
	<p>Asia Clean Energy Forum Deep Dive Workshop Opportunities for Grid Efficiency Improvements with High-Temperature Low-Sag Conductors 16 June 2015</p>	
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SUMMARY NOTES

BACKGROUND

Re-stringing existing networks of 33 kV and higher voltages presents one of the greatest opportunities for energy efficiency gains worldwide, and one of the least disruptive with respect to environmental and social considerations. HTLS conductors can be an economically viable solution for increasing transmission capacity without acquiring new right-of-way for new lines, and may be the only practical solution for urbanized areas and other areas where right-of-way constraints exist. For new lines, HTLS conductors should be considered where right-of-way constraints exist (e.g., near airports); in general, HTLS conductors deliver built-in efficiency gains which should be considered as part of transmission expansion plans.

HTLS conductors are amenable to a much wider variety of applications than high-voltage direct current (HVDC) systems which are generally limited to very high voltage lines (500 kV and higher) with 1 GW or higher capacity.

HTLS conductors have been on the market for more than 10 years, but are still relatively unknown to donor agencies, multilateral development banks, consultants, and utility professionals. Several varieties of HTLS conductors are commercially available worldwide, with a significant supplier network in developing countries of Asia. Additional background information is included in Appendix 1.

KEY POINTS

The program included an opening presentation by ADB energy specialist with an overview of potential HTLS applications and rationale; 4 presentations from utilities in ADB's developing member countries (India¹, Indonesia, Malaysia, and Nepal); and 2 presentations from HTLS suppliers covering projects in the Philippines and Vietnam. Presentations covered experience with HTLS applications for new transmission lines as well as for re-conductoring projects. HTLS can be used to address a variety of issues in transmission system design and operations, including (i) right-of-way (ROW) constraints, (ii) system rehabilitation, (iii) enhanced reliability and system redundancy, (iv) loss reductions and related financial health of transmission utilities, and (v) reduced emissions of primary pollutants and greenhouse gases (GHGs). The final presentation covered regulatory considerations, noting the need for electricity regulatory commissions to acknowledge the energy savings potential and promote monetization of these benefits.

¹ Unfortunately, the representative from the Maharashtra transmission company was unable to attend, and the presentation was made by a representative from CTC Global.

The presentation on Malaysia covered new lines with ROW constraints including sensitive ecosystems and proximity to major airport operations which imposed a height limit on towers. The Nepal presentation focused on uncertainties in basin-wise hydropower development which require the transmission operator to plan for a 10-fold increase in hydropower capacity from about 150 MW now to 1500 MW within 10-15 years but with minimal certainty on schedule for building larger plants ranging from more than 250 MW to 600 MW: the uncertainty in this build-out led to a decision to utilize HTLS conductors on a 220 kV double circuit line rather than ACSR conductors on a 400 kV double circuit line.

The presentations on India, Indonesia, the Philippines, and Vietnam covered a wide variety of re-conductoring projects where ROW constraints were addressed with HTLS-based solutions. Different case studies concluded that the cost-effectiveness of re-conductoring vs. rebuild or completely new lines is substantial, on the order of >2:1 with the most expensive conductors, e.g., around \$2.2 million per km for a new line vs. about \$1 million per km for re-conductoring. In some cases, re-conductoring is estimated to be 1/5th – 1/6th the cost of new lines. The presentation on the Philippines noted that re-conductoring is possible – although not simple – in locations where “live” distribution lines are present underneath the transmission lines being upgraded.

SCOPE OF OPPORTUNITIES

The scope of potential applications is significant in countries where ROW constraints are a challenge for new lines, e.g., Indonesia, Malaysia, Nepal, and Vietnam, and in urban areas throughout Asia. Vietnam requires about \$2 billion per year in grid investment to keep up with growing energy demand; ADB has programmed about \$1.45 Billion in investments only for the high-voltage network in Vietnam from 2015-2020 (about \$300 million per year); much of the ultimate investment may be in the form of re-conductoring due to ROW constraints. Likewise, Indonesia will need to invest about \$1 billion per year for the foreseeable future to keep up with growing power demand. Lower voltage distribution networks also present substantial opportunities for loss reductions; e.g., India has about 500,000 kilometers of 33 kV lines, much of which may require rehabilitation during the next several years. HTLS applications are scalable both upward and downward from 400 kV to 33 kV and even 22 kV lines.

