FireSafe SWER EFD Trial

Final report

17 June 2022

SWER: Single Wire Earth Return – a powerline technology that uses a single high-voltage wire to carry current to remote customers, the current returning to the source through the Earth.

EFD: Early Fault Detection – a patented powerline monitoring technology that detects incipient powerline faults before they occur, manufactured by IND Technology Pty Ltd in Melbourne Australia.

IND Technology Pty Ltd

Disclaimer

This report describes a project to establish a trial of a new powerline bushfire safety technology at various locations in rural Victoria. It was sponsored by the Victorian Government's Powerline Bushfire Safety Program under a Funding Agreement dated 17th February 2021 between IND Technology Pty Ltd and the Victorian Department of Environment Land Water and Planning.

This report contains observations, analysis, commentary, interpretation, findings, and recommendations.

Subject to the Funding Agreement, no warranty can be offered to any third party for:

- The application of anything in this report for any purpose other than those required by the specific objectives of the Trial as outlined in the body of this report.
- The direct application of anything contained in this report to any situation other than those specific Trial situations that are recorded in this report.

Readers should note the following qualifications:

- The information in this report relates to 12.7kV SWER powerlines. Readers who wish to use information contained in this report to derive conclusions for other types of networks or networks in other locations or environments should rely on their own investigations.
- Reasonable care has been taken to outline the rationale and evidence for the findings set out in this report. Readers should make their own judgements of the merits of any such findings before relying on them.
- Quantification of statistical uncertainty has not generally been possible. Readers should form their own judgement of the level of confidence they should have in the observations and findings set out in this report.
- Many assumptions were used to generate insights, derive findings, and interpret data obtained from the Trial. All reasonable care has been taken to explicitly document these assumptions and explain the rationale in each case. No warranty is offered that such documentation is complete or accurate or that any assumptions used are valid.
- Where mathematical theory has been used to derive insights set out in this report, care has been taken to identify the theory and how it was applied. No warranty is offered that the theory employed is valid or correctly applied.

Readers are advised to rely on their own analysis if they wish to use this report for any purpose other than the specific objectives of the Trial project outlined in this report.

Contents

1. Executive Summary

The FireSafe SWER EFD Trial has successfully demonstrated radically different, enhanced, low-cost, easy-install, EFD technology. Like earlier generations of EFD, the new technology detects and locates deterioration, damage, vegetation encroachment and other defects on SWER powerlines in time for network owners to remedy them to prevent fires and interruptions to customer electricity supply.

Having caused some of the deadliest fires on Black Saturday, Victoria's 30,000 kilometres of SWER powerlines continue to cause fires every year and conventional safety systems cannot fix this. Early Fault Detection (EFD) has been proven to cut SWER powerline fire-risk but is not being deployed on Victoria's SWER. This project has produced a new version of EFD for SWER that is low cost and easy to install, to encourage its adoption on SWER powerlines for the benefit all Victorian communities.

The FireSafe SWER EFD Trial was made possible by funding support from the Victorian Government Powerline Bushfire Safety Program with matching contributions from three industry partners: IND Technology Pty Ltd (IND.T), AusNet Services (AST) and Powercor Australia Limited (PAL).

The $1.5 million establishment phase of the FireSafe SWER EFD Trial reported here included:

- **Successful concept development and proof-of-concept tests** of a radical new approach for monitoring powerlines using sensors attached to low-voltage (LV) customer service wiring.
- **Successful design and manufacture** of low-cost easy-install EFD data collection units using the new sensor approach.
- **Successful deployment** of FireSafe SWER EFD units across Victoria to monitor 1,120 kilometres of SWER powerlines in Victoria's highest fire-risk areas.
- **Successful confirmation** of the new technology's ability to detect and locate powerline defects, documented in case studies.
- **Deployment of add-on weather stations** to allow assessment of the value to network operators of local real-time weather data during high-risk weather conditions.

The findings of this first (establishment) phase of the FireSafe SWER EFD Trial were:

1. **Reduced EFD deployment cost:** Underlying costs of manufacture and installation of FireSafe SWER EFD technology have been successfully reduced to less than half that of earlier SWER EFD technology. First estimates indicate $30 million would suffice to deploy FireSafe SWER EFD technology to cut fire-risk on all 30,000 kilometres of Victoria's SWER powerlines.

2. **Enhanced EFD performance:** Powerline defect detection and location performance of the new FireSafe SWER EFD is better than that of previous technology. It is more sensitive, has lower background noise, and provides data on local mains voltage and quality of supply.

The two-year FireSafe SWER EFD Trial monitoring phase now underway will include progressive performance optimisation via software updates, with improved insights into fire safety benefits. Progressive results from the monitoring phase will be published in mid-2023 and mid-2024.

Based on the results to date, IND.T recommends the Victorian Government and Victoria's electricity network owners work together to plan, fund, and deliver a full rollout of the new FireSafe SWER EFD technology to protect all Victorian communities from fire-risk created by the 30,000 kilometres of SWER powerlines across the State. This work should be started now so it can be completed before the long-term weather cycle brings Victoria back to drought conditions with hot, dry Summers and high risk of catastrophic powerline fires.

2. SWER powerlines continue to start fires

The challenge addressed by this project is deployment of EFD on SWER powerlines to improve the fire-safety of Victorian communities. Despite SWER powerlines' prominence in the Black Saturday tragedy and proven EFD success in cutting this fire-risk, EFD is not being deployed on Victoria's SWER powerline networks.

Victoria continues to average 30-40 SWER powerline fires per year. Fire-risk on Total Fire Ban Days is ten to twenty times higher than this average rate, and Code Red fire-risk is much higher again. SWER powerline defects repeatedly cause major fires – the majority of the major 1977 Trentham fires, half of the deadly 1983 Ash Wednesday fires, and the deadliest of the 2009 Black Saturday fires, were all started by SWER powerlines. In the next decade, the La Niña conditions of the last few years will inevitably swing back to the El Niño pattern for some years, with possible drought, hot dry Summers, frequent high fire-risk days, and potentially catastrophic SWER powerline fires.

Technical options to cut SWER powerline fire-risk are limited. The completed rollout of 'smart' SWER reclosers is expected to have lessened SWER fire-risk but for technical reasons reclosers can never eliminate it. More intense maintenance and inspection will also be of benefit, but it tends to be focussed on codified Electric Line Construction Areas and history shows even recently inspected SWER powerlines can start fires in high-risk conditions. Investment programs to insulate, convert, or bury SWER powerlines address at most about half of one per cent of Victoria's total SWER powerlines each year. These measures cost many hundreds of times more than EFD systems on a per-kilometre basis.

Without new technology like EFD, Victoria's SWER powerlines will continue to start fires. Most other powerline safety technology cannot detect many of the SWER powerline defects that cause fires. SWER powerlines are different: normal (customer load) current and abnormal (fault) current share a common path and cannot be separately monitored. Safety systems cannot be set sensitive enough to detect SWER powerline faults that cause fires because settings must allow customer load current to flow. Victoria's ground-breaking REFCLs are not a solution as they do not work on SWER networks.

EFD continuously detects and locates fire-risk defects on all powerline types, SWER and non-SWER, in time for them to be remedied before they can start fires. The Victorian Government's 2017-2019 EFD SWER Trial confirmed EFD reduces SWER powerline fire-risk. Despite its small scale (half of one per cent of Victoria's SWER powerlines), the SWER EFD systems during and since the Trial, found several high fire-risk SWER powerline defects that were then repaired in time to prevent fires.

In the three years since the successful 2019 Trial, EFD systems have been deployed on thousands of kilometres of non-SWER powerlines, mostly in the USA, with dramatic results – more than 300 case studies of high-risk powerline defects detected and located to date: broken and damaged conductors, vegetation encroachment, leakage current into wood, crossarm failures, loose clamps, failing high-voltage cables, and internal defects in transformers and lightning arrestors. Australian deployments of EFD on non-SWER powerlines have shown similarly dramatic results.

In the same three years, Victoria's EFD deployment on SWER powerlines has been negligible.

The challenge addressed by this FireSafe SWER EFD project is to promote the rollout of a proven technology that will cut fire-risk on all Victoria's SWER powerlines in a few years, so Victorian communities are better protected against catastrophic fires like those of Black Saturday.

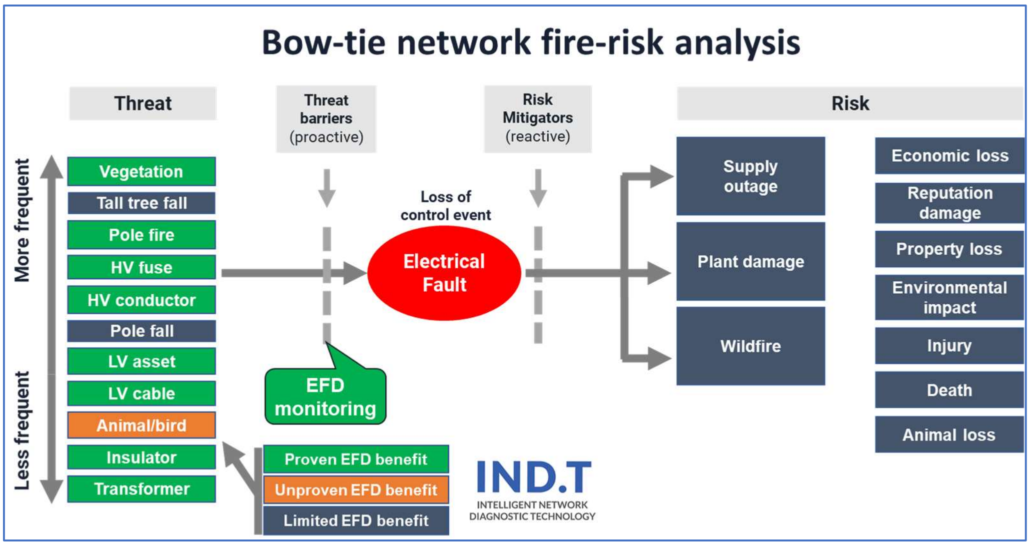
3. EFD technology can make SWER powerlines much safer

EFD is a patented powerline monitoring technology invented by Dr Alan Wong at Melbourne's Deakin and RMIT Universities. Manufactured in Melbourne by IND Technology Pty Ltd, EFD is now used widely in Australia and exported world-wide. More than ninety per cent of IND.T's revenue is now from USA utilities deploying EFD to cut fire-risk on electricity networks.

EFD technology does not suffer the constraints of mains-frequency fault detection; EFD 'listens to' powerline radio signals – which healthy powerlines do not emit. Powerline radio signals almost always come from defects in the powerline – including many types that have caused catastrophic fires: age- or stress-related asset deterioration, damage, or compromise by, for example, vegetation growth. Once a powerline defect is detected and located by EFD, early repair will prevent a fire.

