Hidden High Voltage Safety Risks for Parallel High Voltage Transmission Lines

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Abstract**-- High voltage (HV) infrastructures market is growing due to the corresponding growth in industries and population. To ensure continuous and reliable electrical power supply, existing substation and transmission lines are being upgraded to accommodate the additional load requirements. These upgrades involve up-rating the existing transmission lines or the installation of new lines. To save on easement cost and reduce the environmental impacts, transmission lines are occupied the same easement or path. This parallel option introduces the risk of induced voltage which could reach an unsafe condition and jeopardize the safety of works and people. This paper analysis and highlight the hidden risk associated with two parallel transmission lines that connected the same high voltage substation. The theoretical study which is supported by the case study shows the high risk potential tempering with the OHEW on the isolated circuit while the other one is still energized**

Index Terms**—Earth Potential Rise, Fault Current, High Voltage Transmission, Induced Voltage.**

I. Introduction

Electrical power forms an essential element for human daily ongoing activities. Numerous happenings would have been impossible without the aid of the electrical power. The generated electrical power, at the power station, passes through numerous stages to reach the consumers. One of these stages is the transmittal of the generated energy using transmission lines.

The transmission lines are essential to transfer the electrical energy between numerous high voltage infrastructures such as power station, bulk supply point, transmission substation and zone substation. To reduce the easement cost and the environmental impact, where possible, these transmission lines occupy the same easement route. Figure 1 shows the transmission lines arrangement for the main energy supplier to NSW, Australia, electrical utilities [1]. It is clearly shown within figure 1 the numerous transmission lines run parallel and connect the same high voltage infrastructures. It is worth mentioning, two transmission lines that connects the same substation are usually physically segregated for reliability, serviceability and availability purposes.

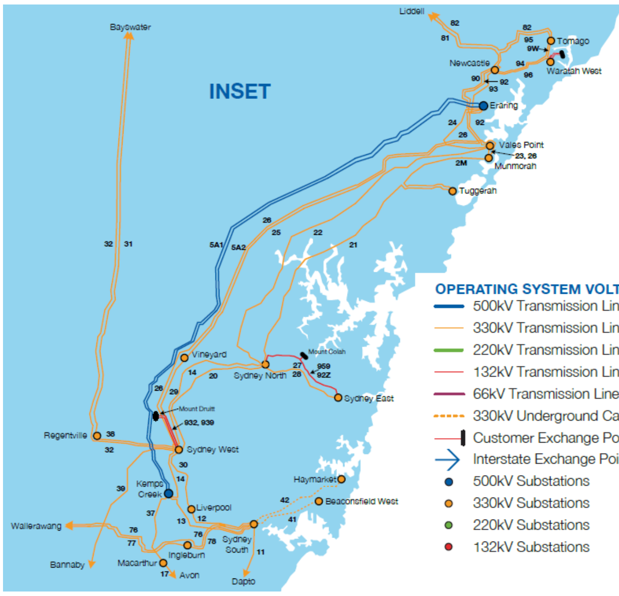

Fig. 1: Transgrid electrical network map for NSW Australia

Induced voltage on parallel conductive object to an energized transmission line could reach an unsafe condition under fault and load conditions [2]. Therefore, parallel transmission lines introduce the risk of induced voltage on each other conductive conductors which include the overhead earth wire (OHEW).

The OHEW form an essential element for the transmission lines when it comes to fault current distributions and lightning protections. The maintenance of high voltage transmission line includes the OHEW. As the OHEW is earthed at each pole, workers assume it is safe to perform the job as long its circuit is isolated and earthed. This theory overlook the hidden risk exists on the isolated and earthed transmission under fault condition on the energized parallel feeder.

The works in this paper analysis and highlight the hidden risk associated with two parallel transmission lines that connected the same high voltage substation. The theoretical study which is supported by the case study shows the high risk potential tempering with the OHEW on the isolated circuit while the other one is still energized.

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II. Analysis

The flow of phase conductor current creates a magnetic field which induces a voltage on any conductive object running parallel to the current. The OHEW current is driven by the split factor and the included voltage concept [2-7]. Figure 2 represents a transmission lines with continuous OHEW that connect both substations [8].

