REPORT

HTLS CONDUCTORS CAN COST-EFFECTIVELY FUTURE-PROOF INDIA'S ELECTRICITY GRID

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SUMMARY

We make the case that India should consider High Temperature Low Sag (HTLS) conductors in new transmission lines because they

1. HTLS conductors have ~25% lower transmission (I2R) losses compared to conventional conductors at equivalent line loadings, enabling their additional capital cost to likely be recovered within just a few years and leading to lower total transmission costs over their lifetime.

2. Composite-core HTLS conductors sag significantly less than conventional steel-core conductors and can safely transfer up to twice as much power for the same conductor diameter, enabling the optionality of additional transmission capacity in the future, which is likely to be valuable given significant load growth and the increasing difficulty of acquiring rights-of-way for new transmission lines

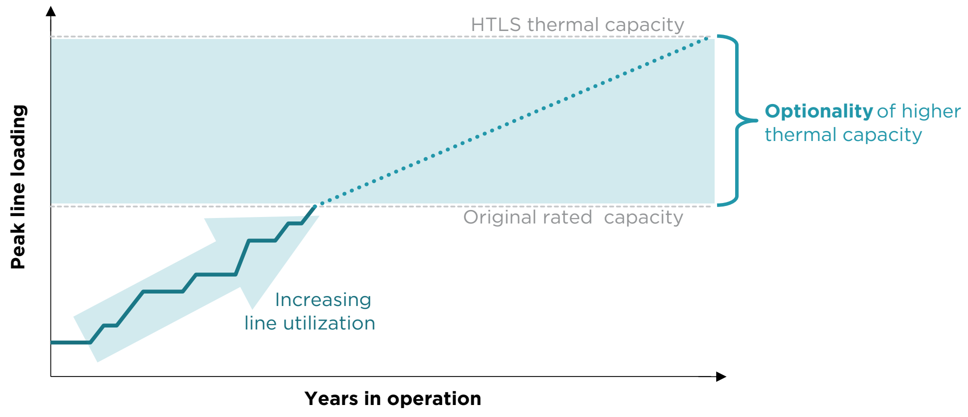
3. During extreme heat events, composite-core HTLS conductors can enhance infrastructure resilience and grid reliability by maintaining high power transmission capacity even at elevated operating temperatures.

We recommend that state and central regulators facilitate such investments through the evaluation of greenfield transmission investments on a total cost of ownership (TCO) basis.

ABSTRACT

As India's electricity demand grows rapidly, the country has a $100 billion plan for major grid expansion by 2032 which includes increasing the length of the transmission network by over 40%. This massive investment offers an opportunity to think strategically about future-proofing grid expansion. To this regard, composite-core High Temperature Low Sag (HTLS) conductors have been widely adopted in India through reconductoring projects to increase transmission capacity within existing right-of-way. However, utilizing equivalent-diameter HTLS conductors in India's planned greenfield transmission projects, in place of the conventional conductors currently planned, would enable the valuable optionality of higher thermal capability. We find that, as a result of HTLS conductors' ~25% lower resistance than equivalent-diameter conventional conductors, the conductors' cost premium would likely be recovered through reduced I2R line losses at equivalent line loadings in approximately 4 years for 220, 400 and 765kV transmission lines, with some variation depending on load factor and electricity cost. Our estimates suggest that utilizing HTLS conductors in all planned greenfield lines by 2032 would cost an additional $22 billion or 22% over the current $100 billion plan with ACSR conductors, but loss savings would likely pay back the investment within 4 years. This can also lead to lower total transmission costs over their line's lifetime while offering the valuable optionality of additional thermal capability for when it may be needed in the future, which is likely to be valuable given significant load growth and the increasing difficulty of acquiring rights-of-way for new transmission lines.

In spite of their small market share today, given both the near-term and long-term benefits as well as the load growth uncertainty, we suggest that the Central Electricity Authority (CEA) recommend composite-core HTLS conductors in new transmission lines. We also recommend that state and central regulators facilitate such investments through the evaluation of greenfield transmission investments on a total cost of ownership (TCO) basis, incorporating line losses.



