Power Systems Technology Center,
a Division of Manitoba Hydro International Ltd.

Harmonizing the Greater Mekong Sub region (GMS) Power Systems to Facilitate Regional Power Trade – Transmission Master Plan Study

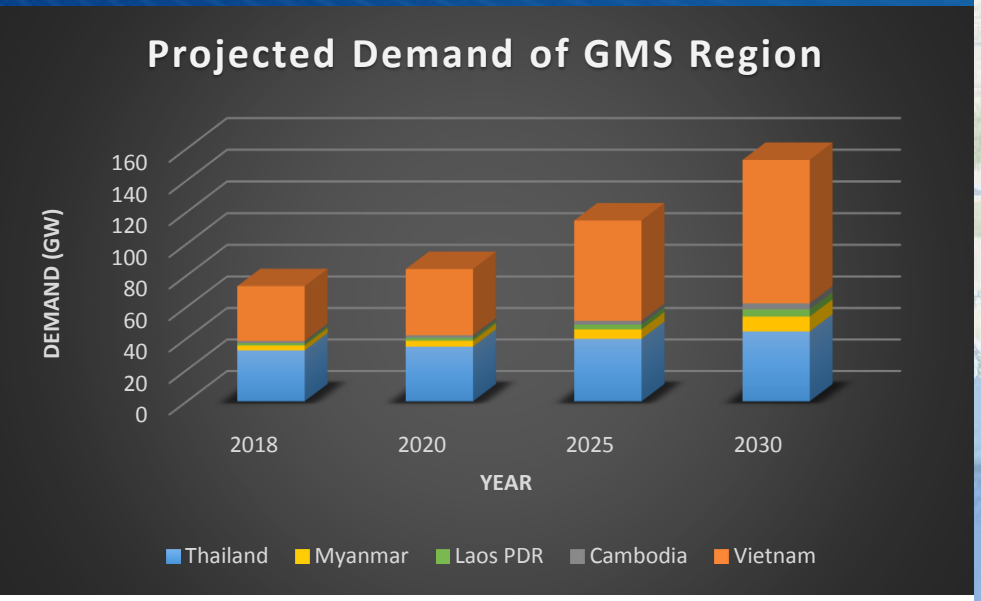
June 2018

Presented by
Dharshana Muthumuni (Team Leader)
Bathiya Jayasekara (Power System Specialist)

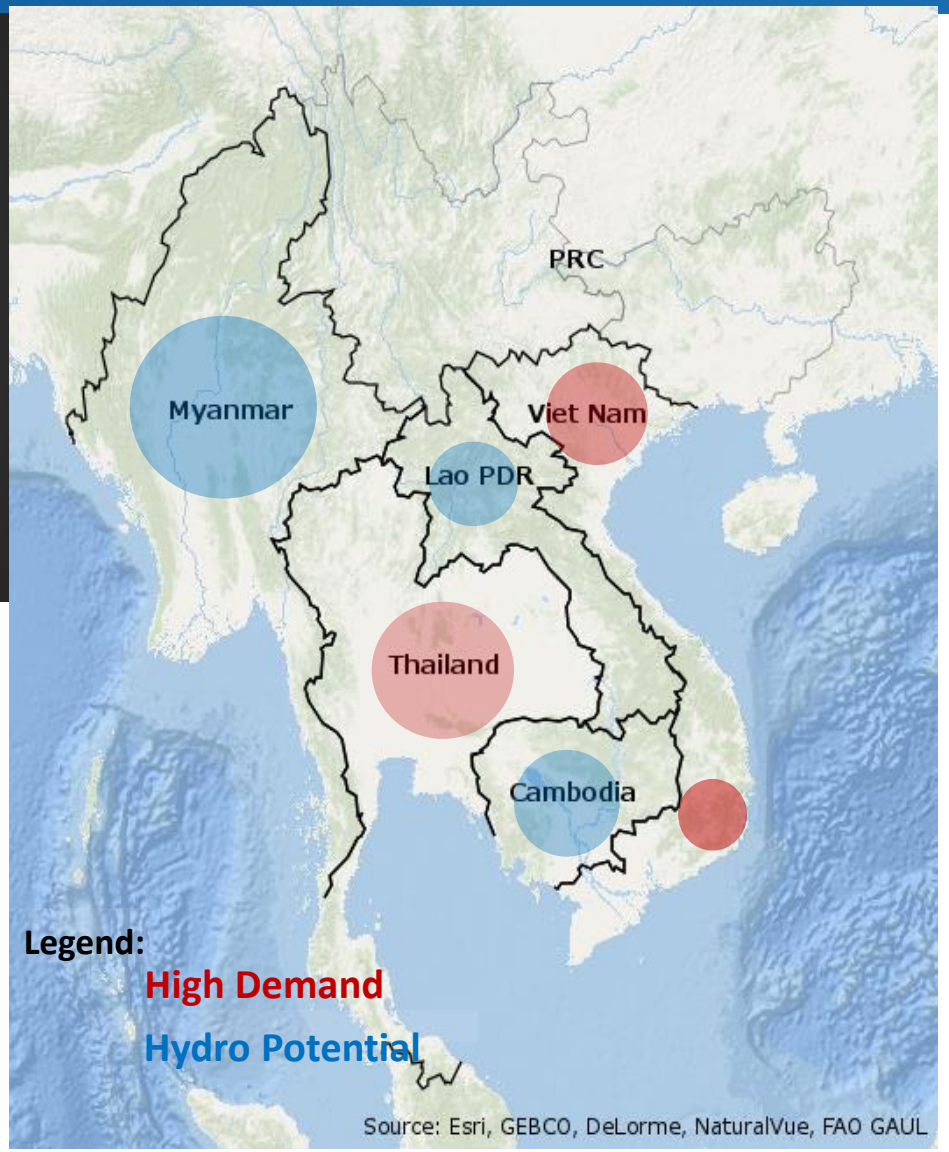
Outline

- Background
- Study Objectives and Methodology
- GMS Transmission Network Modeling
  - Regional Transmission Cross-Border Interconnections
  - GMS Country Data Gathering
- Preliminary Study Scenarios
- Study Results
- Future work

Background

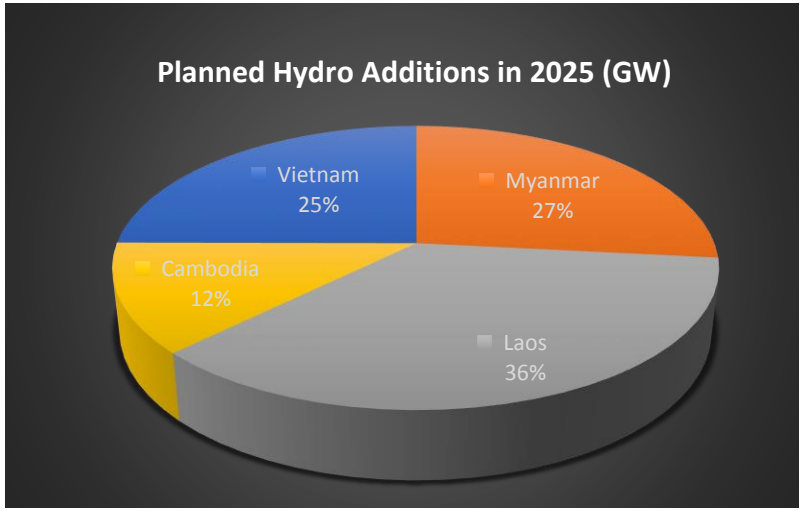


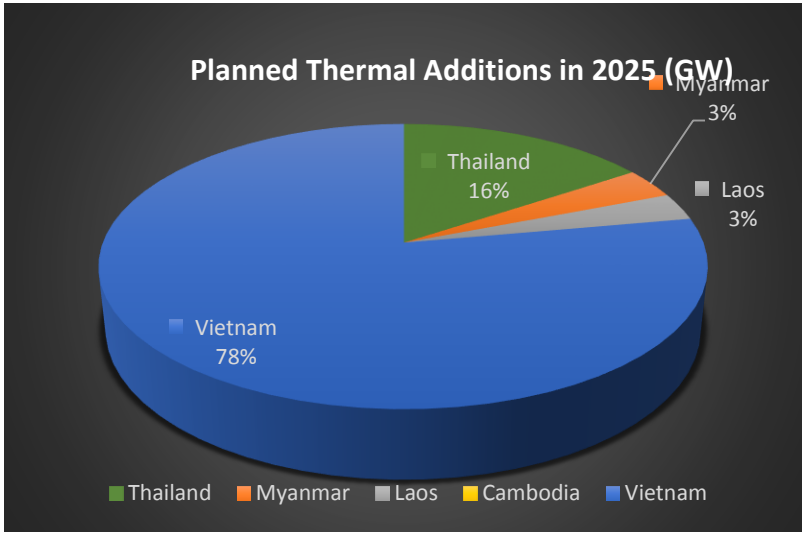
- Greater Mekong Sub (GMS) region has an increasing power demand.
- The load and the generation resources in the region are unevenly distributed.
  - Eg: Myanmar, Laos and Cambodia have high hydro power potentials



Background Cont.

- With the available local resources, meeting the future demand can be expensive and challenging.
- It is economical to move towards import or export regimes as a whole region than power development at country level or on bilateral basis.
- Utilization of these energy sources through cross-border power transfer will result in:
  - ❑ Improvement in the quality and reliability of the regional power system
  - ❑ Improved economic benefit to both power exporters and importers
  - ❑ Minimizing greenhouse gas (GHG) emission



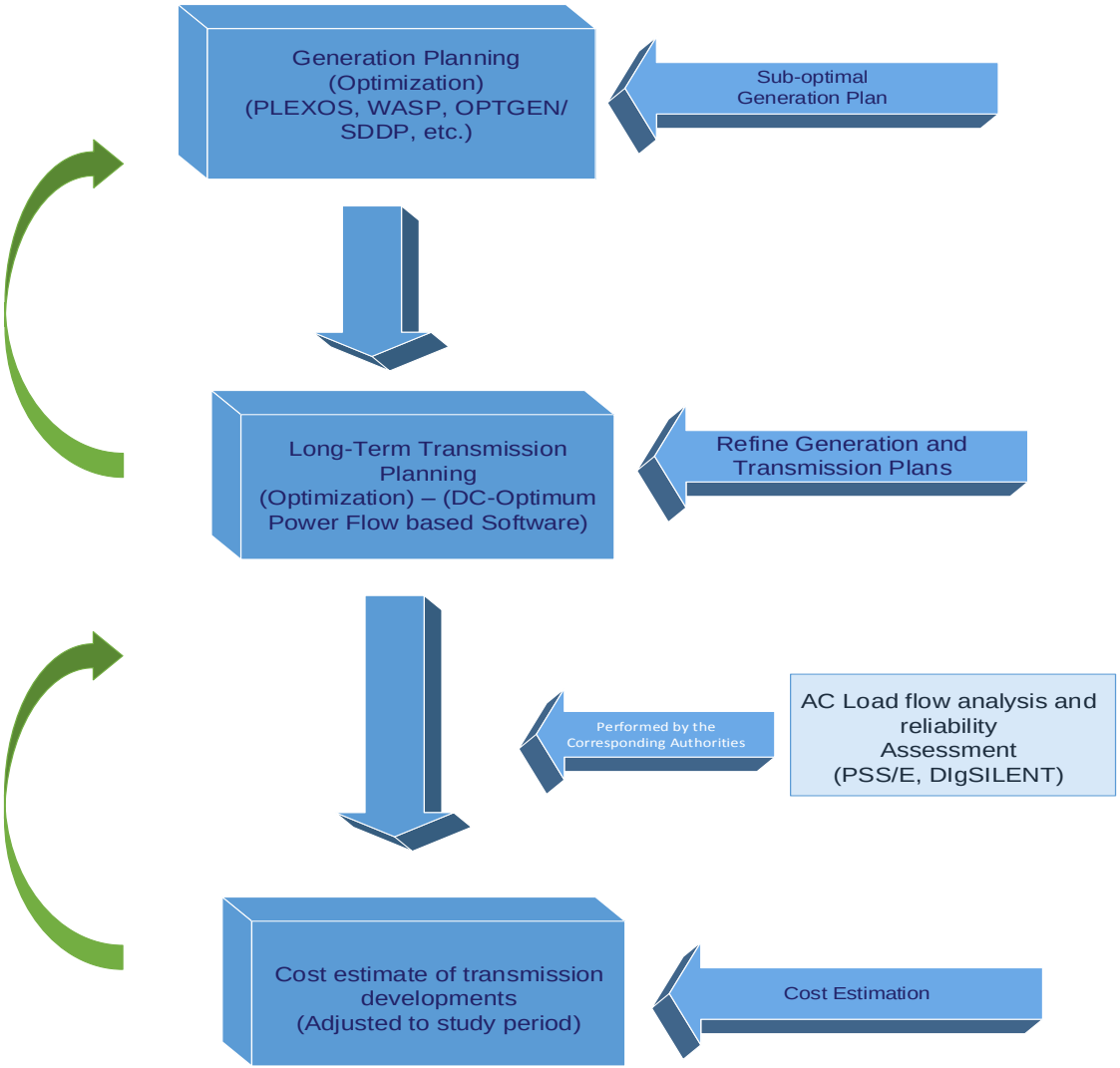


Note: Above pie charts indicate how much hydro, thermal and gas generation is introduced in year 2025, in addition to the installed capacity of year 2020. Coal, Combined Cycle, Cogeneration/Natural Gas, Diesel and Biomass generation are considered under Thermal Generation

