Integrating Transmission and Distribution Engineering Eventualities

Task 1.1

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PSERC

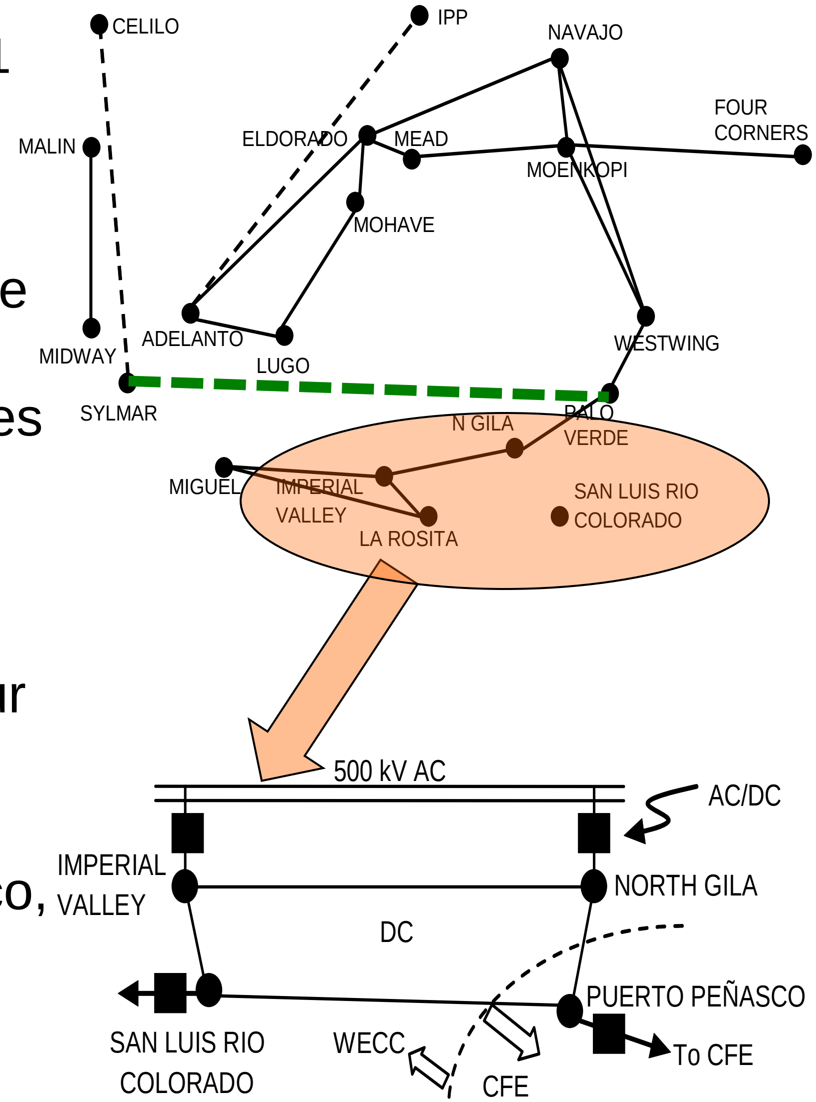
PSERC Future Grid Initiative
May 29, 2013

Innovative HVDC systems

Two innovative HVDC concepts[1]

Multiterminal HVDC: illustrated by extending the Pacific DC intertie to Palo Verde NPS. Increases transfer capability into Southern California dramatically, and alleviates many transmission bottlenecks. Entails implementation of a multiterminal control mechanism, and HVDC circuit breakers.

