Establishing Sufficient Redundancy: Protection & Telecommunication

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Abstract:
The principles of using telecommunication links to improve the performance of protection schemes are well known and are standard practice throughout the world.

Distance protection relays often use signalling channels to speed up or control the response of relays at the remote end, current differential relays use medium speed communication links to enable comparison with currents measured at the remote end, or circuit breaker fail schemes send direct trip signals to the remote ends to ensure system stability and fault isolation. “Wide area protection” principles and generator “run back” schemes are increasingly relying on telecommunications as the enabling technology.

A key principle for ensuring power system security is using duplicated protection systems. In this respect, the basic principles of protection have not varied significantly despite the change from electromechanical to static to numeric/digital designs.

Telecommunication networks also encompass continuity of service provision as a key objective. However electric power utilities have seen a significant change in technologies and, as a result, also a dramatic change to telecommunication network designs. Copper pilots and power line carrier are now being superseded by microwave radio and optical fibre networks. These networks have been progressively established and interconnected using principles of duplication and geographic route diversity relative to the provision of individual services giving a sense of duplication as implying overall reliability of the power network.

Many countries are now introducing regulations (also known as codes or rules) as over arching standards around the design and performance of the electricity networks including the features and operation of the protection and telecommunication systems. These standards increasingly create more stringent requirements on the primary system design and the associated protection and telecommunication systems. This paper explores some of these issues in respect of mesh networks and tee- line configurations for high voltage systems. These systems typically use distance protection or current differential protection, and hence this paper considers the telecommunication network design and the associated service or channel allocation strategy.

The key conclusion is that the protection engineer cannot simply rely on the existence of two telecommunication paths at the substation as sufficient evidence of compliance to the power system performance, operation and design rules.

1. Reliability Fundamentals

Protection systems have long held a basic principle that at least two forms of protection must be able to clear a power system fault independently of each other. This principle is born out of the essential requirement to ensure the power system is adequately and appropriately isolated before consequential damage to other plant and equipment or instability of the power system itself sets in.

Recent events around the world have added a further dimension to protection system principles to prevent wide spread power system collapse. Certainly the potential for widespread disturbances needs to be better

considered in protection design but the essential principle of reliability under all circumstances will never change, albeit a better understanding of “all circumstances” will continue to evolve.
This fundamental principle has generally been achieved by either redundancy of equipment or at least some form of back up system.

Typically high voltage protection systems have opted for system redundancy involving segregated battery banks, fully independent protective relays, independent trip coils and even segregated CT cores. Generally voltage transformers are not duplicated; however individual circuits are created within the VT in order to at least provide some redundancy against wiring faults from the VT terminals. Circuit breakers themselves are not duplicated due to the cost; however independent duplicated trip coils provide a high confidence level that the breaker will operate successfully as a result of either protection system operation. It simply then remains to ensure the breaker is well maintained, and in some cases even continuously monitored, to ensure correct performance.

Lower voltage protection systems however tend to rely more on back up protections, which either locally or remotely, provide a second means of clearing the fault. These back up systems may operate slightly slower than the primary protection system and may result in a more widespread power system outage. However using a second stage of protection to isolate the fault before more significant damage or power system instability occurs is the prime objective.

2. National Rules

Australia now operates, as many countries, with a deregulated industry operated by the Australian Energy Market Commission (AEMC)[1] In order that the overall power system can be expected to perform reliably for all network participants, AEMC have established a performance code to provide guidance for the design, operation and maintenance of the power system. In Australia this code is known as the National Electricity Rules (NER).

Whilst some utilities are not participants in the National Electricity Market, and hence are not bound by the NER, the mere existence of the NER sets a benchmark for “good industry practice”. Hence, even non-market participants could be judged against the NER by the public or their clients simply as a measure of their professional standing and service delivery.

The Australian NER has a number of references to protection performance and the associated telecommunications links. The most relevant sections for this discussion are[2]:

> *S5.1.2 Network reliability*
> *S5.1.2.1 Credible contingency events*
> *(d) The Network Service Provider must ensure that all protection systems for lines at a voltage above 66 kV, including associated intertripping, are well maintained so as to be available at all times other than for short periods (not greater than eight hours) while the maintenance of a protection system is being carried out.*

And:

> *S5.1.9 Protection systems and fault clearance times*
> *Network Users*
> *(d)….the primary protection system must have sufficient redundancy to ensure that it can clear short circuit faults of any fault type within the relevant fault clearance time with any single protection element (including any communications facility upon which the protection system depends) out of service.*

Noting that the Rules apply to market participants operating above 66kV, the use of telecommunication systems and their degree of redundancy when applied to transmission and sub transmission networks needs to be evaluated.