1. INDIA HAS A $100 BILLION PLAN FOR MAJOR GRID EXPANSION BY 2032

India's electricity consumption has grown tremendously in recent years: demand increased at a Compound Annual Growth Rate (CAGR) of 5% between 2017-2022 and a CAGR of nearly 9.5% between 2022-2024 (GOI, 2024). Driven by industrial expansion, urbanization, economic growth and increasing electrification, the country is expected to continue to see one of the highest rates of electricity consumption growth in the coming decades. However, meeting this demand affordably and reliably requires a robust and reliable power grid that is capable of integrating large-scale renewable generation from resource-rich regions to urban load centers. Announced in fall 2024, India has a $100 billion National Electricity Plan for grid expansion which includes increasing the length of the transmission system by 191,474 ckm (+40%) by 2032 over 2022 levels; within the same time period, substation capacity is set to increase by 1,274,185 MVA (+120%) (GOI, 2024).

TABLE 1: Summary of India's transmission network expansion by voltage level (data from: GOI, 2024).

DC/AC	Voltage class	Length in 2022 (ckm)	Length in 2032 (ckm)	2022-2032 addition (ckm)
HVDC	320/500/800 kV	19,375	34,887	+15,512
HVAC	765 kV	51,023	114,719	+63,696
	400 kV	193,978	249,585	+55,607
	220/230 kV	192,340	248,999	+56,659
	HVAC Subtotal	437,341	613,303	+175,962
Total		**456,716**	**648,190**	**+191,474 (+40%)**

Expanding the transmission system by 40% in less than a decade presents a significant challenge, requiring careful planning, substantial investment, and coordinated execution across multiple stakeholders. It simultaneously offers an opportunity to think strategically about future-proofing investments, taking into account that grid infrastructure - which typically has a multi-decade lifetime - should be deployed not only thinking about short-term needs, but also long-term considerations. This is often referred to as "future-proof" or "least-regrets" system planning.

To this regard, it appears that the majority of greenfield transmission development plans to utilize conventional conductors such as Aluminum Conductor Steel Reinforced (ACSR) based on the L1 (lowest cost) condition. However, given the significant uptake of High Temperature Low Sag (HTLS) conductors in brownfield reconductoring projects across India in the past several years, here we build the case for consideration of HTLS conductors in greenfield development as well.

2. HTLS CONDUCTORS OFFER AN OPPORTUNITY FOR FUTURE-PROOF GRID PLANNING

WHAT ARE HTLS CONDUCTORS?

Today, the majority of power grids are wired with a centuries-old conductor known as Aluminum Conductor Steel Reinforced (ACSR). However, over the past two decades, a new generation of conductors - known as High Temperature Low Sag (HTLS) conductors - has entered into widespread use. Also referred to as advanced conductors, these conductors swap the conventional steel core in the conductor for a composite-based core, made of materials such as carbon fiber or glass fiber as seen in Figure 1 (Chojkiewicz et al., 2024). As a result, HTLS conductors can operate at higher temperatures, with up to ~2x higher thermal ampacity and ~25% lower resistance than an equivalent-diameter ACSR conductor. The higher thermal ampacity is largely a result of the possibility of operating at higher temperatures, in turn resulting from the different core materials. In India, these HTLS conductors are also often referred to as “CCC”, Composite Core Conductor.

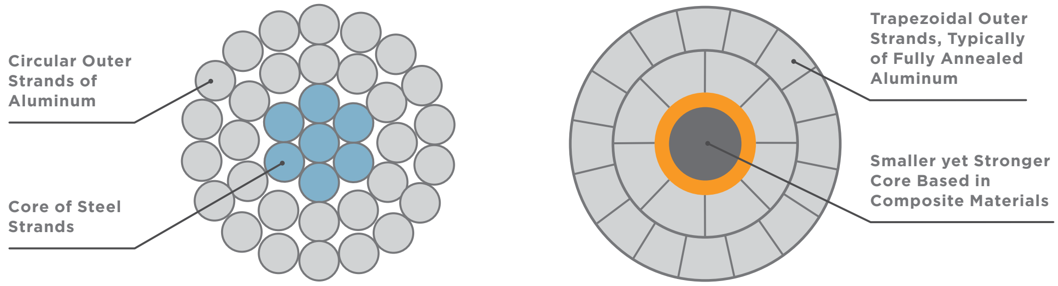


FIGURE 1: Cross-section of an ACSR conductor (left) and an HTLS conductor (right) (Chojkiewicz et al., 2024).