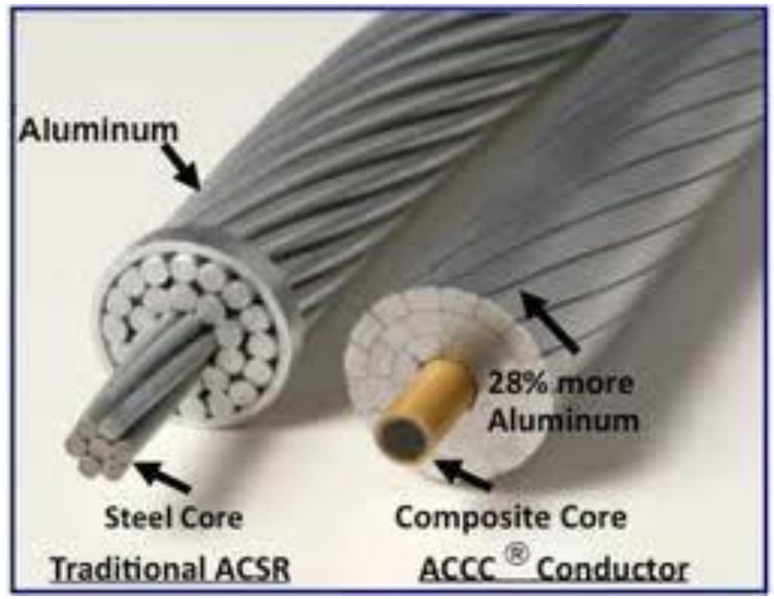
Networked HVDC: illustrated by a four terminal mesh at the US-Mexico border. Increases transfer into Southern California, effectuates an asynchronous to CFE in Mexico, and allows CFE to access its own system in Baja California.

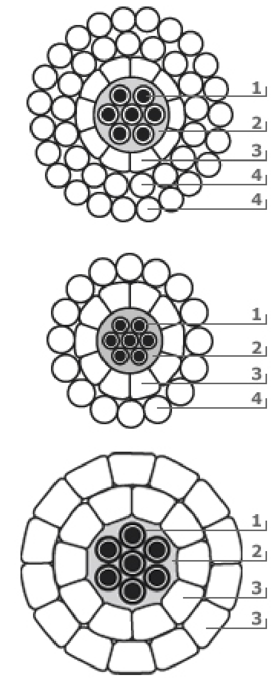


[1]A. Salloum, G. T. Heydt, "Innovative HVDC connections in power transmission systems," *Proc. IEEE PES Transmission & Distribution Conference & Exposition*, Tampa FL, May 2012

High temperature low sag overhead conductors to alleviate thermal limits

HTLS: a commercialized technology used presently to reconductor relatively short overhead transmission that is thermally limited. If compact phase spacing is added, there is an added advantage of higher security limits due to reduced positive sequence line reactance.





1 High Strength Al-Clad Steel core

2 High temperature filling grease

3 Trapezoid Al wires
TAL – Heat resistant
ZTAL – Super heat resistant

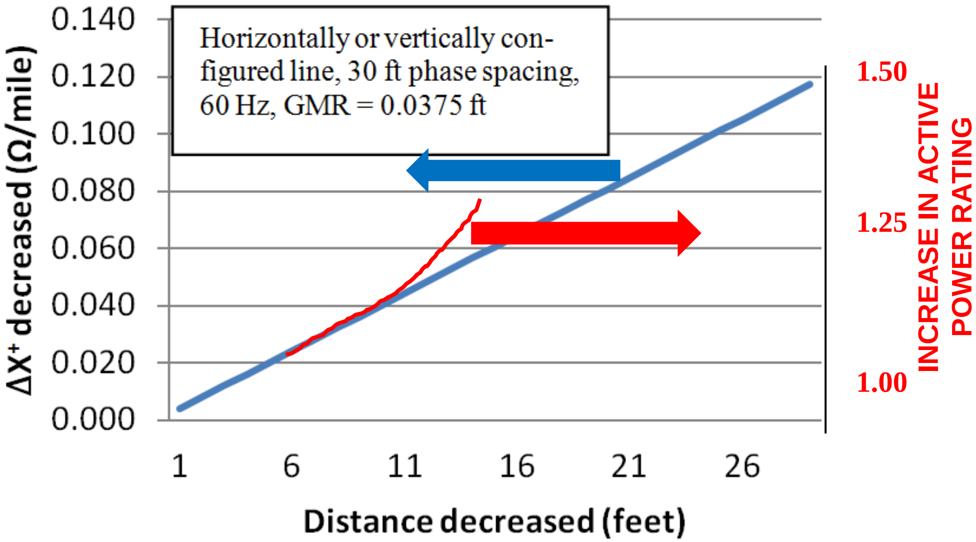
4 Round Al wires
TAL – Heat resistant
ZTAL – Super heat resistant

Reconductoring can proceed rapidly with relatively short outage period. Disadvantage is cost. Being researched now is the short term thermal rating.

