ECONOMIC ASPECT OF HVDC TRANSMISSION SYSTEM FOR INDONESIA CONSIDERATION IN NUCLEAR POWER DEVELOPMENT

Edwaren Liun
Centre for Nuclear Energy Development – BATAN
Jl. Kuningan Barat, Mampang Prapatan, Jakarta 12710
Telp/Fax: 021-5204243, Email: edwaren@batan.go.id

Masuk: 6 Oktober 2009 Direvisi: 19 Oktober 2009 Diterima: 18 November 2009

ABSTRACT

ECONOMIC ASPECT OF HVDC TRANSMISSION SYSTEM FOR INDONESIA CONSIDERATION ON NUCLEAR POWER DEVELOPMENT. *As a country with hundreds million people, Indonesia needs to generate large scale power and distribute it to thorough country to improve gross domestic product of the population. In the power transmission domain, the High Voltage Direct Current (HVDC) transmission system should be considered for the next decades concerning any technical and economical problems with HVAC transmission. HVDC transmission system is the answer for the Indonesian condition. This system can connect the high energy potential regions to the high energy demand regions. HVDC is the most efficient to transport energy from one region to another one region. Dismantling and removing assets costs are included to the estimated for capital costs, while the environmental and property costs are the costs of securing designations and resource consents, and valuation and legal advice for the HVDC investment. Although converter terminals are expensive however, for long transmissions HVDC system can compensate the costs over breakeven distance through very efficient transmission system. Efficiency of HVDC is appearing from conductor wire, supporting tower, low energy loses and free space used by route of the transmission line. HVDC system is also free from some problem, concerning stability, inductive and capacitive load components, phase differences and frequency system. In the economic aspect the HVDC capital costs for the transmission options comprise estimates of the cost to design, purchase and construct new HVDC transmission components. While operating and maintenance costs of HVDC assets comprise the costs for replacement the old existing overhead transmission lines, underground and submarine cables, and HVDC converter station components.*

Keywords: *HVDC, energy transport, economic aspect, long distance.*

ABSTRAK

ASPEK EKONOMI SISTEM TRANSMISI HVDC UNTUK PERTIMBANGAN PEMBANGUNAN PLTN DI INDONESIA. *Sebagai negara dengan ratusan juta penduduk, Indonesia perlu membangkitkan listrik skala besar dan mendistribusikannya ke seluruh wilayah untuk meningkatkan produk domestik bruto penduduk. Didalam wilayah kerja transmisi listrik, Sistem Transmisi Arus Searah Tegangan Tinggi (HVDC) perlu dipertimbangkan untuk dekade mendatang berkenaan dengan masalah teknis dan ekonomi pada transmisi HVAC. Sistem transmisi HVDC merupakan jawaban untuk kondisi Indonesia. Sistem ini dapat menghubungkan daerah potensi energi tinggi ke daerah permintaan energi tinggi. HVDC adalah yang paling efisien untuk mengangkut energi dari satu daerah ke daerah lain. Biaya pembongkaran pembersihan aset sudah termasuk kedalam perkiraan biaya modal, sedangkan biaya lingkungan dan properti adalah biaya untuk mengamankan sumber daya, perjanjian, evaluasi dan nasihat hukum bagi investasi HVDC. Meskipun terminal converter mahal, namun sistem transmisi HVDC yang panjang dapat mengkompensasi biaya di atas titik impas jarak melalui sistem transmisi yang sangat efisien. Efisiensi HVDC diperoleh dari kawat konduktor, menara pendukung yang ramping, kehilangan energi rendah dan ruang bebas yang digunakan oleh rute dari saluran transmisi. Sistem HVDC juga bebas dari beberapa masalah yang berkenaan dengan stabilitas, komponen beban induktif dan kapasitif, serta perbedaan fase dan frekuensi sistem. Dalam aspek ekonomi biaya modal HVDC untuk pilihan transmisi terdiri dari estimasi biaya disain, pembelian dan konstruksi komponen transmisi HVDC baru. Sedangkan biaya operasi dan pemeliharaan untuk aset HVDC meliputi penggantian komponen saluran transmisi udara, kabel bawah tanah serta aset jalur laut dan stasiun konversi HVDC yang telah usang.*