WHAT IS RECONDUCTORING?

As load grows, transmission lines must correspondingly carry increasingly higher power flows. Yet as these flows approach the maximum line limits, grid planners must explore options to upgrade or reinforce the existing system to maintain reliability. If the transmission line in question is thermally limited (as opposed to limited by voltage or stability constraints), then reconductoring can be one solution. Reconductoring replaces a line's existing conductors with a higher ampacity conductor, leveraging the existing towers and the existing right-of-way (ROW) and upgrading substation equipment as needed (Chojkiewicz et al., 2024). However, reconductoring with conventional High Temperature (HT) conductors such as Aluminum Conductor Steel Supported (ACSS) may risk a sag violation at high operating temperatures, as seen in Figure 2. Else, the line may have to be under-rated below its thermal limit to avoid the sag violation, or the towers must be raised to accommodate the larger sag, which can be costly. Meanwhile, the minimal sag of HTLS conductors enables reconductoring projects to avoid sag violations and thus the costs of tower raising, while utilizing the full range of thermal ampacity the conductor offers - as the ratings of terminal equipment allow. This becomes especially critical during extreme heat events, when composite-core HTLS conductors can enhance infrastructure resilience and grid reliability by maintaining high power transmission capacity even at elevated operating temperatures.

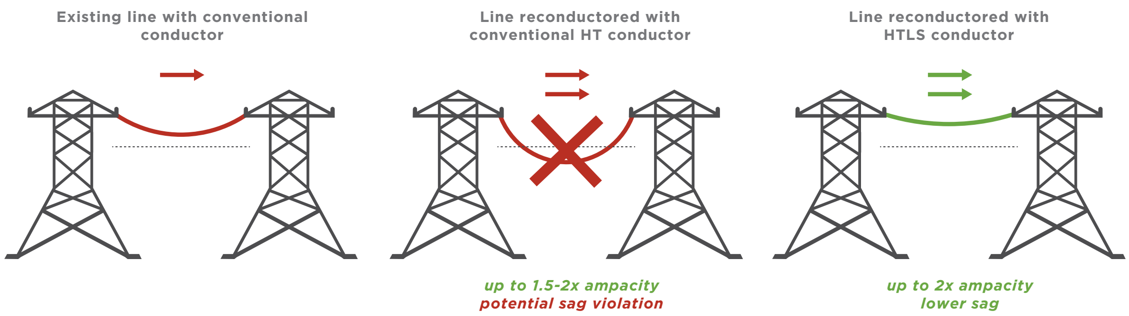


FIGURE 2: Lines reconductored with HTLS conductors can double thermal ampacity while avoiding the risk of sag violations.

WHAT IS THE STATE OF HTLS CONDUCTORS IN INDIA?

HTLS conductors are in widespread use in many parts of the world, increasingly recognized for their value in rapid and cost-effective capacity increases that support load growth, renewable integration, and addressing congestion. As of early 2025, India has completed hundreds of projects with HTLS conductors. The vast majority of these projects have consisted of reconductoring, spanning tens of thousands of circuit-km, over 24 states and 2 union territories, over 30 public/private customers, with a handful of greenfield projects as well. Reconductoring is most commonly performed on low transmission voltages (i.e. 132 kV) in order to accommodate the rapidly growing power demand of urban centers, yet is also increasingly being performed on higher voltage levels such as those on the interstate transmission system (i.e. 400 kV). Table 2 displays a non-comprehensive list of Indian utilities which have used HTLS conductors. At present, the two main suppliers of composite-core HTLS conductors in India are CTC Global's Aluminum Conductor Composite Core (ACCC) as well as Epsilon (Pillai, 2024; Pillai, 2025). Both companies have partnerships with stranding companies such as Apar, Sterlite, Lumino, Transrail, JSK, Shashi, et al. Reflecting the high domestic demand for HTLS conductors, CTC Global has recently opened a new core manufacturing facility in Pune, and Epsilon similarly plans to open a local production facility as well (Pillai, 2024; Pillai, 2025). Other HTLS conductors that have historically been used in India include 3M's Aluminum Conductor Composite Reinforced (ACCR) as well as Tokyo Rope.