Phase compaction for overhead circuits

Compacting the phase spacing in overhead designs reduces the positive sequence reactance and therefore increases the security rating

Compact phase spacing (e.g., reduction of ~30' phase spacing to 15' or even 9') has an advantage of reduced positive sequence reactance ($x^+ = x_s - x_m$). This can give higher security limits for long lines. The disadvantages include failure to comply with some industry and accepted state standards, safety issues in live line maintenance. Compact spacing can be combined easily with HTLS. Report available[2].

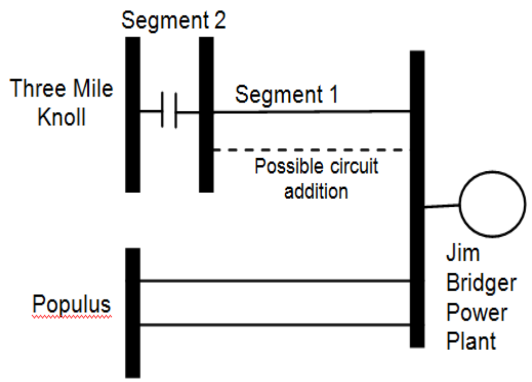


[2]Brian J. Pierre, G. T. Heydt, "Increased ratings of overhead transmission circuits using HTLS and compact designs," *Proc. North American Power Symposium,* Champaign IL, September 2012.

HTLS + Phase compaction

HTLS + phase compaction for alleviating long distance transmission bottlenecks.

Example in WECC (Bridger West – WY-ID) Dynamic studies for double line outage contingencies



Case**		Case 1: present construction	Case 2: HTLS* reconductoring + compact phase spacing by 25%	Case 3: HTLS + compact phase spacing to 50% plus new circuit addition
Double line outage contingency #1	Limitation	Transient voltage dips / voltage magnitude stability	Transient voltage dips / voltage magnitude stability	Transient voltage dips / voltage magnitude stability
	TSAT solution	Bus voltage oscillations: 0.93 Hz mode damped at -2.9%; 1.67 Hz mode damped at -5.5%	Bus voltage oscillations: 0.93 Hz mode damped at -2.9%; 1.67 Hz mode damped at -5.5%	Bus voltage oscillations: 0.93 Hz mode damped at -3.14%; 1.67 Hz mode damped at -6.28%

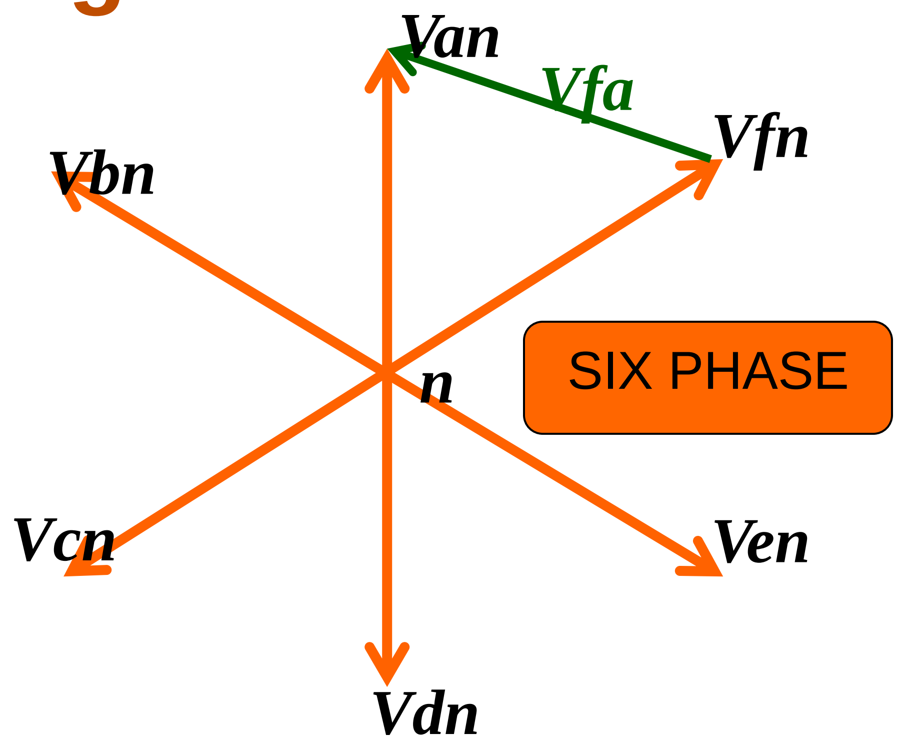
*Note that the HTLS construction does not materially modify the circuit reactances, and therefore the dynamic response is about the same as for the present construction. **The contingency #2 gives the same results as contingency #1