Study Objectives

- Development of the Transmission Development Master Plan for the power trade of GMS region for the study period of 2022-2035.
  - Determine the potential cross-border power transmission options based on generation and transmission master plan scenarios.
  - Identify and rank most economically and technically feasible transmission upgrades and corresponding generation development

Study Methodology - Overview



Study Methodology

$$\text{Expected Operating Cost } \approx \left\{\begin{array}{c}\text{Expected}\\ \text{Operating Cost}\\ \text{without Scheme}\end{array}\right\} - \left\{\begin{array}{c}\text{Expected}\\ \text{Operating Cost}\\ \text{with Scheme}\end{array}\right\}$$
$$\textit{Advantage}$$

$$\textit{Total Expected Cost Advantage} = \left\{\begin{array}{c}\textit{Expected}\\ \textit{Operating Cost}\\ \textit{Advantage}\end{array}\right\} - \left\{\begin{array}{c}\textit{Expected}\\ \textit{Cost of Transmission}\\ \textit{Upgrades}\end{array}\right\}$$

Note: Cost of transmission development is adjusted to the study period

- **Step 1**: Long term generation plan will be developed based on load demand projections and availability of resources.
- **Step 2**: DC Load flow optimization technique used to optimize generation costs and transmission upgrades.
- **Step 3**: AC Load flow based reliability analysis to refine and update preliminary transmission master plan (developed in Step 2)
- **Step 4**: Expected cost advantage of given generation and transmission development scenario is calculated using the following figure

Data required to complete the study

In order to perform the study following the methodology described, power system data of individual countries are required.

- Transmission system model – in PSS/E format
- Generation plans
- Load forecast
- Seasonal Daily Load curves
- Cost of generation
- Planned and potential cross boarder lines

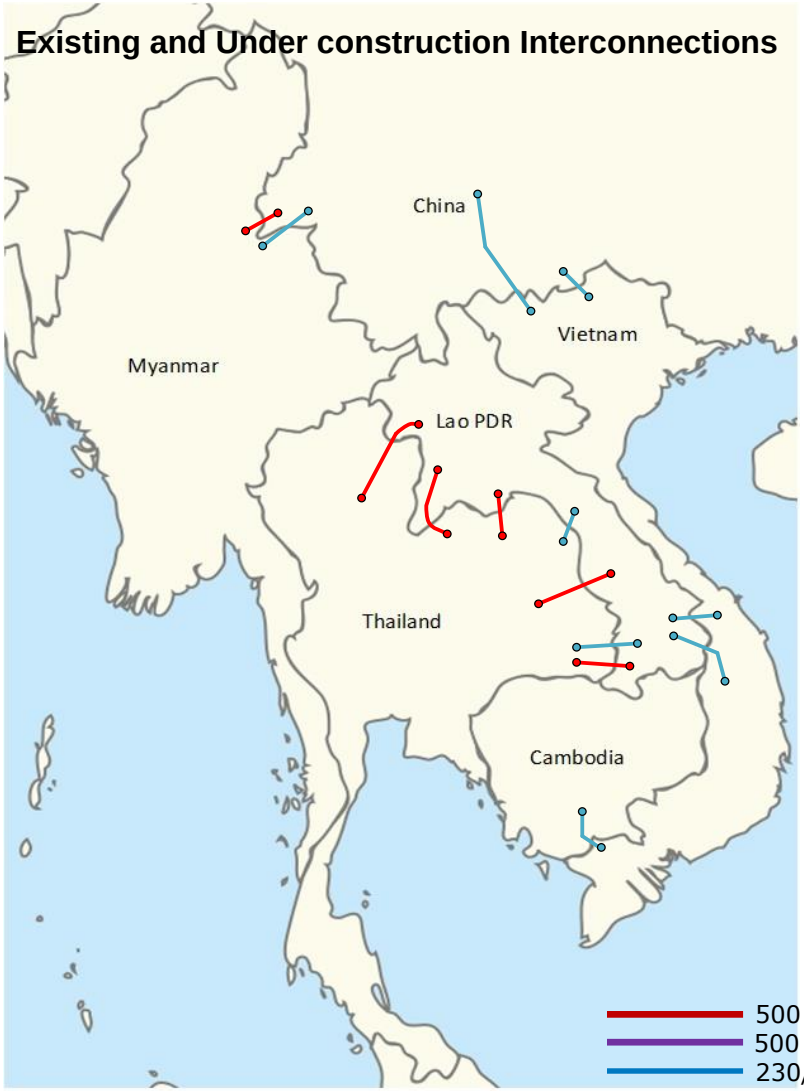
MHI has gathered data from publicly available resources and has developed transmission network model of four countries.

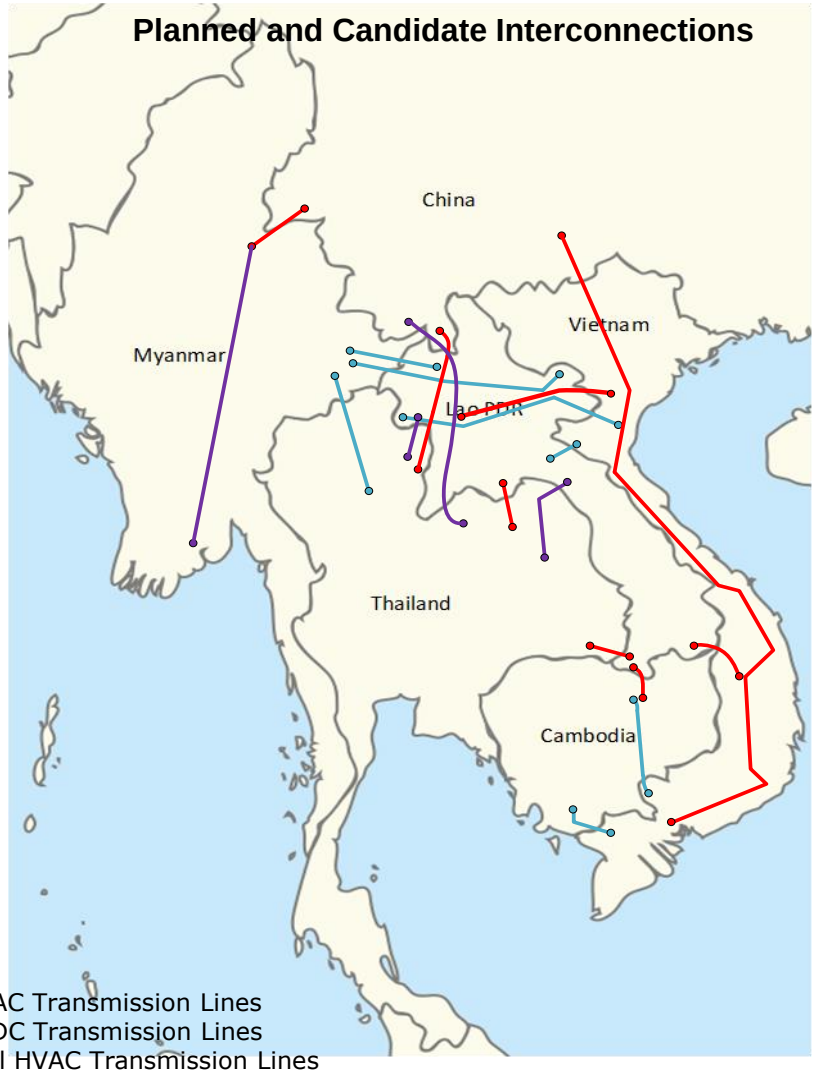
GMS Regional Transmission Network Model Development Status

Country	Transmission system model
China	Single node or multiple nodes based on data availability
Laos PDR	High level model being developed by MHI
Thailand	High level model is developed by MHI
Vietnam	High level model being developed by MHI
Cambodia	High level model being developed by MHI
Myanmar	High level model being developed by MHI

Preliminary Study Scenarios

Regional Cross-Border Transmission Interconnections





500 kV Level HVAC Transmission Lines
500 kV Level HVDC Transmission Lines
230/220 kV Level HVAC Transmission Lines