CONCLUSION

If Alexander Graham Bell were alive today, he would not recognize the telephone business (or modern mobile phones and certainly not the supercomputers known as “smart phones”), but if Thomas Edison were alive today, he would recognize the electricity grid. In the 21st century, we need – and can deliver – 21st century technology and business models for ADB’s developing member countries to address enormous growth in electricity demand. Developing country governments, energy planners, regulators, and utilities will benefit from growing experience in HTLS applications, particularly in the realm of adding capacity without building new power lines and power plants. We need to better optimize capacity and to minimize the use of right-of-way power lines, particularly in vulnerable eco-systems.

ADB is in an excellent position to provide technical and financial assistance for transmission system efficiency improvements including use of HTLS lines. We already see great potential in Vietnam, Indonesia and India to upgrade transmission lines where there are chronic problems obtaining new right of way. Based on the current knowledge and project experience base, ADB and other financial institutions should consider making HTLS conductors the default choice for transmission investments including re-conductoring and new lines.

PROGRAM

09:00 – 09:15 Overview of HTLS technology and applications

Prospects for rapid scale up of HTLS installations as an alternative/complement to new power plants -- the world's biggest unexploited energy efficiency opportunity; Takafumi Kadono, ADB Southeast Asia Energy Division

Practical experience in developing countries:

09:15 – 09:45 *Transmission Line Capacity Upgrading: The TNB Technology Road Map,* Zulkili M. Yusof, Chief Engineer, Overhead Lines and Cables, TNB Malaysia

09:45 – 10:15 *Installation of Advanced Composite Core Conductors,* Donny Reinaldi, PT PLN

10:15 – 10:30 *Increasing Line Capacity using HTLS: First ACCR Installation in SE Asia,* Glenmar Cambri, Sr. Applications Engineer, 3M Electrical Markets Division

10:30 – 10:45 Coffee break

10:45 – 11:00 *HTLS Projects in India,* Hitesh Mundhada, CTC Global

11:00 – 11:15 *Introduction of Low Sag Up-Rating Conductor in Vietnam,* Hiroaki Ida and Toyomitsu Kumata, Sumitomo Electric Industries/J-Power Systems.

11:15 – 11:45 *Financing New High Voltage Transmission Lines in Nepal Using HTLS Conductors;* Surendra Rajbhandari, Nepal Electricity Authority, & Zhang Lei, ADB South Asia Energy Division

11:45 - 12:15 *Regulatory Considerations,* presentation and discussion led by Priyantha Wijayatunga, former Director General, Public Utilities Commission of Sri Lanka, Principal Energy Economist, ADB South Asia Energy Division.

12:15 - 12:30 Summary and Wrap up Dan Millison, Manager, Transcendergy, LLC

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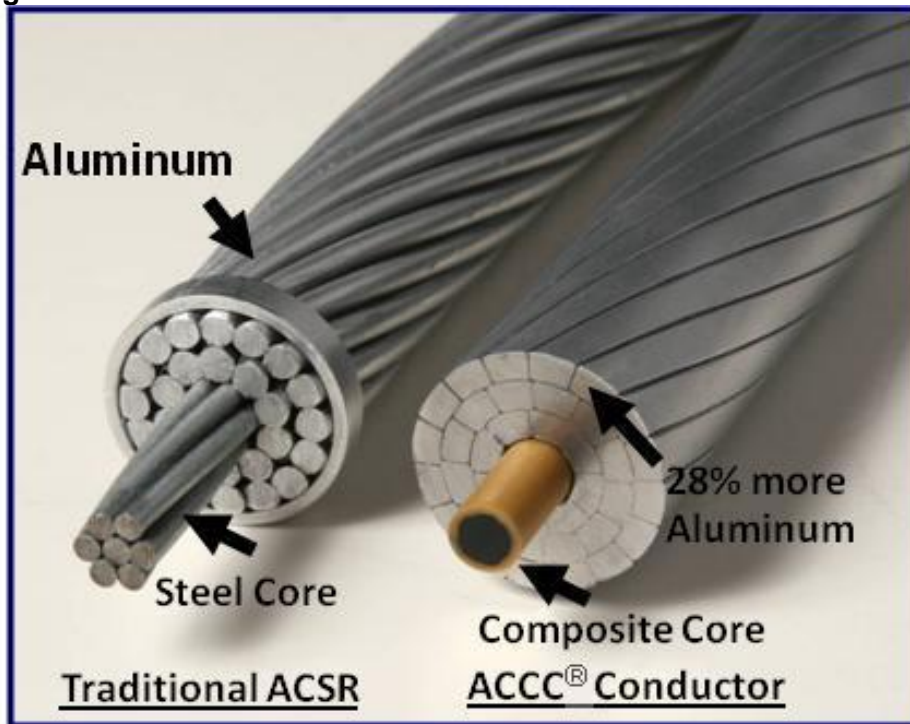