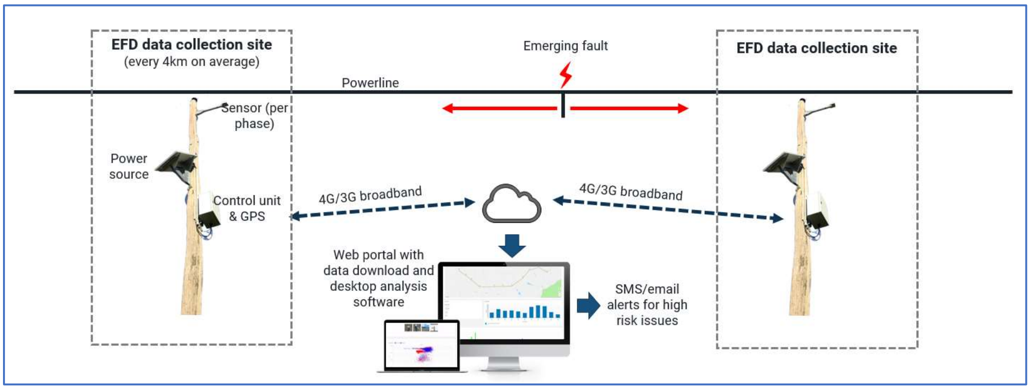
EFD embodies the fundamental safety principle of "prevention is better than cure". On the bow-tie threat and risk diagram (Figure 1), EFD is a threat-barrier, rather than a risk-mitigator. It prevents asset failures and powerline fires rather than trying to manage the consequences after they happen.

Figure 1: Electricity distribution threat/risk Bow-tie diagram



As shown in Figure 2, an EFD system comprises pole-mounted EFD radio-frequency data collection units spread across the powerline network and time-synchronised by GPS satellites. These EFD units feed data to cloud-based EFD data processing algorithms and an EFD web portal that delivers results to network operators. EFD systems locate powerline problems accurately to within ten metres.

Figure 2: Schematic view of EFD system operation



EFD systems combine many of the latest ‘smart’ technologies – Internet of Things, autonomous smart sensors, edge computing, machine learning, signature recognition, and big data analysis, to deliver dramatically enhanced results. An EFD system scans the powerline every second. It finds defects hidden inside equipment, and intermittent ones missed by point-in-time line inspections.

Other than EFD, there is no technology known today that can remotely detect and accurately locate powerline defects before they develop into faults and cause fires. To quote one senior US utility engineer: “I have been searching for thirty years for something that will do this and you guys have cracked it”. An executive in one of the largest US utilities commented “Of all the new fire-safety technologies we are trialling, EFD is the only one that tells me *where* things are breaking.”

EFD also provides a low-cost add-on option for collection of real-time local weather data. Good local weather data aids remote diagnosis of powerline problems and can de-risk operational decisions. Bureau weather stations are too slow and usually too far away. This project will assess the value of local real-time weather data in network operational decisions during high-risk conditions.

4. This FireSafe SWER EFD Project addressed the challenge

This report covers the development, design, manufacture, and deployment of a radical new enhanced FireSafe SWER EFD technology to monitor 1,100 kilometres of SWER powerlines spread across the diversity of local environments in Victoria’s highest fire-risk areas.

4.1. Project objectives and target outcomes

The FireSafe SWER project had clear objectives: to -

1. Produce an EFD product to monitor SWER networks with -
    a. Half the previous EFD ‘procure and install’ deployment cost; and
    b. Enhanced ‘detect and locate’ EFD performance.
2. Assess the value of local real-time weather data to network operators during high-risk weather.

Achievement of these objectives was guided by two target outcomes: reduced fire-risk from Victoria’s 30,000 kilometres of SWER powerlines; and a new hi-tech export market for Victoria.

4.2. Project partners

Project activities were jointly resourced and funded by four project partners:

1. The Department of Energy, Land, Water and Planning, as host of the Victorian Government Powerline Bushfire Safety Program’s Research and Development Stage 2 Fund.
2. IND Technology Pty Ltd, the inventor and supplier of EFD products and developer of the new FireSafe SWER EFD technology.
3. AusNet Services, owner of SWER networks in high fire-risk areas in the North and East of Victoria.
4. Powercor Australia Limited, owner of SWER powerline networks in high fire-risk areas in the North and West of Victoria.

The project was managed by IND.T and governed by the four project partners in collaboration.

4.3. Project scope and budget

The project scope and budget were:

1. Deploy new FireSafe SWER EFD systems to monitor 1,100 kilometres of SWER powerlines spread over a wide range of environments across Victoria.
2. Deploy fifty local EFD add-on weather stations.
3. Total budget: $1.45 million, 50% funded by a Victorian Government grant.

4.4. Project phases

This report covers the fifteen-month establishment phase of the FireSafe SWER EFD Trial, including product concept development, proof-of-concept tests, design, prototype tests, manufacture, installation, and commissioning of 300 EFD data collection units on SWER networks across Victoria.

The FireSafe SWER EFD powerline monitoring systems deployed in this project will operate for the next 24 months until mid-2024 as IND.T continuously optimises their performance through software updates. This period will constitute the optimisation, monitoring, and benefit estimate refinement phase of the overall Trial. Reports in mid-2023 and mid-2024 will document progressive results. FireSafe SWER EFD systems installed for the Trial will likely remain in place for the long term to protect the Trial's SWER powerlines – four per cent of Victoria's total SWER powerline inventory.

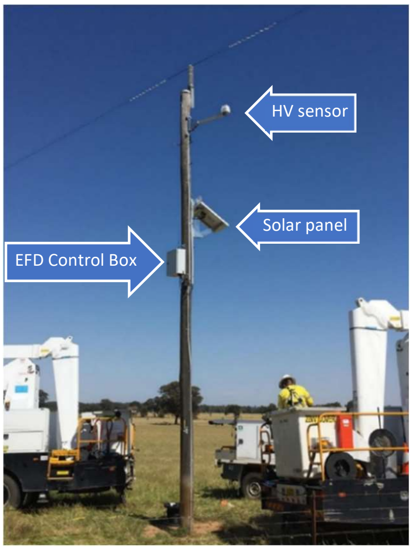
5. The FireSafe SWER EFD design concept was a radical step change

A completely new concept was developed in this project to deliver the target fifty per cent deployment cost reduction without impact on EFD's 'detect and locate' performance.

The FireSafe SWER EFD radical redesign successfully cut the size, weight, component count, and installation effort. The EFD design in the original 2017-2019 EFD SWER Trial was critically examined to identify the drivers of total deployment cost in two inter-linked categories: equipment manufacture; and equipment installation. Brainstorming identified 'outside the square' options to address these drivers. Assumptions were tested in the laboratory and proof-of-concept field trials.

EFD deployment cost is mainly determined by the EFD data collection hardware design, so this was the focus of concept development. The starting point was the design used for the 2017-2019 EFD SWER Trial shown in Figure 3. It used a high-voltage (HV) capacitive sensor.

Figure 3: 2019 SWER EFD Trial equipment



5.1. Cost Drivers

Three main drivers of EFD deployment cost were identified for scrutiny. These are listed in Table 1.

Table 1: Cost drivers in EFD SWER deployment in the 2019 Trial

2019 Trial EFD hardware	Impact on deployment cost
Solar power supply - **Panel** - **Panel bracket** - **Battery** - **Charger**	This was a set of high-cost items. Further, it required the EFD control box enclosure to hold a large heavy battery to carry the unit through several days of cloudy weather. The panel bracket was also heavy, costly, and very awkward to pack for transport and to install.
HV capacitive RF sensor - **Sensor** - **Bracket** - **Coaxial cable**	This was a medium-cost item, offering smaller cost savings. However, HV sensing of radio signals meant data collection units could not be installed on standard SWER customer substation poles, so EFD installations often had to be well away from roads, increasing installation cost. SWER powerlines terminate at a customer substation, so this constraint also created 'beyond the path' sections of unmonitored powerline at network boundaries.
EFD Control box - **Metal enclosure** - **Internal metal chassis** - **Printed Circuit Boards (PCBs)** - **Internal cables**	The Zinc-plated, powder-coated steel enclosure was high-cost and heavy. Total weight with electronics and battery was 33kg. Experience showed water was hard to keep out and the powder coating tended to separate from edges of metal sheets where the Zinc coat was thin and corrosion likely. Fitment of PCBs to the internal metal chassis added assembly time. Multiple PCB-to-PCB cables added a lot of cost and assembly time.

Each of these was addressed in the redesign to produce the new FireSafe SWER EFD equipment.

5.2. Objectives of the FireSafe SWER EFD redesign

The cost-driver analysis pushed design of the new FireSafe SWER EFD data collection unit toward three specific objectives:

1. Eliminate the solar power supply – to save cost and have one less item to install on the pole.
2. Eliminate the HV capacitive sensor – to allow installation on customer substation poles.
3. Optimise the Control Box – cut cost, weight, size, and ease of installation.

The first two objectives led to the same outcome: installation of the new FireSafe SWER EFD units at customer substation poles with almost no modification to the existing pole equipment. This would provide mains power for the EFD control box, extend EFD monitoring coverage to the end of the SWER powerline, and provide better access for installation crews as most customer substations are close to houses, sheds, etc. with relatively good road, track, or driveway access.

5.3. The key assumption in the new design: low-voltage (LV) sensing

The key assumption required for the redesign to work was that radio-frequency signals from defects on the high-voltage powerline would pass through the customer substation transformer and could be picked up from the low voltage side – from the customer 230V supply wiring.

There were already grounds for this hypothesis: existing EFD systems with high-voltage capacitive sensors were regularly finding defects on low-voltage customer service wiring, so why shouldn't the opposite apply: sensors on low voltage wiring detecting defects on the high-voltage powerline?

Laboratory tests confirmed radio signals travelled easily in both directions through a typical SWER customer substation transformer. IND.T patented the new concept and commenced development of a suitable low-voltage sensor for the new FireSafe SWER EFD design to use in proof-of-concept tests.

5.4. Design optimisation of the EFD Control Box

Optimisation of the EFD control box, including its internal electronics, was multi-faceted. Many design improvements were made:

1. A new electrical safety design was developed based on industry principles used to ensure the electrical safety of double-insulated plastic-encased household appliances.
2. A plastic enclosure replaced the metal box. Modern high-strength durable plastics can now deliver a long service life outdoors in Australia.
3. The GPS antenna was moved inside the enclosure. Radio frequency (RF) signals used by the GPS satellite network can easily penetrate a plastic enclosure.
4. Connectors were moved to the bottom surface of the enclosure. A simple plastic top cover sealed by an O-ring eliminated water ingress risk and simplified enclosure production.
5. The 4G/3G data communications antenna was mounted upside down under the enclosure. Tests showed this worked just as well as the previous top-mounted design.
6. Apart from the data communication antenna, only a single connector was required – for 230V mains power. Power draw was low enough for a shielded-contact connector to be used as the safety isolator, eliminating power switches. A second connector was fitted on the base of the 50 units that were to have add-on weather stations. A third connector was fitted to all units as a fall-back option to add a high-voltage capacitive sensor should LV sensing prove unsuccessful. On initial results, it is unlikely this connector will be used.
7. The enclosure was designed for easy swap-out and not field-serviceable. This eliminated hinges, door handles, padlocks, etc. Firmware was developed to perform all maintenance functions (except battery replacement of course) over the Internet.
8. The internal metal chassis and many internal cables were eliminated. The multiple PCBs were assembled as a single block with plug-and-socket connectors between boards. This composite block of electronics was then slid into place in the plastic enclosure base before the plastic top cover was pressed into place to seal the unit.
9. The mains power supply was redesigned to eliminate a heavy bulky transformer and to add the new low-voltage sensor on the incoming 230V power connection.
10. All the enhancements developed for polyphase Gen4 EFD technology were incorporated, and redundant circuitry required for polyphase operation was eliminated.
11. Lower internal signal noise and remotely controllable input attenuation improved the sensitivity and signal-to-noise ratio of the EFD data passed to the cloud for EFD processing.

The result was a sealed, light, compact unit which had only to be connected to the 230V power at the customer substation to start feeding EFD data to the cloud. The final design is shown in Figure 4.