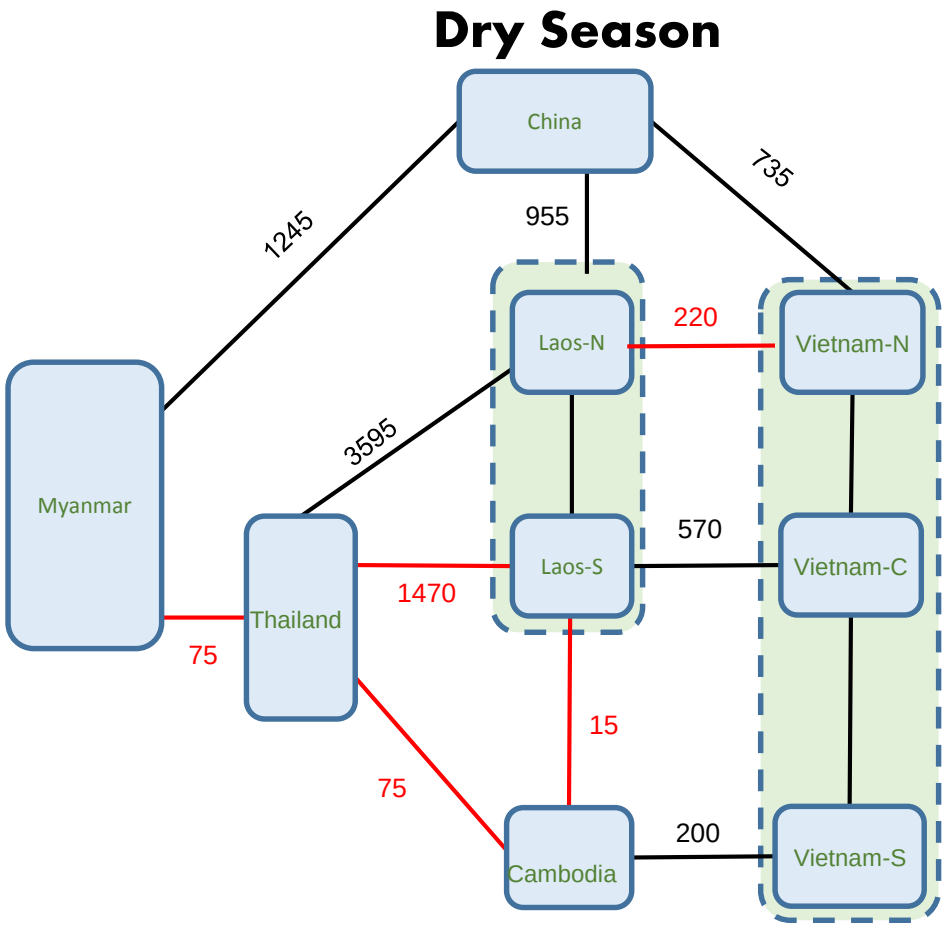
Scenario Development

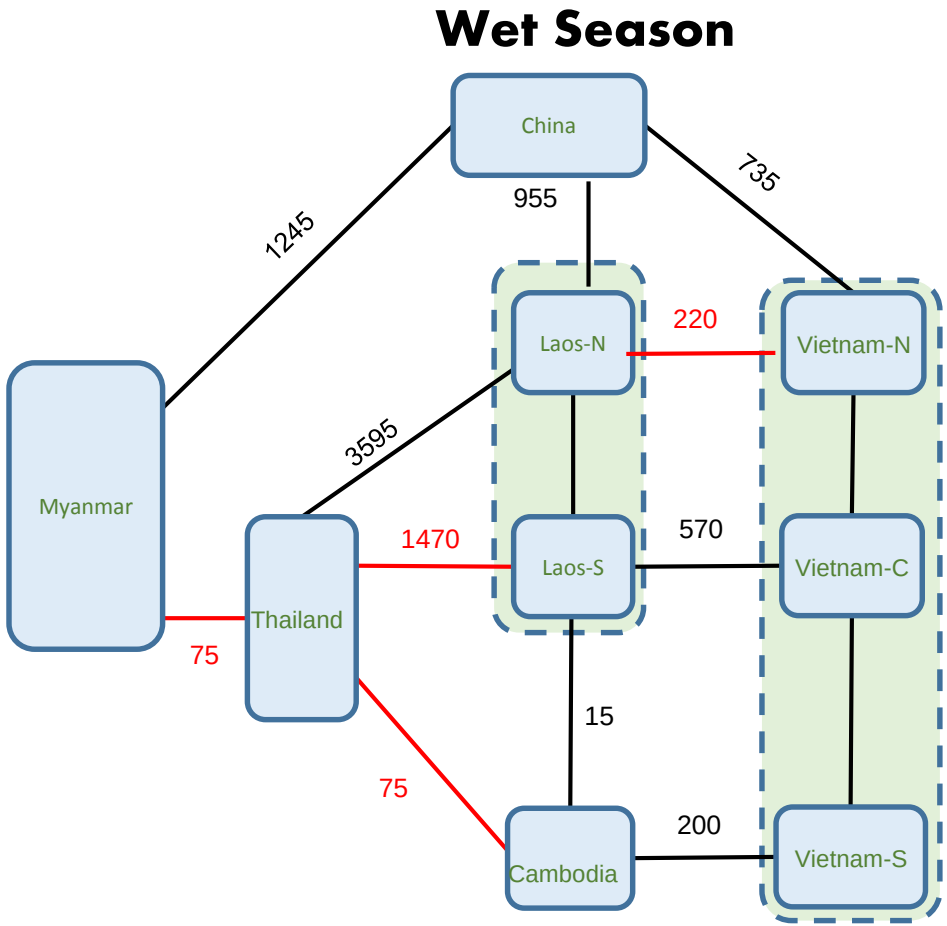
- Dry and Wet seasons are considered separately in the analysis to take into account seasonal hydro availability (analysis based on year 2025).
  - Scenario 1:
    - Base case scenario
    - Existing and under construction cross border transmission links are considered.
  - Scenario 2:
    - **'Planned and proposed'** cross border transmission links are added to the base case (based on individual country plans and reports; ex. RPTCC 21 and RPTCC 23).
  - Scenario 3:
    - Under utilized **'planned and proposed'** transmission lines are excluded.
  - Scenario 4:
    - Capacities of the highly utilized transmission links are increased.

Scenario 1: Existing Cross Border Transmission Links are considered (Base Case)

Interconnection	Location 1	Location 2	Voltage (kV)	Capacity (MW)	Length (km)
Vietnam South - Cambodia	Chau Doc (VTN)	Phnom Penh (CAM)	220	200	200
Vietnam North – China	Lao Cai (VTN)	Xinqiao (Guman) (CHN)	220	145	350
	Ha Giang (VTN)	Maguan (Malutang) (CHN)	220	145	320
	Mong Cai (VTN)	Shengou (CHN)	110	75	300
	Ha Giang (VTN)	Maomaotiao (CHN)	110	75	300
	Lao Cai (VTN)	Hekou (CHN)	110	75	300
Vietnam Centre – Lao	Thanh My (VTN)	Xekaman 3 (LAO)	220	250	250
	Pleiku (VTN)	Xekaman 1 (LAO)	220	320	250
Lao – Cambodia	Stung Tren (LAO)	Ban Maisivilay (CAM)	22	15	10
Lao – China	Mengla (Mongla) (LAO)	Nam Ou 2 (Namoi) (CHN)	110	75	100
Lao North – Thailand	Hong SA (LAO)	Mae Moh 3 (THI)	500	880	344
	Nabong (Ban Na Bong) (LAO)	Udon Thani 3 (THI)	500	880	106
	Tha Na Laeng (Nam Theun 2) (LAO)	Nong Khai (Roi ET 2) (THI)	115	75	50
Lao North -- Thailand (Under Construction)	Xayaburi (LAO)	(Loei 2) (THI)	500	880	300
	Pak Xe (Ban Lak 25) (LAO)	Ubon Ratchathani 3	500	880	150
	Paklay (LAO)	Tha Li (THI)	115		86.2
Lao South – Thailand	Savannakhet (LAO)	Roi Et (THI)	500	880	157
	Theun Hinboun (LAO)	Nakhone Panom (THI)	230	145	70
	Houay (LAO)	Ubon 2 (THI)	230	145	250
	Pakxan (LAO)	Bung Kan (THI)	115	75	10
	Thakhek (LAO)	Nakhone Panom (THI)	115	75	10
	Pak bo (LAO)	Mukdahan (THI)	115	75	30
	Bang Yo (LAO)	Sirindhorn (THI)	115	75	100
Cambodia – Thailand	Poipet (CAM)	Watthana Nakhon (THI)	115	75	40
Thailand – Myanmar	Chang Rai (THI)	Tarchilake (MNR)	110	75	50
Myanmar – China	Shweli I (MNR)	Hannong (CHN)	220	145	50
	Dapein I (MNR)	Dayingjiang (CHN)	500	880	100
	Jing Yang (MNR)	Menglongzhen (CHN)	110	75	150

Scenario 1: Base Case (Existing and Under Construction Cross-Border Interconnections)





Fully Utilized corridors

Moderately Utilized corridors

Operating Cost For the Wet Season 15.2 Billion

Operating Cost For the Dry Season : 19.3 Billion

Annual Operating Cost: 34.5 Billion

Scenario 2: (Planned and Proposed Cross Border Transmission Interconnections)

Planned

Interconnection	Location 1	Location 2	Voltage (kV)	Technology	Capacity (MW)	Length (km)
Vietnam South - Cambodia*	Chau Doc - Vietnam South	Takeo	220	HVAC	145	70
Lao North - Thailand*	Muang Houn	Nan 2	500	HVAC	880	150
	Tho Pheung	Mae Chan	xx	HVAC	300	20
Lao North - Thailand	Ban Tho Pheung	Mae Chan	xx	HVAC	300	60
	Na Bong	Udon Thani 3	500	HVAC	1800	107
	Pah Beng or Pak Nguyen	Tha Wang Pha	500	HVAC	800	120
Lao North - Vietnam North	Luong Prabang	Nho Quan	500	HVAC		322
	Pak Beng or Pak Nguyen	Thanh Hoa	220	HVAC		495
	Nam Mo 1 and Nam Mo 2	Ban Ve	220	HVAC	100	18/70
Lao North - Myanmar*	Louang Namtha	Shan state	230	HVAC	145	200
Lao South - Vietnam Centre*	Hat Xan	Plei ku	500	HVAC	880	150
Lao South - Cambodia*	Ban Hat	Stung Tren	500	HVAC	145	170-200
Lao South - Thailand	Ban Lak25	Ubon Ratchthan 3	500	HVAC	1400	150
Lao - Myanmar		-	230 or 500	HVAC		tbd
Cambodia - Vietnam South	Stung Treng	Tay Ninh	220	HVAC	207	250
China - Vietnam	Yunan	-	500	HVAC		tbd
China - Thailand	Banab, Yunnan	Xayaburi	500	HVAC+DC B2B	1000 to 3000	460
Vietnam North - China	Sonla	Denggao	220	HVAC	145	150
Vietnam North - China	Ho Chi Min – Vietnam North	Denggao	500	HVAC	880	1700

Scenario 2: (Planned and Proposed Cross Border Transmission Interconnections)