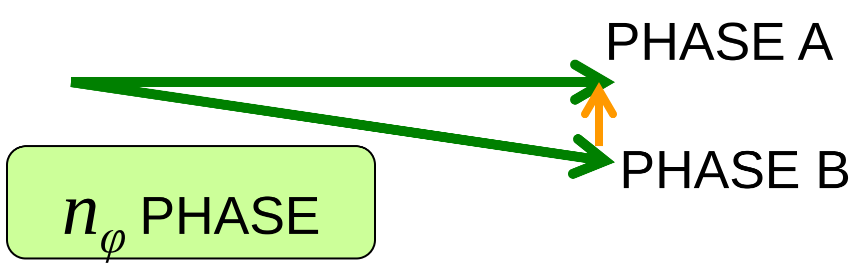
Higher phase order transmission technologies

For an n_φ *system,*

$$|V_{ll}| = \sqrt{2\left(1-\cos\left(\frac{360}{n_\varphi}\right)\right)}\,|V_{ln}|$$

The line-line voltage decreases with increasing phase order. And phase B lags phase A by $360/n_\varphi$ degrees; V_{LL} for phases AB leads V_{AN} by $90-(180/n_\varphi)$ degrees.

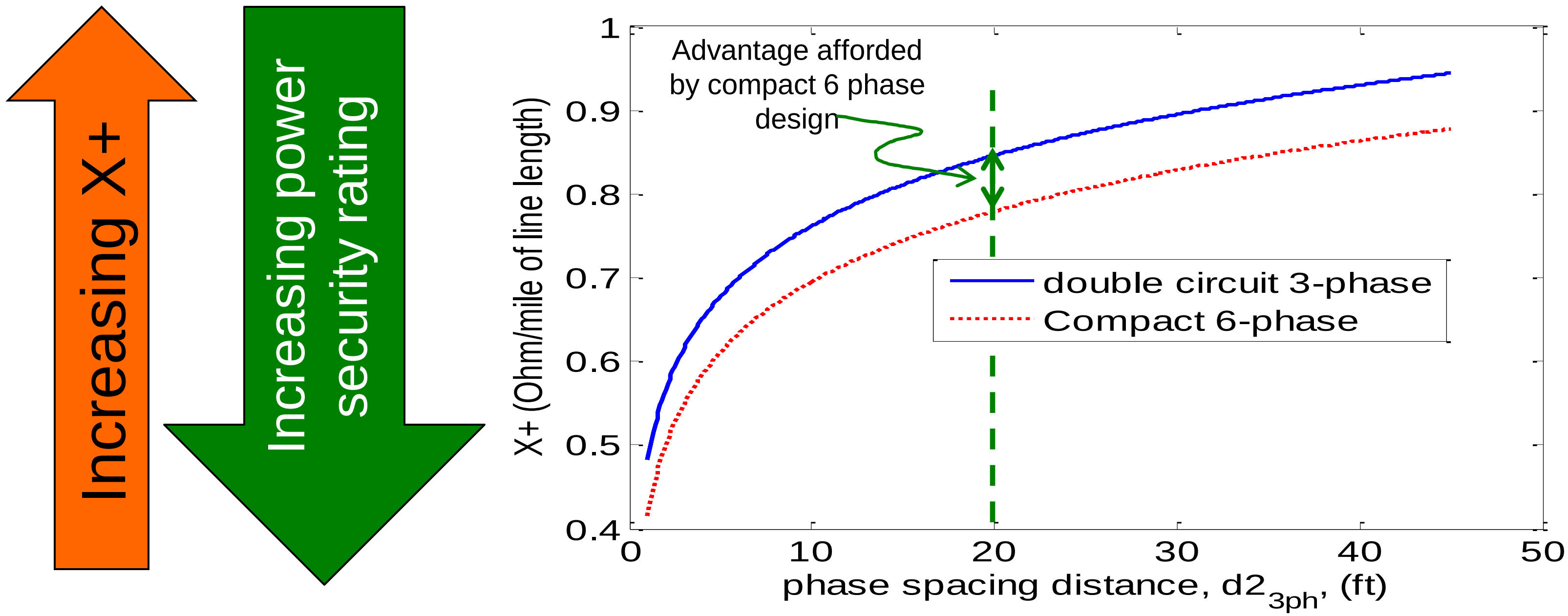




The line-line voltage becomes nearly in quadrature with the line-neutral voltage, and phase—ground fault currents become readily detectable.