APPENDIX 1
Deployment of High-Temperature Low-Sag Conductors
For Electricity Grid Efficiency Improvements¹

I. Background

1. The vast majority of the world's electricity grids utilize above-ground conductor technology that was first deployed before 1900: aluminum conductor steel reinforced (ACSR) cables. In the United States (US) alone, more than 800,000 kilometers (km) of ACSR are used on transmission lines of 230 kilovolts (kV) and higher. As the name implies, ACSR utilizes a steel core for strength surrounded by aluminum which conducts the electricity. High-temperature low-sag (HTLS) conductors have several advantages and have been commercially available for more than a decade, but ACSR remains the default choice for most transmission projects due to lack of knowledge or due to the higher cost of HTLS. HTLS conductors utilize cores made of steel alloys, composite-reinforced metal, or carbon fiber composite material; the greater core strength can support more aluminum conductor, with reduced sag at higher operating temperatures. Figure 1 illustrates the basic designs of ACSR and a type of HTLS conductor which uses trapezoidal aluminum conductors wound around a carbon fiber composite core. The HTLS conductor has the same outer diameter as ACSR but has more conductor area and higher capacity; the two conductors have comparable weight because the composite core is much lighter than a steel core. Figures 2, 3, and 4 illustrate other commercially available varieties of HTLS conductors.

Figure 1: ACSR and HTLS Conductors



¹ Prepared by Dan Millison, Transcendery, L.L.C., and Paul White, Wedgewood White, Ltd., September 2013.

Figure 2: Aluminum conductor, composite reinforced metal matrix core (ACCR)



Figure 3: Aluminum conductor steel supported / trapezoidal wire (ACSS/TW)



Figure 4: CTACSR (“gap”) at left; and ACIR (Invar core) at right



2. Table 1 summarizes types of HTLS, capacities and prices relative to ACSR, and the approximate total length of conductors installed globally. Market prices will vary with the costs of aluminum, steel, and other alloy metals.² The common design factor is a stronger core surrounded with more aluminum conductor than conventional ACSR. Most of the aluminum conductors have trapezoidal cross section (also known as “trap wire”) which increases the conductor area. The ACSS / TW type conductor is a minor design advance over ACSR, as it utilizes a steel core; other varieties utilize alloys and composites for greater core strength.

Table 1: Summary of HTLS Types and Deployment

Conductor	Manufacturer	Current Capacity	Price	Installed Length (conductor-km)
ACSR	Various	1	1	800,000 ^a
ACSS / TW	Southwire	1.8 – 2.0	1.2 – 1.5	56,000
CTACSR (“gap”)	J-Power	1.6 – 2.0	2	10,000
ACIR (Invar core)	LS Cable	1.5 – 2.0	3 – 5	20,000
ACCR	3M	2 – 3	5 – 6.5	1,600 ^b
ACCC	CTC Global	2	2.5 – 3.0	22,000 ^c

ACSR = aluminum conductor steel reinforced, ACSS/TW = aluminum conductor steel supported / trapezoidal wire, CTACSR = aluminum conductor steel reinforced, ACIR = aluminum conductor invar reinforced, ACCR = aluminum conductor composite reinforced, ACCC = aluminum conductor composite core

Source: Clairmont, Bernie. 2008. *High-Temperature Low-Sag Conductors*, Electric Power Research Institute (EPRI), Transmission Research Program Colloquium, Sacramento California, 11 September 2008.