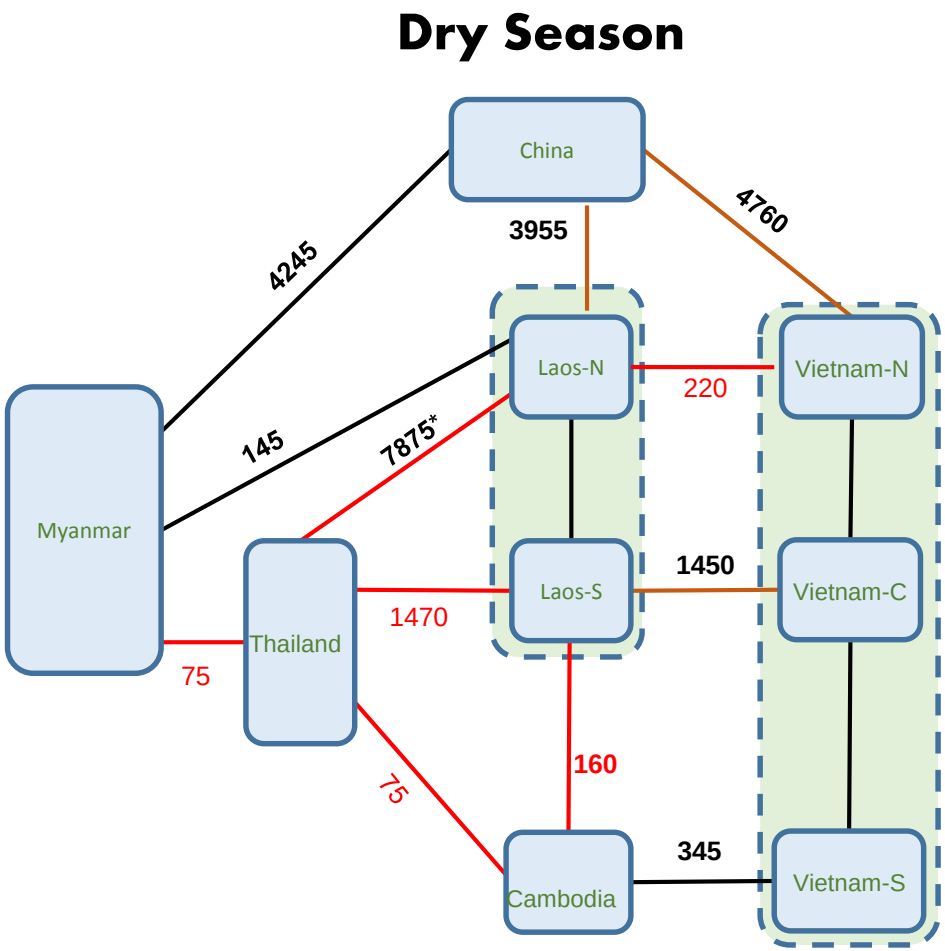
Proposed

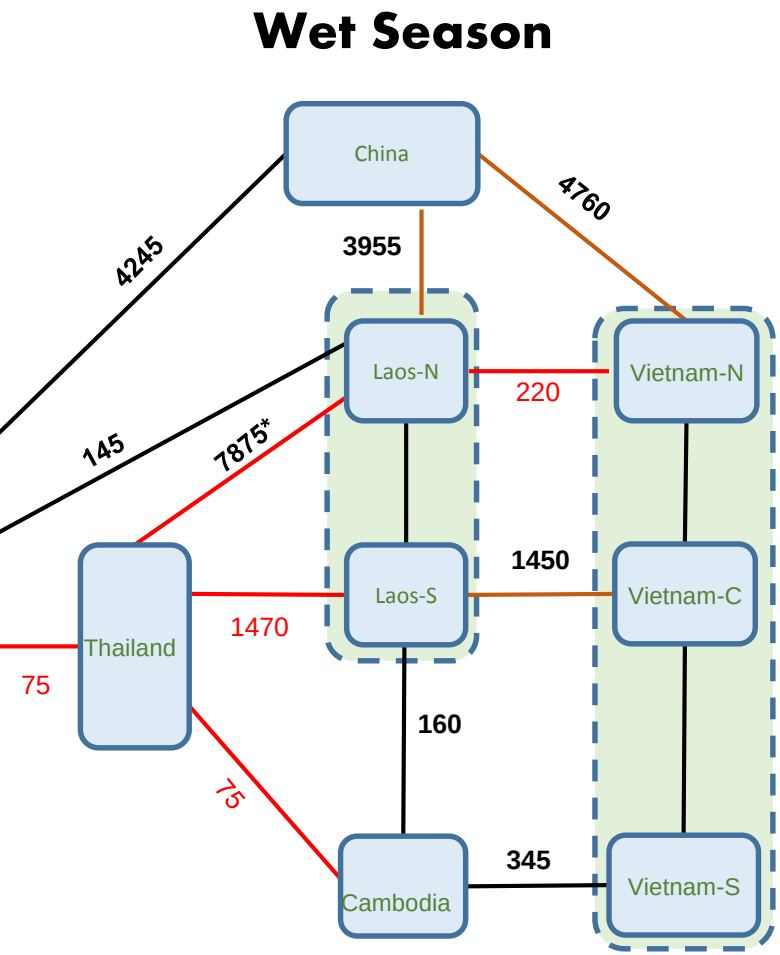
From Country	To Country	Voltage (kV)	Technology	Year	Capacity (MW)	Length (km)
China (Yunnan)	Myanmar (Karmanat)	500	HVAC/HVDC		3000	1030
China (Yunnan)	South Vietnam (Ho Chi Minh)	500	HVAC		3000	1700
Thailand (Ban Na Bong)	Laos (Nam Theun 1)	500	HVDC		1600	165
Laos (Meung Long)	Myanmar (San State)	150 or 230	(considered in Scenario 4)			
Lao PDR (Luang Namtha)	Myanmar (Shan State and extend)	230 kV or 500 kV	(considered in Scenario 4)			

Proposed Interconnections involving more than two countries

Terminal 1	Terminal 2	Terminal 3	Voltage (kV)	Technology	Max Capability (MW)	Length (km)
China (Ban Na)	Laos (Pakbeng)	Thailand (Thawangpha)	500	HVAC	3000	380

Scenario 2 : Planned and Proposed Interconnections





Under utilized corridors
Fully Utilized corridors
Moderately Utilized corridors

* Note: Only the HVDC line between Laos North and Thailand is fully utilized.

Operating Cost For the Dry Season : 17.4 Billions

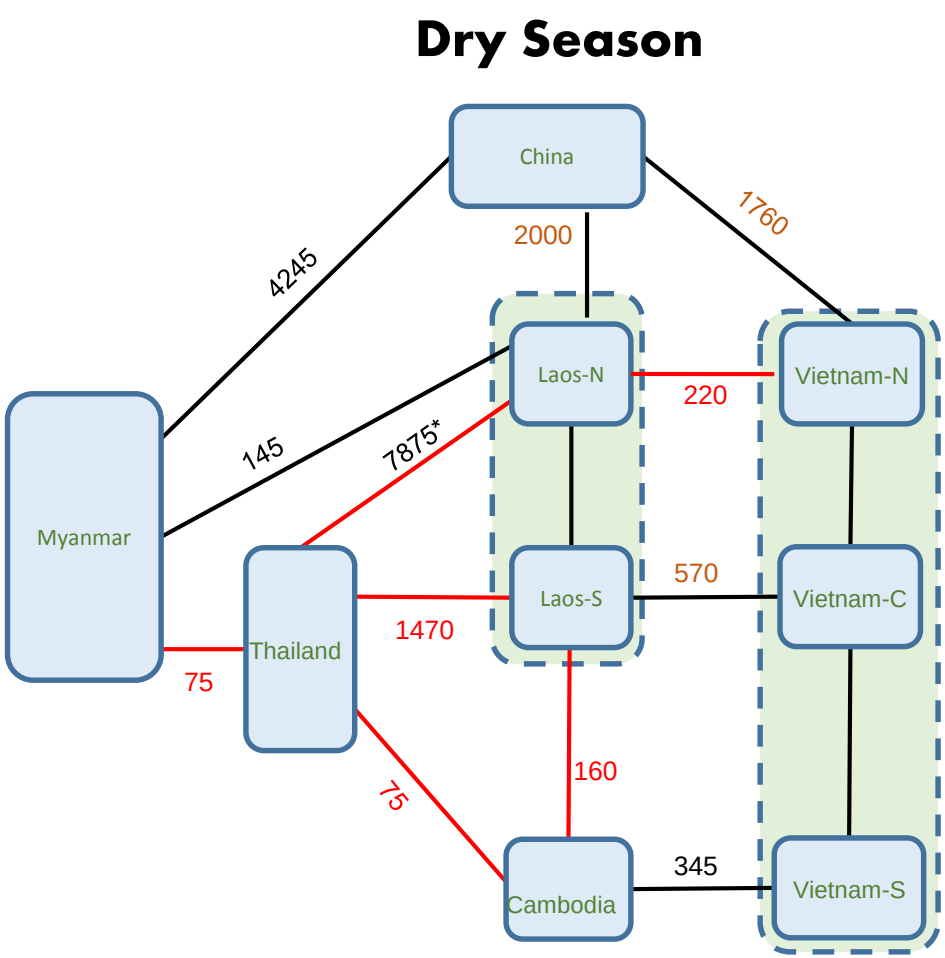
Operating Cost For the Wet Season : 13.6 Billions

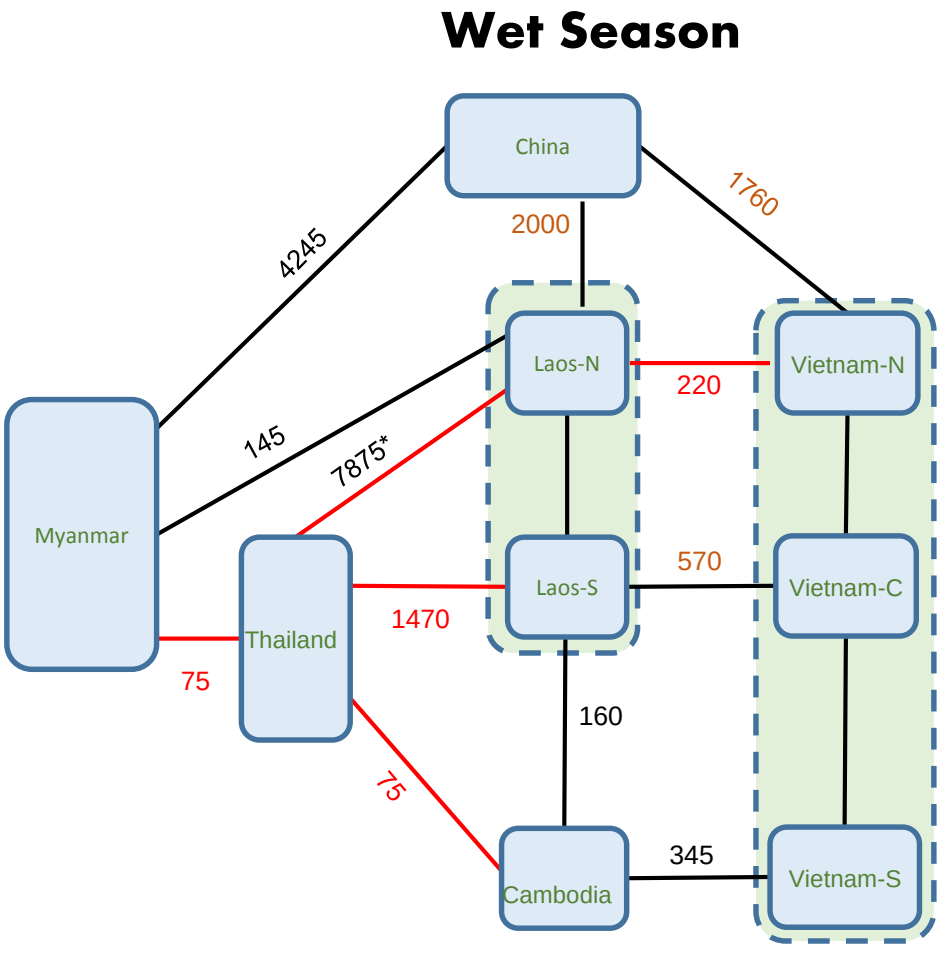
Annual Operating Cost: 31.0 Billions

Scenario 3 Development

- Three proposed lines on underutilized corridors (as identified from Scenario 2) were removed.

Scenario 3: Exclusion of under utilized proposed transmission interconnections





Fully utilized corridors

Moderately utilized corridors

* Note: Only the HVDC line between Laos North and Thailand is fully utilized.