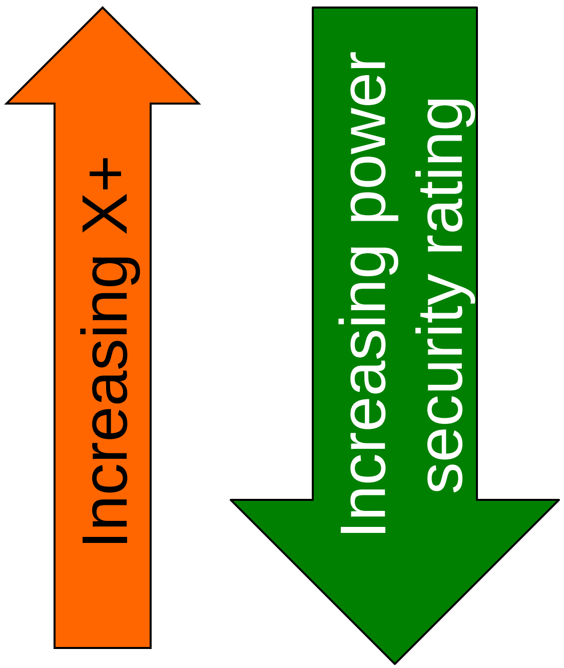
Advantages of six phase transmission

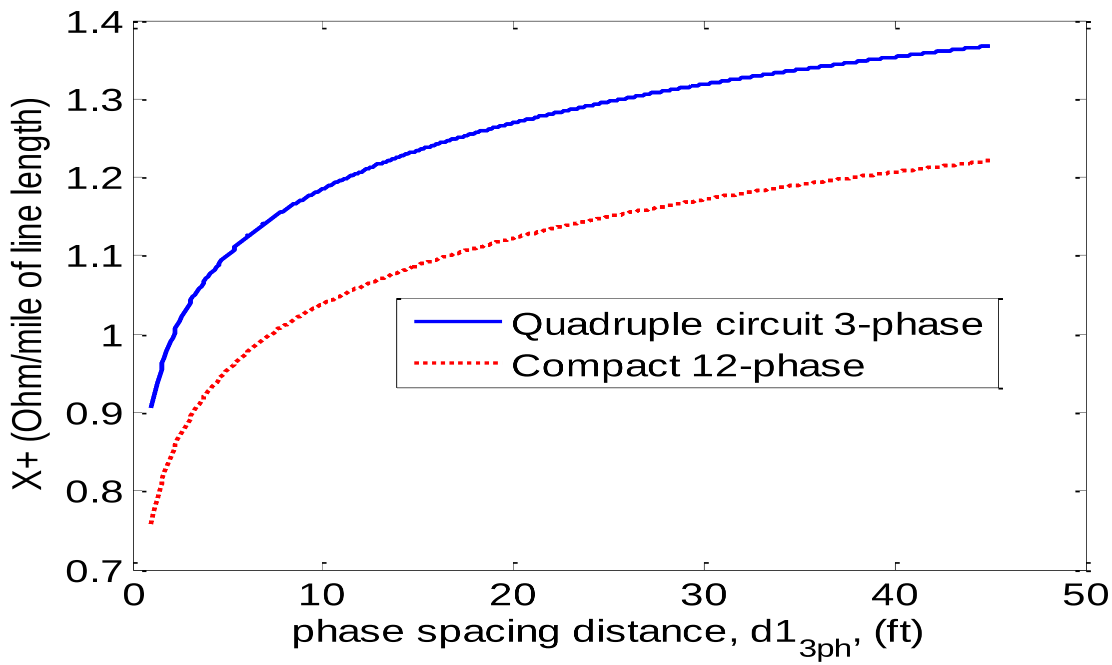
Lower positive sequence reactance per mile thus allowing higher security ratings. Single pole switching offers the potential of loss of 16.7% transmission if one phase is out of service. Very low transposition requirements. Disadvantage of more complex relaying – but fairly simple relay strategies seem to be effective.



Comparison of X^+ for double circuit 3φ, and compact 6φ vs. phase spacing of the original double circuit 3φ (for GMR of 0.0375 ft. Drake conductor).

An example of phase compaction *and* twelve phase technology