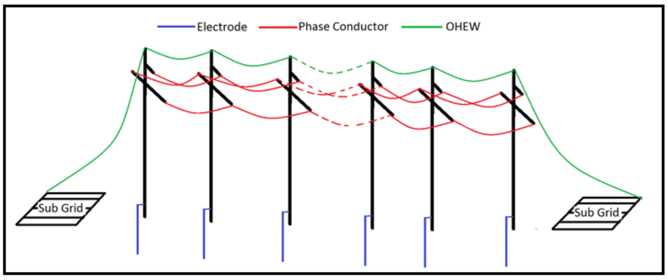

Fig. 2: Transmission lines with continuous OHEW between two substations

Figure 3 shows the electrical circuit for fault current distribution under the continuous OHEW shown in 2 [8].

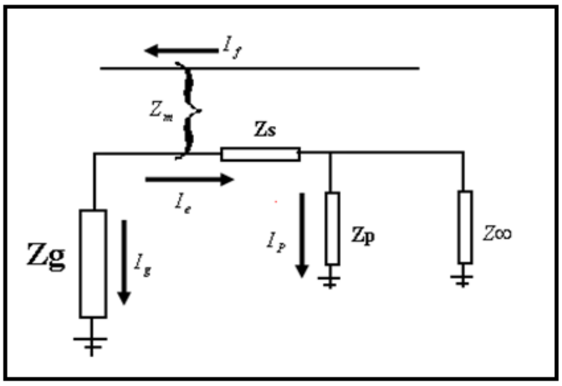

Fig. 3: Split Factor circuit analysis

where,

Z_s is the OHEW self-impedance for the average span,

Z_p is the pole earth grid resistance,

Z_∞ is the OHEW input impedance [8],

Z_m is the mutual impedance between the faulted phase and the OHEW,

I_f is the fault current,

I_g is the earth grid current,

I_P is the transmission pole earth grid resistance,

I_e is the OHEW return current.

Equations 1, 2 and 3 can be used to determine the OHEW section current and the transmission pole earth grid current along the transmission lines [9]

$$I_{Pn} = \left[\frac{Z_P}{Z_\infty + Z_P} \right]^{n-1} I_{P1} \quad (1)$$

$$I_{P1} = \frac{\delta_e Z_\infty - Z_m}{Z_\infty + Z_P} I_f \quad (2)$$

$$I_n = \delta_e I_f - \sum_{1}^{n-1} I_{Pi} \quad (3)$$

where, n is the number of pole and δ_e OHEW split factor which can be computed using equation 4

$$\delta_e = \frac{Z_g + Z_m}{Z_\infty + Z_g} \quad (4)$$

Based on the above equations and previous research, figures 4 and 5 show the current behavior within the OHEW and transmission pole earth grid current under fault condition.

The OHEW section current dives until reach a limit where it maintains its current magnitude within the OHEW. The pole earth grid current dives until reaches the zero value. Based on these two figures, there is no pole earth potential rise (EPR) in the middle of the transmission line under substation fault. Furthermore, the OHEW section current is at its minimum value in the middle of the transmission line.

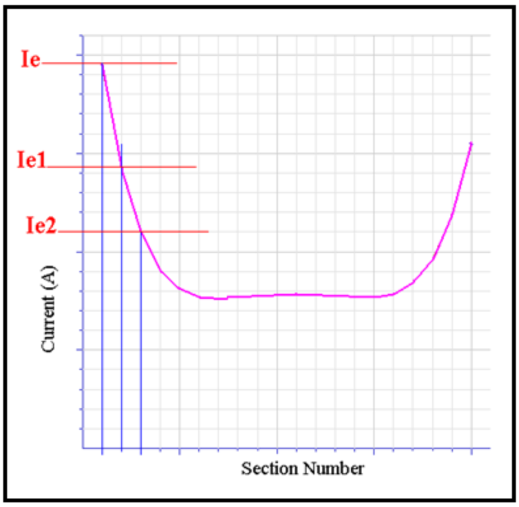

Fig. 4: OHEW section current for a continuous OHEW

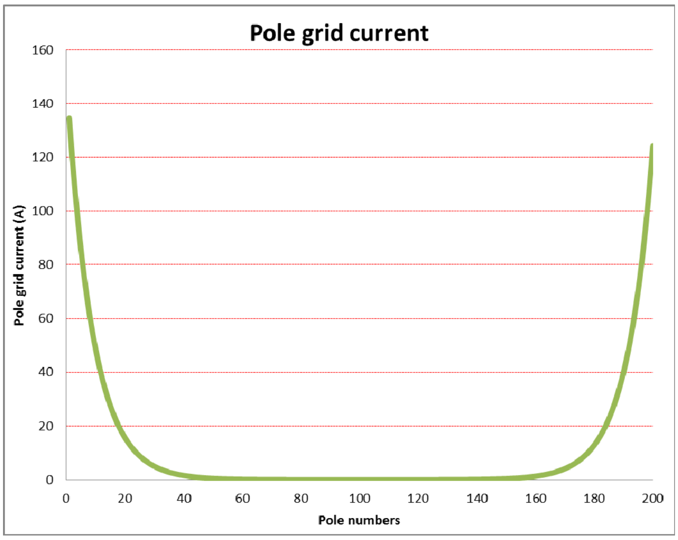

Fig. 5: Pole earth grid current under substation fault

When two transmission lines are running parallel and connect the same substations, the OHEW on the second feeder acts as a second OHEW for the first line due to the followings:

- Both OHEW are bonded at both substations
- Both OHEW are running parallel to the energized transmission line

Figure 6 represents two parallel transmission lines. Both lines has continuous OHEW between substations. When a fault fed by TL1 at Sub1 while TL2 is isolated, the OHEW on TL2 act as a second OHEW for TL1 and aid with the return current.

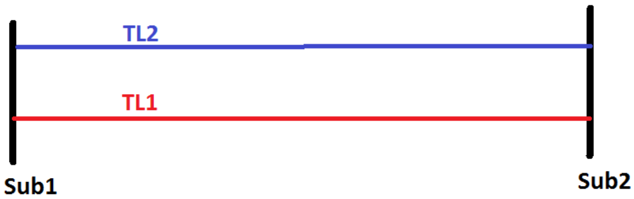

Fig. 6: OHEW for the parallel transmission lines

The return current in OHEW on TL2 behaves as per figures 4 and 5 under continuous OHEW condition. Therefore, based on this information, works at the middle of the transmission line has minimum exposure to EPR under substation fault.

III. Hidden Risk

As previously discussed, the parallel arrangement of the transmission lines introduces the induced voltage risk. Add to this fact that both transmission lines are connected to the same substation which traduced additional return current into the connected OHEW or earthed phase conductor.

Working on high voltage the transmission line involves the following steps from the electrical operator:

- Isolate the transmission lines at all viable sources
- Earth the phase conductors of the transmission lines.

The earthing will depend on the location of the work site. If the work site is located near the substation, an earth will be placed at the substation switchgear as well as the fields. If the work site located in a remote area of the substation, a field earth will be installed at both side of the work location. It is worth mentioning that the working earth will be installed on the phase conductors only and not on the OHEW as it is already earthed at each pole. Figure 7 shows an example of working earth location along a transmission line.

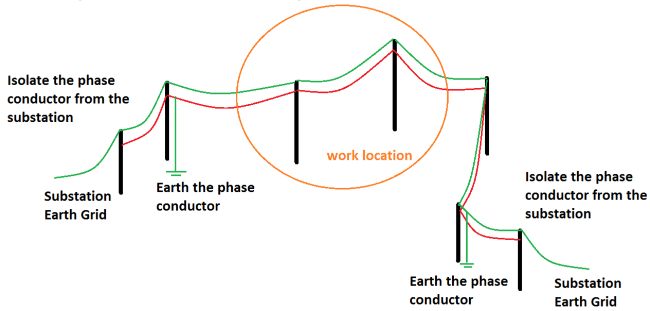

Fig. 7: Field earth location for a working site along the transmission lines

If a substation fault fed by the parallel transmission line, the phase conductor on the isolated line is exposed to an induced voltage while the OHEW of the isolated line is exposed to the split factor concept.

If the proposed scope of work involves breaking the existing OHEW on the isolated line, the behavior of the OHEW section current changes to the one discussed in figure 4 for both layout, finite and infinite conditions. Based on the published work [8], for a non-continuous/broken OHEW the current behave as per figure 8 [8]. The highest current will be discharged on the last few poles; therefore, the worst case scenario will be represented on the last few poles.

- Infinite System: When the OHEW input impedance at the fault location cannot capture the entire length of the system and therefore only a section of the OHEW system is considered for Z_{∞}
- Finite System: When the OHEW input impedance at the fault location can capture the entire length of the system.

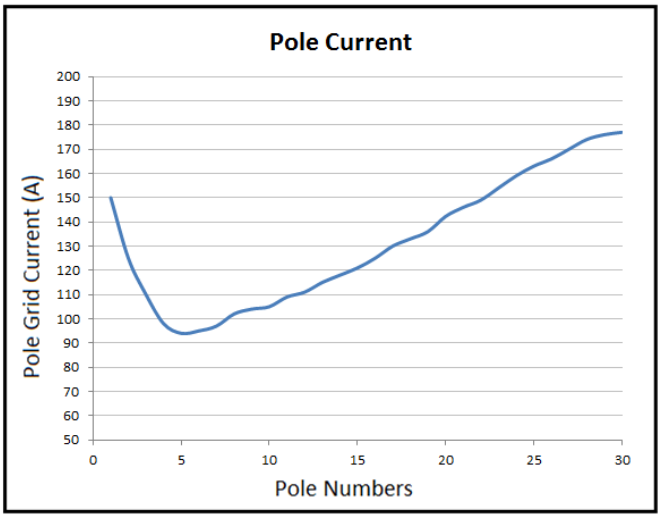

Fig. 8: Pole current behavior for non-continuous/broken OHEW infinite condition [8].