Whilst the concept of protection system redundancy is not unusual, the NER now firmly ties the telecommunication system to the same

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Footnotes:
[1] AEMC web site http://www.aemc.gov.au/

[2] Extracts from AEMC web site http://www.aemc.gov.au/pdfs/rules/NER%20-%20v14%20-%20Chapter%205.pdf page 80 and 88

requirements. Telecommunication links may well have been duplicated in some areas however some utilities have not employed redundant systems throughout their network, whether due to cost benefit considerations in remote or less critical areas or simply just due to the evolution of the network. The telecommunications network may also have not completely ensured that a telecommunication link does not affect performance of both protection systems i.e. one bearer may be carrying both protection services.

These two clauses in combination place a higher level of service for both protection and telecommunication technologies and imply a greater degree of impact when such technologies fail. In such instances, whether planned maintenance or equipment failure, the power system may continue to operate with only one form of protection in service for up to eight hours. <u>At the end of this period</u>, if there is <u>only one protection system</u> operating capable of clearing faults within the allowable fault clearance times, the implication is that the <u>line must be taken out of service</u>. It is this implication that must drive careful analysis of the telecommunication redundancy levels.

3. Telecommunication Technologies

Before considering a typical simple power system configuration and the application of the NER principles to the telecommunication system design, the differences between the general telecommunication technology choices should be noted. It is not the intent or need of this report to indicate any specific preference of technology as there are many influencing factors to this decision. These include existing systems (or lack thereof), strength of structures to support new technologies (line and radio towers), visual and environmental impact, terrain, capacity (bandwidth) requirements for the number of services (signals) to be carried, maintenance and response staff skills, spares requirements, network management systems, remote configuration and re-routing capabilities to name a few.

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Table 1 Telecommunication Bearer Risk Considerations

Technology	Copper pilots	Power Line Carrier	Radio	Fibre optic
Benefit	Simple technology	Easily applied but very limited bandwidth – basic protection signalling functions only	Good bandwidth. Power system route independent	Large bandwidth OPGW type installations generally don’t suffer fibre breaks. May be difficult to retrofit
Main risks	High risk of 3rd party induced failure (digging through cables) Tend to be old and more prone to ageing failures or breakdown due to lightning strikes	Electronic equipment at each end Limited bandwidth	Electronic equipment failure Tower failure Path interference Atmospheric effects.	Electronic equipment failure Low fibre break risk for OPGW Higher break risk for ADSS and buried cable
Response time	Long reinstatement times to repair cables	Influenced by travel time and spares	Influenced by travel time and spares Tower failure has long reinstatement times SDH network may provide remote rerouting capability	Influenced by travel time and spares Fibre breaks have long reinstatement times SDH network may provide remote rerouting capability

This leaves the utility with a decision regarding likelihood vs. risk. On one side is the likelihood that a link will fail and remain out of service for eight hours vs. the increased telecommunication cost to manage that risk. Depending on the technologies used, the location of the transmission lines relative to service centres, the call out response time and the "mean time to restore" times will modify each utilities answer to this decision. The likelihood issues will include such factors as noted in Table 1. It is these factors that will heavily influence the degree of impact the Rules have on the telecommunication network design

An additional consideration of the choice of technologies for an individual link is the possibility of nominally diverse routes sharing some form of common mode of failure.

This is a complex issue needing careful risk assessment; however they must cover such issues as:

- Radio links sharing a common tower
- 2 Power Line Carriers on the same tower but different circuits
- Power Line Carrier and OPGW[3] / ADSS[4] on the same tower
- 2 OPGW / ADSS on the same tower
- 2 fibres in one OPGW / ADSS cable

Many utilities have also questioned the use of their own private networks vs. contracted services from a general telecommunications carrier. Such considerations should be treated very carefully in respect of having sufficient control of the network and its configuration for true redundancy, i.e. the carrier may divert nominally diverse signals over a common bearer without reference to the utility. More importantly, typically carriers cannot provide the eight hour service restoration response times of less than eight hours, especially in regional areas (where even just the call out time may be as much as 48 hours) which effectively rules out such considerations as the carrier is not likely to accept market or consumer penalties for loss of electricity supply or non compliance to the Rules.

4. Applying NER Principles to a Simple Network

It is well known that no two power systems are the same and even similar systems may well have widely varying solutions to different aspects of their design. It is therefore a tall order to attempt to define a standard interpretation of the application of the NER principles to all power systems. However, it is useful to consider a reasonably simple section of a typical network at least to understand the underlying issues for consideration in more complex networks.