Comparison of *X*+ for quadruple circuit 3φ, and compact 12φ vs. original quadruple circuit 3φ, phase spacing (for GMR of 0.0375 ft. Drake conductor).

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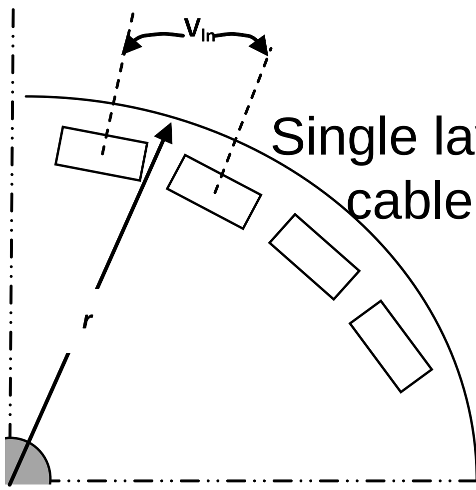
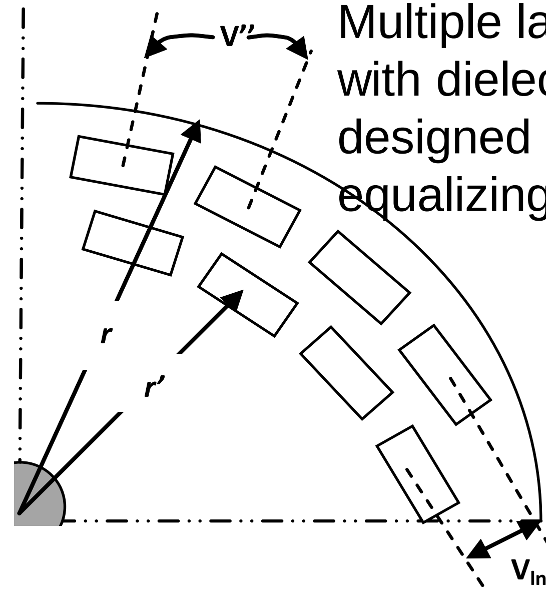
Polyphase cables

High phase order cables are possible and may take advantage of lower phase-phase voltage. Placement of the conductors allow equalizing the dielectric stress throughout the cable, and may maximize the transmission capability for a given diameter. The proposal is for both transmission and distribution.