Kata kunci: *HVDC, pengankutan energi, jarak jauh, aspek ekonomi.*

1. INTRODUCTION

1.1. Background

By the end of 2007, the electrification ratio of thorough Indonesia is 60.78%. This is 65.97% for Java and 52.73% for out side Java, while sold energy in kilowatt hour per capita was 708.32 for Java and 207.10 for outside Java[1]. In many remote and isolated areas capacity factor of electricity system are very low, because many diesel generator plants are turned on at the night only, therefore not support regional economic activity.

As an archipelago country, Indonesia faces more challenges to distribute electricity energy generated to many regions or islands separated by long distances and by a lot of wide seas. Because of the Indonesian geomorphic condition, electricity energy potential in certain region is very high with very low demand. On the other hand, any other regions have very low electricity energy potential with very high demand. This situation is detrimental to their economies to transmit power generated in the few areas that have high energy resources. Correspond to Indonesian geomorphic condition that has too many islands, transmitting electricity energy is a heavy challenge by using alternating current transmission system. This system is not efficient to transmit electricity energy for long distance and/or inter island. This issue reflects that Indonesia needs the strong transmission system with reliable and efficient for long distance increasing the capacity factor to support economy activity of Indonesian people.

Some of power plants such as hydro in large scale, mine mouth coal steam power plant and nuclear power plant if any can be connected by relatively short AC lines to the grid. But some of them have to locate far from the load and the electricity energy has to be transmitted to the load centre. Isolated loads mean loads that due to geographical or other conditions are not connected to a major grid but have to rely on small local generation that generally are small and medium size of diesel units. For examples are Riau Archipelago, Bangka-Belitung, West and East Nusa Tenggara, Maluku and North Maluku, and any other Regions in other sides of Indonesia. The local generation is usually expensive and not environmentally sound. If an isolated load can be connected to a main grid, the cost of electricity goes down. The transmissions options are often HVDC.

In today electricity industry, in view of the liberalisation and increased effects to conserve the environment, HVDC solutions have become more desirable for the reasons of environmental advantages; economical (low cost solution); asynchronous interconnections; power flow control; and added benefits to the transmission such stability, power quality etc.[2].

Figure 1: Map of Indonesia's archipelago

In Indonesia, most of energy resources are located in main islands outside Java, while 73.36% installed capacity of electricity are located inside Java[1]. On such condition a large

AC Systems with long distance transmission and synchronous interconnections, technical problems are the main issue to solve. Indonesia has a large geographic extension as a large archipelago country and has to transmit large power over long distances. Main problems occur regarding load flow, system oscillations and inter-area or inter-island interconnection.

1.2. Objective of Study

As the experienced transmission system in a lot of country, HVDC can be a choice for energy transport system that should be considered in the future for electricity generation expansion plan in Indonesia. The objective of this study is to analyze the economic competitiveness of HVDC transmission systems in connection with the development of nuclear power with other types of power plants to supply the electricity needs of the future in many regions of Indonesia.

2. TRANSMISSION SYSTEM TECHNOLOGY

2.1. HVAC Transmission

AC source of electrical power changes constantly in amplitude and regularly changes polarity, as shown in the Figure 2. The changes are smooth and regular, endlessly repeating in a succession of identical cycles, and form a sine wave as depicted here. Due to the changes are so regular, alternating voltage and current have a number of properties associated with any such waveform. These basic properties include the following several important quantities:

Frequency, the most important properties of any regular waveform identifies the number of complete cycles, as sinus wave shown in Figure 2;

Period, time required to complete one cycle of the waveform, rather than the number of cycles per second of time. This is logically the reciprocal of frequency. Thus, *period* is the time duration of one cycle of the waveform, and is measured in seconds/cycle. AC power at 50 Hz has a period of 1/50 = 0.02 seconds/cycle as used in Indonesia electricity network;