Figure 4: The FireSafe SWER EFD data collection unit design

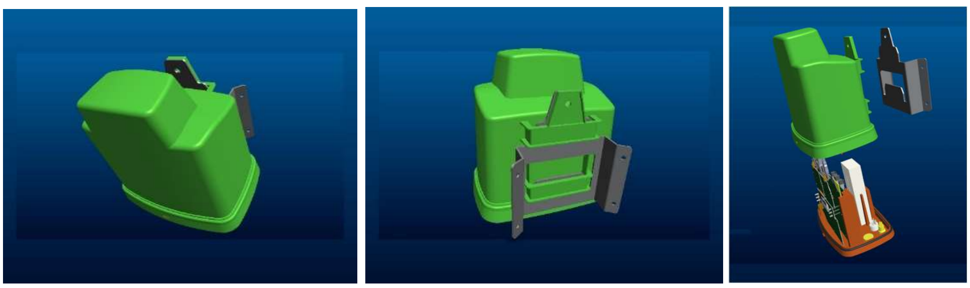
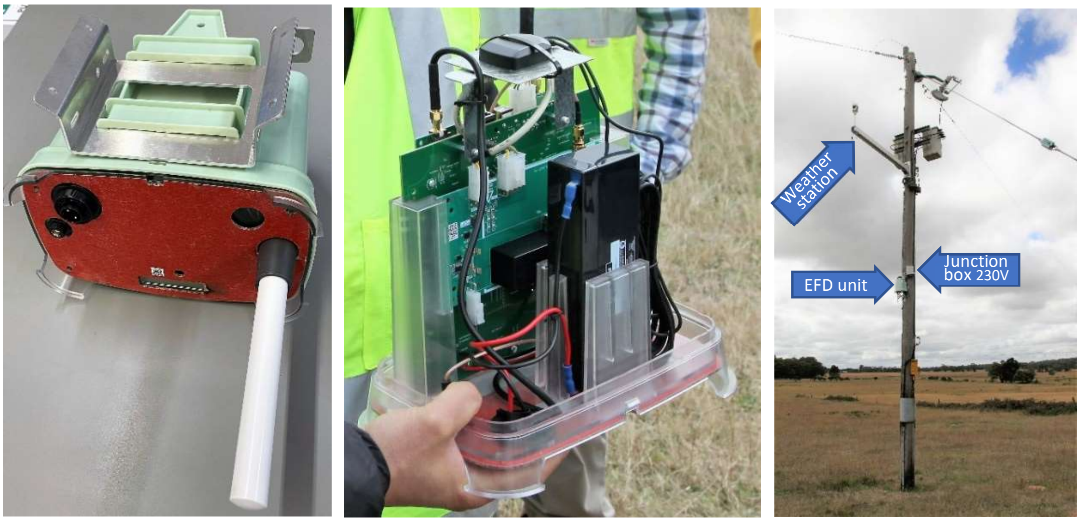


Figure 5: The final SWER EFD data collection unit and an installation with weather station



The new design bettered the target fifty per cent reduction in unit manufacturing cost. Only a few radical design ideas did not reach the strict standards set for adoption:

1. On-PCB GPS antenna. Tests showed a separate internal GPS antenna with a small metal ground plane was required for reliable GPS connection.
2. Ultra-capacitor. Investigations showed long-term performance data for these devices was not yet sufficiently mature. The existing sealed battery was retained for now.

The 2021 FireSafe SWER EFD product was much simpler, 70% smaller, and 90% lighter than the 2017 model. A summary of the design changes from the 2017 SWER EFD design is set out in Table 2.

Table 2: Summary of design changes in the FireSafe SWER EFD data collection unit

Design facet	**2017 SWER EFD**	**2021 FireSafe SWER EFD**
RF signal acquisition	HV capacitive coupler	Internal LV power supply tap
Power supply	Solar panel	90-264V mains
Enclosure	Powder-coated Zinc-plated Steel	UL94v0 Plastic
GPS signal acquisition	External ‘puck’ antenna	Internal antenna and ground plane
Back-up battery	Four days (12V55Ah)	Two hours (12V2.2Ah)
Electronics assembly	Metal chassis with PCBs	Integrated multi-PCB stack
4G/3G antenna	Whip on top of enclosure	Short stub on base of enclosure
Interface	Multiple LEDs	One LED
Earthing	Heavy-duty Q-lug	No safety earth required
Circuit breakers	Two: solar, battery	None, internal fuses only
Cables	Two: sensor, solar panel	One: mains power
Serviceability	Field serviceable	Field swappable
Maintenance	New battery each five years	Swap/refurbish every ten years
Field access	Lockable door	Sealed, no internal field access
Weight	33kg	4kg
Size (DCU)	500Hx400Wx290D (incl. bracket)	263Hx267Wx228D (incl. bracket)

6. Proof-of-Concept Tests showed the radical design worked

After successful tests in the high-voltage laboratory, the LV sensing concept was tested in the field by installing modified polyphase EFD units on two SWER powerline paths known to contain long-term persistent seasonally active intermittent low-energy signal sources. The sites of these long-standing signal sources had been inspected from ground level and assessed as low risk with no remedial action warranted, so they continue to reappear every Summer.

Figure 6: Modified Generation 3B EFD units (NB: no high-voltage sensor) installed on SWER customer substation poles

Experience and conclusions from the proof-of-concept (POC) tests on the two selected SWER powerline paths were different. Both provided valuable information for the final design.

6.1. POC test on Anderson network Path F-G

The Anderson SWER network is an AusNet network located near Wangaratta in northeast Victoria. The first observation in this test was that LV sensing increased EFD system sensitivity to external radio interference. Strong radio signals from ABC RN 756 Wangaratta were recorded at the new LV sensor near Sensor F. Inspection of the installation indicated this might be exacerbated by the wide separation (up to a metre) between the 230V active conductor and the neutral conductor as they drop down the pole from the substation transformer to the EFD unit. A review of EFD historical experience indicated radio station interference might affect a small minority, perhaps five per cent, of future FireSafe SWER EFD sites.

The mild, wet 2020/21 Summer meant the seasonal signal source on this path was quiescent most of the time. A single brief burst of low-energy activity from the source (at Pole 5111682) was detected by existing Path F-G EFD monitoring at 4:22pm on the 16th of January 2021. The new POC sensor-pair did not detect this activity as one POC sensor was swamped by the continuous radio interference near Sensor F. The activity burst became visible when the existing Sensor F was paired with the POC sensor near Sensor G, forming a hybrid monitored path made up of one FireSafe SWER EFD unit with LV sensing (the POC sensor) and one (Sensor F installed in 2017) with HV sensing.

The continuing inactivity of the source at Pole 5111862 due to the mild wet Summer prompted an attempt to use heavy rainfall events as a substitute. An intense rainband crossed the Anderson F-G path between 4:00pm and 6:00pm on the 15th of July 2021. The Path F-G record showed a very heavy burst 250-650 metres from Sensor F between 4:45pm and 4:55pm. The same burst appeared in EFD data from the POC sensor-pair.

Analysis showed EFD detections from this rain burst recorded by the old and new EFD technologies correlated fourteen times more than baseline time coincidence and six times more than baseline location coincidence, where the baseline values were for random data. Four detections were recorded by the two technologies at identical times and locations. This was taken as confirmation of the FireSafe SWER EFD design assumption. However, rain-burst correlation was considered indirect compared to detection of an actual network asset signal source.

Conclusions drawn from the Anderson F-G POC test path were:

1. LV sensing appears likely to work well provided external radio interference can be effectively mitigated.
2. The new FireSafe SWER design should include measures to mitigate interference from nearby radio stations.
3. Mixing EFD units with HV sensing with those with LV sensing works but may add a small location offset, of perhaps up to about ten metres.

The FireSafe SWER EFD installation design was modified to use public lighting cable to bring the 230V supply down the pole to the EFD unit. This type of cable holds the active and neutral wires close together side-by-side, minimising pickup of external radio signals. An additional layer of precaution was to add a tuneable input digital filter to FireSafe SWER EFD software update plans.

Since the results were less direct than hoped, the new FireSafe SWER EFD design was also altered to add a fall-back option of a HV capacitive sensor should this prove necessary. The additional cost would not threaten project targets and the additional connector was seen as prudent risk management. Experience since rollout indicates this fall-back option is now unlikely to be used.

6.2. POC test on Carween West network Path A-C

The second POC test path also encountered challenges. Data communications outages and poor solar conditions severely affected EFD monitoring of this path until December 2021 by which time the FireSafe SWER EFD design had been largely finalised. Fortunately, the POC results confirmed it.

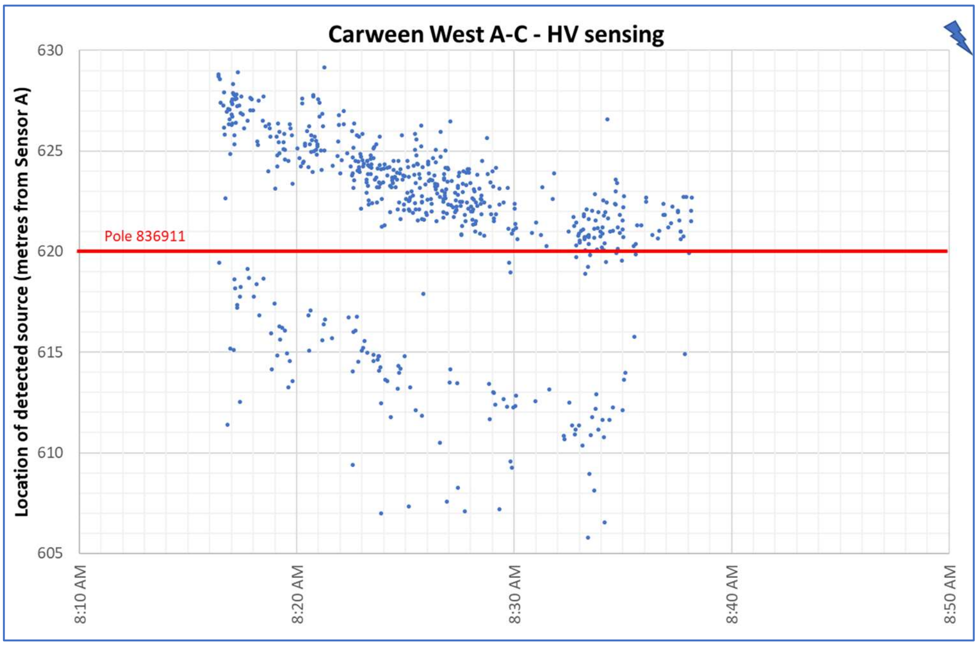
Radio interference in the Carween West Path A-C POC test was much less prominent and the signal sources were more active, so once data communication and solar power issues were resolved, this test path yielded solid and repeated confirmation of the effectiveness of LV sensing in the new FireSafe SWER EFD design. Figure 7 shows an example of an activity burst seen by both methods.