Operating Cost For the Dry Season : 17.7 Billions

Operating Cost For the Wet Season : 13.6 Billions

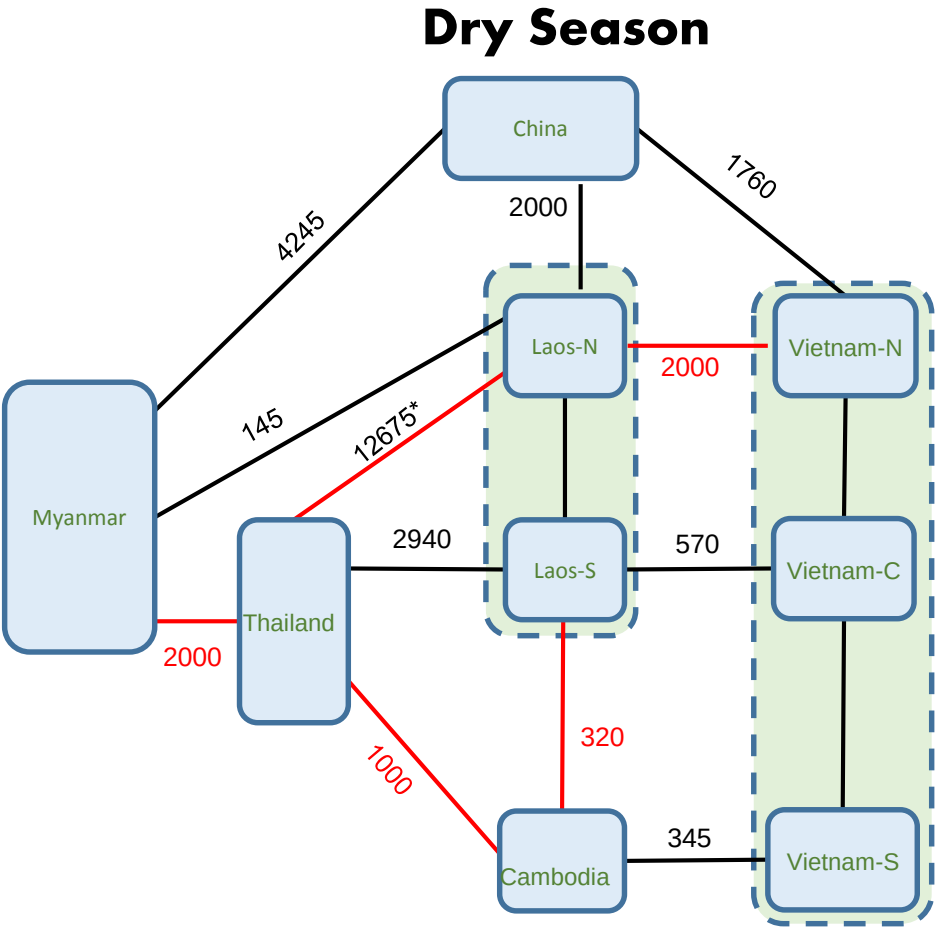
Annual Operating Cost: 31.3 Billions

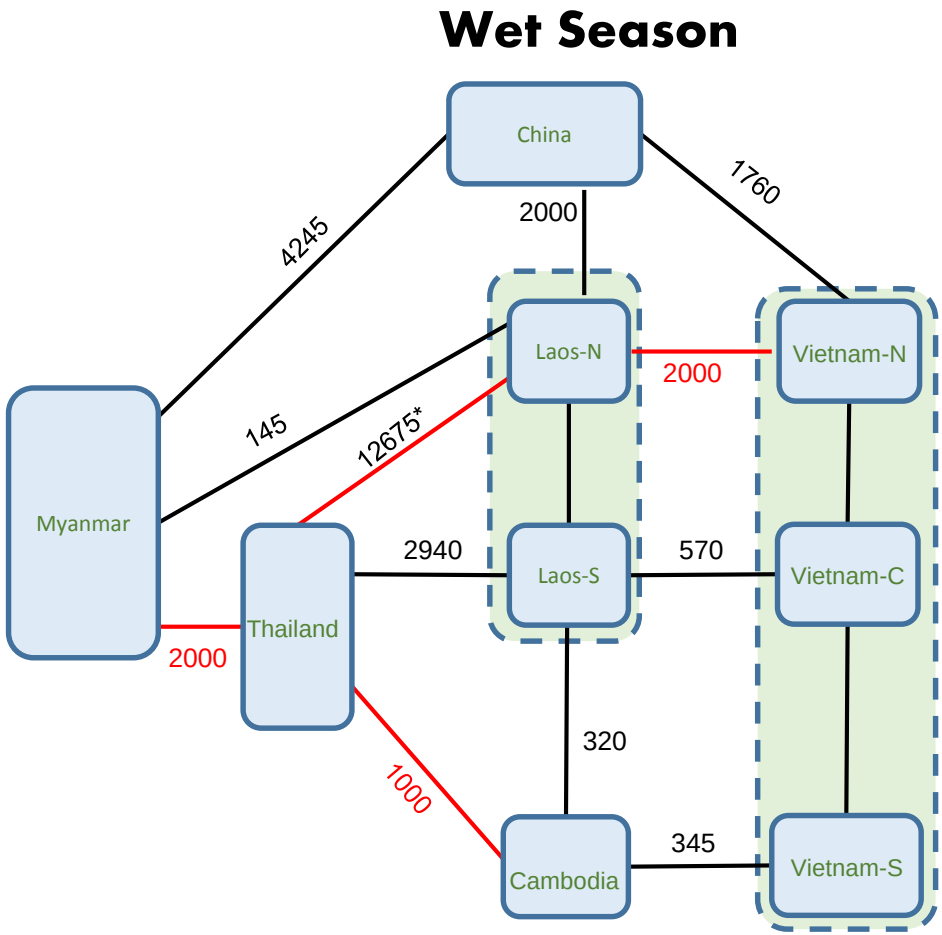
Scenario 4 Development

- Following ‘heavily’ utilized corridors were identified based on Scenario 3 results;
  - Laos North to Vietnam North Corridor
  - Cambodia to Thailand Corridor
  - Myanmar to Thailand Corridor
  - Laos North to Thailand Corridor
  - Laos South to Thailand Corridor
  - Laos South to Cambodia Corridor

- For Scenario 4, capacities of the above corridors are increased

Scenario 4: Increased capacities of the highly utilized transmission interconnections





Fully utilized corridors

Moderately utilized corridors

* Note: Only the HVDC line between Laos North and Thailand is fully utilized.

Operating Cost For the Dry Season : 15.6 Billions

Operating Cost For the Wet Season : 11.1 Billions

Annual Operating Cost: 26.7 Billions

Summary of Results

Scenario Name	Season	Operational Cost ($ Billions)	Annual Operational Cost - 2025 ($ Billions)
Scenario 1 (Base Case)	Wet	15.2	34.5
	Dry	19.3	
Scenario 2	Wet	13.6	31.0
	Dry	17.4	
Scenario 3	Wet	13.6	31.3
	Dry	17.7	
Scenario 4	Wet	11.1	27.7
	Dry	15.6	

- Addition of proposed transmission lines (Scenario 2) have reduced the operational cost by $3.5 Billion.
- Reducing the capacities of the under utilized transmission corridors (Scenario 3) has a minimal affect on the operational cost.
- Increasing the capacities of the heavily utilized transmission corridors (Scenario 4) will result in reduced operational cost ($6.8 Billion).
  - Thailand - Gas power generation is reduced and power is imported from Laos, Cambodia and Myanmar. These corridors are very well utilized.
  - Vietnam Thermal and Coal generation are reduced and power is imported from Laos, Cambodia and China. Laos and Vietnam North transmission corridor is well utilized.
  - In general, the available hydro power generation is fully dispatched in the region in both seasons.

Summary

- Main objective of the project is to develop a regional generation and transmission master plan from year 2025 to year 2035
  - Identify the technically and economically feasible cross-border transfer scenarios.
- A comprehensive study methodology is developed to achieve the identified study objectives.
- Detailed network models of Thailand, Myanmar, Cambodia, Vietnam, Laos are developed based on available information.
- An economic analysis is carried out using a simplified model of the GMS network.
  - Preliminary results show that there can be significant cost advantages to strengthening the cross-border transmission corridors between GMS countries.

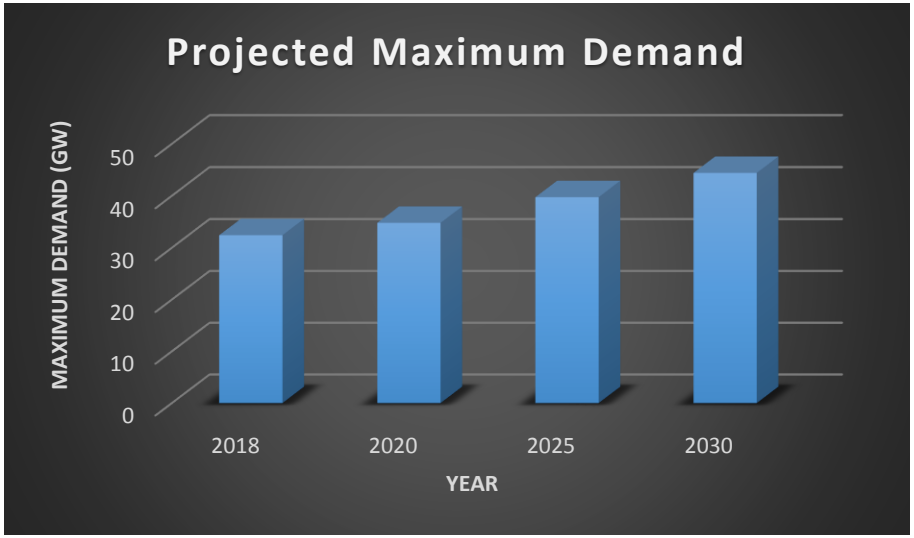
Future work

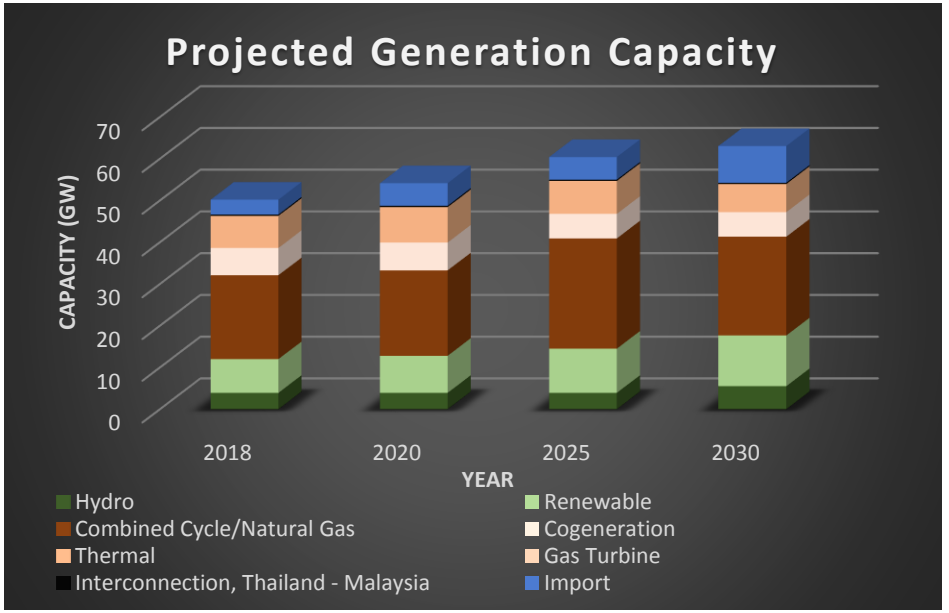
- Complete the transmission system model (PSSE)
- Verify the transmission system model – by individual countries
- Identify credible cross boarder transmission options
- Perform techno economic studies based on DC Load flow optimization
- Identify and rank most economically and technically feasible transmission upgrades and corresponding generation development
- Study report