Figure 1 Typical simple mesh power system

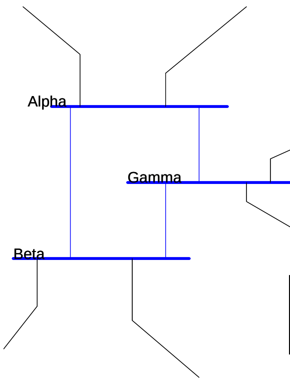


Figure 2 Simplified triangle mesh

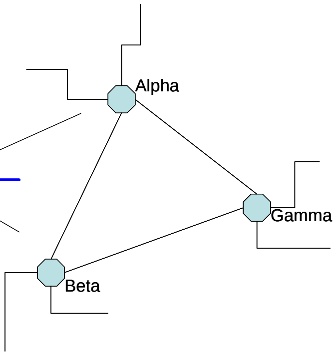


Figure 1 shows a simple but typical power system arrangement between 3 substations: Alpha, Beta and Gamma.

On the assumption that this particular network and protection system design requires a telecommunication network between the substations, the principles of duplication and independence must also apply to the telecommunication system. This has been shown more simply in Figure 2 as a simple triangle mesh.

Clearly there are three lines to be protected each with duplicated systems.

- Alpha-Beta
- Beta-Gamma
- Alpha-Gamma

Footnotes:

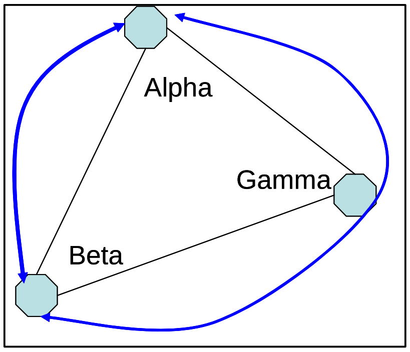
[3] OPGW: Optical Pilot Ground Wire – optical fibres inside the overhead earth wire strung on top of transmission lines

[4] ADSS: All Dielectric Self Supporting cable – optical fibre cable slung underneath power lines

The basic requirement is that the two telecommunication path for each set of protection for each line must follow a diverse route.

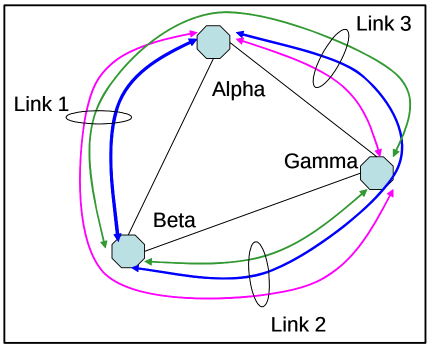
Hence there are two communication paths between Alpha and Beta as shown in Fig 3. One path is direct, whilst the other is via some other route.

Figure 3 Minimum Telecommunication Link Requirement for Alpha –Beta line



Similarly for each of the other two lines, there are two paths required which can be satisfied using three links.

Figure 4 Total Telecommunication Network



It is not surprising therefore that the first consideration is to use a direct communication bearer between each of the substations. Each bearer would carry the direct path between the two substations and the diverse route for the other two lines as shown in Fig 4. Each link is therefore carrying two protection services – one direct service and two alternative route services.

Such solutions provide a very simple and low cost system for the telecommunication requirements to support a duplicated protection system with just two telecommunication links at each substation. However, the broader aspect of the Rules must be considered.

Therefore considering Fig 4, failure of any one of the telecommunication links will have significant consequential outages if not restored within eight hours.

Considering failure of any one link, say Alpha-Beta Link 1, the Alpha-Beta transmission line will only be protected by the alternative route via Link 2 and 3. Hence after eight hours, Alpha-Beta transmission line must be considered for being taken out of service if Link 1 is not restored.

In addition, Link 1 is also providing the alternative route for the duplicated protection for Beta-Gamma which will therefore be left with only its direct telecommunication via Link 2. Therefore the Beta –Gamma line will have the same eight hour limit before being required to be taken out of service for failure of Link 1.

Similarly, the Alpha-Gamma line will only have its direct telecommunication link operating via Link 3 and will also have the same eight hour limit before necessitating being taken out of service.

Therefore after eight hours, if Link 1 cannot be restored, there may be no connections left in service between the three substations. Table 2 summarises the risk implications for each of the lines with respect to the failure of each of the links. Two or more "Yes" against a link failure represents a heightened level of electricity network risk – this arrangement is obviously an extreme risk profile.