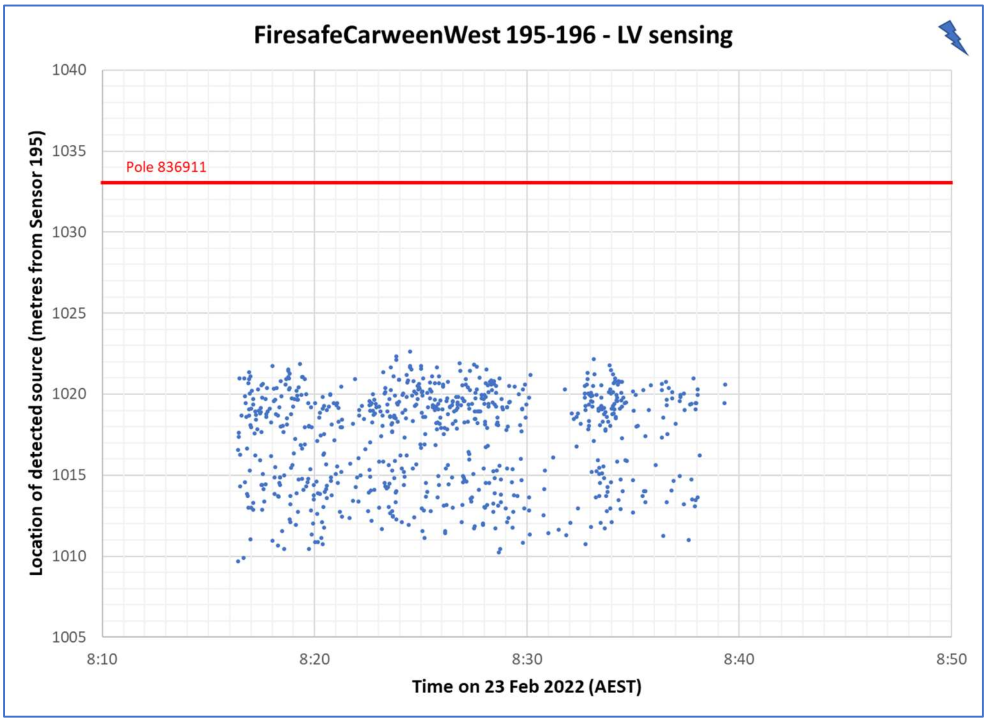
Information gathered from the Carween West POC test included:

1. LV sensing found known powerline defects just as effectively as HV sensing.
2. LV sensing can be much more sensitive than HV sensing.
3. There may be a small (ten to twenty metres) location displacement between the two methods.
4. LV sensing moves EFD detections towards lower bandwidths on the Frequency-Time Chart.
5. LV sensing may be more prone to echoes, but the ‘true’ location is usually still clear.

The small location offset observed between the two sensing methods was probably due to slight differences in signal transit-times through the customer substation transformers at each site.

Figure 7: Example of 20-minute activity burst detected on Carween West Path A-C, comparing HV and LV sensing





On these results, plans to fit back-up HV sensors on FireSafe SWER EFD units were scaled back.

7. Manufacture of FireSafe SWER EFD was impacted by global issues

The FireSafe SWER EFD units were manufactured in Melbourne, using a mix of locally manufactured and imported components. Most of the semiconductors and more complex PCBs were imported, as Australia does not have domestic capacity for their manufacture. The plastic enclosures were also produced overseas as local plastic injection moulders regard a run of 300 units as too small.

Manufacture of the FireSafe SWER EFD units was adversely affected by two major issues:

7.1. Supply chain disruptions

The severe global shortage of Silicon chips had a major impact on the plan. It was caused by many factors: the US-China trade war halted major US plants in China, fires at plants in Germany and Japan, storms in Texas shut two plants, the drought in Taiwan shut more, as well as the spike in demand as people working from home in COVID lockdowns upgraded their home-office technology.

Each FireSafe SWER EFD unit uses hundreds of chips, including some very specialised ones also used by automotive manufacturers. Direct adverse impacts of the global chip shortage on the project included chip unavailability, price gouging (up to 6000%), and the presence of defective chips in the supply chain. IND.T's response included greatly increased vigilance, multi-sourcing, more testing, and substantial levels of rework, as well as circuit redesign to use substitutes when chips could not be obtained. All these contributed to delays in delivery of the manufactured FireSafe SWER EFD units.

A further impact late in the production run was a coal shortage in China due to its ban on Australian coal imports. This created power rationing in China's major cities with factories asked to work part-time. It significantly slowed production of the plastic enclosure and baseplate.

7.2. Direct COVID impacts

China was the source of some key components and its zero-COVID policy of stringent lockdowns of whole cities delayed and disrupted supply, as factories shut down for long periods. COVID also had severe effects on transport channels as passenger flights (which normally carry airfreight) paused. Melbourne's own lockdowns had minimal direct impact, though the post-lockdown period with the Omicron variant widespread in the community affected the installation and commissioning program.

These issues caused two months slippage that added to the two months slippage in the execution of the Funding Agreement, to move the date of product delivery to HNOs from the original plan of mid-October 2021 to February 2022. The impact on the project schedule was mitigated by closely coordinating production with just-in-time delivery to the HNOs' progressive installation programs.

7.3. Increased testing

To address residual quality uncertainty in chip supply, IND.T introduced a 48-hour 'soak' test (Figure 8) including repeated power-cycles. The switch to LV sensing introduced additional test complexity. The first 10% (30 units) of the production run was treated as a final prototype test. It revealed a few last changes which were then incorporated in production of the remaining 90%. These changes will be retrofitted to the original thirty units early in the next phase of the project.

Figure 8: A batch of new FireSafe SWER EFD units undergoing a 48-hour power-cycling 'soak' test

8. Deployment of FireSafe SWER EFD systems was straightforward

There were three main stages in the deployment of FireSafe SWER EFD data collection units:

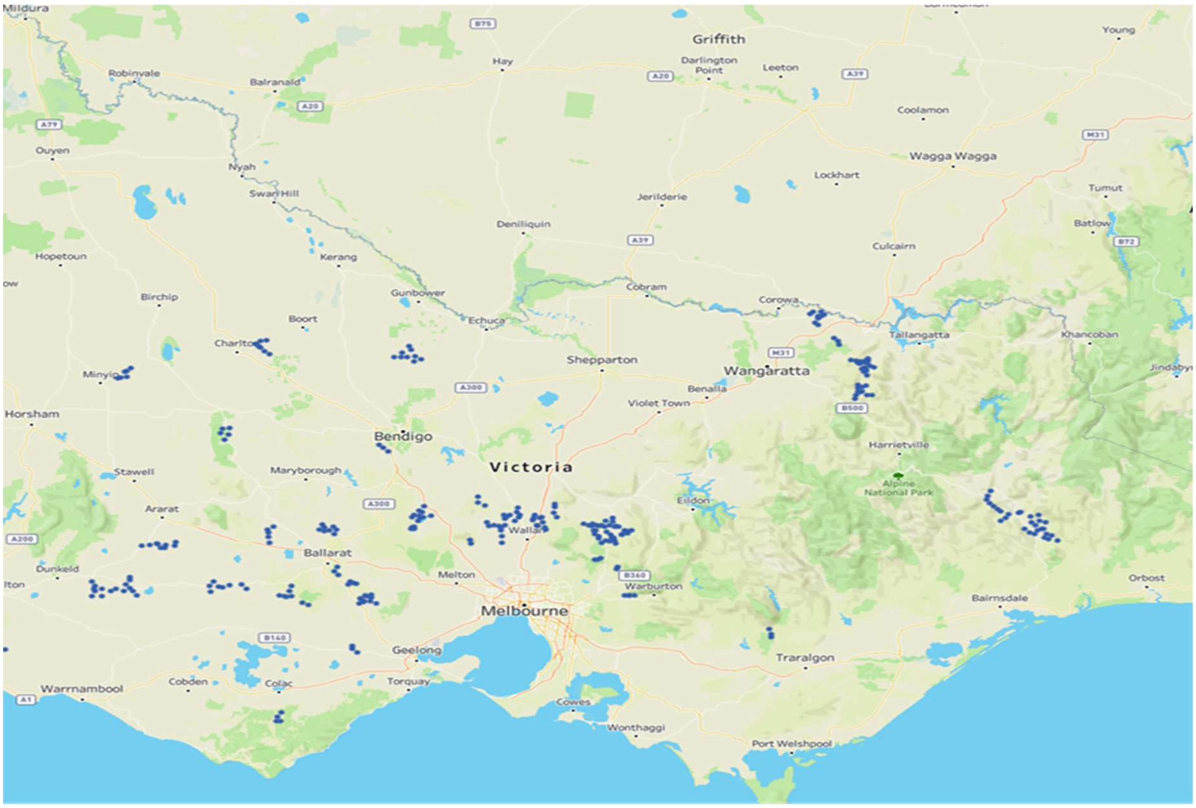
1. **Planning** to select and confirm target networks and EFD unit installation sites.
2. **Installation** to fit the EFD equipment on the selected pole.
3. **Commissioning** to add the new FireSafe SWER EFD units to the EFD web portal.

Each of these is described briefly here.

8.1. Planning

The goal of the planning phase was to decide installation locations for the FireSafe SWER EFD data collection equipment and weather stations. Each Host Network Owner (HNO) was assigned a nominal 150 units to cover SWER networks they chose for the Trial. The project advice for selection of Trial SWER networks was simple: ensure the network covers an area of high fire-consequence and spread the selection of networks over a diversity of local environments. The SWER networks selected by the HNOs for the Trial were spread across Victoria as shown in Figure 9.

Figure 9: FireSafe SWER EFD Trial networks



Using guidelines provided by IND.T, the Host Network Owners (HNOs) selected EFD unit installation sites to define a deployment concept for effective coverage of some or most of the SWER powerlines in each selected network. The IND.T guidelines were simple and already familiar to the HNOs:

1. No monitored path between two adjacent sensors is to be longer than five kilometres.
2. All powerline spans on spurs are to be within five kilometres of two EFD sensor locations.

In most cases, the HNOs designed the deployment concept for full coverage of the network. In some, they opted for partial coverage. The concepts provided EFD coverage in sixty-seven SWER networks spread across Victoria, comprising a total of 1,100 kilometres of SWER powerlines with 1,783 customer substations. Forty-five of the sixty-seven selected networks were in codified Electric Line Construction Areas, signifying extreme fire-consequence. The remaining one-third were in High Bushfire Risk Areas.

Ideally, one of the EFD data collection units in each network should be located at the isolation transformer (ISO), which is the point at which the 12.7kV SWER network takes supply from a two- or three-wire 22kV polyphase feeder. However, the only 230V power supply at most ISO locations is derived from the 22kV two-wire side to supply the SWER network automatic circuit recloser. There was uncertainty about whether this 230V supply would collect radio signals from the SWER side of the ISO and the location was changed to the first customer substation on the SWER side of the ISO.

For many networks, this fall-back placement was only one span from the ISO and the impact on EFD system coverage was slight. For others, it was a considerable distance from the ISO. The powerline between this EFD data collection unit and the ISO became 'off-path', only indirectly monitored by the EFD system. Installation of EFD data collection units at ISOs has been noted as an issue for future resolution as more experience is gained with EFD's use of LV sensing to collect radio signals.

EFD deployment concepts were overlaid on network maps, as illustrated in Figure 10. The 'as installed' FireSafe SWER EFD systems and network assets protected by them are shown in Table 3.