Thank You

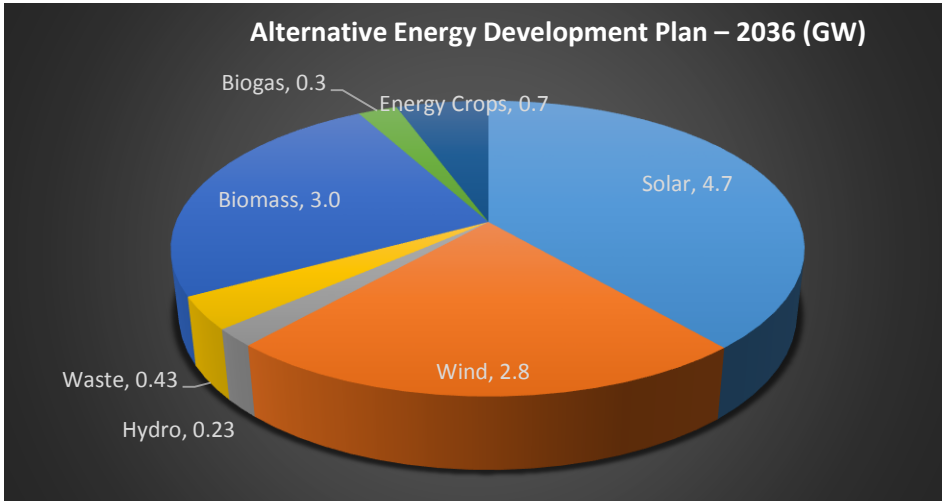
Back up slides

Status of the Thailand Power System

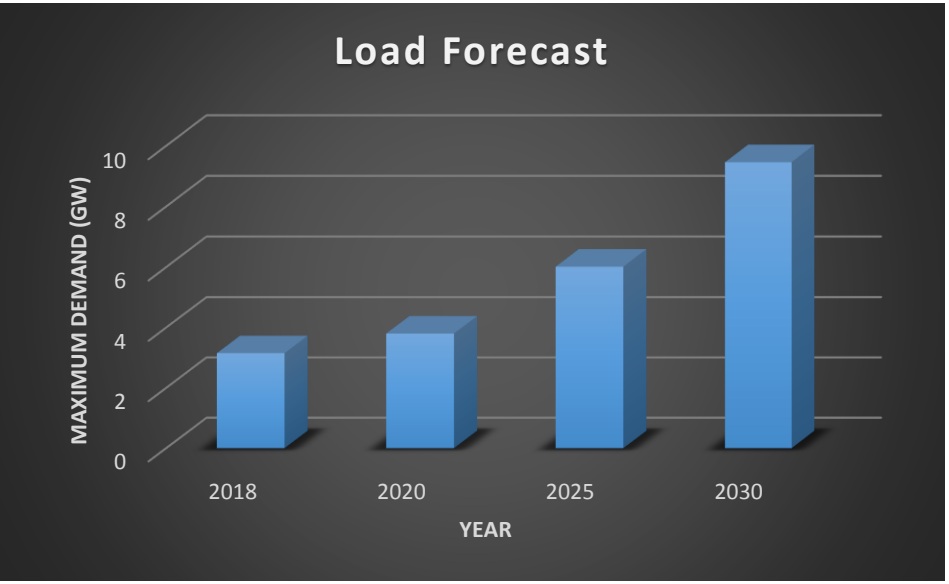


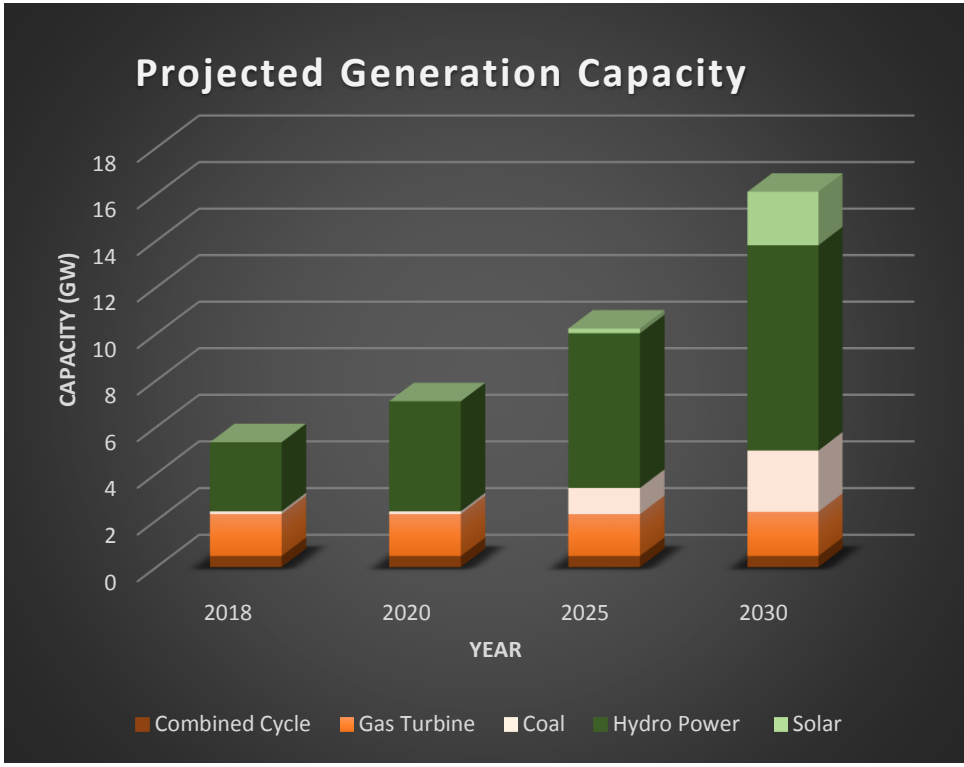


- Increasing the reliability of the Southern, Metropolitan, and Central areas by replacing the retiring power plants and introducing new power generation.
- Moving towards “Alternative Energy” / “Renewable energy” to build a low Carbon society.
  - Improve the energy security, Economy and Ecology.
- Power to be imported from Myanmar, Laos and Cambodia.



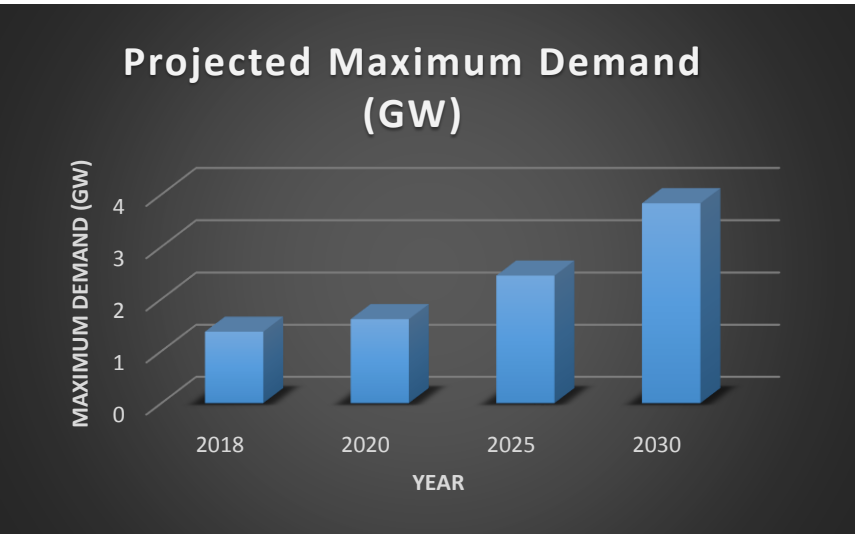
Status of Myanmar Power System

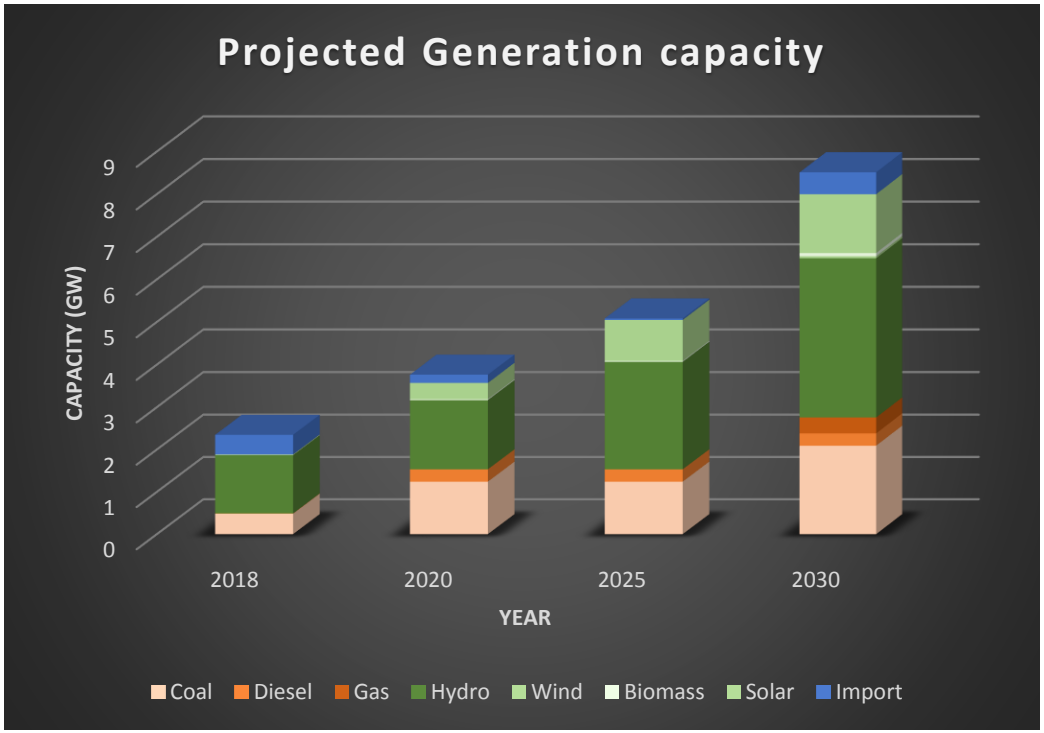




- Myanmar is a potential exporter to China, Thailand, and Laos.
- High hydro power potential.

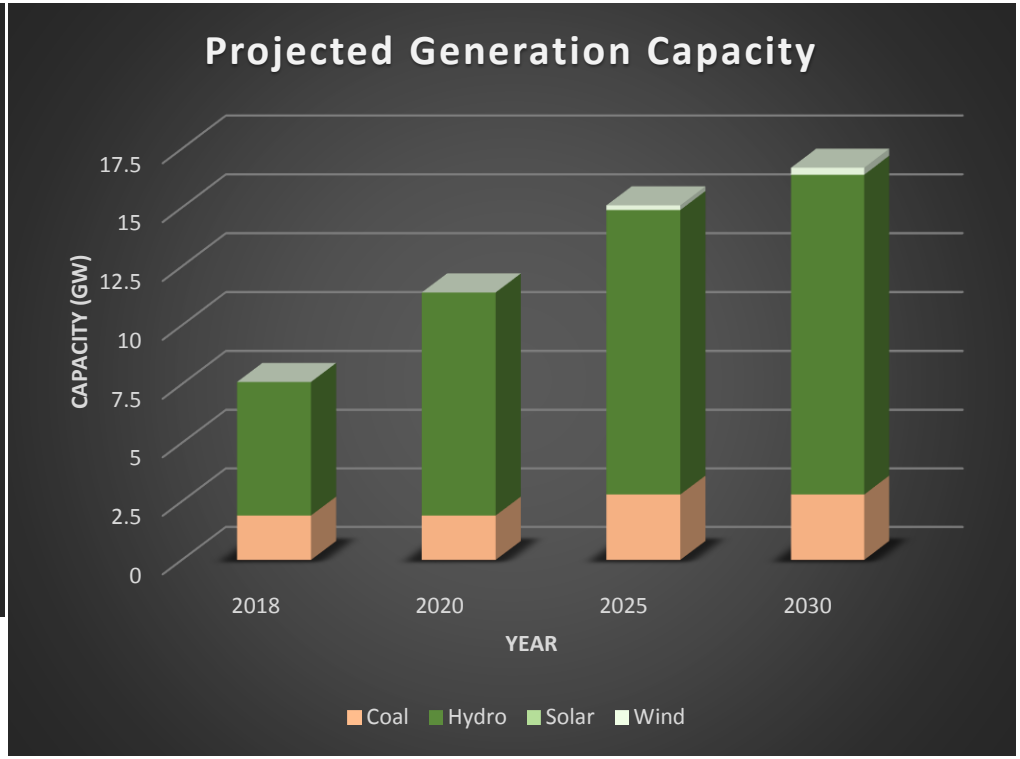
Status of the Cambodia Power System





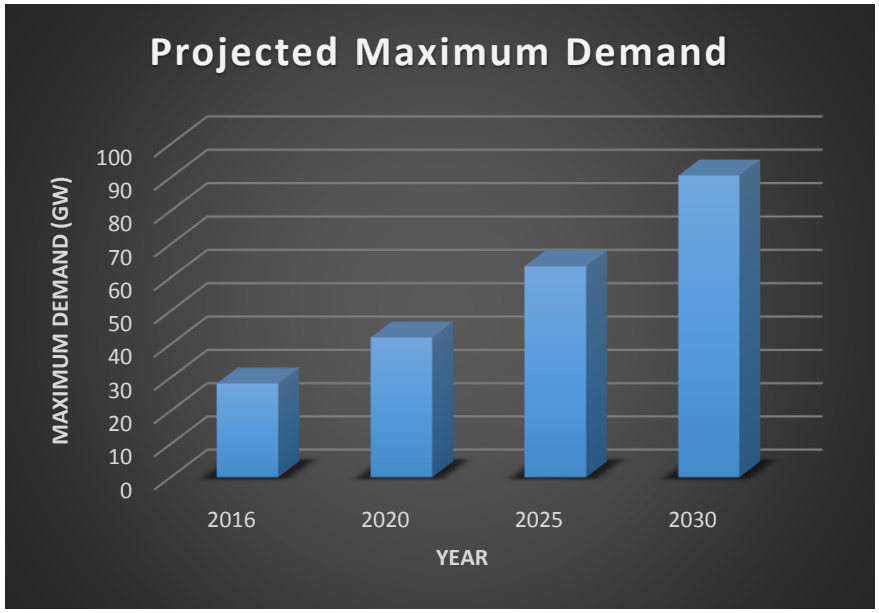
- Cambodia is a potential exporter to Vietnam South and Thailand.
- Possible power trade between Laos.
- High hydro power potential.

