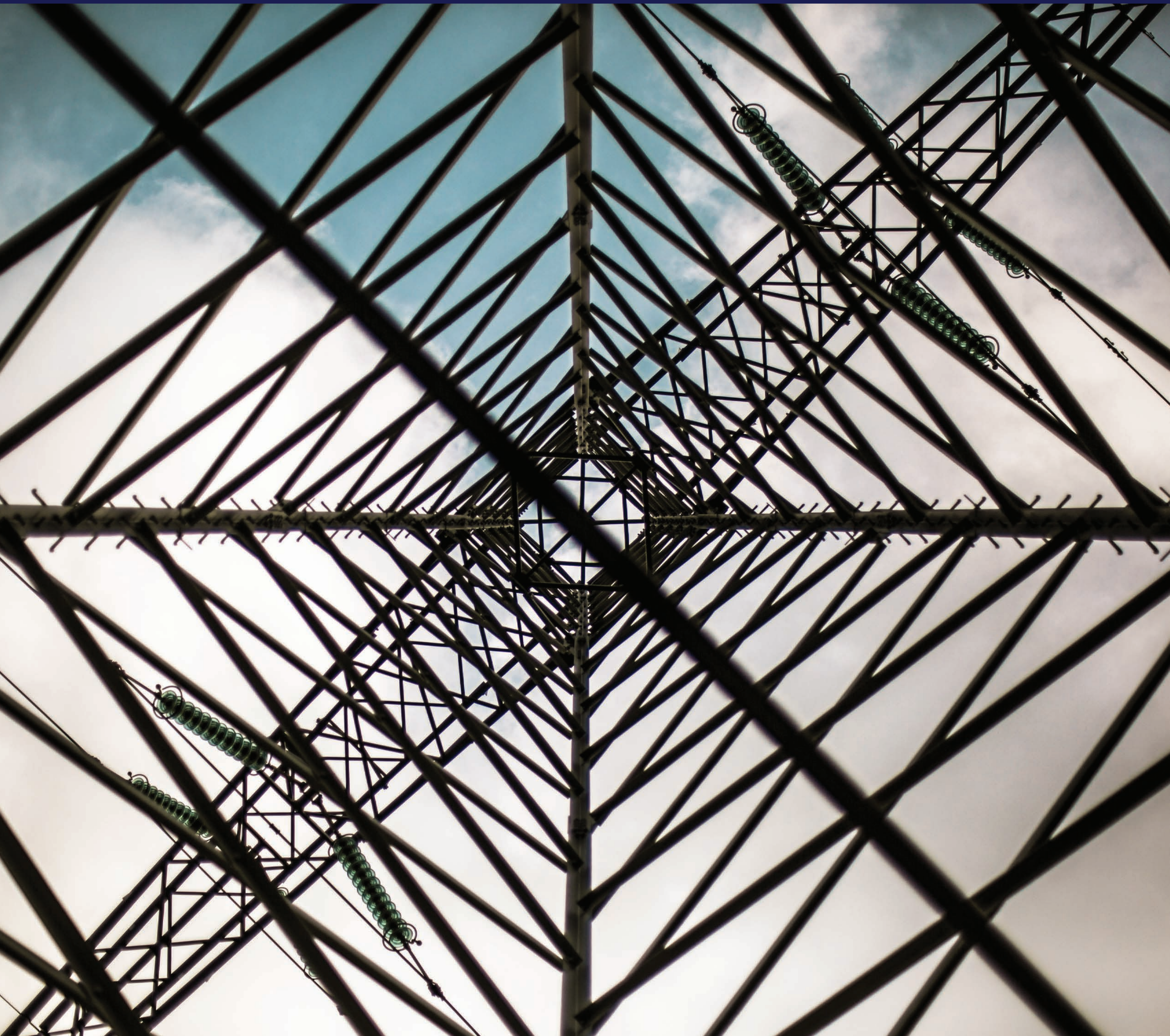
LEVERAGING EXISTING INFRASTRUCTURE

Increasing the Capacity of Transmission Lines and Rights-of-Way



LEVERAGING EXISTING INFRASTRUCTURE – INCREASING THE CAPACITY OF TRANSMISSION LINES AND RIGHTS-OF-WAY

INTRODUCTION

Significant efforts are underway to transition from fossil fuel-based generation to renewable and other low-carbon resources and sources and timing of demands are changing, but this cannot be done in isolation as the existing transmission system needs to evolve to handle the resulting change in system. The following factors are or will be driving changes to the current transmission system:

- The balancing of large-scale renewables with more traditional generation resources when renewable output is low, for example, when there is little wind (for wind power) or at night with no sun (for solar photovoltaic [PV]). Adding energy resources throughout the grid can create possibilities for overloading lines and equipment during normal or contingency operation. Also, large-scale renewables are often located in remote areas, presenting the challenge of transmitting bulk power over long distances to load centers and creating new connections to the existing grid and changing the direction and timing of flows through it.
- Electricity demand increases due to electrification, for example, by the transportation sector converting from fossil fuels to electricity. Concentrations of increased power flow created by the new demands can overload lines and equipment.
- Stricter resilience and reliability requirements due to society's increasing dependance on electricity. Low-probability contingencies that might not have been acted on previously, will begin to inform transmission expansion plans.
- Loop flows (power flows that go through systems for which they were not intended) or other overload conditions could be created by market incentives and open access to transmission. These might need to be mitigated through transmission expansion.
- Difficulty siting and financing new transmission. Leveraging existing lines and rights-of-way can potentially save both money and time.

Given rapidly changing demands and the challenges in rapidly building new transmission, an important option to reach carbon emission reduction goals can be to significantly increase the power transfer capacity of the existing transmission system and the utilization of existing rights-of-way (ROW). There are numerous technical challenges that must be met to ensure that the required transmission capacity is reached while maintaining or improving the reliability of the system. Increasing capacity will require new action in all aspects of the transmission process, including grid operations and planning, and addressing new and existing asset designs.

EPRI research is exploring options for increasing the capacity of existing and new lines to increase the capacity of power flowing along ROWs.

APPROACH

This paper outlines opportunities and challenges faced in efforts to increase the capacity of existing transmission ROWs and introduces approaches to better utilize ROWs. It is based upon the experience EPRI's transmission team has gained working with individual members to execute increased power flow projects. These studies include the detailed modeling, analysis, laboratory tests, and field implementations needed to evaluate cost, reliability, compatibility, and future maintenance needs.

Through EPRI's collaborative model, the lessons from each project can provide broader member and societal benefit.

The paper provides a preview of much more detailed assessments of line and ROW uprating approaches that are planned for publication later in 2021.

BACKGROUND: TRANSMISSION CAPACITY LIMITATIONS

For alternating current (ac) lines, power flow is limited by one of the following:

- *Thermally limited.* The rated current of the conductor system, which is largely determined by the characteristics of the conductor, e.g. the area of Aluminum Strands.
- *Voltage drop limited.* The voltage at the end of the line drops below the established operational limits due to current flowing through the line impedance.
- *Stability limited.* On long lines, small changes in load can result in unstable receiving-end voltages due to the relatively large series impedance of the line.

In general, the dominant limitation depends on the line length as illustrated in Figure 1.

In contrast to ac lines, the power flow on high-voltage direct current (HVDC) lines, is limited only by the rated current of the conductor system and is thus primarily thermally limited.

Depending on the type of limitation, the power flow capacity of a line can be increased by:

- Increasing the maximum allowable current flow in the line (line uprating);
- Increasing the nominal operating voltage of the line (voltage upgrading);
- Reducing or compensating for the line impedance (reduce impedance; for ac lines only). Line compensation is achieved by capacitors, reactors or power electronics installed in substations. Discussion of this approach is outside of the scope of this paper.

Each of these options can address different types of limitations, as shown in Table 1.