Table 3: FireSafe SWER EFD systems 'as installed'

Supply Zone Substation (ZSS)	SWER Networks	Route km	Path km	Off-path	Spurs	Customer Subs	EFD Units	Weather Stations
Ararat	4	91.6	72.3	29.8	28	83	24	3
Bairnsdale	1	105.4	83.7	24.8	34	119	26	1
Ballarat North	4	27.8	23.2	8.2	7	27	8	2
Ballarat South	1	104.5	78.2	40.0	65	207	30	1
Barnawartha	4	39.9	26.7	15.3	20	60	12	4
Bendigo	1	20.7	2.5	18.2	23	49	2	1
Charlton	3	31.3	24.4	11.3	7	19	8	2
Colac	1	16.0	12.2	9.1	13	35	5	0
Eaglehawk	8	29.6	29.1	2.4	1	18	9	4
Gisborne	1	6.9	4.1	2.8	9	23	2	1
Hamilton	1	118.8	92.4	41.5	33	126	30	1
Kilmore South	1	50.9	28.1	27.1	37	122	12	1
Kinglake	1	76.8	46.2	37.4	52	134	19	1
Lilydale	1	9.5	8.8	3.0	5	22	4	1
Moe	6	8.1	5.6	2.5	2	13	3	6
Murrindindi	1	21.3	14.8	8.0	14	39	6	0
Myrtleford	7	58.5	47.3	17.8	22	90	16	4
Seymour	4	102.2	65.2	45.7	60	205	28	3
Stawell	6	18.5	14.9	7.1	3	12	6	4
Winchelsea	5	12.1	6.0	6.6	8	23	3	5
Wodonga	3	63.1	41.0	28.3	47	160	19	3
Wood End	2	95.9	59.0	62.1	74	168	23	1
Woori Yallock	1	8.7	5.6	3.1	7	29	4	1
Totals	**67**	**1118**	**791**	**452**	**571**	**1783**	**299**	**50**

Figure 10: Typical SWER network maps showing EFD deployment concepts for Gatum and Glenburn Rd networks

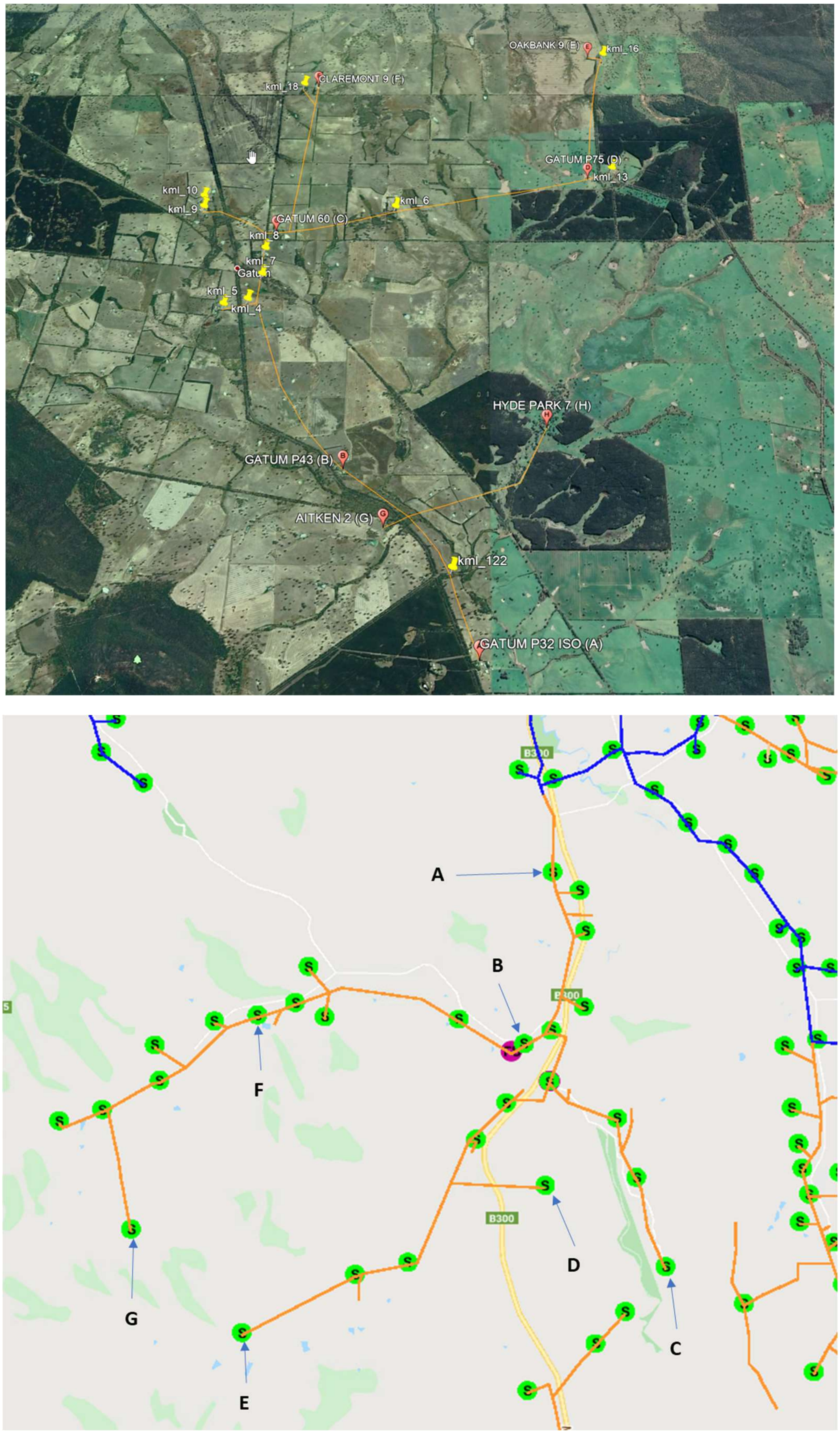


Figure 10 shows the deployment concepts for Gatum (Powercor, ex Hamilton ZSS, 8 EFD units, 37 substations) and Glenburn Road (AusNet, ex Seymour ZSS, 7 EFD units, 40 substations).

Once each EFD deployment concept had been defined, proposed installation sites were visited to confirm access, broadband data service, and pole construction. If a site had problems (locked gate, poor 3G coverage, etc.), it was usually moved to the nearest suitable pole.

8.2. Installation

The first FireSafe SWER EFD data collection unit was installed on the 9th of February 2022 and the 299th (final) unit was installed on the 26th of May 2022. Each HNO developed standard construction drawings and standard work practices for the FireSafe SWER EFD installations. One used an external contractor for all its installation work, and the other used internal resources drawn from multiple local depots that serviced the selected network. SWER network assets monitored by FireSafe SWER EFD units across the whole Trial matched the project scope and are summarised in Table 4.

Table 4: Summary of SWER network assets monitored by FireSafe SWER EFD systems in the Trial

	Total monitored	Average per EFD unit
SWER powerlines	1,118 kilometres	3.7 kilometres
SWER customer substations	1,783 substations and ISOs	6.0 substations and ISOs
SWER Poles	4,573 poles	15.3 poles

8.3. Commissioning

The commissioning of each FireSafe SWER EFD data collection unit consisted of five tasks:

1. Add network pole data associated with that unit to the EFD web portal.
2. Turn on the unit for it to find and connect to a local public mobile broadband data service.
3. Record key installation parameters and photos in the EFD portal Site Page.
4. Initiate EFD cloud data processing of the unit's output data to start EFD system monitoring.

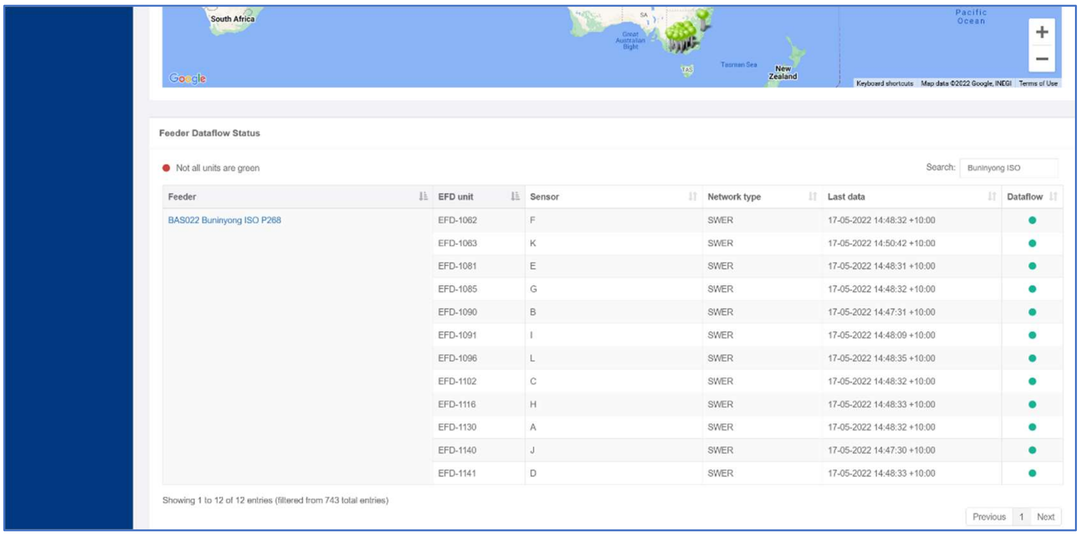
To the extent possible, these steps were automated to cut the cost and effort involved. IND.T produced a simple online commissioning tool for installation crews to use. A quick scan of the QR code on the base of the EFD unit using a mobile smart phone opened a site page on the EFD web portal which showed the unit's connection status and location. The crew simply confirmed this data and uploaded a specified set of photos to the portal via their smart phone or tablet. Ideally, Steps 2 and 3 above were done in the new EFD web portal commissioning facility by the field crew before they left the site. Crew compliance varied but was generally better than seventy per cent. Where the steps were not performed as intended, IND.T would liaise with the HNO project supervisor to get them completed.

The average rate of installations was 20 per week with a peak rate of perhaps twice this. The installation program started slowly and accelerated to full speed after a few weeks. Once it was in full swing, the challenge moved to IND.T staff who entered the latitude and longitude of nearly three thousand poles (all those on monitored powerline paths) into the portal, verifying each location using Google Earth images to correct any errors in HNO asset data. This activity was finally completed a few weeks after the installation program.

8.4. EFD web portal – results presentation

Once all FireSafe SWER EFD data collection units on a SWER network were commissioned, the EFD web portal offered a rich set of views of the EFD system and its monitoring results for that network. These are illustrated in Figure 11 to Figure 16.

Figure 11: EFD web portal Home Page for a large SWER network (Buninyong) and dataflow status of its EFD units