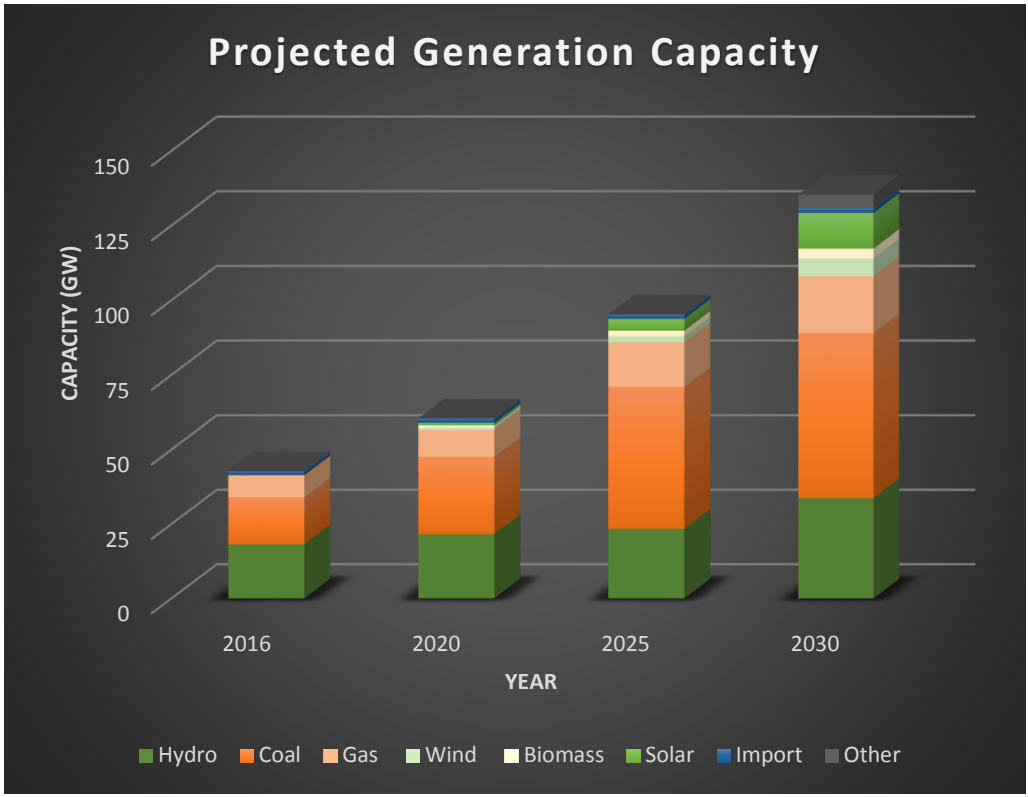
Status of the Lao PDR Power System



- Lao PDR is a potential exporter to Vietnam North and Centre, and Thailand. Also possible power trade between China and Myanmar.
- High hydro power potential.

Status of the Vietnam Power System



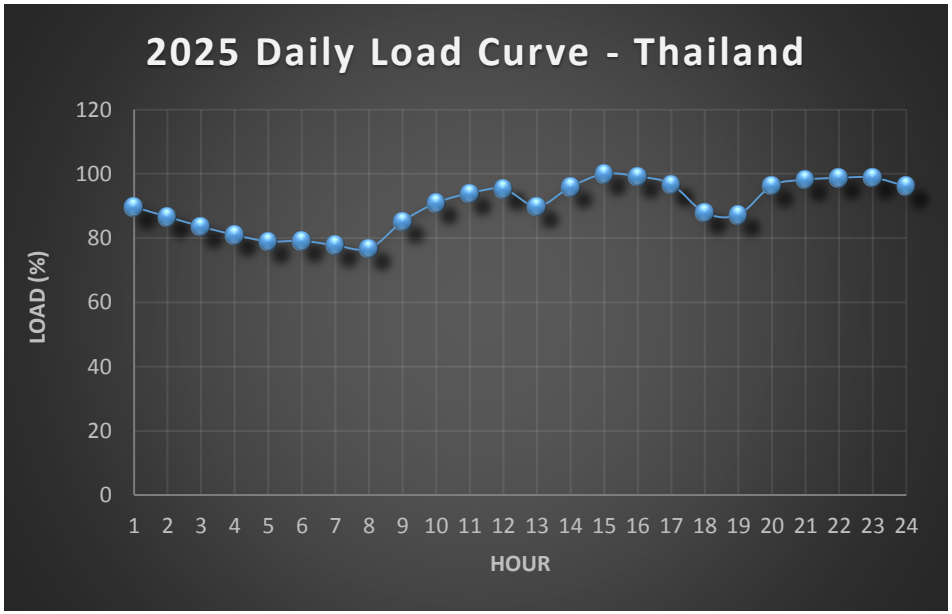


- Power to be imported from China, Laos North and South and Cambodia.
- In power development plan, wind energy, solar energy, and bio energy generation are prioritized.

Note: 1. For year 2016, coal (14595 MW) and oil (1242 MW) fired thermal are included under Coal Category
2. Large, Medium, Small hydro plants and Pump Storage generation are included under Hydro category.

GMS Country Data: Thailand

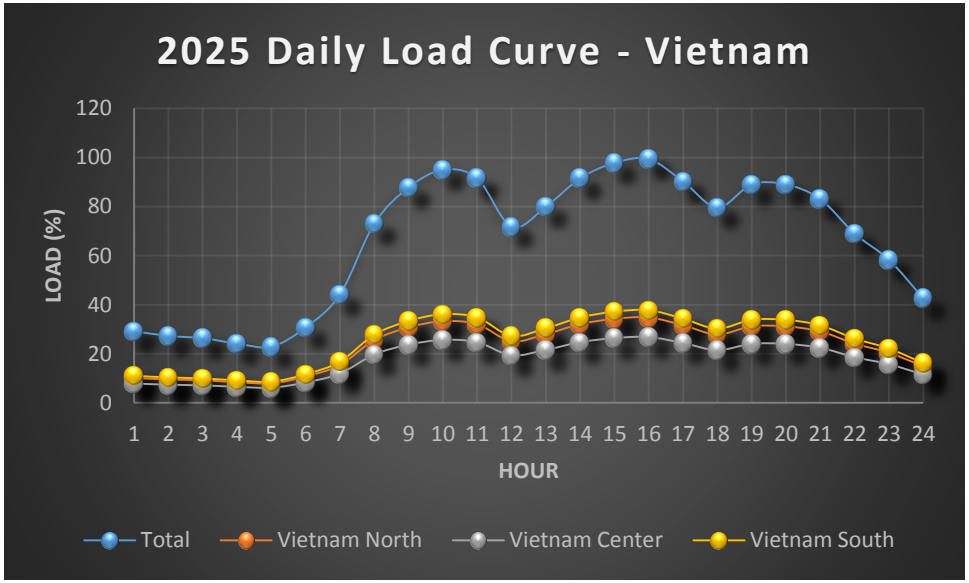
- MHI received following data from EGAT;
  - Single Line Diagram (as of 2017)
  - Load distribution by substation
  - Load curve data for different seasons
- MHI has built the high level transmission network database of Thailand (PSS/E format) for year 2017.



- MHI has gathered information on existing/ Under construction, and planned generation and transmission projects.
- To be reviewed by EGAT

GMS Country Data: Vietnam

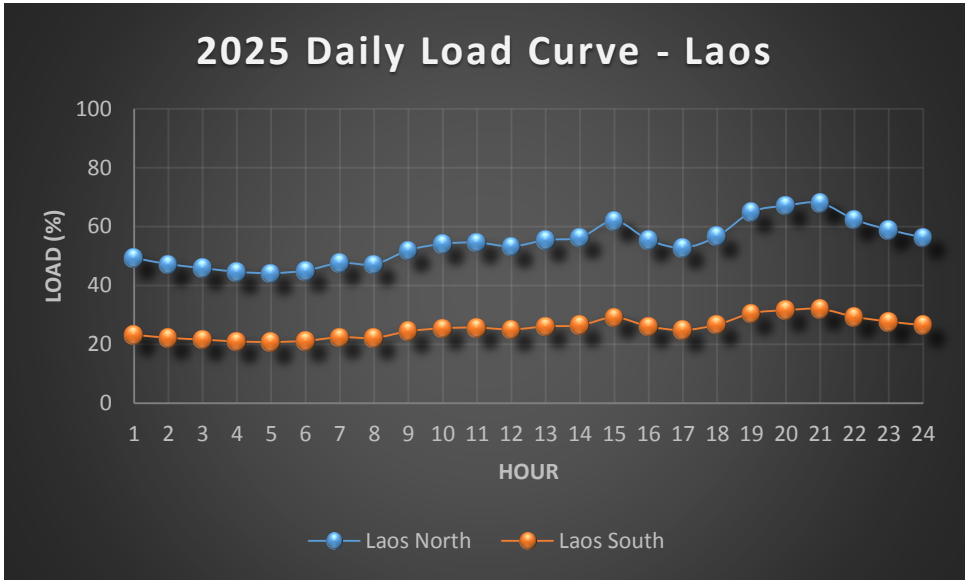
- MHI has gathered information on the existing, under construction, planned, and candidate generation and transmission projects from;
  - Vietnam Energy Map (as of 2010)
  - Revisions of Power Development Plan for the 2011-2020 period with a vision of 2030
  - Individual country presentations (RPTCC 21 and RPTCC 23)



- MHI has built the high level transmission network database of Vietnam (PSS/E format) for year 2010 and to be reviewed by the corresponding authority.

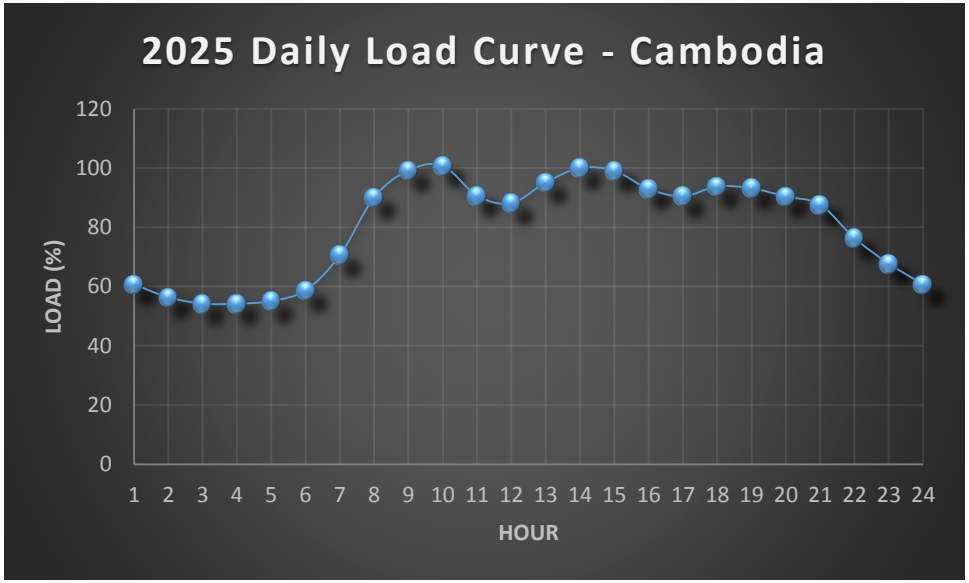
GMS Country Data: Laos

- MHI has gathered information on the existing, under construction, planned and candidate generation and transmission projects from;
  - Laos planned power system diagram in year 2022 – (Long term power development plan PDP 2012-2022)
  - Individual country presentations (RPTCC 21 and RPTCC 23)
- MHI is building the high level transmission network database of Laos (PSS/E format) for year 2022.



GMS Country Data: Cambodia

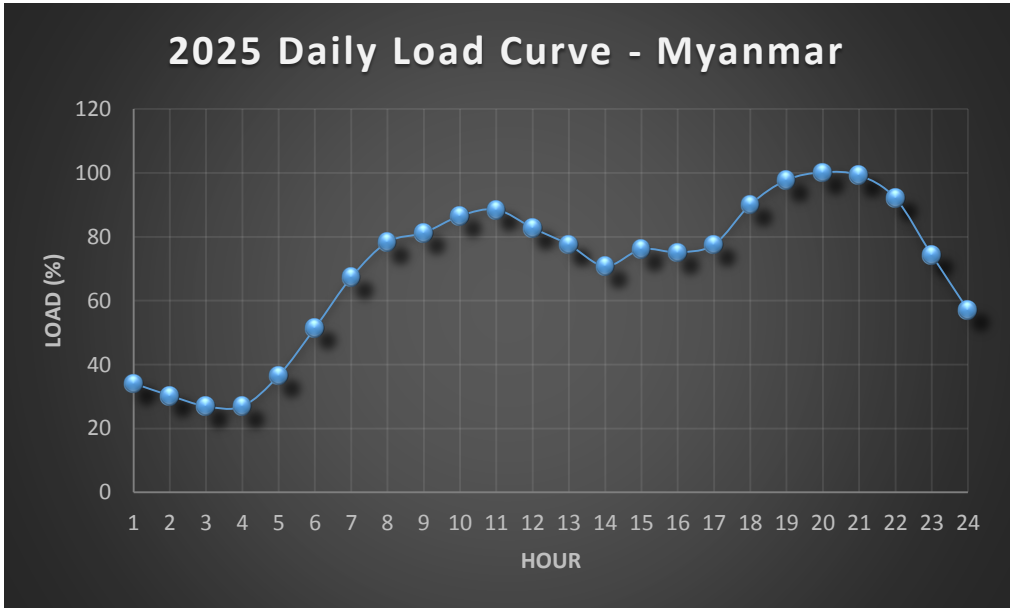
- MHI has gathered information on the existing, under construction, planned, candidate generation and transmission data from;
  - Cambodia National Transmission grid 2016 - 2018
  - Report on power sector of the Kingdom of Cambodia – Data for the year 2015
  - Individual Country Presentations (RPTCC 21 and RPTCC 23)



- MHI has built the high level transmission network database of Cambodia (PSS/E format) for year 2016 and to be reviewed by the corresponding authority.