Notes:

^a US installations 230 kV or higher

^b Installed length reported by Dawson, Donna. 2013. *Composite-cored Conductors: Holding the Line*. Composites World. 1 February 2013. Accessed online 28 August 2013 from:

^c Installed length as reported on CTC Global website.

II. Technical Issues and Benefits

3. Thermal sag places a limit on the amount of electric current which occurs when the electric current that a conductor can carry. Thermal sag arising from overloaded conductors has contributed to large-scale blackouts such as that which occurred on the US east coast in 2003,

² Market prices for carbon fiber composite are less volatile than for aluminum, steel, and alloys.

and may have been the cause of the catastrophic blackouts in India in July-August 2012. Figure 5 illustrates the difference in sag between ACCC and ACSR conductors strung on the same towers; the ACCC conductor exhibits less sag due to lower coefficient of thermal expansion.

Figure 5: Sag Characteristics



4. A logical response to overloaded transmission lines is to add more conductors, which normally requires a new transmission line including right-of-way (ROW), towers, substations, etc. New lines may not be feasible due to lack of ROW because of competing land uses and/or environmental and other social constraints. HTLS conductors -- which have less sag at high temperatures, reduced resistance, and higher capacity -- can replace conventional conductors to increase capacity while also reducing line losses³. The simplified formula for the power transmitted by a conductor at a given voltage and current ("Watt's Law") is:

$$P = I \times V$$

Where: P = power in watts (W)
I = current in amps (A)
V = voltage (V)

5. The simplified formula above shows that if the current in a conductor is doubled, the power transmitted is also doubled without changing the voltage. This simple relationship means if the current rating of an existing line can be increased, the line's power carrying capacity can be increased without upgrading the voltage (which would require a new line, or extensive modification of an existing line).

³ Line losses are typically 7% or more of energy sent out in developed countries and are typically much higher in developing countries.

III. Financial and Economic Considerations

6. As shown in Table 1, most of the HTLS conductors available today have up to twice the capacity of ACSR conductors of equivalent diameter, with some manufacturers reporting up to 25% reduction in line losses as well. This presents opportunities to upgrade existing transmission corridors via conductor replacement at much lower cost than constructing new transmission lines.⁴ For new lines, HTLS conductors offer economic benefits in terms of reduced line losses and higher capacities.⁵ HTLS conductors provide a quicker route to reducing emissions intensity of a grid than most other alternatives, as transmission upgrades can be accomplished in a matter of weeks or months compared to multi-year development and commissioning for large-scale fuel switching or RE projects, and demand-side management interventions that require a very large number of small-scale actions (e.g., residential switching from incandescent to CFL or LED lighting).

7. Table 2 summarizes the imputed value of the energy savings of HTLS conductor with respect to avoided line losses. In the 2 scenarios shown in Table 2, the HTLS conductors exhibit 26% and 28% lower line losses than similarly sized conventional conductors transmitting the same amount of power. In this example, loss reduction is valued at the avoided cost of generation in megawatt-hours (MWh), but in a system suffering from a generation deficit, the value could be significantly higher. Using the examples from Table 2, Table 3 summarizes the imputed value of capacity savings (MW) with respect to avoided line losses. Again, the capacity value of avoided losses would be higher in a system with a generation deficit.

Table 2: Energy Value of Line Loss Reductions

Conductor	Peak Amps	T (°C) at Peak Amps	Energy (MVA) ^a	Line Losses (MWh/y)	Loss reduction (MWh/y)	Value of Reduction @\$50/MWh (\$/y)	Implied Value of Conductor (\$/meter) ^b
ACSR	1000	95	398	76,917	--		
ACCC	1000	82	398	56,588	20,329	\$1,016,450	\$67.80
ACSR	1600	194	637	251,998	--		
ACCC	1600	156	637	179,022	72,976	\$3,648,800	\$243.20

Source: CTC Global

Notes: Assumed 100 km installation, single circuit, 3-phase line, with 300,000 meters total conductor length

^a Load factor is 53% for all cases.