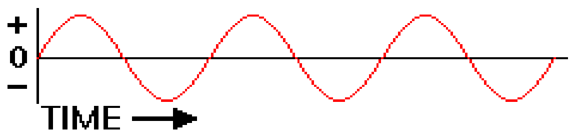

Figure 2: AC Sine Wave

Wavelength, AC wave moves physically as well as changing in time that sometimes we need to know how far it moves in one cycle of the wave, rather than how long that cycle takes to complete;

Amplitude, the thing we have to know is just how positive or negative the voltage is, with respect to some selected neutral reference. With DC, this is easy; the voltage is constant at some measurable value. But AC is constantly changing, and yet it still powers a load. Mathematically, the *amplitude* of a sine wave is the value of that sine wave at its peak.

2.2. HVDC Transmission

A transmission grid is a network of power stations, transmission circuits, and substations. Energy is usually transmitted within the grid with three-phase AC. DC systems require relatively costly conversion equipment which may be economically justified for particular projects. Single phase AC is used only for distribution to end users since it is not usable for large poly-phase induction motors. In the 19th century two-phase transmission was used, but required either three wires with unequal currents or four wires. Higher order phase systems require more than three wires, but deliver marginal benefits.

It is acknowledge that AC transmission has some limitation for long distance including voltage stability, reactive power problem, steady-state stability and sub-synchronous oscillation. Within AC interconnected system the problems are including load flow problem, frequency control, voltage stability, oscillation stability, inter-area oscillation, blackout risk due to cascading effect and physical interaction between power systems. There are significant differences of HVDC and HVAC interconnections mainly in relative capacity, reliability, stability, and economic aspects.

Cost characteristics are obviously to be reason for HVDC consideration in long distance transmission option for Indonesia's geographic condition. HVDC transmission has some advantage for economic aspects, mainly in large scale and long term of electricity expansion plan. Generally large scale generation units are more efficient than small. By HVDC transmission system, electricity generated at a selected site such as mine mouth, best geological site or free from population disturbances or objected, can be sent to load centre in long distance. With HVDC system, there are no limits in transmitted distances. This is valid for both over head lines and sea or underground cables.

The other benefit are demand diversity in a large region, fuel source diversity, most stable geological condition for nuclear power plants, and the availability of hydro potential in the remote area can be exploited by enclosing HVDC transmission system. Advantages of HVDC transmission system normally are: [3]

- No limits in transmitted distance, valid for both over head lines and sea or underground cables.
- Very fast control of power flow, which implies stability improvements, not only for the HVDC link but also for the surrounding AC system.
- Direction of power flow can be changed very quickly (bi-directionality).
- An HVDC link does not increase the short-circuit power in the connecting point. This means that it will not be necessary to change the circuit breakers in the existing network.
- HVDC can carry more power for a given size of conductor.
- For the same transmitted power, the need for ROW (Right Of Way) is much smaller for HVDC than for HVAC. Therefore environmental impact is smaller with HVDC.
- VSC (voltage source converter) technology allows controlling active and reactive power independently without any needs for extra compensating equipment.
- VSC technology gives a good opportunity to alternative energy sources to be economically and technically efficient.
- HVDC transmissions have a high availability and reliability rate, shown by more than 30 years of operation.

HVDC transmission system consists of two options of monopole and bi-pole as shown in Figure 3, where the option is based on the economic, environmental impacts and the power capacity considered. Figure 3 is the configuration of the both.

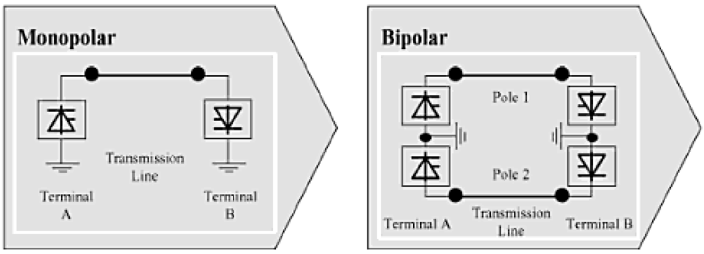

Figure 3: HVDC Line Network

3. THE ECONOMIC OF TRANSMISSION

3.1. Characteristic and Economic Aspects

Figure 4 reflects the benefits of interconnecting power system that can be described out below:

Economics scale. In general, large generation unit are more efficient than small. However, too large a unit size runs the risk of a major disturbance if it develops a fault. The large the interconnection system, the easier it withstand the loss of a large unit.