TABLE 2: Non-exclusive list of Indian utilities which have performed projects with HTLS conductors.

• AEGCL (Assam)	• PSTCL (Punjab
• BSPTCL (Bihar)	• Reliance Industries via PGCIL
• DTL (Delhi)	• RRVPNL (Rajasthan)
• GED (Goa)	• PTCUL (Uttarakhand)
• GETCO (Gujarat)	• TANTRANSCO (Tamil Nadu)
• JUSNL (Jharkhand)	• Tata Power (Maharashtra)
• KPTCL (Karnataka)	• Torrent Power (Gujarat)
• MPPTCL (Madhya Pradesh)	• UPPTCL (Uttar Pradesh)
• MSETCL (Maharashtra)	• WBSETCL (West Bengal)
• OPTCL (Odisha)	

HOW DOES POLICY SUPPORT RECONDUCTORING?

India's transmission planning philosophy mandates the "optimization of ROW utilization", which includes the use of Grid Enhancing Technologies (GETs), reconductoring with higher ampacity conductors, and the use of HVDC transmission. Documents such as the Central Electricity Authority's (CEA) Manual on Transmission Planning Criteria (CEA, 2023) or the Guidelines for Rationalised Use of High Performance Conductors (CEA, 2019) provide helpful information for the utilization of HTLS conductors. When evaluating reconductoring, many factors are considered, including: the cost of electrical losses, frequency and magnitude of high current loads, the cost of structure reinforcement, existing clearances, the cost/benefit ratio of increased capacity, and availability of additional ROW.

3. UTILIZING HTLS CONDUCTORS IN GREENFIELD TRANSMISSION OFFERS SWIFT COST RECOVERY FROM LINE LOSS SAVINGS

While HTLS conductors have historically been used primarily for reconductoring projects both in India and around the globe, HTLS conductors can definitely be used in greenfield transmission projects as well - with potential I2R line loss savings. This is derived from the fact that HTLS conductors typically have a ~25% lower resistance than an equivalent-diameter ACSR conductor. For instance, a commonly-used ACSR "Drake"-size conductor (795 kcmil) has an AC resistance of 0.0263 ohms/kft at 75°C, while an equivalent-diameter ACCC conductor (1026 kcmil) has an AC resistance of 0.0205 ohms/kft at 75°C. This stems from two primary reasons. First and foremost, HTLS conductors utilize trapezoidal-shaped aluminum wires rather than conventional round wires stranded around the core - which is also slightly smaller in diameter than the conventional steel core - which increases the amount of current-carrying aluminum within the conductor's cross-sectional area. The secondary reason is that HTLS conductors typically use 1350-O fully annealed aluminum, which has a slightly lower resistance than the 1350-H19 aluminum found in conventional ACSR conductors. Recently, a new type of advanced conductor - called the HVCRC Lite - has been developed, which offers similar low-sag as well as I2R loss reduction benefits yet with a lower range of thermal operation and thus a lower cost (Pillai, 2025).

Simply swapping the ACSR conductor for an equivalent-diameter HTLS conductor could up to double the thermal capacity the line is capable of carrying, making additional line capacity available for when it may be needed in the future. This optionality is particularly relevant given the large uncertainty around the timing and magnitude of load growth and generation additions over the next few decades. It could also help support smooth power system operations by providing spare thermal capacity in the event of a contingency, for example. The idea would be to simply swap the currently-planned conventional conductor for an equivalent-diameter HTLS conductor while keeping the other project specifications the same; further, most HTLS conductors can be installed with the same equipment as conventional ACSR conductors. In the future, when additional line capacity may be needed in order to support higher load growth, higher generation additions, contingency risks, etc., the optionality offered by HTLS' higher thermal capacities can be called upon - as summarized in the schematic shown in Figure 3. Additional upgrades to terminal equipment, such as transformers, circuit breakers or protection equipment, to accommodate higher ampacities may then be necessary.