Grounded by the above information, workers touching the broken OHEW (to do maintenance for example) will be exposed to the highest EPR along the line. This hidden EPR on the OHEW, that usually considered the safest assets as it is earth at each pole, has the potential to cause serious damage to workers.

IV. Analytical Discussion

Based on the information provided in this section, the following can be concluded:

- Under continuous OHEW condition, if the worksite is located in the middle of the transmission lines, the pole EPR under substation fault is at its minimum value
- If the scope of works requires breaking the existing OHEW, the higher pole EPR is located at the broken OHEW location.
- This change in conditions, introduce a high safety risk situation that required mitigations

The mitigation process can take one obtained using one of the followings:

- Isolate both transmission lines, usually this not an option due to network reliability and availability.
- Disconnect the OHEW at the substation to eliminate the split factor concept and rely only on the induced voltage risk.
- Prior breaking the OHEW, create a short circuit that bypass the work location. This could be easily established by bonding the OHEW to the phase conductor both side of the work location as shown in figure 9

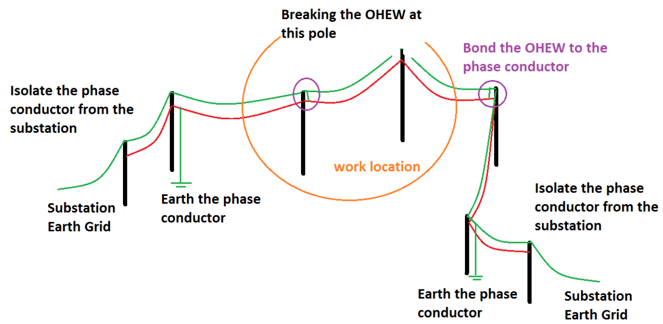

Fig. 9: Bonding the OHEW to the phase conductor

The established bond ensure the returned OHEW current has a continuous pass back to the source and ensure the lowest pole EPR is maintained at this location.

It is worth mentioning, this option is the proposed paper preferred option to mitigate the high risk hidden risk for parallel transmission lines.

V. Case Study

The case study is based on two 132kV feeders running parallel for 20km and connects two zone substations. The followings form the design inputs for both feeders.

- Sub A earth grid resistance is 0.1 ohm
- Sub B earth grid resistance is 0.1 ohm
- Average span on both feeders (FDRA, FDRB) is 10m
- Transmission poles earth grid resistance is 10 ohms
- Single line to ground fault at substation is 10kA
- Delta configuration on the transmission pole
- Separation between the two feeders is 10m
- Separation between the phase conductor and OHEW is 2.4m
- 19/3.25 is the OHEW on both feeders
- Primary clearance time is 0.3S
- Soil resistivity of the area is 50ohm.m

The first assessment is completed by considering the presence of only one feeder. FDR A transmission pole earth grid current for a substation fault supplied by FDR A is computed using equation 1 which illustrated in figure 10. Equation 3 is used to compute the OHEW shunt current. Figure 11 shows the computed result.