Feeder Dataflow Status

Not all units are green

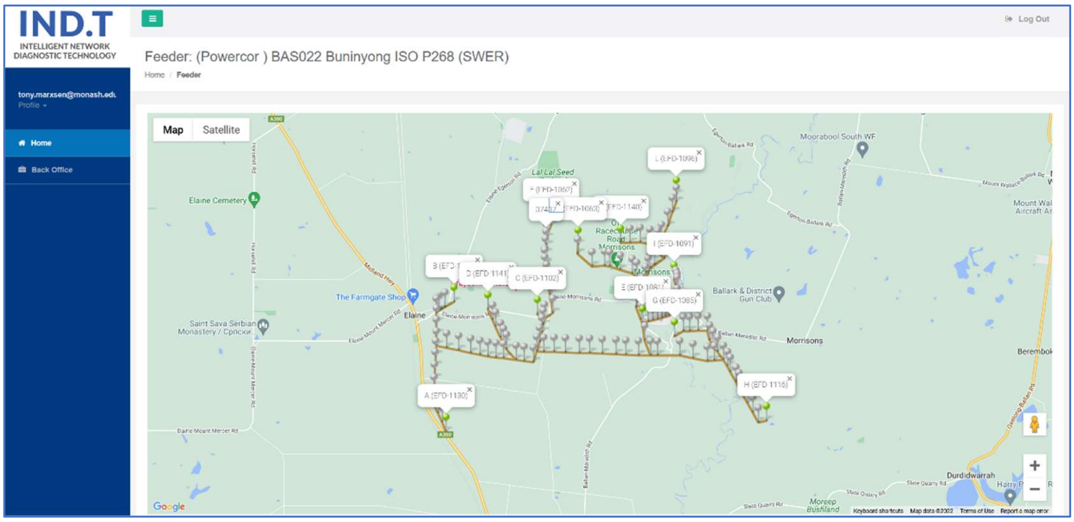
Search: Buninyong ISO

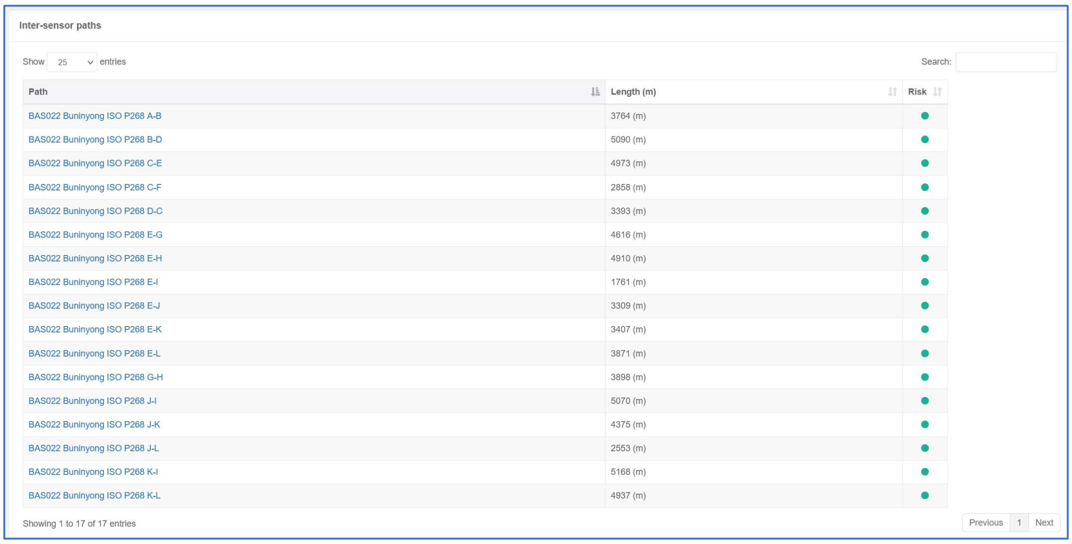
Feeder	EFD unit	Sensor	Network type	Last data	Dataflow
BAS022 Buninyong ISO P268	EFD-1062	F	SWER	17-05-2022 14:48:32 +10:00	●
	EFD-1063	K	SWER	17-05-2022 14:50:42 +10:00	●
	EFD-1081	E	SWER	17-05-2022 14:48:31 +10:00	●
	EFD-1085	G	SWER	17-05-2022 14:48:32 +10:00	●
	EFD-1090	B	SWER	17-05-2022 14:47:31 +10:00	●
	EFD-1091	I	SWER	17-05-2022 14:48:09 +10:00	●
	EFD-1096	L	SWER	17-05-2022 14:48:35 +10:00	●
	EFD-1102	C	SWER	17-05-2022 14:48:32 +10:00	●
	EFD-1116	H	SWER	17-05-2022 14:48:33 +10:00	●
	EFD-1130	A	SWER	17-05-2022 14:48:32 +10:00	●
	EFD-1140	J	SWER	17-05-2022 14:47:30 +10:00	●
	EFD-1141	D	SWER	17-05-2022 14:48:33 +10:00	●

Showing 1 to 12 of 12 entries (filtered from 743 total entries)

Previous 1 Next

Figure 12: EFD web portal Network Page of Buninyong SWER network showing network map and list of monitored paths




Inter-sensor paths

Show 25 entries

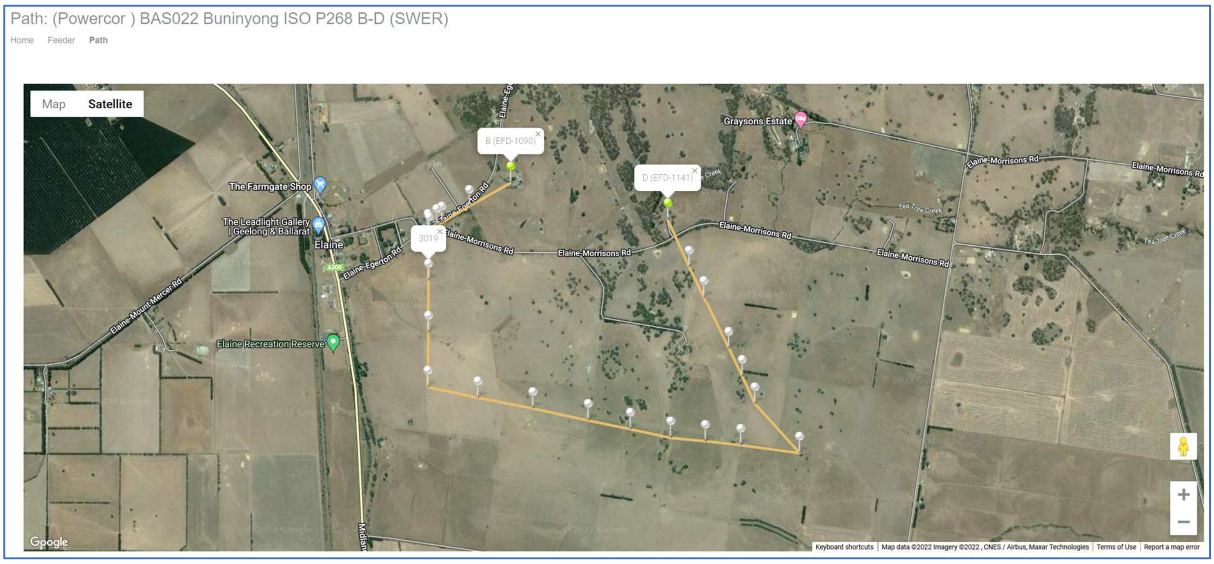
Search:

Path	Length (m)	Risk
BAS022 Buninyong ISO P268 A-B	3764 (m)	●
BAS022 Buninyong ISO P268 B-D	5090 (m)	●
BAS022 Buninyong ISO P268 C-E	4973 (m)	●
BAS022 Buninyong ISO P268 C-F	2858 (m)	●
BAS022 Buninyong ISO P268 D-C	3393 (m)	●
BAS022 Buninyong ISO P268 E-G	4616 (m)	●
BAS022 Buninyong ISO P268 E-H	4910 (m)	●
BAS022 Buninyong ISO P268 E-I	1761 (m)	●
BAS022 Buninyong ISO P268 E-J	3309 (m)	●
BAS022 Buninyong ISO P268 E-K	3407 (m)	●
BAS022 Buninyong ISO P268 E-L	3871 (m)	●
BAS022 Buninyong ISO P268 G-H	3898 (m)	●
BAS022 Buninyong ISO P268 J-I	5070 (m)	●
BAS022 Buninyong ISO P268 J-K	4375 (m)	●
BAS022 Buninyong ISO P268 J-L	2553 (m)	●
BAS022 Buninyong ISO P268 K-I	5168 (m)	●
BAS022 Buninyong ISO P268 K-L	4937 (m)	●

Showing 1 to 17 of 17 entries

Previous 1 Next

Figure 13: Map view (with satellite view turned on) of one monitored powerline path (Buninyong Path B-D – 5.1 kilometres)



The Path Page also shows calculated Risk Scores for the section of network near each pole. These are calculated weekly and displayed for each of the 23 poles along the path as soon as sufficient EFD data has been gathered to reliably establish trends (first calculation is 28 days after commissioning and the risk score is fully mature after one year of data has been collected). A risk score of more than 300 warrants attention. A risk score above 400 warrants action.

Figure 14: Asset risk scores for Buninyong Path B-D

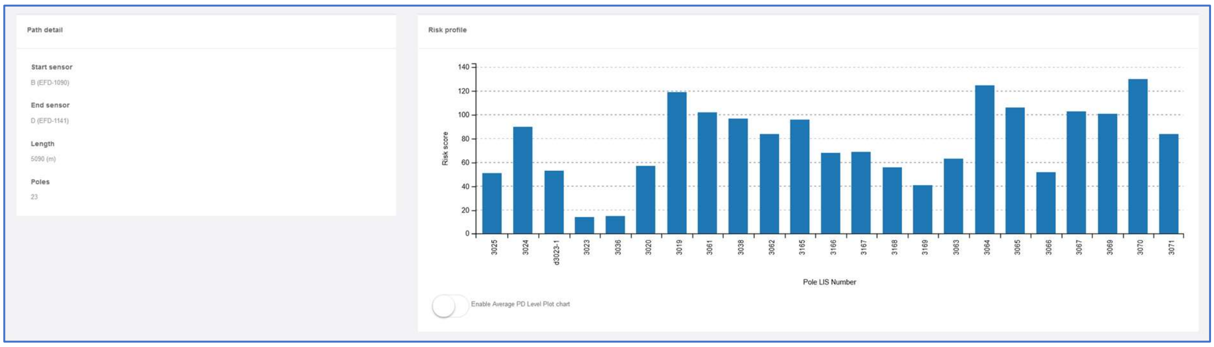


Figure 15: Site page for Buninyong network Sensor D showing history and signature of the radio signal data collected by it

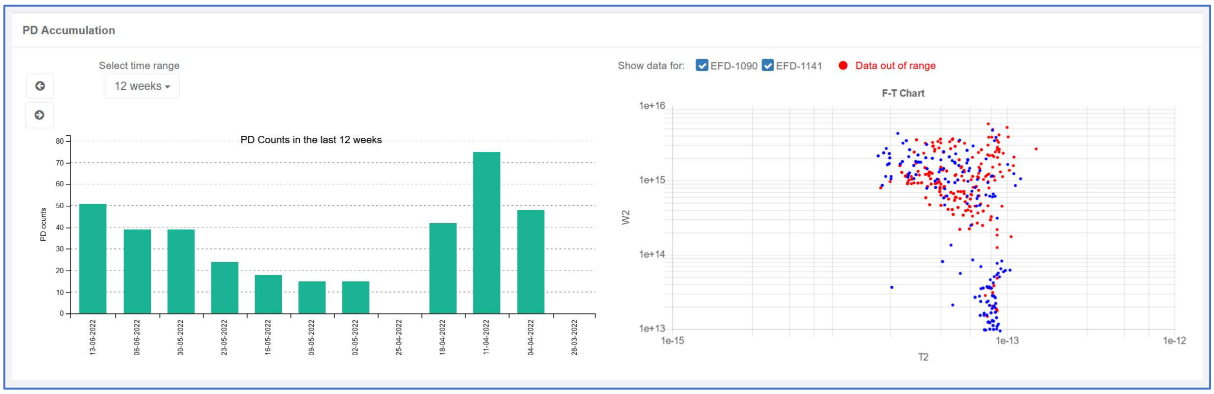


Figure 16: Installation photos of Sensor D, available with one click on the Site Page thumbnails

8.5. Tableau data visualisation

Tableau is a powerful data visualisation platform. IND.T's Tableau facility is still in pre-release but is already used intensively to find and investigate powerline defects – for example, when considering a field inspection visit. The case studies in Section 9 include a small sample of the standard EFD result-visualisation charts it offers. For ease of formatting for inclusion in this report, these examples were produced using an MS Excel macro on downloaded portal data. The same charts are available (plus many others) with a few clicks on the Tableau platform.

