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Reducing Induced Voltages on Parallel Facilities in Shared Transmission Corridors with Aerial Counterpoise

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SUMMARY

Routing, siting, and environmental constraints are pushing more transmission lines and other linear facilities such as pipelines and railroads into shared corridors. The future power system will see a greater number of these situations, often coupled with transmission lines with heavier loading than historic lines have experienced. When a transmission line is parallel or semi-parallel to an adjacent linear facility, the magnetic fields will induce voltages onto these facilities proportionally to the line loading and length of parallelism.

This paper briefly explores the general mechanisms of magnetic induction, a summary of some traditional mitigation approaches, and non-traditional designs to reduce the induction. These methods include shield wire and aerial counterpoise conductor configurations on a sampling of typical voltage levels and transmission line configurations.

KEYWORDS

Transmission line, induction, magnetic fields, aerial counterpoise, pipelines, railroads

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INTRODUCTION

Metallic objects parallel to electric transmission lines are subject to induced voltages due to magnetic field coupling. The amount of induced voltage on a parallel object is proportional to the amount of current on the transmission line, the distance of parallelism, and the separation distance. These voltages present concerns related to personnel protection and equipment damage, such as pipeline corrosion or railroad signaling systems [1][2][3]. Typically these induced voltages are required to be below 50 V under steady-state conditions, with varying compliance criteria. More transmission lines that are more commonly heavily loaded are being co-located with other linear facilities including pipelines and railroads, sometimes running parallel for very long distances. As a result, there are more concerns with magnetic induction on these facilities and the methods to reduce the voltages.

A variety of methods can be used to reduce this induction. The most commonly implemented involve gaining additional separation, optimizing phase spacing/configurations and cross-phasing multi-circuit corridors, and installing parallel buried counterpoise conductor alongside the parallel facility. This latter option provides some electromagnetic shielding by absorbing some of the magnetic field, reducing the fields on the pipeline or railroad, thus reducing the induced voltage. However, some of these options are not practical, particularly for existing lines. Even the buried counterpoise may pose challenges where the transmission line owner does not have permission to install it on the property of the adjacent facility.

One less commonly used method of mitigation, as suggested by EPRI, to reduce the induced voltage on a rail system is the use of aerial counterpoise on the transmission line structures [2]. Designing an aerial counterpoise system requires an understanding of the interactions of the magnetic fields between the phase conductors, shield wires, and the object under analysis. Some shield wire configurations can even increase the magnetic coupling between a transmission line and parallel object, depending on the phasing.

The remainder of this paper explores the effects of shield wire and aerial counterpoise conductor configurations on magnetically induced voltages for parallel metallic objects. The results presented allow the reader to quickly understand the impacts of shielding type and whether to consider the inclusion of an aerial counterpoise conductor for their transmission line project.

SHIELD WIRE AND AERIAL COUNTERPOISE CONFIGURATIONS

Transmission lines typically have shield wires overhead to provide lightning protection, communication paths, and fault current return paths. These shield wires are often steel but may consist of aluminum or other conductive metals. Optical Ground Wire (OPGW) provides for both lightning protection and communication paths.

Transmission lines can induce voltage on parallel metallic objects. One way to mitigate magnetically induced voltages away from the transmission line is to place aerial counterpoise between the phase conductors and the object of interest. The aerial counterpoise has a current induced on it that opposes the net magnetic field of the transmission line. Placing aerial counterpoise in this way can reduce the magnetic field intensity at the object of interest.

Multiple options exist for the placement of this aerial counterpoise conductor. The three most common locations are: near the centerline of the transmission circuit, underneath the phase conductor closest to the parallel object, or on an additional set of structures between the transmission line and the parallel object. This analysis concentrated on the underbuild conductor being placed ten feet under the lowest phase conductor. Placing an aerial counterpoise near the centerline of the transmission line typically produces less benefit compared to the selected solution because it is not directly between the transmission line and object of interest. Building additional structures for an improved aerial counterpoise can be an option but is substantially costlier and time consuming then an underbuilt conductor.