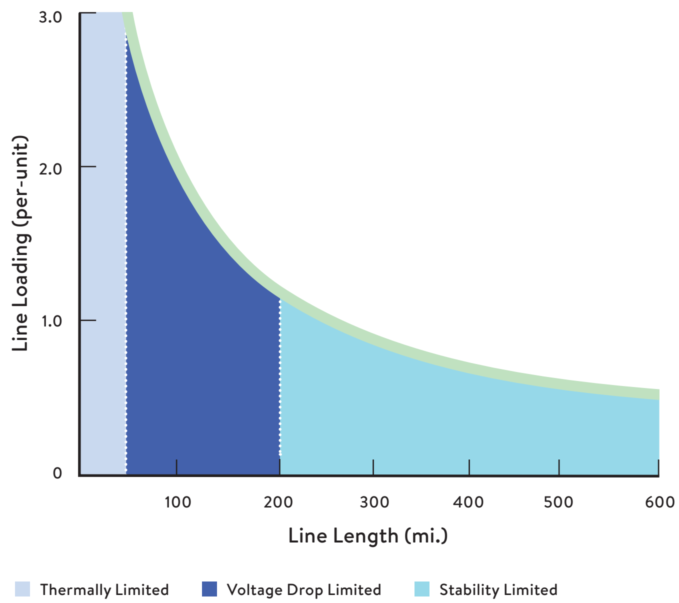
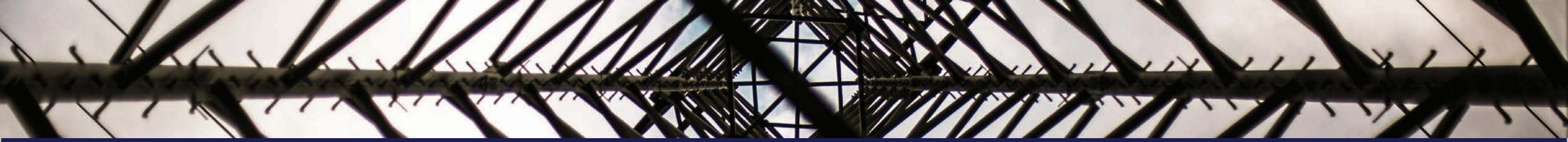


Figure 1. *Universal loadability curve of ac lines*[1]

Table 1. *Options for increasing power flow in transmission lines (* For ac lines only; **reducing impedance at the line terminations is not discussed in depth in this paper)*

	Limitation		
	Thermal	**Voltage Drop***	**Stability***
Line uprating	X		
Voltage Upgrading	X	X	X
Reduce Impedance*		X	X

[1] P. Kundur, Power System Stability and Control. EPRI and McGraw-Hill, 1994. ISBN0-07-035958-X.



Although this paper is focused on lines, power flow may also be limited by the rating of the terminal equipment (at the ends of the lines) or other system operational constraints.

INCREASING THE CAPACITY OF EXISTING ROWS

A Right of Way (ROW) is a strip of land used to construct, operate, maintain, and repair transmission lines that are installed on the ROW. The ROW is generally clear of trees, vegetation and structures that could interfere with a line. Obtaining new ROWs for transmission lines is an uncertain and lengthy process because easements must be acquired, regulatory requirements must be met, and public opposition can be significant. Thus, it is advantageous to use existing ROWs whenever possible to increase transmission capacity.

A recent Electric Power Research Institute (EPRI) report[2] summarizes 37 projects where utilities have increased the power flow in existing ROWs. Figure 2 graphs the potential increase in capacity of each option against the cost range relative to building a new line.[3]

Line Uprating

For short lines the current-carrying capacity can be increased by 5–50% through a range of methods aimed at addressing conductor temperature, which in-turn impacts sag (i.e., clearances) and the probability of exceeding the conductor system temperature rating. These methods are situation-dependent and include:

- Reconductoring by increasing the temperature rating, size or number of conductors per phase.
- Addressing ground clearance issues by applying advanced low-sag conductors, or implementing structure modifications and/or conductor re-tensioning can be used to overcome clearance limitations.
- Implementing ambient adjusted line ratings by using real-time or forecasted ambient temperatures to predict the conductor temperature, assuming that all other factors in the rating equations are held constant (i.e., windspeed / direction and solar radiation).
- Deploying dynamic line ratings which directly measure or infer (using monitoring technologies or multivariable weather stations that measure wind speed/direction, ambient temperature, and solar radiation) the conductor temperature can allow line ratings to change with real-time conditions rather than assuming a static (unchanging) rating.
- Applying high-emissivity coatings to conductors that enable more heat to radiate, providing increased line ratings under certain conditions.
- Adjusting static ratings using a risk-informed approach based on a probabilistic assessment of the simultaneous occurrence of variables such as the minimum wind speed, maximum temperature, and load.