^b Assuming 20 years of operations; undiscounted for net present value.

Table 3: Capacity Value of Line Loss Reductions

Loss reduction (MWh/y)	Generation Capacity to Supply Losses (MW) ^a	Value of Reduction @\$1 million/MW (\$)	Implied Value of Conductor (\$/meter)
20,329	3.3	\$ 3,300,000	\$ 11.00
72,976	11.9	\$ 11,900,000	\$ 39.67

Source: Line losses are from CTC Global as shown in Table 2.

Notes: Assumed 100 km installation, 3-phase line, 300,000 meters total conductor length

^a Generation load factor assumed at 70%, which is typical for fossil fuel, geothermal, and some hydropower plants.

8. Table 4 illustrates the value of avoided line losses assuming that electricity from renewable energy plants is being carried. Comparing the value of loss reductions between Tables 3 and 4 shows clearly that the cost of line losses increases with the wholesale cost of

⁴ E.g., a recent example of reconductoring in an urban area can be found at: <http://www.businesswire.com/news/home/20120118005036/en/Russia%E2%80%99s-MOESK-Utility-Installs-3M-ACCR-Upgrade>

⁵ E.g., it may be possible to avoid a mix of voltage ratings in a transmission corridor by utilizing HTLS conductors for increased capacity instead of a higher voltage segment.

generation. This makes a compelling case for using HTLS conductors for evacuation of power from utility-scale RE plants, especially for transmission lines which connect solar and wind farms to the grid wherein the transmission load factor may be on the order of 30% to 40% vs. 70% or higher for coal and gas fired power plants.

Table 4: Capacity Value of Line Loss Reductions with Renewable Generation

Loss reduction (MWh/y)	Generation Capacity to Supply Losses (MW) ^a	Value of Reduction @\$3 million/MW (\$) ^b	Implied Value of Conductor (\$/meter)
20,329	5.8	\$ 17,400,000	\$ 58.00
72,976	20.8	\$ 62,400,000	\$ 208.00

Source: Line losses are from CTC Global as shown in Table 2.

Notes: Assumed 100 km installation, 3-phase line, 300,000 meters total conductor length.

^a Generation load factor is assumed at 40% which might be achieved with a mix of solar and wind farms.

^b Installed cost assumes a mix of utility-scale solar and wind farms.

9. Table 5 shows the potential monetary value of greenhouse gas (GHG) reductions from line loss reductions based on the high end of current carbon market prices. Comparison of the implied value of conductor presented in Tables 2 through 5 suggests that current carbon prices undervalue the transmission efficiency advantages of HTLS conductors.

Table 5: Value of Line Losses in Carbon Markets

Loss reduction (MWh/y) ^a	GHG Reduction (tCO ₂ e/y) ^b	Value of Reduction @ \$5 / tCO ₂ e (\$/y)	Implied Value of Conductor (\$/meter) ^c
20,329	18,296	\$91,480	\$ 6.10
72,976	65,678	\$328,392	\$ 21.89

Source: Line losses are from CTC Global as shown in Table 2.

Notes: Assumed 100 km installation, 3-phase line, 300,000 meters total conductor length

^a Loss reductions as shown in Table 2.

^b Assumes loss reduction shown in the first column is based on coal-fired generation with grid emission factor of 0.9 tCO₂e/MWh.

^c Assuming 20 years of revenue from sale of carbon credits.