Table 2 Outage vs. Failure Risk Profile - 3 links

Link Failure	Alpha-Beta	Beta-Gamma	Alpha-Gamma
1	Yes	Yes	Yes
2	Yes	Yes	Yes
3	Yes	Yes	Yes

Given that failure is inevitable at some time, the risk of exceeding the eight hour limit must be weighed against the cost to mitigate this risk.

Noting that just using three links may lead to an unacceptable islanding of the power system, the next best solution is to consider a fourth link in order to isolate some services. As shown in Fig 5, the 4th link could be installed as a second direct path Alpha-Gamma and its failure will only affect Alpha-Gamma operation.

In this situation, failure of Link 3 will no longer affect the Alpha – Gamma line at all since no relevant services are carried on it. Hence a significant reduction in consequential outage is achieved.

However failure of Links 1 or 2 still places all three transmission lines at risk of suffering the eight hour rule.

Figure 5 First Stage Risk Mitigation - 4 Links

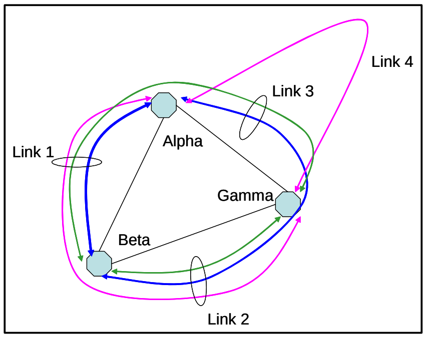


Table 3 Outage vs. Failure Risk Profile - 4 link

Link Failure	Alpha-Beta	Beta-Gamma	Alpha-Gamma
1	Yes	Yes	Yes
2	Yes	Yes	Yes
3	Yes	Yes	
4			Yes

Further improvement is achieved by adding a fifth link as shown in Fig 6 with one section of the alternative route for Alpha-Beta routed independently of Link 2 but still utilising Link 3 to complete the path.

As shown in Table 4 choosing to divert one section of the alternative path for the Alpha – Beta line also changes the risk profile with less red sections.

Figure 6 Second Level Risk Mitigation – 5 Links

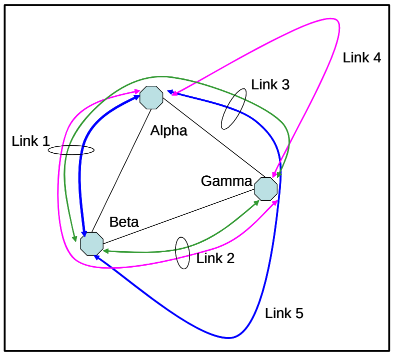


Table 4 Outage vs. Failure Risk Profile - 5 links

Link Failure	Alpha-Beta	Beta-Gamma	Alpha-Gamma
1	Yes	Yes	Yes
2		Yes	Yes
3	Yes	Yes	
4			Yes
5	Yes		

An alternative arrangement whilst still only using five links is shown in Fig 7 where the fifth link is another “direct” link Alpha-Beta, i.e. not passing through Gamma and Link 3.

Clearly this pattern indicates that wherever there are two protection paths sharing a common bearer, there will remain situations where the failure of one link may impose the eight hour limit on two, if not all three transmission lines.

Figure 7 Third level risk mitigation – alternative 5 Links

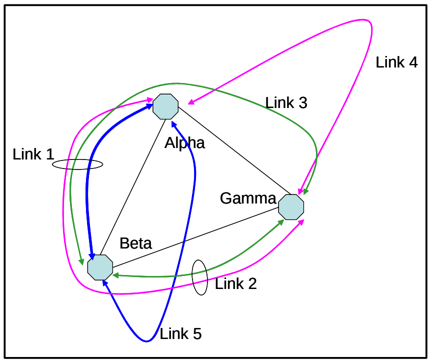


Table 5 Outage vs. Failure Risk Profile - alternative 5 links

Link Failure	Alpha-Beta	Beta-Gamma	Alpha-Gamma
1	Yes	Yes	Yes
2		Yes	Yes
3		Yes	
4			Yes
5	Yes		

It is therefore not surprising that the only total risk limitation of any link affecting only one transmission line is to provide six links as shown in Fig 8 with four fully independent and diverse route links at each substation. Naturally and not unexpectedly, such a simple system can only be fully protected with complete risk limitation through the use of six fully independent telecommunication links. Of course this must be weighed up as mentioned previously as the balance of total cost vs. likelihood vs. mean time to restore as well as the importance of the transmission line elements themselves.