TRANSMISSION CONFIGURATIONS EVALUATED

The effects of transmission line shielding are greatly affected by the physical configuration of the transmission line tower. To evaluate the effect of aerial counterpoise placement multiple cases were analyzed. The configurations also included typical phase spacing for 115 kV and 345 kV transmission circuits. These configurations produce varied magnetic fields due to the varied phase conductor geometry. Sample configurations are shown in Figure 1, followed by description of all transmission line configurations that were analyzed.

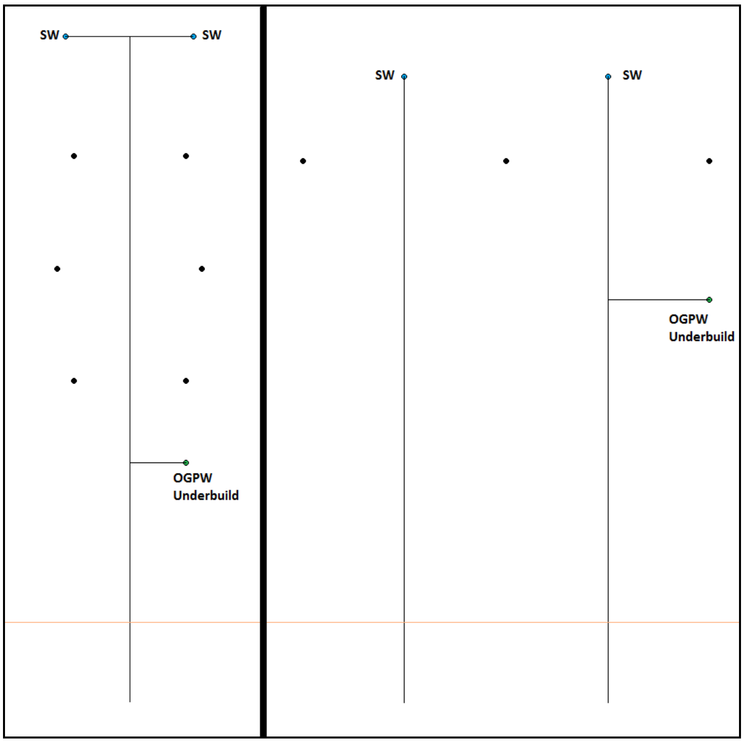

Figure 1: OPGW Underbuild Examples

Single-Vertical Configuration: All phases stacked vertically on one side of the tower, closest to the parallel metallic objects. The base model placed a shield wire and Optical Ground Wire (OPGW) overhead. When aerial counterpoise is modeled, either ACSR or OPGW is placed ten feet below the lowest phase conductor closest to the parallel object.

Double-Vertical Configuration: Similar to the Single-Vertical Configuration, however the two circuits are cross phased for magnetic field cancellation. The base model placed a shield wire and OPGW overhead. When aerial counterpoise is modeled, either ACSR or OPGW is placed ten feet below the lowest phase conductor closest to the parallel object.

H-Frame Configuration: All phases at a uniform elevation with the SW and OPGW placed atop each pole in the base model. For this configuration, results differ significantly depending on which of the poles the OPGW is placed on. The effects of these differences are detailed in the results section. When aerial counterpoise is modeled, either ACSR or OPGW is placed ten feet below the lowest phase conductor closest to the parallel object.

Delta Configuration: Two phases stacked vertically on one side of the structure, closest to the parallel metallic objects, with the third phase positioned on the opposite side of the structure. The delta configuration only has one overhead wire, which is modeled as OPGW in the base model. When aerial counterpoise is modeled, either ACSR or OPGW is placed ten feet below the lowest phase conductor closest to the parallel object.

As previously discussed, transmission lines often have a steel shield wire and an OPGW placed overhead. OPGW is primarily aluminum, which is more conductive than the steel shield wire allowing more current to flow for the same induced voltage. Therefore, a third configuration investigated in this analysis moved the OPGW from an overhead position to an underbuild counterpoise position. As shown in Figure 1, when the OPGW is used as an aerial counterpoise, the overhead shield is replaced with a steel shield wire.