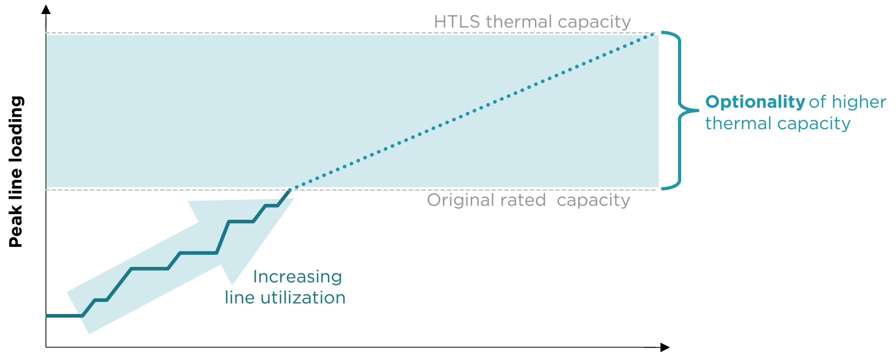


FIGURE 3: Schematic representation of how using HTLS conductors in greenfield projects provides optionality in the long-term.

While this optionality would come at a cost premium of the HTLS conductor over the conventional conductor, the cost premium could likely be recovered through savings in reduced I2R line losses, owing to the reduced resistance of HTLS over ACSR conductors at equivalent line loading. At present, most HTLS conductors are typically priced at 1.5-3.5x conventional conductors on a unit length basis; how quickly this cost premium would be returned would largely depend on the utilization of the line in its first years of operation.

To assess the net benefits of using HTLS conductors in greenfield projects, we analyze three examples: a 220, 400 and 765 kV transmission line. For each voltage level, we assume a standard India-specific ACSR conductor and bundle configuration (see Table 4 in the Appendix). For the upgraded HTLS conductor, we assume an ACCC conductor that is of an equivalent diameter to the original ACSR conductor. We additionally assume each circuit consists of 3 phases; all calculations are performed on a unit length basis, meaning results hold constant whether the line consists of one circuit or two.

We then calculate the payback period: the amount of time it would take to recoup the HTLS conductor's capital cost premium through the lower operational costs stemming from I2R line loss savings. For a standard load factor of 30% and an electricity cost of 5.5 INR/kWh, we find that the payback period is four years. For a higher load factor of 50% and an electricity cost of 5.5 INR/kWh, the payback period is just under two years for both single and double circuit lines. For a lower load factor of 20% and an electricity cost of 5.5 INR/kWh, the payback period is only slightly higher, at seven years.

Figure 4 explores how the payback period varies with electricity cost and load factor, with very similar results across all evaluated voltage levels. Details on the calculation found in the methods in the Appendix. Note that electricity cost refers to wholesale electricity prices; however, transmission utilities typically also charge wheeling fees, which amount to 0.5-1 INR/kWh.

a. Payback period for a 220 kV greenfield line with HTLS instead of ACSR(yrs)