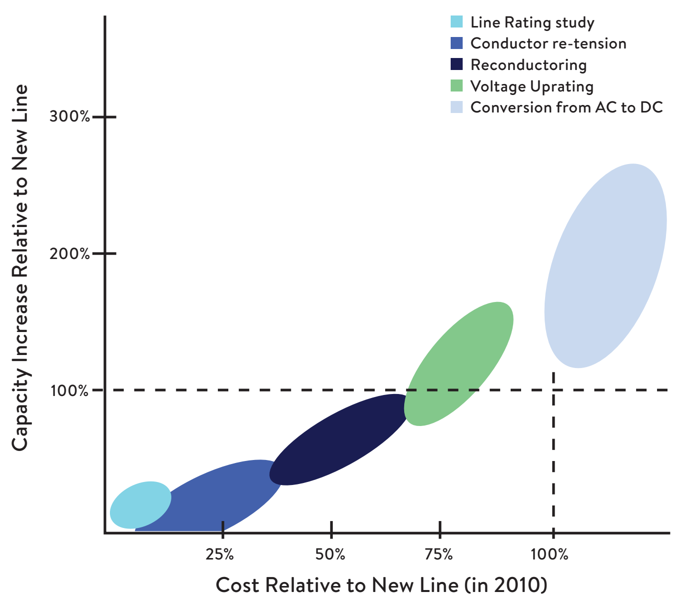


Figure 2. *Potential capacity increase of each option and the associated cost relative to building a new line on an existing ROW.* [3] [4]

[2] Summary of Recent Increased Transmission Line Utilization Projects: 115 kV and Above. EPRI, Palo Alto, CA: 2020. 3002020158.

[3] CIGRE Technical Brochure 425, "Increasing Capacity of Overhead Transmission Lines", Joint Working Group, B2/C1.9, Electra No. 251, August 2010.

[4] EPRI Increased Power Flow Guidebook–2020: Increasing Power Flow in Lines, Cables, and Substations (Platinum Book). EPRI, Palo Alto, CA: 2020. 3002019086.

Table 2. *Summary of line uprating approaches and challenges*

	Reconductoring, re-tensioning, structure mods	Advanced Conductors	Ambient Adjusted Ratings	Dynamic Ratings	Risk- Informed Ratings	High-Emissivity Coatings
Current Increase	Continuous	Continuous	Weather- dependent	Weather-dependent	Continuous	Continuous but lower
Experience	>100 years	~ Decade	< Decade	Pilot projects	5 years	< 3 years of pilot projects
Challenges	Structural strength & sag	Life expectancy & maintainability	Planning & operations integration. Uncertainty in forecast	Planning & operations integration. Limited forecasting capability.	Presently assumed risk may already be high.	Life expectancy and maintain ability.

Table 2 summarizes challenges to these approaches along with the general experience level that the electric utility industry has applying them. Some of the approaches yield increases in power flow under all conditions (denoted as continuous) while others provide weather-dependent increases.

An assessment of terminal equipment is paramount when considering line uprating. An EPRI survey found that a significant percentage of transmission circuits are limited by the substation equipment rating rather than the line rating.[4]

Voltage Upgrading

Line capacity can be increased by more than 100% by raising the operating voltage. In some cases, a modest increase in system voltage can be made with limited physical changes, e.g., from 380 kV to 420 kV, without impacting reliability. In other cases, a larger increase can be obtained through more significant physical changes. For example, insulator assemblies, and phase spacings, are modified to convert a line to a higher voltage e.g. from 115 kV to 230 kV (see Figure 3).[2]

When voltage upgrading results in phase spacings and insulator lengths shorter than normal, the design is referred to as compact. Voltage upgrading, with due consideration of insulation coordination practices, clearance requirements, audible noise from corona and the ability to perform maintenance under energized conditions, is only feasible for line designs that offer sufficient margins.

Conversion from a.c. to DC

Converting an existing a.c. line to HVDC operation can significantly increase the capacity of longer lines for the same insulator lengths and phase spacing. Capacity increases of up to 250% have been achieved in some cases. Conversion to HVDC lines creates engineering challenges, such as electric field issues, contamination flashover, and audible noise; all