10. Detailed cost information is not readily available for the various conductors listed in Table 1. However, some information from a recent re-conductoring project in the US provides an educated guess for simple cost-benefit analysis.⁶ US-based utility AEP and HTLS manufacturer CTC Global announced a project for re-conductoring about 2700 kilometers of a 345 kilovolt double-circuit, double bundle line in Texas, at a total price of US\$225 million including substation upgrade. Dividing the total cost by total length yields an aggregate estimated installed cost of \$83,333 per kilometer (\$41,666 per circuit-km), with an imputed price of \$6.90 per meter of conductor,⁷ which is lower than earlier prices noted by CTC Global which ranged from \$12.47 per meter to \$15.68 per meter⁸. The price for the Texas re-conductoring

⁶ See press releases, accessed on 4 September 2013 from:

<http://www.aep.com/newsroom/newsreleases/Default.aspx?id=1720>

and from: <http://www.ctcglobal.com/news/ctcglobal-signs-contract-with-aep/>

⁷ A 3-phase double-circuit line with double-bundle conductors has a total of 12 conductors. The unit cost is estimated as \$225 M / 2700 km = \$83,000 / km; \$83,000 per km / 12 = \$6944 / km = \$6.94 / meter of conductor.

⁸ Pat Avery, VP of Business Development for CTC Global. *High Capacity / Low Sag Conductor for the Power Industry*. Presentation notes dated 9 November 2010. Prices noted were \$12.47 / meter for "Linnet" size conductor for 1000 amp load, \$15.68 / meter for "Drake" size for 1760 amp load, and \$30 / meter for "Bluebird" size for 3240 amp load.

project is substantially lower than recent estimates and bids for 220 kV and 400 kV lines in India and Nepal, which range from \$250,000 per km to \$800,000 per km.⁹

11. HTLS applications in developing countries should be reasonably attractive with respect to technical, financial, and economic benefits. For example, Nepal Electricity Authority (NEA) reported that in 2011-12 it supplied 4178 GWh of energy (vs. 5194 GWh demand) with aggregate losses of about 23% (961 GWh). In 2011-12 NEA's average realization from the sale of electricity was around \$48/MWh. NEA cannot meet customer demand for most of the year, and so a reduction in energy losses to 10% would result in incremental revenue to NEA of approximately \$5.0 million per annum (\$100 million over a 20-year period). Additionally, 17 MW of new generating capacity (assuming 70% plant factor) at a cost of approximately \$2 million per MW (\$34 million in total) could be avoided. The total gross impact of incremental revenue for NEA and avoided investment in generation capacity is about \$134 million over a 20-year period.¹⁰

12. The Nepal grid includes 2130 circuit-kilometers of 132 kV lines which comprise the bulk of the transmission system. Using the inferred price of reconductoring of \$41,666 / circuit-km (noted in para. 10 above), upgrading the entire 132 kV network would require investment of about \$89 million, roughly equivalent to the savings from avoided losses and generation capacity as estimated in paragraph 11.¹¹ The financial internal rate of return (FIRR) for such a systematic upgrade may not appear commercially attractive, but the economic viability should be compelling considering that increasing the capacity of the 132 kV network by just 50% would delay the need for much of the planned 220 kV network which is estimated to cost upwards of \$250,000 / km (for double-circuit lines). Alternatively stated, at a price of \$250,000 / km or higher, \$134 million will buy at most 536 km of new 220 kV lines.

IV. Market Competition and Procurement Issues

13. As shown in Table 1, there are 5 known technology vendors offering a variety of HTLS products. At least one of these vendors (CTC Global) licenses its technology to various manufacturers globally; the composite core is manufactured in the US, with the aluminum conductors added by licensees who then sell finished products. In Vietnam, the state electricity company (EVN) recently completed a 270 km reconductoring project which utilized ACCC. According to CTC Global representatives, 6 bids were submitted for the EVN project. In order to promote competition on ADB-funded projects, procurement should utilize performance-based specifications rather than technology-based specifications, whether for simple supply contracts, turn-key installation, or engineering, procurement, and construction (EPC) mode.

⁹ It is critical to note that the prices noted for the AEP project in the US are not necessarily applicable to developing countries in Asia. The discussion on costs, prices, and value in this document are indicative only.

¹⁰ As a benchmark, the most recent ADB-funded transmission project in Nepal (approved in 2011) provided \$100 Million in financial assistance.

¹¹ Again, the actual cost for a large-scale upgrade may be significantly higher due to transportation requirements, import duties, and higher costs attributable to installation in "remote" areas. EVN's project in Vietnam, noted in paragraph 13, may provide a better reference price for the Asia region.