Electricity cost (INR/kWh)	Transmission line load factor												
	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%
3	30.6	18.6	12.9	9.5	7.4	5.9	4.9	4.1	3.5	3.0	2.6	2.3	2.0
3.5	26.2	16.0	11.0	8.2	6.3	5.1	4.2	3.5	3.0	2.6	2.2	2.0	1.8
4	22.9	14.0	9.6	7.1	5.5	4.4	3.7	3.1	2.6	2.3	2.0	1.7	1.5
4.5	20.4	12.4	8.6	6.3	4.9	4.0	3.2	2.7	2.3	2.0	1.7	1.5	1.4
5	18.3	11.2	7.7	5.7	4.4	3.6	2.9	2.5	2.1	1.8	1.6	1.4	1.2
5.5	16.7	10.2	7.0	5.2	4.0	3.2	2.7	2.2	1.9	1.6	1.4	1.3	1.1
6	15.3	9.3	6.4	4.8	3.7	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.0
6.5	14.1	8.6	5.9	4.4	3.4	2.7	2.2	1.9	1.6	1.4	1.2	1.1	0.9
7	13.1	8.0	5.5	4.1	3.2	2.5	2.1	1.8	1.5	1.3	1.1	1.0	0.9
7.5	12.2	7.4	5.1	3.8	3.0	2.4	1.9	1.6	1.4	1.2	1.0	0.9	0.8
8	11.5	7.0	4.8	3.6	2.8	2.2	1.8	1.5	1.3	1.1	1.0	0.9	0.8

b. Payback period for a 400 kV greenfield line with HTLS instead of ACSR(yrs)

Electricity cost (INR/kWh)	Transmission line load factor												
	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%
3	30.6	18.6	12.9	9.5	7.4	5.9	4.9	4.1	3.5	3.0	2.6	2.3	2.0
3.5	26.2	16.0	11.0	8.2	6.3	5.1	4.2	3.5	3.0	2.6	2.2	2.0	1.8
4	22.9	14.0	9.6	7.1	5.5	4.4	3.7	3.1	2.6	2.3	2.0	1.7	1.5
4.5	20.4	12.4	8.6	6.4	4.9	4.0	3.3	2.7	2.3	2.0	1.7	1.5	1.4
5	18.4	11.2	7.7	5.7	4.4	3.6	2.9	2.5	2.1	1.8	1.6	1.4	1.2
5.5	16.7	10.2	7.0	5.2	4.0	3.2	2.7	2.2	1.9	1.6	1.4	1.3	1.1
6	15.3	9.3	6.4	4.8	3.7	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.0
6.5	14.1	8.6	5.9	4.4	3.4	2.7	2.2	1.9	1.6	1.4	1.2	1.1	0.9
7	13.1	8.0	5.5	4.1	3.2	2.5	2.1	1.8	1.5	1.3	1.1	1.0	0.9
7.5	12.2	7.4	5.1	3.8	3.0	2.4	1.9	1.6	1.4	1.2	1.0	0.9	0.8
8	11.5	7.0	4.8	3.6	2.8	2.2	1.8	1.5	1.3	1.1	1.0	0.9	0.8

c. Payback period for a 765 kV greenfield line with HTLS instead of ACSR(yrs)

Electricity cost (INR/kWh)	Transmission line load factor												
	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%
3	30.6	18.6	12.9	9.5	7.4	5.9	4.9	4.1	3.5	3.0	2.6	2.3	2.0
3.5	26.2	16.0	11.0	8.2	6.3	5.1	4.2	3.5	3.0	2.6	2.2	2.0	1.8
4	22.9	14.0	9.6	7.1	5.5	4.4	3.7	3.1	2.6	2.3	2.0	1.7	1.5
4.5	20.4	12.4	8.6	6.4	4.9	4.0	3.3	2.7	2.3	2.0	1.7	1.5	1.4
5	18.4	11.2	7.7	5.7	4.4	3.6	2.9	2.5	2.1	1.8	1.6	1.4	1.2
5.5	16.7	10.2	7.0	5.2	4.0	3.2	2.7	2.2	1.9	1.6	1.4	1.3	1.1
6	15.3	9.3	6.4	4.8	3.7	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.0
6.5	14.1	8.6	5.9	4.4	3.4	2.7	2.3	1.9	1.6	1.4	1.2	1.1	0.9
7	13.1	8.0	5.5	4.1	3.2	2.5	2.1	1.8	1.5	1.3	1.1	1.0	0.9
7.5	12.2	7.5	5.1	3.8	3.0	2.4	2.0	1.6	1.4	1.2	1.0	0.9	0.8
8	11.5	7.0	4.8	3.6	2.8	2.2	1.8	1.5	1.3	1.1	1.0	0.9	0.8

FIGURE 4: Payback period varies significantly depending on load factor and electricity cost, but does not vary significantly with voltage level. For details on the calculation, please see the methods in the Appendix.