EVALUATION DETAILS

For the evaluation the induced voltage on a one-mile parallel pipe was calculated based on a 1,000-amp balanced steady-state current. The OPGW and ACSR are modeled as aluminum conductors, while the shield wire is modeled with electrical characteristics consistent with steel. Each shield wire and underbuild conductor was grounded at regular intervals between 600 and 800 feet equivalent to typical spans lengths.

The parallel metallic objects are modeled as steel pipe six inches in diameter, buried three feet deep, and are perfectly insulated. These pipes were considered at distances of 50, 100, 150, 200, 300, 400, 500, 600, 800, and 1,000 feet from the centerline of the transmission line. By modeling with perfect insulation, the voltage on the metallic object is only developed by magnetic effects from the modeled transmission line. In practicality, both pipelines and railroads have leakage paths to the adjacent soil; utilizing perfect insulation allows for comparison of worst-case results.

RESULTS

The results are broken down by configuration type as the effects for the cases analyzed are predominately impacted by the phasing configuration.

Vertical Configurations

With single circuit vertical phasing configuration, the underbuilt ACSR conductor provides the greatest reduction in ground potential rise (GPR) along the parallel object for both the 115kV and 345kV transmission lines. The single circuit results can be seen in Figure 2 below. The underbuilt OPGW option provides very little benefit and could produce higher voltages as seen in the objects farther from the line in the 345kV model.

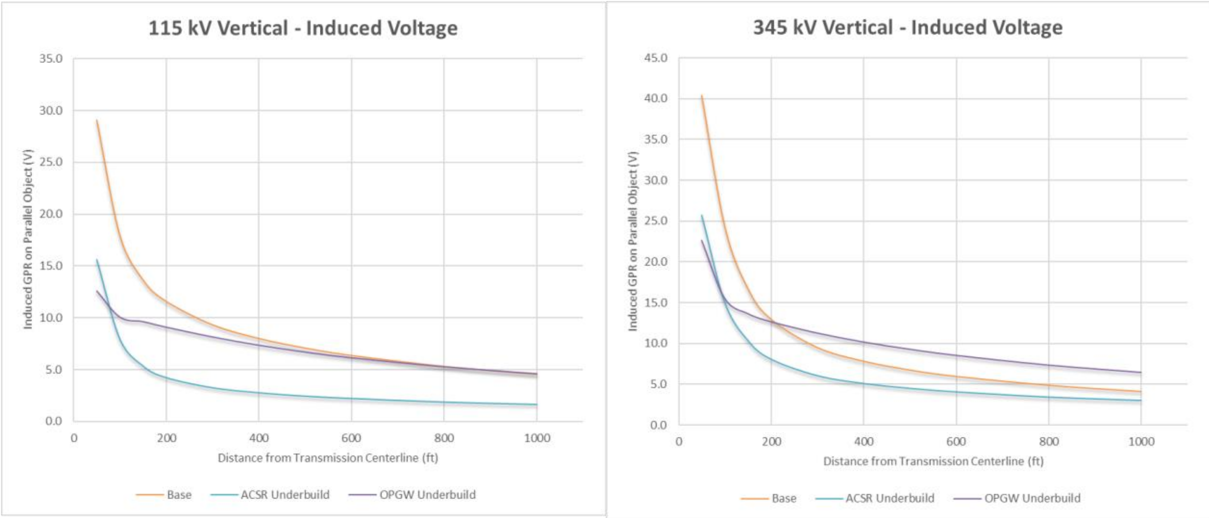

Figure 2: Single Circuit Vertical Configuration Results

An underbuilt conductor actually amplifies the magnetic induction for a cross phased double circuit line. Figure 3 shows the increased induced voltages versus a standard shielding configuration. This happens because the induced current in the aerial counterpoise reduces the balance provided by the cross phased transmission line. One important consideration is that single circuit operation of the transmission line may need to be considered for any actual AC interference analysis.