Figure 8 Ultimate risk limitation – 6 links

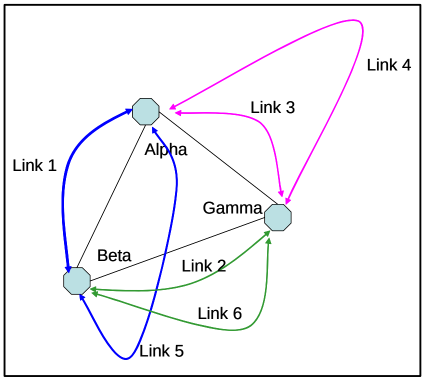


Table 6 Outage vs. Failure Risk Profile - 6 links

Link Failure	Alpha-Beta	Beta-Gamma	Alpha-Gamma
1	Yes		
2		Yes	
3			Yes
4			Yes
5	Yes		
6		Yes	

Certainly the essential point of learning in this analysis is that the protection engineer cannot ignore the obligation of understanding how the telecommunication links are provided. Simply accepting that there are two independent paths from each substation is not sufficient evidence that compliance with the Rules has been achieved.

5. Application to general networks

The above analysis focuses on a fairly simple, but typical section of a power network. The direct conclusion of this analysis is in essence quite simple – no telecommunication link should carry more than one protection channel. This is essentially obvious as if any link anywhere in the entire network which normally carries protection services for two lines is out of service, those two transmission lines will be at risk of being forced to be isolated at the end of the eight hour rule.

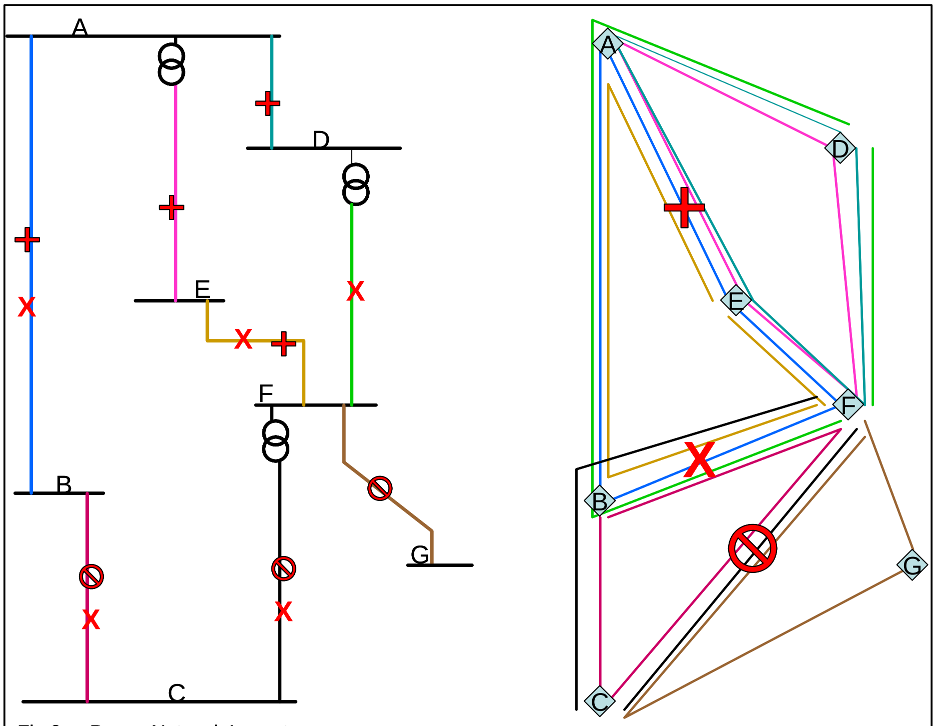


Fig 9-a Power Network Impact

Fig 9-b Telecommunications Network Backbone failures

This conclusion has a very large impact on telecommunication network and power system planning, operation & design.

Telecommunication networks are generally designed with redundancy in mind by providing two separate paths between locations. However it is generally common practice that the paths may carry more than one protection signal provided they are not for the same section of transmission line. The Rules now directly challenge that practice.

Some degree of pragmatism is clearly required to provide a reasonable balance between minimising risks of dual line outages as a result of a telecommunication link failure vs. the total cost of individual links for each protection signal.

The simple network presented above would result in three islands of network if the original minimal implementation is adopted. It would need a broader understanding of the rest of the networks to establish if there were other power system connections will keep the three sections connected to prevent islanding.