While it should be noted that, if and when the additional line capacity of HTLS conductors is utilized at some point in the future, I2R line losses may increase - due to the mathematical fact that line losses increase with the square of the line current - this would likely happen after the cost premium has already been paid off. It should also be noted that using HTLS conductors in greenfield projects has potential for reducing the number of structures required and/or lowering the height of the structures (due to the increased strength and reduced sag of HTLS conductors) and thus additional savings in project capex, yet this opportunity should be evaluated on a case-by-case basis.

4. DEPLOYMENT OF HTLS CONDUCTORS IN INDIA'S GREENFIELD TRANSMISSION LINES CAN LEAD TO SIGNIFICANT SAVINGS

What if all the planned greenfield transmission lines in India, as outlined in the $100 billion National Electricity Plan, used HTLS conductors? To answer this question, we look at the planned HVAC lines at the 220, 400 and 765 kV voltage levels. Our estimate suggests that the HTLS conductors would cost an additional $22 billion over the current $100 billion plan with ACSR conductors, but I2R loss savings (assuming a load factor of 30% and a cost of electricity of 5.5 INR/kWh) would pay back the investment in approximately four years - as displayed in Table 3. We also estimate the 30-yr unadjusted line loss savings, representing the economic lifetime of the transmission line, which measures over $160 billion. Although the lifetime I2R loss savings would depend heavily on the line utilization, this provides an approximate idea of the potential cost savings afforded by HTLS conductors. India's utilities should thus consider evaluating the conductor choice on a total cost of ownership (TCO) basis, rather than solely on a capital cost basis as is the conventional standard in the industry.

TABLE 3: Annual I2R loss savings versus the HTLS cost premium by voltage level, assuming a load factor of 30% and a cost of electricity of 5.5 INR/kWh.

Voltage class	2022-2032 addition	Annual loss savings	HTLS cost premium	Payback period	30-yr unadjusted savings
765 kV	+63,696 ckm	3.7 billion USD/yr	14.9 billion USD	4 yrs	111 billion USD
400 kV	+55,607 ckm	1.1 billion USD/yr	4.6 billion USD	4 yrs	34 billion USD
220/230 kV	+56,659 ckm	0.5 billion USD/yr	2.2 billion USD	4 yrs	16 billion USD
Total	**+175,962 ckm**	**5.3 billion USD/yr**	**21.7 billion USD**	-	**161 billion USD**

These results simultaneously suggest that, even if the probability that a given transmission line would benefit from additional transmission capacity in the longer term is low - in other words, the future optionality may not be needed - there still remains significant benefit in swapping a conventional conductor for a HTLS conductor in greenfield transmission. At equivalent line utilization, the HTLS cost premium would be quickly recouped within the first few years of the line's operations. This also holds true if the terminal equipment - such as transformers or protection systems - are not rated to the same thermal ampacity of the conductor; additional cost-benefit analysis would have to be performed to identify what upgrades would be necessary in order to bring the terminal equipment's ratings to the level of the HTLS conductor.

We therefore recommend that the Central Electricity Authority (CEA) and Indian utilities consider HTLS conductors in new transmission lines and that state and central regulators help facilitate such investments, given both the near-term and long-term benefits as well as the significant uncertainty around the timing and magnitude of load growth and generation additions in the coming decades.

It is crucial to act swiftly to revise the framework now, because India's massive grid investment plans are already taking shape; and once project procurement is in motion or lines begin construction, course corrections become costly and complex. Presently, India is one of the largest markets in the world for conductors. Composite-core HTLS conductors represent only around 5% of the total market demand, although their market share is growing rapidly. Given their potential to unlock higher capacity and future-proof investments, it is essential that planners and policymakers weigh their benefits alongside conventional options during this pivotal planning phase.

