are estimated to cut total powerline fire risk in Victoria by about seventy to seventy-five per cent on average across all fault types and all powerline types. This is more than the fifty per cent assumed for the published 2015 Regulatory Impact Statement as that figure did not take into account research results published in late 2015.

Fire-risk reduction of seventy to seventy-five per cent is more than a simple approach to the theory of powerline faults and REFCLs would indicate. One can see from all of the above information where the higher figure comes from.

Is overseas experience a useful guide?

Can overseas experience be used to predict the fire-risk benefits of Victoria's REFCL rollout? The short answer is: no, it cannot.

The REFCLs being installed in Victoria are unique in the world. REFCLs are complex combinations of traditional power grid hardware, some modern power electronics, and a lot of software (called firmware) that determines their response to powerline faults of all types. The firmware developed in Victoria's research program and refined in the rollout to date is light-years ahead of any currently being used overseas. Specifically, Victoria's REFCLs have an unmatched ability to detect faults that create very small amounts of current, to identify (without causing a fire) which powerline has the fault, and to quickly disconnect that powerline. They are controlled by very sophisticated control systems developed by Victoria's electricity network owners to reflect operating policies that co-optimise fire-risk and supply reliability for maximum overall community benefit.

REFCLs in Europe, New Zealand, Brazil, China, Russia and other areas of the world are generally quite basic compared to the ones being installed in Victoria and they are operated very differently. For example, many other countries with REFCLs use them mainly on underground cable networks and for particular reasons greatly prolong the duration of the voltage disturbance caused by a fault. REFCLs in Victoria are being applied to very different circumstances: to networks of more than a thousand kilometres of overhead high-voltage lines. Victoria is now an internationally recognised leader in the use of REFCLs for fire-risk reduction on large rural powerline networks.

The only other area of the world that is installing the same type of REFCL as Victoria is California. Two California utilities are preparing to install REFCLs for major trials after reviewing Victoria's program and independently satisfying themselves of the potential benefits through extensive laboratory tests. Those REFCLs are not yet in service.

Experience overseas offers very little value for the estimation of REFCL fire-risk benefits in Victoria. This is one of the reasons Victoria invested millions of dollars in ground-breaking powerline ignition research that is now being used all around the world as the authoritative reference database on how powerlines start fires and how to stop them. This research validated the basis of a large investment in REFCLs to cut fire-risk from Victoria's rural powerlines.

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Published by

Tony Marxsen
Chairman, Grid Innovation Hub at Monash University

Why Victoria has confidence in REFCLs as a way to reduce fires from powerlines.

Recently there has been some debate about the effectiveness of Victoria's Rapid Earth Fault Current Limiter (REFCL) rollout as a means of cutting the risk of catastrophic fires on high risk days. It has generated articles in engineering forums and even been aired on current affairs television. It's good to see debate when it is well-informed and I offer this article in support of that goal.

This article sets out my own summary of the rationale for Victoria's confidence in REFCL fire-risk benefits. To get the essence of it quickly, just read the first section. To delve into the detail, it's a long-ish read but worth it if you really want to understand the whole train of logic. It certainly beats reading through the 2,000 pages of highly technical test program reports and regulatory impact statements, etc. that have been published over the years.

It contains my own views and observations from being involved on Victoria's ten-year journey since Black Saturday and has no official status. I hope you find it useful.