Most power systems have multiple power routes and multiple voltage levels with a variety of power flow scenarios. The telecommunications network in support of these power systems can develop into quite a complex web of telecommunication links. It is not surprising that in such situations the telecommunication links may incorporate a backbone arrangement where several protection services for various lines and voltages are carried on the one telecommunication link as shown in Fig 9.

The two protection signals for each section of transmission line are coded the same colour and as a continuous line – e.g.D-F green transmission line has one green telecommunication signal line direct D-F and the second green telecommunication line D-A-B-F.

Figure 9 Complex network with backbone telecommunications

This places a high risk factor for widespread system outage at the end of the eight hour limit for a failure of any of the main back bone links. Fig 9b shows 3 of the many scenarios of backbone failures indicated by ⊘, ✚ and ✕ with Fig 9a showing the affected lines respectively.

The complexity of this interrelation can be seen in Fig 9 where the telecommunication link B-F, failure mode ✕, does not have any directly corresponding transmission line connection between these two substations, yet the link carries services for five transmission lines which will therefore have the eight hour criterion applied should it fail, and hence splitting the network into four islands.

Even radial or spur lines to substations such as G, as well as 2 other transmission lines, may be affected by backbone link failures of the link C-F ⊘.

This implies the electricity network planning and telecommunication network planning sections must work closely to ensure that projects take these issues into consideration. The important consideration is that where a telecommunication link does fail, taking the associated transmission line segments out of service will not lead to islanding or instability of the grid.

Modern telecommunication technologies are in themselves also providing more options for carrying individual transmission line protection signals.

Power Line Carrier (PLC) has been a well proven direct substation-substation communication bearer.

Similarly OPGW based optical fibre installations offer the same sub-station-substation direct telecommunications path.

Hence OPGW and PLC do provide a degree of independent direct path diversity, to this simple network presented above. However the debate regarding common mode failure of the tower does need to be considered.

Microwave radio of course may provide direct line of sight for some transmission lines whilst in other areas may require repeater sites. In some instances, signals may be routed through backbone sections of the network along with other protection signals which in itself must be evaluated carefully at the individual signal layer.

Beyond these technologies is of course non – OPGW based optical fibre routes such as buried cable or indeed via a general telecommunications service provider (SP).

This then gives a range of combinations to be considered as shown for typical combinations in Table 7.

Table 7 Bearer Combination Considerations

Combination	Considerations
PLC + OPGW	same tower
PLC + radio	other signals on same radio path
OPGW + radio	other signals on same radio path
PLC + buried cable	low risks
OPGW + buried cable	low risks
Radio + buried cable	low risks
PLC + SP	control over routing and other signals on same path

6. Applying NER Principles to a Tee Network

Having considered a typical mesh network arrangement, some other aspects become evident in considering tee network arrangements

In first principles the 3-ended aspect of a Tee transmission line is exactly the same as the mesh arrangement, i.e. there are three nodes with information to be shared to every other node.

However the operation of the transmission line and the protection devices must be considered in a slightly different context.

A Tee connection is most likely to have been established as part of a low cost augmentation of the network to create a mid line substation with minimal plant and equipment. It is therefore most likely that there are already two telecommunication links serving the existing line.

In order to adequately protect Tee lines, 3-ended current differential protection is generally the preferred scheme. Distance protection schemes are rare due to the variations in network impedances under 2-ended and 3-ended configurations which may lead to mal-operation or no operation at all. Current differential schemes, or their alternatives, are immune to these problems and also will require information to be sent to each end of the line.

These 3-ended protection relays will therefore each require two communication links to connect to the other two ends. Using the “Set 1” and “Set 2” naming, , Set 1 requires two telecommunication links at each substation and so does Set 2. Hence four telecommunication links, each fully independent and route diverse, must be provided at each substation. This totals six telecommunication links as shown in Figure 10. The low cost substation solution of a tee connection therefore demands four new telecommunication links to be established. Hence there is no savings in telecommunication system between a mesh network and a Tee line arrangement, both requiring six links in total, four at each substation.