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APPENDIX

METHODS FOR PAYBACK PERIOD CALCULATION

We use IEEE Standard 738-2006 for Calculating the Current-Temperature of Bare Overhead Conductors, assuming an ambient temperature of 25°C, elevation of 0 m, wind angle of 90 degrees, latitude of 37 degrees, wind at 2 m/s, emissivity and absorptivity of 0.5, solar radiation of 1029 W/m2, June 21st at noon, with clear atmosphere (IEEE, 2007). Deriving the ampacity versus operating temperature as well as the resistance versus operating temperature relationships allows us to calculate the line capacity of a 220, 400 or 765 kV transmission line operating at 75°C, from which we obtain the phase current and calculate the line loss by:

$$\text{Line loss (MWh/mile/year)} = \left(\frac{\text{Phase current}}{\text{\# of conductors per phase}}\right)^{2} \cdot \text{(Resistance per mile)} \cdot$$

$$\text{(\# of conductors per phase)} \cdot \text{(\# of circuits per line)} \cdot \text{(\# of phases)} \cdot \text{(loss factor} \cdot 8760\text{)}$$

with the transmission loss factor calculated by:

$$\text{Loss factor (\%)} + (0.3 \cdot \text{load factor}) + (0.7 \cdot \text{load factor}^{2})$$

We assume 3 phases/circuit. The 0.3 and 0.7 coefficients in the loss factor calculation reflect commonly used coefficients in transmission loss calculations (CTC Global, 2018). For Figure 3, we assume each line is a single circuit, although results hold for a double circuit line as well as calculations are performed on a per unit length basis. As for the number of conductors per phase, we assume a standard-India conductor bundle configuration for each voltage level as seen in Table 4. We next substitute the ACSR conductor for an equivalent-diameter ACCC conductor per Table 4 and repeat the process of calculating the line capacity, phase current and respective line loss, assuming the load factor remains the same. All relevant conductor information including resistance values, diameters, and rated ampacities is obtained from (CTC Global, 2018). Due to the ~25% lower resistance of the equivalent-diameter ACCC conductor over the ACSR conductor, the line loss (in MWh/mile/year) is similarly ~25% lower, holding all other parameters constant. We then calculate the cost of losses using various costs of generation in India and find the delta loss savings. As a baseline, we use the average cost of generation of 5.5 INR/kWh.

To calculate the cost premium of using HTLS conductors over ACSR conductors, we obtain the latest local conductor costs from industry sources which can also be seen in Table 4. We compare these values with MISO's Transmission Cost Estimation Guide (TCEG) for 2024, in which ACCC conductors are shown to have a 2.1-2.8x cost premium over ACSR conductors on a unit length basis (MISO, 2024). This is slightly higher, but still similar, to the 3-3.5x cost premium observed in India, resulting from slightly lower costs of ACSR and slightly higher costs of ACCC. Next, to find the delta cost increase, we multiply the delta conductor unit cost by the desired number of circuits/line, the reference number of conductors/phase, and 3 phases/circuit along with a 4% sag and wastage adder. We then divide the delta cost increase by the losses cost savings to find the unadjusted payback period.

TABLE 4: Reference conductor sizing, conductor cost, and HTLS alternative in India based on (CEA, 2023; UPPCTL, 2023; industry sources).

Voltage	Conventional conductor (British sizing)	Alternative HTLS conductor
220 kV	ACSR "Zebra", single bundle 425,000 Rs/km	ACCC "Hamburg", single bundle 1,476,000 Rs/km
400 kV	ACSR "Moose", twin bundle 535,000 Rs/km	ACCC "Fortworth", twin bundle 1,645,000 Rs/km
765 kV	ACSR "Zebra", hexa bundle 425,000 Rs/km	ACCC "Hamburg", hexa bundle 1,476,000 Rs/km

Notably, using HTLS conductors in greenfield projects has the potential for reducing the number of structures required and/or lowering the height of the structures (due to the increased strength and reduced sag of HTLS conductors) and thus additional savings in project capex; some estimates find these project capex savings can measure up to 40% (i.e., 40% lower project capex with composite-core HTLS conductors due to fewer/shorter structures). However, this requires further project-specific analysis (also depending on terrain, weather conditions, proposed structure type, etc.) that is out of scope for this analysis.