9. First Results are very promising

Even at this early stage while initial debugging of the new systems is still underway, the new EFD technology has detected some issues with SWER powerlines in the Trial's coverage areas. The following case studies illustrate the power of the new FireSafe SWER EFD technology to identify issues on the SWER powerlines it monitors. The emphasis in these cases is on very early detection of conditions that are currently low risk, but which might be expected to develop over time into potential fire-starters.

9.1. Case Study 1: Vegetation encroachment

Wodonga Cencic SWER network Path A-B: An abnormal concentration of higher-energy detections was first identified by IND.T on the 27th of March 2022, the day after the path was commissioned. Figure 17 shows the abnormality in detection energy along the path and daily detections profile that locates the signal source to a point on the powerline 530 metres from EFD Sensor A, nine metres short of Pole 5218270. Signal to noise ratio was about one hundred to one. Figure 18 shows the intermittent nature of the activity and confirms it has disappeared since the vegetation was cut.

IND.T visited the site on the 8th of April 2022 and confirmed an apparent vegetation encroachment into the Code clearance space at the signal source location. IND.T informed AusNet and a vegetation crew attended on the 9th of May 2022. They confirmed the encroachment by a tree under the powerline (vegetation within 600mm of the conductor) and cut it back to Code compliant clearance. Figure 18 shows the signal anomaly and the timing of tree clearing. It has not been seen since.

Figure 17: Wodonga Cencic SWER network Path A-B showing detection energy anomaly and daily detections profile

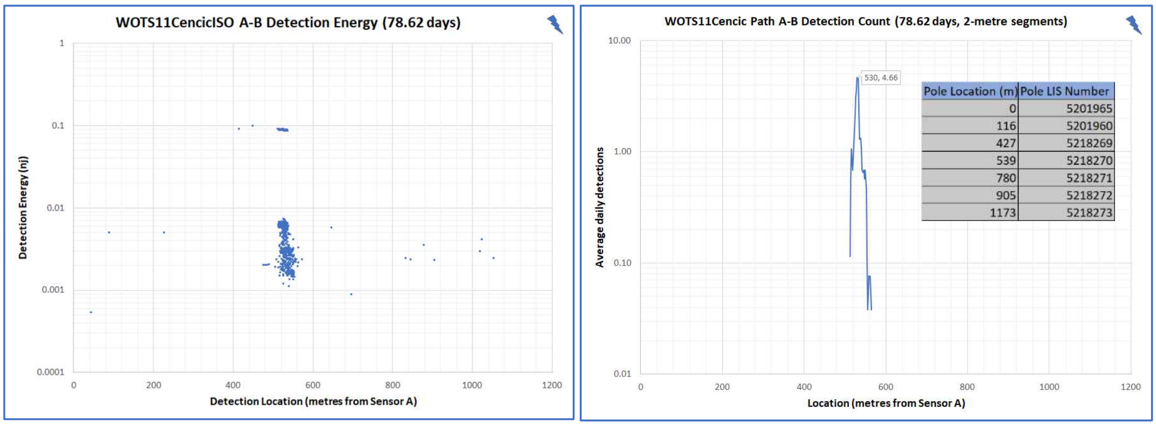


Figure 18: Wodonga Cencic SWER network Path A-B vegetation encroachment

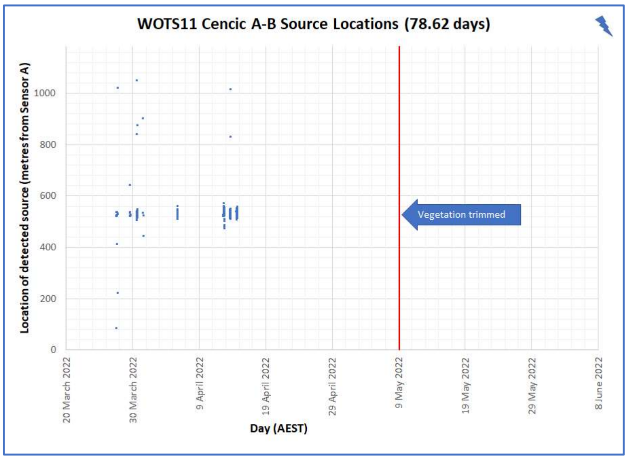


Figure 19: Vegetation close to Wodonga Cencic SWER powerline on Path A-B

Polyphase EFD systems have detected vegetation at a separation of 100-200mm from the conductor, but not so far detected it as far away as 600mm.

9.2. Case Study 2: Conductor splice

Conductor splices are used on SWER powerlines to repair damaged or broken conductors, or simply to join new conductor to old. Many different types of splices have been used over the years and some have proven prone to failure. The consequence of a failed splice is a live conductor fallen to the ground creating public safety risk from electrocution and fire. The early days of the FireSafe SWER EFD Trial included several detections of splices emitting radio signals.

Myrtleford Blacks Flat SWER network Path C-D displayed detection energy anomalies from the day of commissioning. There were two apparent peaks in the daily detection profile (three if the 'polarity match' filter was turned off) and the source location chart showed the activity in each mirrored the other so there was probably only one signal source – at 3,830 metres from Sensor C, as shown in Figure 20. The second peak was due to signal diffraction (as revealed by the sensitivity of the third peak to the polarity match filter).

Although the signal source had gone quiet for a few days, IND.T visited the site on the 8th of April 2022. It was confirmed to be the location of the splice shown in Figure 21.

Figure 20: Myrtleford Blacks Flat SWER network Path C-D showing EFD detected radio signal emission from a splice

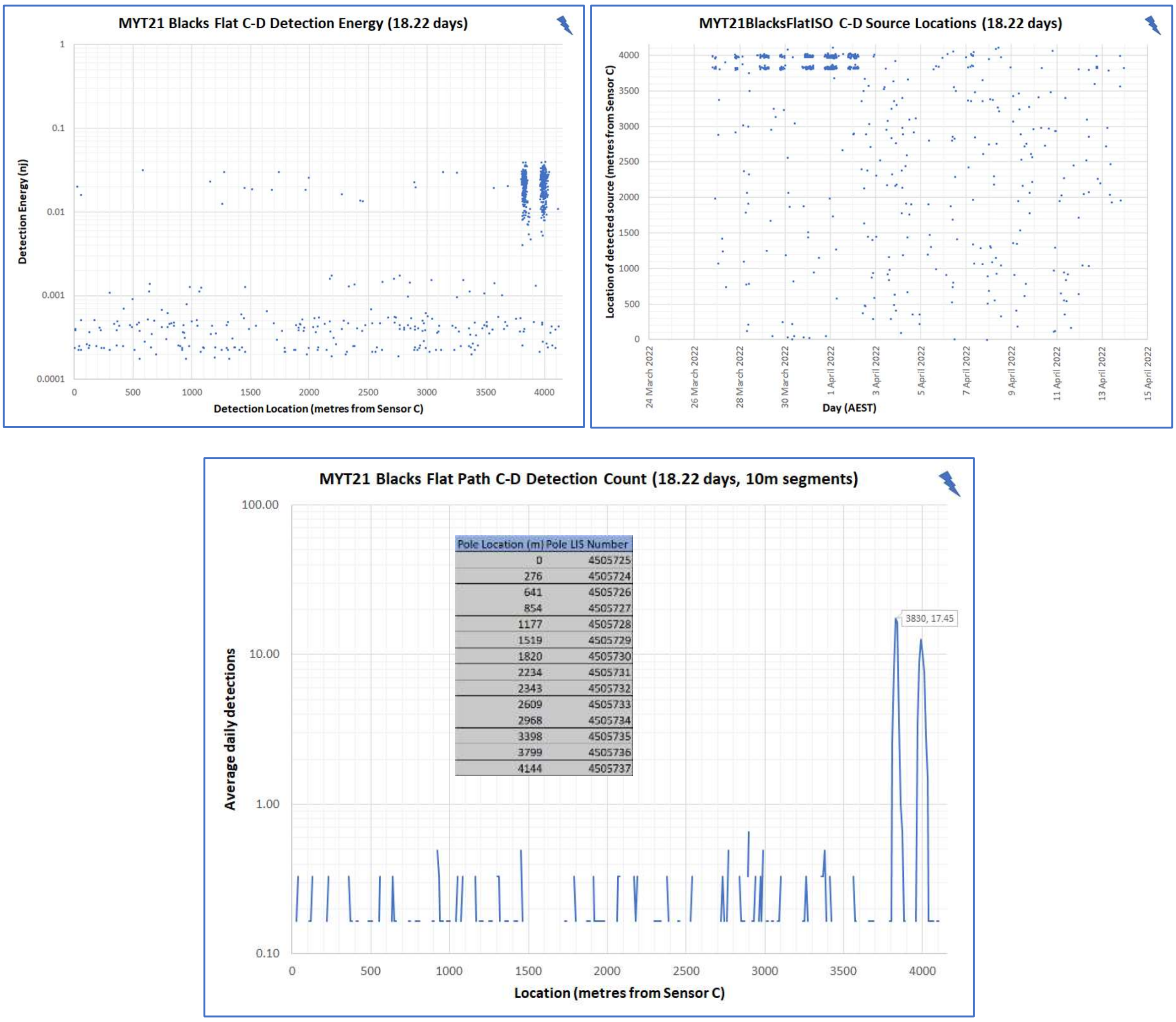


Figure 21: Defective splice on Wodonga Blacks Flat SWER Path C-D

AusNet advised this type of splice involved an undesirable combination of different metals – a Copper sleeve on a galvanised Steel conductor. This type of splice has been marked by many utilities for replacement because of this. Following the EFD detection, this example was scheduled for replacement.

9.3. Preliminary observations: tie-wire and conductor corrosion

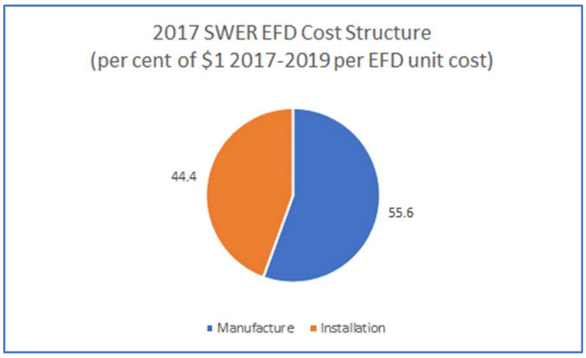
Some brief site visits were carried out during preparation of this report and powerline anomalies were tentatively identified in the vicinity of FireSafe SWER EFD location results. They included corroded tie-wires and conductors, and more splices. However, more data collection is required before these can be confirmed as case studies.

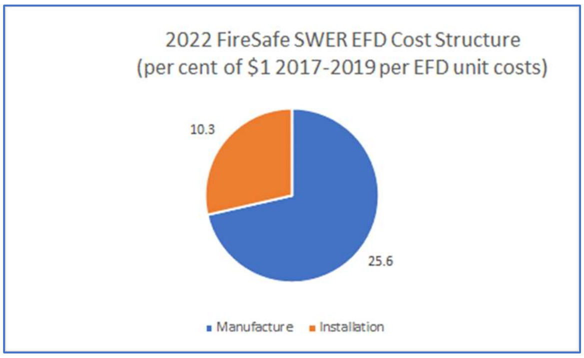
10. SWER EFD deployment cost was cut by sixty-four per cent

The per-unit 'procure and install' cost of SWER EFD systems has been cut by an estimated sixty-four per cent in this project, easily exceeding the project target of fifty per cent reduction. This estimate is based on analysis of detailed cost data for this project and best available data from the 2017-2019 EFD SWER Trial. It accords with subjective guesstimates and expectations of key technical staff who were closely involved in both projects.

The total procurement and installation cost of a FireSafe SWER EFD unit was thirty-six per cent of the 2017-2019 deployment cost per EFD unit expressed in 2022 dollars, as illustrated in Figure 22.