Figure 10 Full Tee Line Arrangement

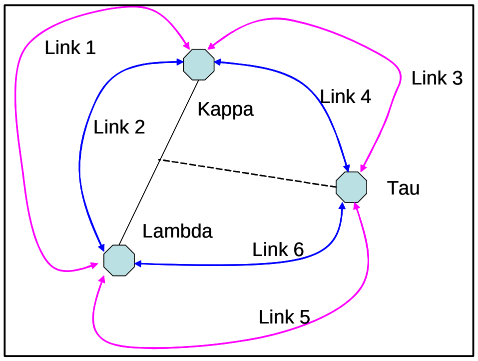
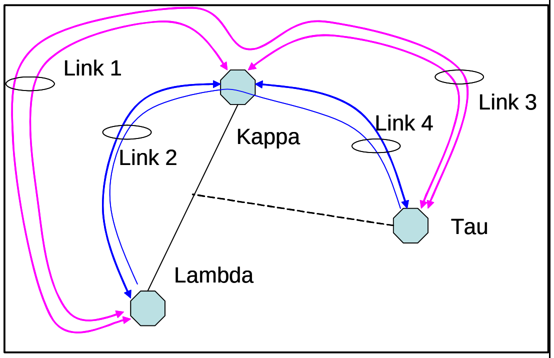


Figure 11 Minimised Tee Configuration



There is one simplification of this arrangement using only four links as shown in Figure 11. On the basis that information has to be sent to all three ends via one common node end, two of the links could be removed. There are two significant downfalls of this scheme to be noted.

The first is that the links must be totally dedicated to either Set 1 or Set 2 as shown. It is not permissible that Set 1 is carried over Link 1 and Link 4 whilst Set 2 over Link 2 and Link 3. In such circumstances failure of any one link will render all protection inoperative or at best revert to a degraded performance with risk of mal-operation or no operation at all for a power system fault condition. In such circumstances, the fundamental principle that permits the eight hour rule is not met because neither protection system is still fully operational. Hence all three substations must be tripped immediately any one telecommunication link fails.

The second aspect of this minimum arrangement is that there is no tolerance in the protection system for failure of any one link. In the full scheme Figure 10, the current differential relays of each Set can still obtain information of the other two ends via the remaining operating links, ie both protection systems can still be operating normally despite the failure of the telecommunications link. It is only on failure of a second link that the relays are forced to revert to distance protection mode. However in the Figure 11 arrangement, failure of any one link will render one of the current differential schemes totally inoperative, or at best will revert to a back up distance protection mode with the pursuant risks of mal-operation under normal network operation or no operation for a true system fault. Hence the system would only have one protection system operating.

Yet another alternative arrangement that could be considered depends on the nature of the Tee connection. The discussion so far assumes that all substations have a requirement for ongoing operation and connection to the grid at all times. However some substations may be considered as volatile connections. As such it may be acceptable that the Tee substation is switched off as a result of certain conditions that would otherwise put the network in breach of the Rules.

In the most simple of such volatile substations a very low cost telecommunication system could be proposed as just one telecommunication link providing both Set 1 and Set 2 protection services as shown in Figure 12. This would require a contractual agreement that should that telecommunication link fail, then the Tee would be also switched off, reverting the line to traditional 2 ended line with an open stub line.

At first this seems an ideal minimum cost solution. A single telecommunication link with a contractual arrangement to switch the tee off when the link is out of service.

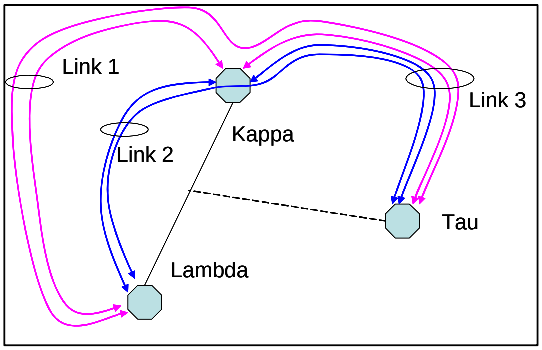


Figure 12 High Risk Volatile Tee Arrangement

However this arrangement is in reality putting the system at far greater risk.

Consider the situation where the single Tee telecommunication link fails. The relays at Tau substation would detect the failure and initiate opening of the Tau breaker. The relays at Kappa and Lambda substations would also detect the loss of signal from Tau. . On the basis that the scheme is designed to trip the Tau breaker, Kappa and Lambda would assume they can now revert to the two-ended line configuration.

If all works correctly, the network would remain stable and properly protected. However, the requirements of the Rules and general protection principles require a more detailed consideration, including that of a circuit breaker failure (CBF) condition. Opening of a circuit breaker (CB) is one of the most important actions in ensuring system security and reliability as this is the process of isolation of the network. If the CB fails to open, the network may be subject to more widespread damage as a result of the original fault, or may lead to more widespread outage, consequential network instability, islanding and shutdown in a domino effect.

In order to cater for CBF situations, it is common practice to provide some form of signalling to remote substations to cause the CB at the remote substations to open to still contain the extent of the network outage to the minimum possible zone.