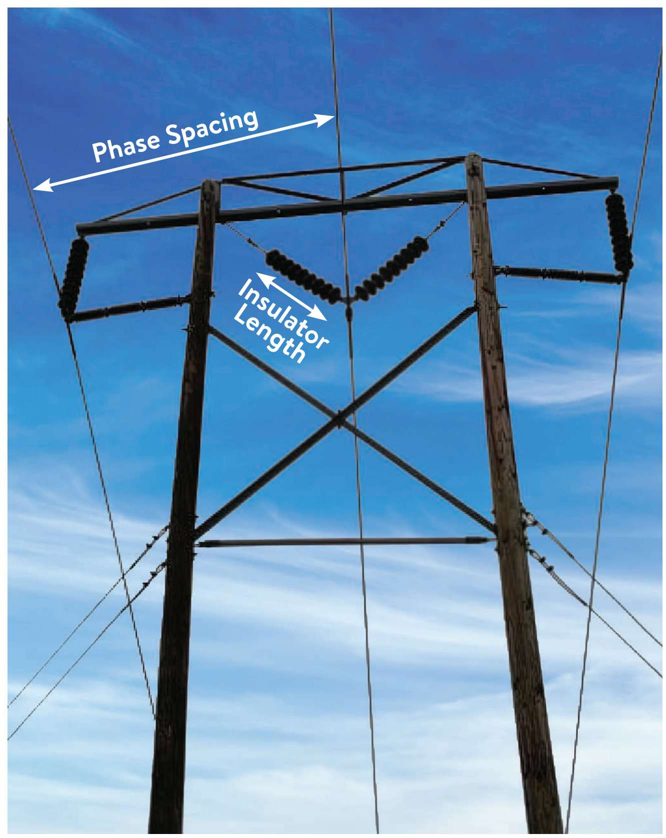
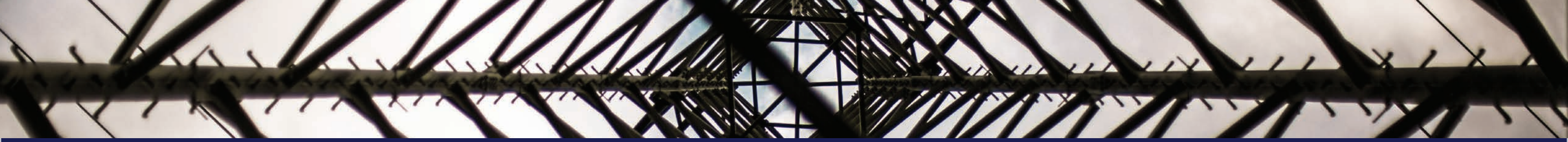


Figure 3. *Example of a 230kV H-frame structure upgraded from 115kV.*

[2] Summary of Recent Increased Transmission Line Utilization Projects: 115 kV and Above. EPRI, Palo Alto, CA: 2020. 3002020158.

[4] EPRI Increased Power Flow Guidebook–2020: Increasing Power Flow in Lines, Cables, and Substations (Platinum Book). EPRI, Palo Alto, CA: 2020. 3002019086.



can be mitigated and managed through existing engineering practices. A bigger challenge is that converter stations connecting the HVDC line to the ac grid are expensive, but they also provide additional capabilities, such as increased controllability and islanding, aiding network operation.

Adding Cables to the ROW

Adding cables, where the energized wire strands are covered with an insulating material which is then surrounded by a metallic layer, to an existing ROW can be used to increase the capacity of a ROW. Cables can be placed below ground or on the surface.

In general, underground cables are significantly more expensive than overhead lines due to the cost of civil work and the cables themselves. Public acceptance is often greater because they are less visible, and the ROW is already acquired. Interactions between the overhead and underground lines need to be addressed. These include access for maintenance, corrosion, and the concern that faults on the overhead lines may result in faults on the cable reducing the redundancy of the transmission system.

Opportunities & Challenges with upgrading, AC-DC conversion and cable addition

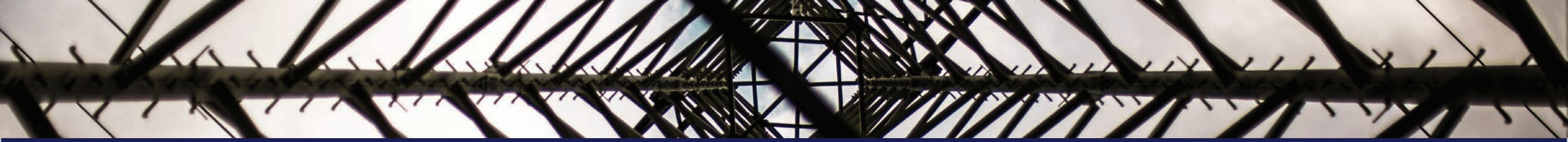
Table 3 provides a summary of the opportunities and challenges that may be encountered when increasing the capacity of existing ROWs by voltage upgrading, AC-DC conversion and adding cables. Broad ranges are given for power flow increase and cost as they are project dependent and can only be refined by performing detailed studies. Furthermore, the cost basis for the new line in Table 3 does not include ROW acquisition, clearing and access roads costs, which can be significant.