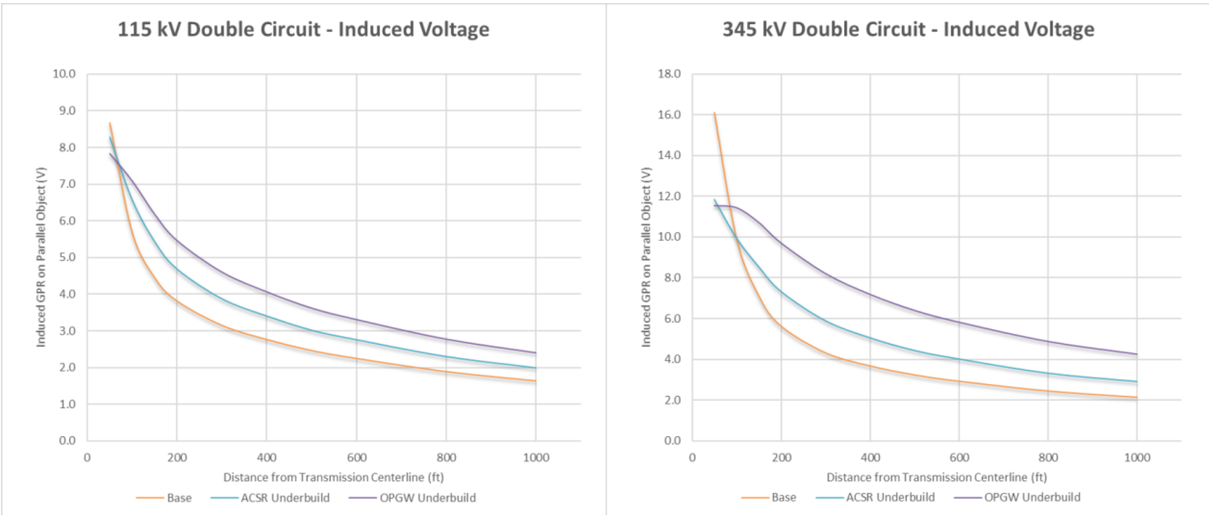

Figure 3: Double Vertical Configuration Results

H-Frame Configurations

The H-frame configuration is unique in both the separation of conductors and total separation of the shield conductors. For this configuration, when the OPGW is overhead it is located atop the pole closest to the object of interest. Placement of an OPGW below the phase conductor closest to the object produces the largest reduction in magnetic coupling. The ACSR aerial counterpoise actually increases the GPR on the parallel object due to the interaction between the ACSR underbuild and the overhead OPGW conductor. As a result, there is a voltage increase on objects farther from the transmission line but still reduces voltages for objects closer to the line. The results for this configuration are in Figure 4.