With the failure of the single Tau telecommunication link, the Tau CB must be opened. If a CBF occurs at this instant, Tau will remain connected to the grid as a 3-ended Tee arrangement. However Kappa and Lambda protection will have re-configured to the 2-ended arrangement, assuming Tau to be isolated.

Clearly with the loss of Link 3, the CBF signal will not be sent to Kappa and Lambda.

It is also highly likely that the Kappa and Lambda protections will mal-operate seeing the Tau load/generator inside the tripping characteristic as a fault condition, resulting in the main line to be tripped at Kappa and Lambda. Equally the relays may not operate at all for a true fault condition because the Tau load/generator is still connected.

Hence the process of complying with the contractual arrangements by initiating tripping of the CB could lead to the CBF and total shutdown of the main line.

Of course it could also be the case that a fault has occurred in Tau necessitating opening of the Tau breaker and a failure of the telecommunication link occurs at the same time.

Furthermore, as there is only one telecommunication link out of Tau, the system control operators will have no status or load signals from Tau, essentially making them blind to the status of Tau. Nor will the operators be able to initiate any open or close commands of their own in attempts to restore the network. It is also highly likely that the operators could assume that Tau is off line having noted the telecommunications link failure and seek to re-close the Kappa & Lambda breakers unaware that Tau is still connected to the line. This may lead to unexpected power flows when those breakers are closed leading to further network instability as a result of closing on to load or a live generation source which would normally require a synchronising process between the two networks.

Hence whilst a contracted volatile Tee arrangement may appear to permit a low costs arrangement with only a single link, the remaining grid is left in a high risk condition with all the risk and liability resting on the network owner, not the Tee connection.

7. Tee lines with split distance protection

A slight variation to a Tee arrangement is the partial Tee. This is an arrangement where electrically the transmission network looks like a Tee but the protection system splits the network into 2 or 3 legs either side of the Tee point. This is achieved by establishing a minimum equipment facility at the Tee point where CTs and isolators, but no CBs, along with associated protection and telecommunication equipment can be located.

This configuration then allows each leg to be protected using standard distance protection schemes as the Tee load no longer influences the distance relay tripping characteristic.

This arrangement now works on the assumption that a fault in one leg will be seen by a distance relay at one of the substations and by the distance relay at the Tee point. Naturally the substation relay can initiate trip of its CB directly. The Tee point relay looking back to the fault must initiate tripping of the other two ends by a direct intertrip signal. The whole line is still tripped but with the aid of remotely controlled isolators at the Tee point, the faulted section may be isolated and the other two ends quickly reinstated.

However analysing both the distance protection and direct tripping communication requirements from the Tee point for each leg with Set 1 and Set 2 requirements, it is quickly evident that there is no saving in telecommunication links compared to a full substation arrangement instead of a Tee facility, i.e. two links are definitely not sufficient and at least four links will be required at each location for proper compliance.

8. Conclusion

The analysis of these principles presented here is straight forward and hardly a revolution in engineering.

However the subtle implications of the two clauses in the Australian National Electricity Rules combine to challenge how the telecommunication network is developed and the number of telecommunication links that are required at each location. Noting that the Rules do not encompass a risk assessment or cost/benefit criteria of compliance to these requirements, i.e. compliance is mandatory and assumed; there is a significant impact to market participants with geographically dispersed networks.

Certainly for the protection engineer these requirements demand a good understanding of the “black art” of the telecommunication network and how it operates. In particular it must be recognised that two telecommunications paths from a substation is highly likely to be not sufficient to achieve compliance to the Rules.

These Rules place a strong requirement that the electrical network planners must work closely with the protection and telecommunication engineers to establish the correct arrangements for compliance. Certainly if there has been any tendency in the past to treat telecommunications as an after thought or only implement low cost network solutions, these must be re-evaluated, especially where 8 hour response times may be a critical factor.

9. Biography

Rod Hughes[5] has worked in the electric power industry for over 25 years in engineering and management roles covering applications, R&D, manufacture and marketing of protection products and systems. He has worked for (now) AREVA manufacturing and supplying products and systems to the world market.

Rod also served in ElectraNet for 3 years responsible for the technology and project strategy implementation for the 132 and 275kV network in South Australia covering lines, primary equipment, secondary equipment and telecommunications.

Over the last three years, Rod has been in the engineering consulting industry and is currently Technical Director – Power Advisory Services for Maunsell Australia Pty Ltd[6] based in Adelaide.

As a long serving member of the CIGRE Australia B5 Protection & Automation panel from 1985, Rod is currently serving as Convenor of the Panel being involved in the international Study Committee B5 and a number of the B5 Working Groups including B5.11 Implementation of IEC61850.

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