For high phase order, it is possible to generalize the concept of symmetrical components through the use of properties of the line impedance matrix. This matrix is a symmetric circulant Toplitz matrix with $a_{n-1} = a_1$, $a_{n-2} = a_2$, …

$$CT = \begin{bmatrix} a_0 & a_1 & a_2 & \cdots & a_{n-1} \\ a_{n-1} & a_0 & a_1 & \cdots & \cdots \\ \cdots & a_{n-1} & a_0 & \cdots & a_2 \\ a_2 & \cdots & \cdots & \cdots & a_1 \\ a_1 & a_2 & \cdots & a_{n-1} & a_0 \end{bmatrix}$$

For matrices of this type, the eigenvalues are readily found by a simple formula, and these are the sequence impedances of the Z_{line} matrix. It is found that the positive sequence impedance decreases with the number of phases, and therefore the security rating of the line increases. For example, for a 12 phase conductor,

$$X_{12seq} = T_{12} X_{12\phi} T_{12}^{-1} = diag\begin{bmatrix} 2M_1 + 2M_2 + 2M_3 + 2M_4 + 2M_5 + M_6 + S \\ \sqrt{3}M_1 + M_2 - M_4 - \sqrt{3}M_5 - M_6 + S \\ M_1 - M_2 - 2M_3 - M_4 + M_5 + M_6 + S \\ -2M_1 + 2M_4 - 2M_5 - M_6 + S \\ -M_1 - M_2 + 2M_3 - M_4 - M_5 + M_6 + S \\ -\sqrt{3}M_1 + M_2 - M_4 + \sqrt{3}M_5 - M_6 + S \\ -2M_1 + 2M_2 - 2M_3 + 2M_4 - 2M_5 + M_6 + S \\ -\sqrt{3}M_1 + M_2 - M_4 + \sqrt{3}M_5 - M_6 + S \\ -M_1 - M_2 + 2M_3 - M_4 - M_5 + M_6 + S \\ -2M_2 + 2M_4 - M_6 + S \\ M_1 - M_2 - 2M_3 - M_4 + M_5 + M_6 + S \\ \sqrt{3}M_1 + M_2 - M_4 - \sqrt{3}M_5 - M_6 + S \end{bmatrix}$$

Positive sequence X

The sequence impedances are the discrete Fourier transform of arranged elements of Z_{line} for a circulant Toplitz matrix

For these high phase orders,

•A single phase outage (single pole switching) results in low lost power capability (e.g., 8.3% loss for 12 phase, 4.2% loss for 24 phase)

•Phase – ground fault currents readily detected

•Low phase-phase voltages are possible for high phase order

•High power density in the cable – maximal use of the dielectric

•Low (or no) requirement for transposition

•Relaying may be more complicated, but some simple concepts exist (e.g., pilot wire relaying)

•Distribution applications may exist by multiplexing several three phase circuits

Concluding remarks

Accomplishments: Analyzed advantages and disadvantages of selected innovative transmission technologies such as high phase order AC, multi-terminal and meshed network HVDC, and high temperature, low sag transmission, phase compaction.

Results and their Relationship to Enabling Sustainable Energy Systems: By identifying technological and cost issues associated with alternative transmission technologies, informed transmission expansion planning to support renewable generation technologies.

Concluding remarks

Technologies ready for deployment

Multiterminal HVDC

Phase compaction for overhead AC transmission

HTLS for thermally limited circuits

Technologies for deployment in the next 5 years

Multiterminal HVDC

Six phase AC transmission

Combination of technologies: HTLS, phase compaction, six phase

Longer term technologies

High phase order technologies for transmission and distribution

For the maximization of the use of overhead and underground assets, and maximization of reliability

Examples of future work

Development of actual plans for multiterminal HVDC systems in the US / Canada

Development of actual plans for meshed HVDC systems in the US / Canada / Mexico

Development of 'sweet spots' for interconnection of large synchronous systems / enabling power marketing

Promotion of phase compaction and HTLS technologies where appropriate – formulation of actual plans and road maps for implementation

Promotion of high phase order systems including cable systems.

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