GMS Country Data: Myanmar

- MHI has gathered information on the existing, under construction, planned, candidate generation and transmission data from;
  - Myanmar's Transmission System – Ministry of Electric Power as presented in ADB 2012a
  - Myanmar Energy Master Plan – Dec 2015
  - Individual Country Presentations (RPTCC 21 and RPTCC 23)



- MHI has built the high level transmission network database of Myanmar (PSS/E format) for year 2012 and to be reviewed by the corresponding authority.

References

- Thailand
  - Country Presentation
  - Thailand Power Development Plan 2015-2036 (PDP 2015)
  - Single Line Diagram Thailand 2017
- Myanmar
  - Country Presentation
  - Myanmar Energy Master Plan 2015
  - Myanmar's Transmission System – Ministry of Electric Power as presented in ADB 2012a
- Cambodia
  - Country Presentation
  - Presentation on Scaling Solar in Cambodia, on Feb 1st 2017 at Sofitel Phnom Penh Phokeetra hotel, Cambodia by the Ministry of Mines and Energy, General department of Energy.
  - ERIA(2017), 'Electric Power Policy and Market Structure in ASEAN Member States in Yokota, E. and I. Kutani(eds.), Study on Electricity Supply Mis and Role of Policy in ASEAN.ERIA ResearchProject Report 2015-18
  - Cambodia National Transmission grid 2016 – 2018
  - Report on power sector of the Kingdom of Cambodia – Data for the year 2015
- Laos
  - Country Presentation
  - World Bank: GMS power market development by Ricardo Energy and Environment in the proceedings of the RPTCC-23 on Task 1
  - Laos planned power system diagram in year 2022 – (Long-term power development plan PDP 2012-2022)
- Vietnam
  - Country Presentation
  - Vietnam Energy Map – 2010
  - Revisions of Power Development Plan for the 2011-2020 period with a vision of 2030

Scenario Development

- Scenario 1:
  - Base case scenario
  - In this scenario all the existing and under construction cross border transmission interconnections are considered.
  - Different generation dispatch levels are considered to derive wet and dry seasons in each scenario.
- Scenario 2:
  - All the planned and proposed cross border transmission interconnections are included.
  - Both Dry and Wet scenarios are considered.
- Scenario 3:
  - After analysing the results of Scenario 2, capacities of the proposed transmission lines with low utilization factors are neglected.
    - China – Laos interconnection only 1000 MW (out of 3000 MW) is considered (only the 1st stage).
    - Vietnam Center (Pliek Ku) – Laos South (Hat Xan) 880 MW interconnection is not considered.
    - China – Vietnam North 3000 MW interconnection is not considered.
  - Both Dry and Wet seasons are considered.
- Scenario 4:
  - After analysing the results of Scenario 2, and 3, capacities of the highly utilized transmission interconnections are increased.

Generation Mix in Each Country as of 2025

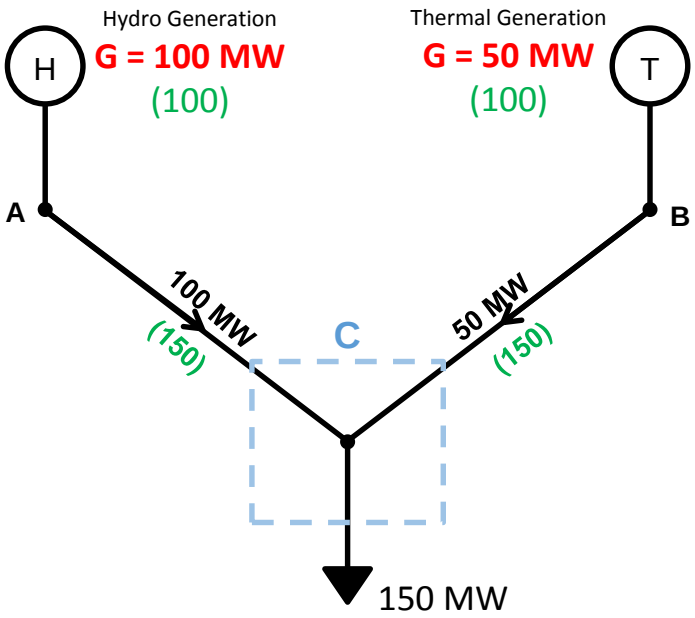
Technology	Country						Cost (M$/MWh)
	Thailand	Myanmar	Laos	Cambodia	Vietnam	China	
	Installed Capacity (MW)	Installed Capacity (MW)	Installed Capacity (MW)	Installed Capacity (MW)	Installed Capacity (MW)	Installed Capacity (MW)	
Hydro	3918	6640	12100	2533	23401	N/A	196.4
Gas	26	1793	0	0	15000	N/A	200.1
Coal	5347	1120	2800	1243	47600	1000	19.5
Diesel	0	0	0	291	0	N/A	145.2
Solar	10580	200	0	961	4000	N/A	210.1
Wind	0	0	200	0	2000	N/A	206.2
Biomass	0	0	0	23	1824	N/A	59.7
Thermal	34811	481	0	0	0	N/A	145.2

For China Coal price is considered to be lower (15 -$/MWh) than other countries for the study.

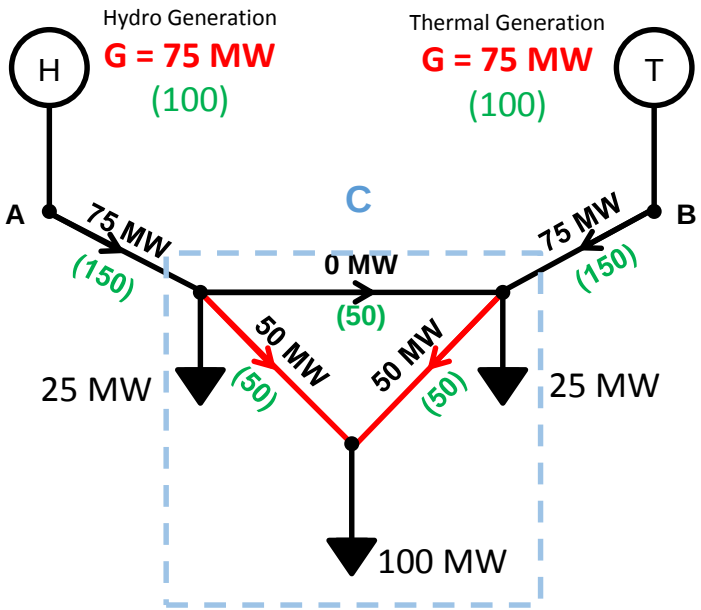
Representation of the Transmission Network

- Significance of representing transmission network with sufficient details is demonstrated using an example.
- Network C is represented using a single node (simplified) and three nodes (detailed).

Simplified Representation



High Level Representation

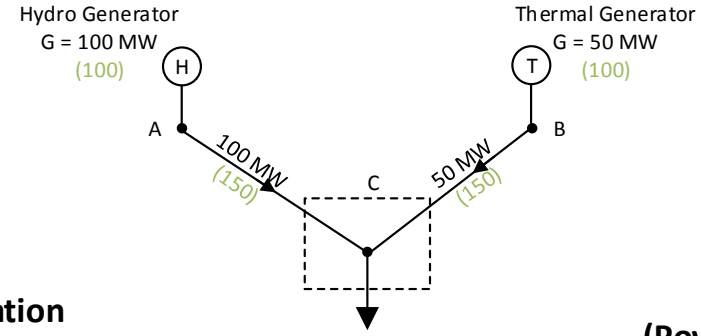


Note: All branch impedances are assumed to be equal.

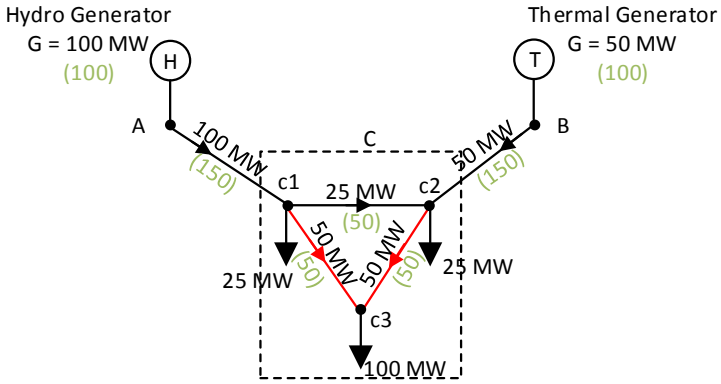
Representation of the Transmission Network

- Significance of representing transmission network details is demonstrated using an example.
- Network C is represented using a single node (simplified) and three nodes (detailed).

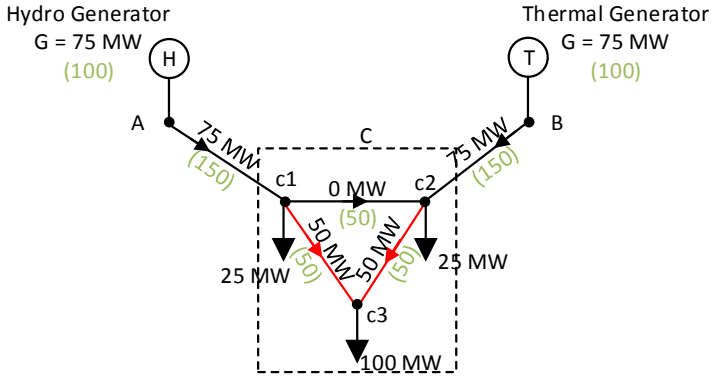
Simplified Representation



Detailed Representation
(Power Angle Relationship Ignored)



Detailed Representation
(Power Angle Relationship Considered)



Note: All branch impedances are assumed to be equal.

Scenario 3 Development

- Following under utilized corridors were identified based on the Scenario 2 optimization results;
  - China to Vietnam North Corridor
  - Laos South to Vietnam Center Corridor
  - Laos North to China Corridor
- For Scenario 3 development capacities of the above corridors are reduced by removing three proposed transmission lines;
  - China – Laos interconnection only 1000 MW (out of 3000 MW) is considered (only the 1st stage).
  - Vietnam Center (Pliek Ku) – Laos South (Hat Xan) 880 MW interconnection is not considered.
  - China – Vietnam North 3000 MW interconnection is not considered.

Scenario 4 Development

- Following 'heavily' utilized corridors were identified based on Scenario 3 results;
  - Laos North to Vietnam North Corridor
  - Cambodia to Thailand Corridor
  - Myanmar to Thailand Corridor
  - Laos North to Thailand Corridor
  - Laos South to Thailand Corridor
  - Laos South to Cambodia Corridor
- For Scenario 4, capacities of the above corridors are increased as listed below;
  - Laos North to Vietnam North Corridor by 1780 MW
  - Cambodia to Thailand Corridor by 925 MW
  - Myanmar to Thailand Corridor by 1925 MW
  - Laos North to Thailand Corridor by 4800 MW
  - Laos South to Thailand Corridor by 1470 MW
  - Laos South to Cambodia Corridor by 320 MW