Building New High-Capacity ROWs

Traditional overhead line designs generally require relatively wide ROWs and have conservative designs that are not specifically optimized for maximal power transmission capacity. Consequently, insulator lengths, clearances, and interphase spacings are large so that lightning and switching surge flashovers are minimized. Another benefit of these large geometric distances is that the extra space makes it easier to perform work under energized conditions.

Table 3. *Challenges that need to be addressed for increasing capacity of ROWs (N/A-not applicable).*

		Voltage Upgrade	AC-to-DC Conversion	Adding Cable to ROW
Power flow Increase		**50–100%**	**150–200%**	**50–100%**
Reliability	Lightning	Medium	Low	Low
	Switching Surges	High	Low	Low
	Contamination	Medium	High	N/A
Compatibility	Electric Fields	Medium	High	N/A
	Magnetic Fields	Low	N/A	Medium
	Audible Noise (Corona)	High	High	N/A
	Ground Clearances	Medium to High	Medium to High	N/A
Maintainability	Live Work	High	High	N/A
	Access to ROW	N/A	N/A	Low
	Corrosion	N/A	High	Medium
	Fault Currents	Medium	Low	Medium
Cost compared to new ac overhead line of 100% capacity (excl. ROW acquisition, clearing and access roads)		50-80%	100-150%	200-500%



Opportunities exist to adjust standard line designs to maximize the utilization of the ROW without compromising reliability, resiliency, or public and environmental compatibility.

A vision of a more highly utilized ROW is illustrated in Figure 4, which shows the possibilities of leveraging various approaches and technologies to increase the power flow capacity. ROWs will preferably contain multiple transmission circuits as well as distribution under-build. Optimized conductor configurations and insulator designs increase capacity while not reducing reliability. Built in monitoring technology is utilized to take advantage of dynamic ratings. The ROW includes buried or above ground high-voltage cables and pipelines that transport various forms of gas, for example energy carriers such as hydrogen or natural gas, or other gases such as CO2. Portions of the ROW could also be used to support the installation of renewable energy resources, such as PV systems. Advantage can be taken of other infrastructure such as highways and railways.

Stakeholder Engagement

Internal stakeholders from diverse parts of the organization should be engaged early in the process to obtain agreement and identify potential obstacles and solutions, and leadership must provide direction and guidance to ease impediments. Key internal stakeholders to engage include:

- Grid planning
- Special studies and insulation coordination
- Line design and standards
- Construction and project management
- Line maintenance
- ROW acquisition and permitting
- Vegetation management
- Policy and compliance