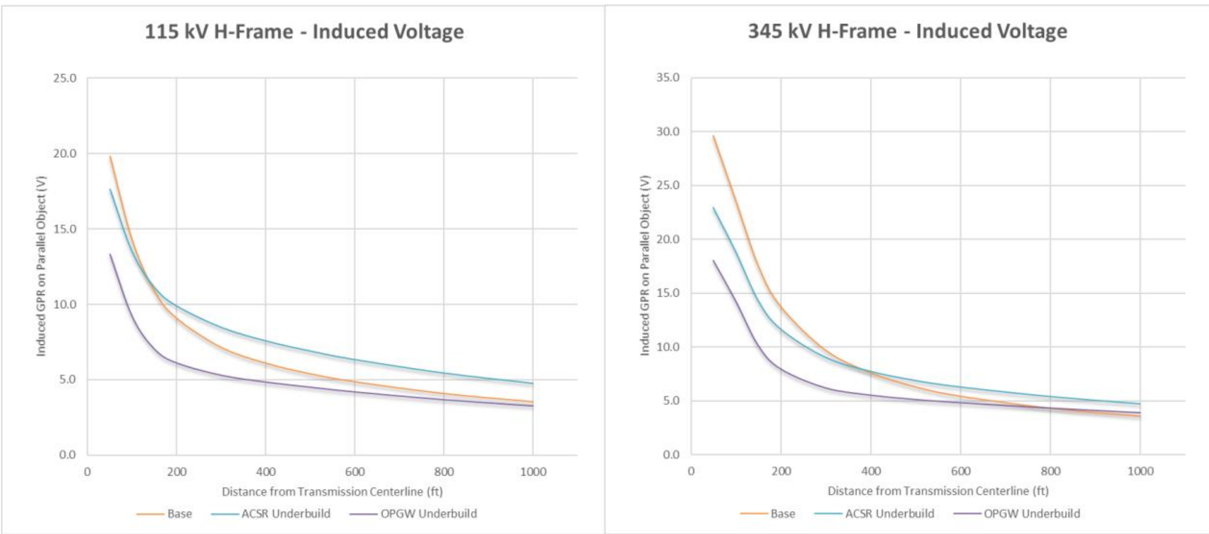

Figure 4: H-Frame Configuration Results

Another option for the H-frame configuration is to place the overhead OPGW atop the pole farthest from the parallel metallic object. Without any aerial counterpoise this increases the magnetic coupling comparing the base results above (Figure 4) to those below (Figure 5). This configuration places the overhead OPGW such that it contributes to a larger net magnetic field on the object of interest. The OPGW underbuild is identical to the previous case as it is replaced with a steel shield wire. In this configuration the ACSR underbuild is an improvement compared to a configuration without underbuild.

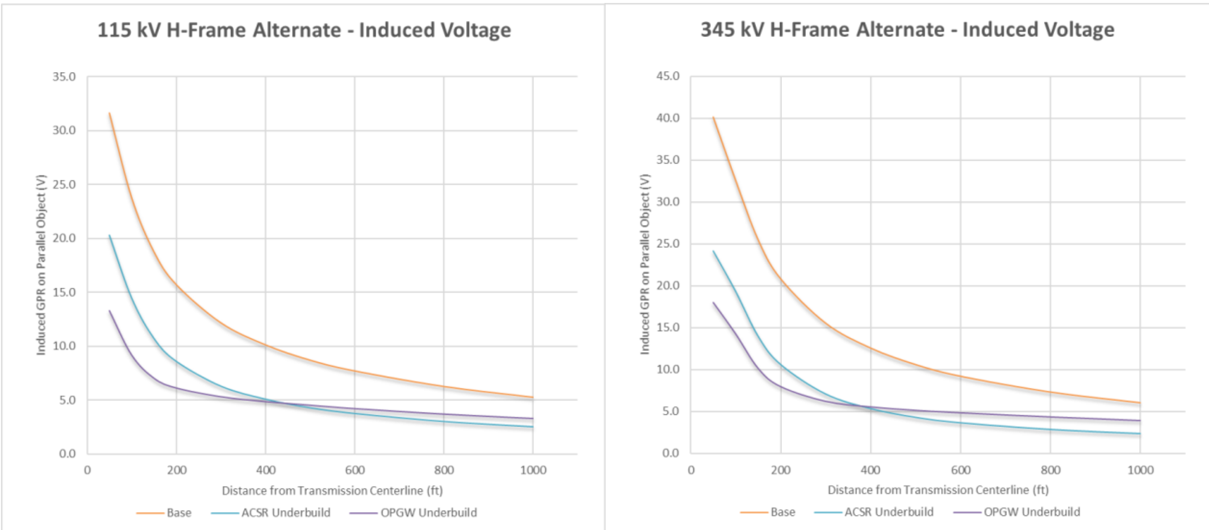

Figure 5: H-Frame Results Alternate OPGW Location

Delta Configuration

The delta configuration has less magnetic coupling to the object of interest with either of the aerial counterpoise options. Which option provides the greatest benefit is dependent on the distance of the object from the transmission line. For objects close to the transmission line the OPGW underbuild provides the greatest reduction in voltage, while objects farther away benefit more from ACSR aerial counterpoise. Figure 6 contains the results for the delta configurations. This figure shows how the larger phase spacing at 345 kV versus 115 kV affects the behavior/performance of the OPGW in particular due to less phase cancellation near the structure.