Figure 22: Cost structure of 2022 FireSafe SWER EFD deployment compared to 2017 SWER EFD costs (both in 2022 dollars)





10.1. Production cost was cut by fifty-four per cent

All EFD unit production costs were incurred solely by IND.T. Both the 2017 and 2022 Bills of Materials (BOMs) provided detailed cost data for components, assembly, test, packaging, and transport. A few adjustments were made to include items omitted from the original 2017 BOM; the

2017 cost data were escalated to 2022 dollars using and average price inflation rate to cover the wide range of different rates for the various materials and labour. The same BOM total for the 2022 FireSafe SWER EFD unit, excluding weather stations (not present in the 2017 production run), was compared with the 2017 total with both sets of costs expressed in 2022 dollars.

The result showed that production costs were reduced by fifty-four per cent by the redesign outlined in Section 5 above.

10.2. Installation cost was cut by seventy per cent

It was more challenging to compare installation costs between the 2022 FireSafe SWER EFD project (for which detailed data was available) and the 2017-2019 SWER EFD Trial which had less detailed cost records for HNO installation activity.

The best available data showed the 2022 installation and commissioning costs per site were about twenty-three per cent of the 2018 costs when both were expressed in 2022 dollars. Consultation with a construction supervisor who had been closely involved in both projects elicited a subjective guesstimate of at least a two-thirds reduction in installation cost. He explained that the redesign meant "It's gone from a job for two or three men plus bucket truck using HV 'glove and barrier' methods, to one that might possibly be done by one man plus ladder wearing LV gloves".

On balance, the evidence points to a saving in installation costs of the order of seventy per cent.

10.3. Levelised whole-of-life annual cost is twenty-two cents per metre

Deployment is only a part of the whole-of-life cost of ownership of an EFD system. An annual service fee covers the cost of broadband data communications via a managed VPN, cloud data processing, warranty, six-monthly software updates, fleet management and technical support, and expert advice on interpretation of EFD results. At seven per cent real annual discount, a fifteen-year service life will incur 9.75 times the current annual service fee. Using realistic assumptions, including a mid-life site visit to replace the battery, perform a visual check, and remedy any environmental problems, the total FireSafe SWER EFD whole-of-life cost in 2022 dollars would be close to twice (197%) the initial deployment cost.

One of the objectives of the two-year monitoring phase of the project now commencing is to explore options to reduce the annual service fee. However, service fee cost reduction opportunities are not expected to be as large or as easy to exploit as those in manufacture and installation cost structures.

Using realistic assumptions, the levelised cost of FireSafe SWER EFD at 30,000-kilometre scale would be around twenty-two cents per metre of monitored SWER powerline per year in 2022 dollars. The required capex would be about eleven cents per metre. This can be compared to current plans to invest in SWER covered conductor ($100 capex per metre) and SWER underground cable ($250 capex per metre). These technologies may have service lives up to about twice that of the new FireSafe SWER EFD equipment and they may incur much lower annual operating and maintenance costs. These factors may reduce the cost advantage of FireSafe SWER EFD somewhat, but the cost comparison would remain compelling.

On any reasonable assumptions, FireSafe SWER EFD systems can address all of Victoria's SWER powerlines within a couple of years, while high capital cost per kilometre will continue to limit deployment of most other approaches to less than one per cent of Victoria's total SWER powerline inventory per year.

10.4. Financial benefits of FireSafe SWER EFD systems are substantial

To offset its cost, FireSafe SWER EFD systems generate multiple classes of benefits which can be monetised by network businesses:

1. **Operational savings:** The ability to group, plan and schedule remedial maintenance work provides direct cost savings compared to the cost of current practices - doing the same work as individual tasks during emergency supply restoration callouts. The reduced numbers of powerline failures and their associated power outages also provides a reduction in the regulatory STPIS incentive penalties, though this benefit is very limited for SWER outages as affected customer numbers are usually small.
2. **Fire-risk reduction:** The annual fire risk of the 11 SWER networks in the original 2017-2019 EFD SWER Trial was valued at $980 per SWER powerline-kilometre per year, nearly five times the per-kilometre cost of a FireSafe EFD system. Of course, long-term averages do not fully reflect the brutal reality of the impact on a network business should one of its SWER powerlines cause a catastrophic fire like those on Black Saturday – historically, this has led to years of litigation, severe reputation damage, and difficulty renewing corporate insurance.
3. **Asset Management ROI:** EFD identifies deteriorating assets, which allows network owners to sharpen the focus of asset replacement investment to get better returns on capital. For example, instead of replacing hundreds of kilometres of conductor based on visual inspection (notoriously uncertain on conductor condition) and asset age, replacement can be done based on actual conductor condition reflected in EFD system monitoring results.
4. **Vegetation management compliance:** EFD identifies locations where vegetation is approaching powerlines, alerting network owners to possible Code compliance breaches and non-ideal performance by contractors, as well as consequential fire-risk. This information can be used to improve the cost-efficiency of vegetation management contracts.

Any business case for adoption of FireSafe SWER EFD technology should include all these benefits.

10.5. A whole-of-SWER rollout is financially and technically feasible

The establishment phase of the FireSafe SWER EFD Trial demonstrated that rollout to all 30,000 kilometres of Victoria's SWER powerlines is feasible and not particularly challenging. The dimensions of such a project would be as shown in Table 5. In infrastructure planning terms, this project is "shovel ready" and benefits to communities are immediate.

Table 5: Whole-of-SWER rollout of FireSafe SWER EFD systems

Dimension	Value	Assumption
SWER powerlines	30,000 km	This is possibly overstated; it may be 25,000 kilometres.
Capital cost	$30 million	7,500 units @ $3,000 buy price and $1,000 install.
Annual service fee	$6 million	7,500 units @ $800/year (2022 $).
Annual operation	Cost neutral	Redeployment of operational savings.
Project lead time	16 weeks	Project setup, planning and manufacturing time.
Project duration	102 weeks	Two dedicated crews @ 40 units/week.
Benefit timing	Immediate	One day for high-energy defects, one month for low.
System service life	15 years	One mid-life site visit for battery change and inspection.
Customer impact	None	No installation outage, no soil or crop damage, minimal consultation needed.
Environmental impact	None	One small item added to an existing pole.
Other impacts	None	No disturbance to native vegetation, etc.

As Victoria's weather cycle relentlessly moves back to hot dry Summers over the next decade, it should be remembered that SWER powerline fires started nine of the sixteen major fires in the 1977 Trentham fires, four of the eight major fires in Ash Wednesday 1983, and five of the eleven major fires on Black Saturday, killing 119 people on that one day alone.

Since Black Saturday, Victoria has spent over a billion dollars making its rural powerlines more fire-safe, but the amount spent on SWER powerlines has been small. From a total program perspective, a thirty-million-dollar whole-of-SWER rollout of the new FireSafe SWER EFD technology appears barely material, and the fire-safety benefits to Victoria's communities would be major. Comments made to IND.T by landowners during site visits indicate they see full EFD rollout on SWER as a 'no brainer'.

11. The outlook is for even more value from FireSafe SWER EFD

The new FireSafe SWER EFD design already performs as well or better than current polyphase EFD systems. For the first few months, system tuning and debugging will bring all installed units up to a common standard of performance and reliability. This period will also include a review of the data communications performance of local 4G/3G services which may prompt action to address local 'black spots', e.g., by fitting of external high-gain YAGI antennas in some cases.

The rollout in this project has established a powerful stable hardware platform capable of many performance and functionality enhancements delivered by firmware updates applied over the Internet. Currently planned enhancements to be delivered this way over the 24 months of the extended FireSafe SWER EFD Trial include:

1. **Input digital filter** to eliminate interference from local radio stations.
2. **Continuous signal sampling** to ensure abnormal events of very brief duration are located.
3. **Streaming signal analysis** for more accurate location and detection energy data.
4. **Active signal matching** for improved noise-immunity and resilience against peak-flooding.

Other enhancements are likely to be identified and implemented by firmware upgrades as further experience is gained in the next phase of the Trial.

The new FireSafe SWER EFD systems provide additional high-accuracy data on the voltage waveform of the 230V power supply, including a full harmonic analysis. This data is likely to be of value in network planning and investigation of quality-of-supply issues as solar power becomes more universal on remote SWER networks. Appropriate data visualisations for this data and the data from the new weather stations are under development.

12. Conclusions Findings and Recommendations

The conclusions, findings and recommendations arising from the project are set out here.

12.1. Conclusions:

The project met its targets despite considerable pressure from external global factors. The project partners developed and delivered a radical new version of Early Fault Detection technology designed for low-cost deployment on Victoria's SWER powerline networks. This met the first project objective: a version of EFD for SWER with enhanced performance and less than half the previous deployment cost. In the first few months of operation, the new FireSafe SWER EFD systems have already proven their effectiveness in finding SWER powerline defects potentially capable of development over time into fire risks.

The second phase of the Trial has now commenced: progressive software optimisation, and SWER network monitoring, plus assessment of the operational value of real-time local weather data supplied by the deployed hardware. The second project objective (benefits assessment) is on track for full achievement in this monitoring phase, though fire-risk reduction benefits of the new technology are already evident.

IND.T's work towards the third objective (export market development) has now commenced with some brief initial discussions with a major Californian utility about the use of the new FireSafe EFD technology on long two-wire tap-lines (spurs). Further discussions will follow as will a marketing plan for other Australian States. NSW and Queensland have already shown interest.

On any objective measure, the project successfully met its targets and objectives while staying within five per cent of its original budget.

12.2. Findings:

The findings from the project are:

1. On single wire powerlines, sensing of radio signals using a tap on the customer's 230V power supply wiring is as effective as sensing using a high-voltage capacitive sensor.
2. The use of low-voltage sensing changes the appearance of some aspects of EFD signal analysis, but the core performance parameters of sensitivity and location accuracy are preserved and enhanced. FireSafe SWER EFD works well and has already started to find anomalies on SWER powerlines in the Trial.
3. 230V power supply wiring can carry high levels of signal from local radio stations, and it is desirable that input digital filtering be added as an option for EFD units affected by this interference. The input 230V wiring to the FireSafe SWER EFD unit should also be designed to minimise radio signal pick-up.
4. The FireSafe SWER EFD technology represents a seventy per cent cut in installation cost and a fifty-four per cent cut in manufacturing cost compared to previous versions of SWER EFD. Overall deployment cost has been cut by sixty-four per cent.
5. Deployment of FireSafe SWER EFD technology to monitor all 30,000 kilometres of Victoria's SWER powerlines is financially and technically feasible. At $30 million, it would represent a minor addition to Victoria's billion-dollar investment in powerline bushfire safety since Black Saturday while delivering major powerline fire safety benefits to Victorian communities.

12.3. Recommendations

Based on the findings in this project, IND.T makes the following recommendations:

1. The project partners should continue the 24-month monitoring phase of the Trial to refine insights into the benefits of the new FireSafe SWER EFD technology and to develop export markets for it.
2. The Victorian Government and the Victorian Electricity Supply Industry should work to plan, fund, and achieve full rollout of the new FireSafe SWER EFD technology to protect Victorian communities from the continuing fire-risk created by Victoria's 30,000 kilometres of SWER powerlines. This work should be started now so it can be completed before the long-term weather cycle brings Victoria back to El Niño conditions with hot, dry Summers.

IND.T would like to thank the Victorian Government and the two network owners AusNet and Powercor for their major resource contributions and excellent and productive collaboration displayed in this project. It was truly a team effort.