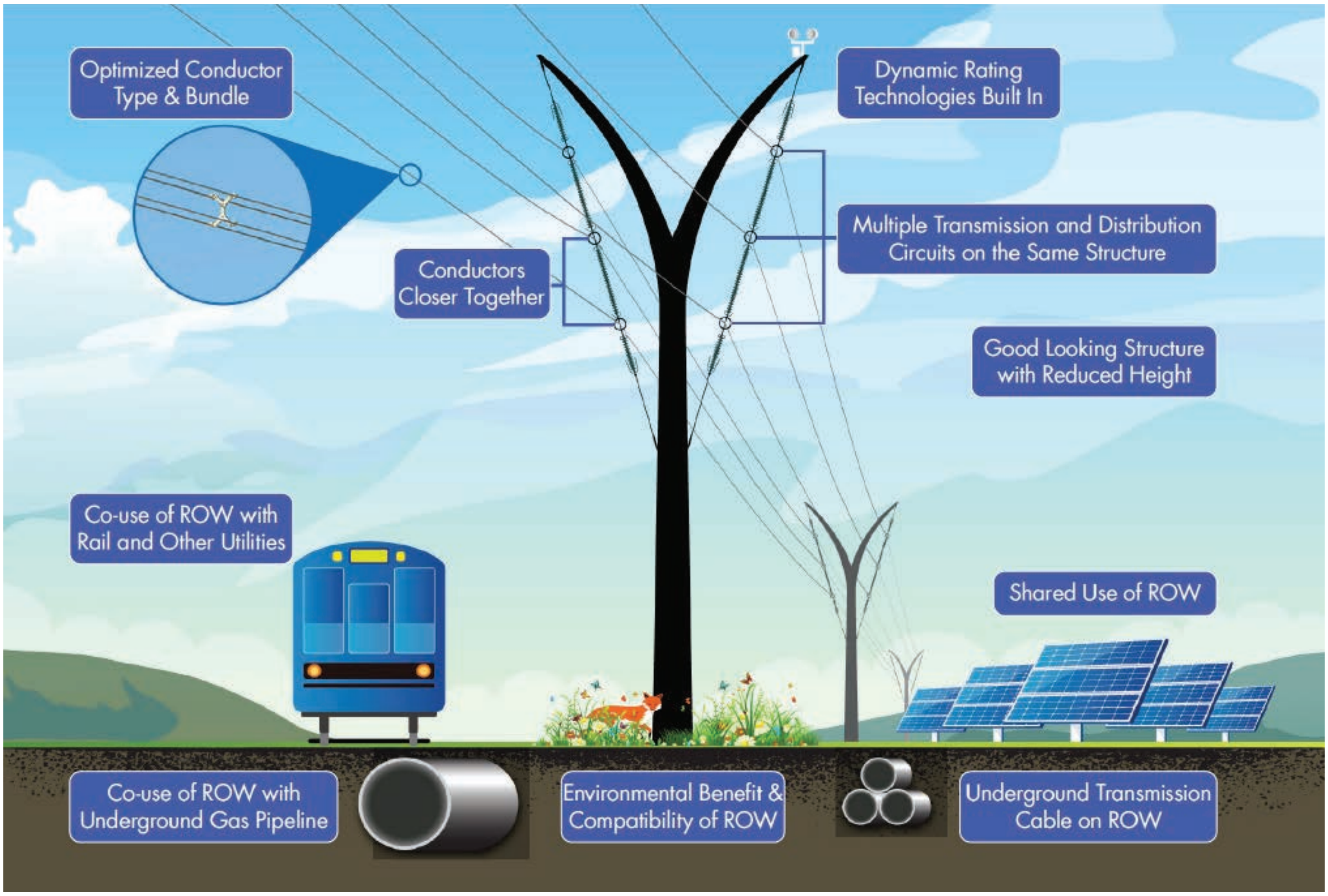
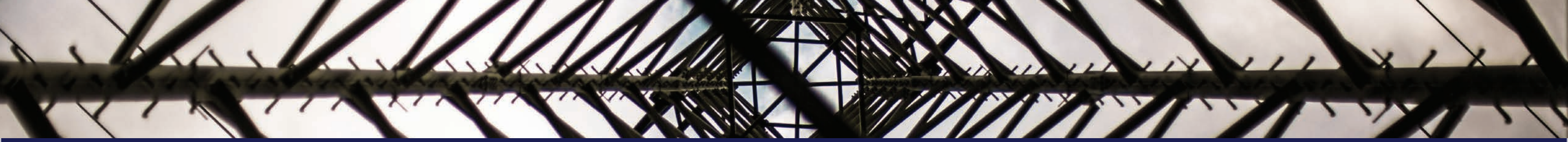


Figure 4. *New transmission ROW taking advantage of multiple options to increase power flow and utilization.*



External stakeholders also need to be engaged, including regulators, the public, and other infrastructure owners, e.g., railway or pipeline owners. The benefits and trade-offs that either the upgraded, or highly utilized new, ROW provides should be clearly articulated. The intention to provide safe, reliable and affordable electricity with reduced impact on the public and the environment should be communicated.

IMPLICATIONS

Increasing the capacity of the transmission system is a vital enabler to meet U.S. and global carbon reduction goals while maintaining or improving the reliability and resiliency of the electric grid.

When increasing the power flow of an existing ROW, the benefits should be traded off against the cost, reliability, and engineering challenges.

The challenges associated with increasing the capacity of existing lines and building new high-capacity ROWs must be addressed through specialized knowledge, analysis and testing combined with field implementation and monitoring.

CONCLUSION

Aesthetic new line designs are needed that maximize the power flow capacity of ROWs, increase public acceptance, and enable increased utilization of other infrastructure, such as pipelines and renewable energy resources.

Collaborating to understand what others have achieved to minimize implementation risks is vital. EPRI is an essential partner that can leverage previous research to provide a strong technical basis to electric utilities for informing decisions.

To support effective utilization of existing ROW, EPRI is developing detailed white papers on each of the options discussed here with publication planned for late 2021.

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