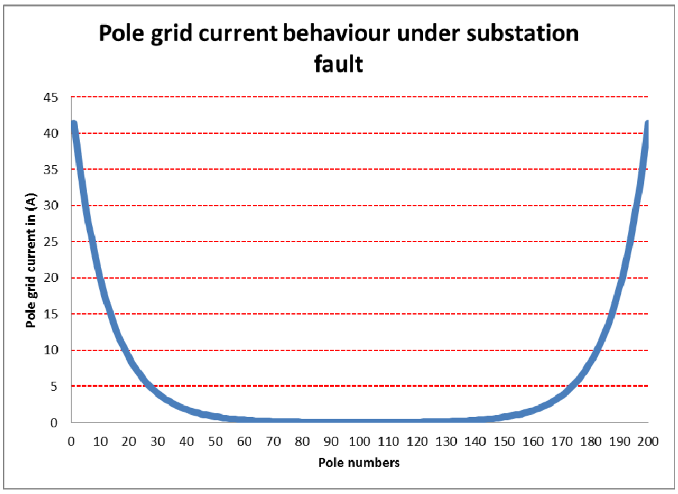

Fig. 10: Transmission pole shunt current

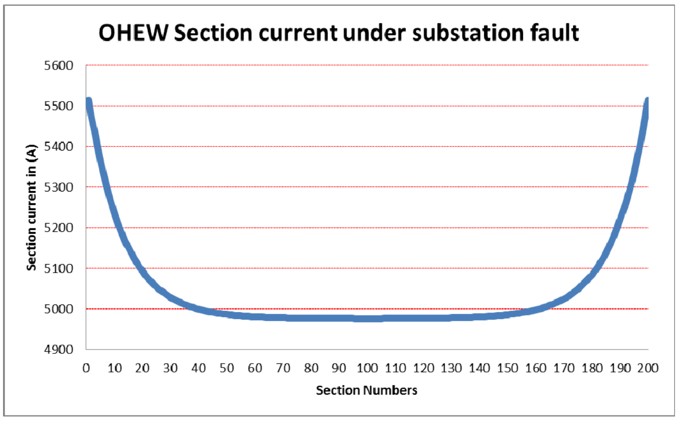

Fig. 11: FDR A OHEW Shunt Current

CDEGS Engineering software is used to compute the transmission pole shunt current on both feeders OHEW when one feeder is under fault at the substation. The followings represent the results:

Total substation fault current supplied by FDR A is 10000 A
Total OHEW on FDR A is 5148.3 A angle: 2.719 degrees
Total OHEW on FDR B is 1263 A angle:1.591 degrees

The simulation shows that the current magnitude in FDR B OHEW is high. The mutual impedance between the faulted phase and the FDR B OHEW is computed to be [8]:

$$Z_{Mutual-\mathrm{Im}\,pdeance} = 0.0494 + j0.2496\Omega.km$$

The magnitude of the mutual impedance that governs the remaining current into the OHEW (this current will return back to the source using the OHEW) is computed to be 0.329. The equations for the calculation can be found in the author previous published works [8, 9]:

The simulation, which is presented in figure 12, shows that 615A will remain in the OHEW. During a break in the OHEW, this 615A will be discharged to the ground and cause the EPR at the break location. This value along with the resistance will create a high potential that could jeopardize the human safety.

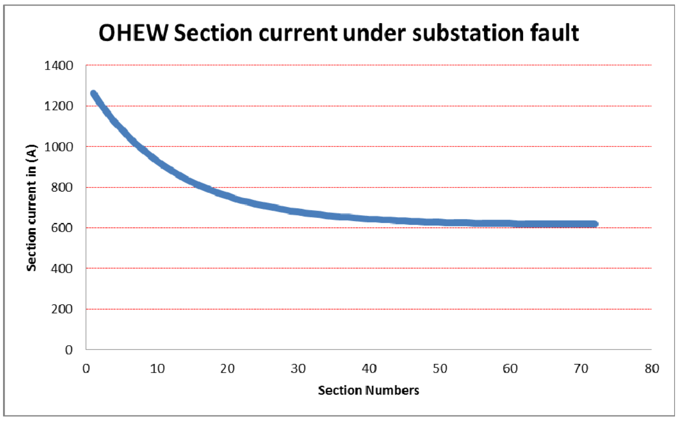

Fig. 12: OHEW section current for FDR B when FDR A is under substation fault

VI. Case Study Mitigation

The consequences of the hidden risk, as detailed in the case study, are high. The high potential could lead to human fatality or permanent damage. This risk is unacceptable and mitigations should be implemented. The paper proses the following mitigation to ensure the risk is reduced:

- When working requires breaking the continuous OHEW, a parallel connection should be established both end of the break.
- The parallel can be achieved as shown in figure 9.

This mitigation ensures the voltage at the work location, under substation fault, will be neglected as the current will be maintained within the OHEW and its parallel section. It is assumed that the mutual coupling between the faulted phase and the small parallel section of the OHEW remain the same as the OHEW.

VII. Conclusions:

The paper addresses the fault current distribution within the OHEW under fault condition. It also shows the fault current behavior under continuous OHEW for a two feeders running parallel within the same easement.

The work highlights the hidden risk when working on the OHEW while the parallel transmission line is. The case study shows that the current magnitude is high and could jeopardize the human safety (the 615A will be discharged to the ground at the breaking OHEW location.

The proposed mitigations ensure the OHEW section current doesn't contribute to any EPR at the break location. Also the mitigations has no cost or time implication to the proposed works.

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