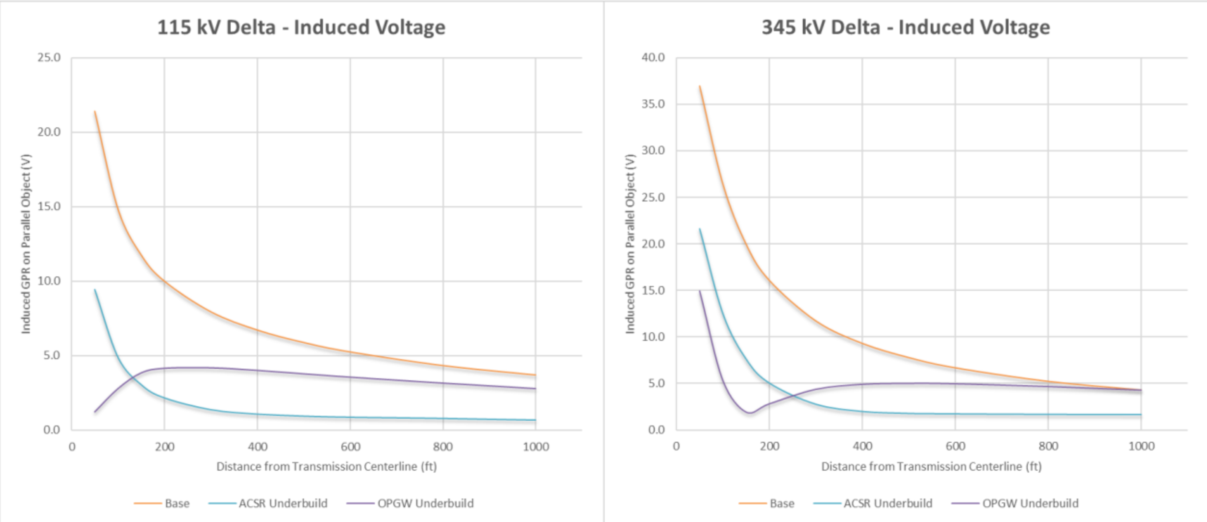

Figure 6: Delta Configuration Results

Summary of Results

The results for the configuration types are similar, even at different voltage levels. There are differences between the voltage levels, but the trends remain very similar. Generally speaking, installing an aerial counterpoise conductor underbuilt:

- Provides benefit to single circuit vertical structures, except under some conditions where the parallel objects are far away
- Provides benefit to delta structures
- Provides benefit to H-frame structures located close to parallel objects, but the effectiveness depends on conductor type and distance
- Generally causes additional induction on double circuit structures when both lines are in service and cross-phased

The plots above can be used to further identify specific behaviors for the structures modeled. However, if the designs are to be implemented, site- and structure-specific analysis is recommended.

RETROFIT APPLICATIONS

The majority of this paper has discussed new construction, or in-place retrofits (e.g. replacing a traditional shield wire with an OPGW). However, in many places existing structures can not support a heavier OPGW or underbuilt shield wire as a possible mitigation technique. In some cases, installing some form of aerial shield wire on an adjacent independent pole may be a practical option within the right-of-way. Generally, placing the shield conductor generally in-line with the path between the phase conductors and the object being exposed to induction.

CONCLUSION

The location and type of shield conductors as well as aerial counterpoise has a large impact on the magnetic coupling to parallel metallic objects in a shared corridor. The optimal solution is largely dependent on the transmission line configuration and the separation distance between the transmission line and object of interest. Installation of aerial counterpoise on a transmission line is significantly cheaper when included in the original design, in part due to structure loading considerations. Whether or not it needs to be installed, including provisions for the installation of an aerial counterpoise conductor maybe a good investment of time and resources for corridors shared with railroads or pipelines.

Installing an optimized shielding or aerial counterpoise configuration does not eliminate the need for detailed analysis of a joint use corridor. Depending on the type of object the acceptable voltage limits on the object may vary widely. NACE and EPRI provide documentation on the acceptable limits and analyses that must be performed for pipelines and railroads respectively [2][3].

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