Fuel Economy. The dispatch of generating plant aims to use plant for continuous load and less efficient for meeting peaks. Wider fuel choices from interconnected system offer opportunities to optimise dispatch on a large system, where more plants option are likely to be available, and thus to reduce supply costs.

Reduction in Relative Reserve Capacity. A margin of reserve capacity has to maintain in operating generation of any system to cater for plant maintenance and/or breakdown. The interconnection of two or more separated systems reduces required reserve capacity and increase reliability[9].

Main loss in electricity network is due to AC losses. Although DC system needs two converter stations that expensive in investment cost, the HVDC transmission system is much more efficient and lower line cost per unit length as compared to an equally reliable AC system due to the lesser number of conductors and smaller tower size (Figure 5). The cost of converter station is around two to three times corresponding AC transformer stations. Thus HVDC transmission is not generally economical for short distances, unless other factors dictate otherwise. Economic considerations call for a certain minimum transmission distance (break-even distance) before HVDC can be considered competitive purely on cost.

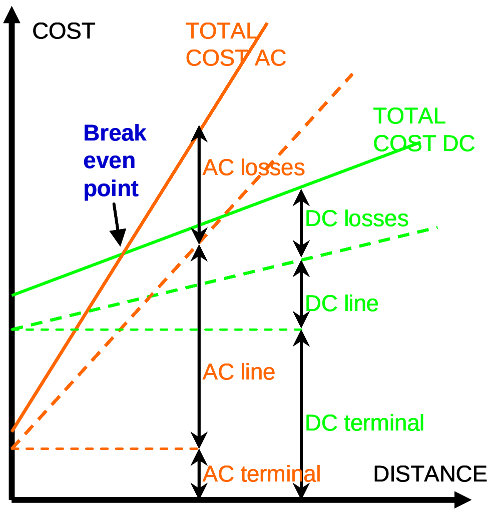

Figure 4: Cost Characteristic of Transmission

Estimates for the break even distance of overhead lines of HVAC and HVDC are around 500 km with a wide variation about this value depending on the magnitude of power transfer and the range of costs of lines and equipment. The breakeven distances are reducing with the progress made in the development of converting devices. For cables, the break-even distance is much smaller than for overhead lines and is of the order of 25 km for submarine cables and 50 km for underground cables.

HVDC can help increase system stability by preventing cascading failures from propagating from one part of a wider power transmission grid to another, because it allows power transmission between unsynchronized AC distribution systems.

For Converter Station, HVDC cost is various by system and technology applied.

3.2. Economic Comparison

Economic advantages of HVDC can be assessed by making some comparison with other energy transport methods, such as HVAC transmission, coal or other fossil fuel types transport system. A case study made by ABB Power Company indicates costs comparison of HVDC Transmission System of 750 mile distance versus Coal Transport of 900 km.

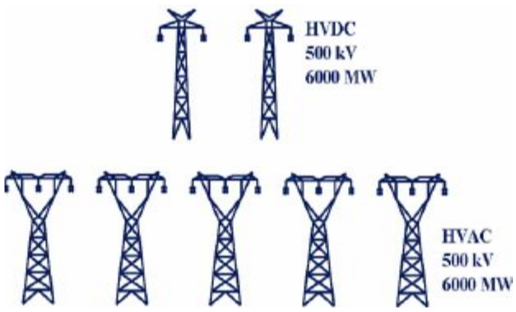

Figure 5: Transmission line comparison of DC and AC

By physically calculation determined that, for the same insulation, direct voltage V_d with the peak value (√2 x average value) of the alternating voltage V_a gives ratio as:

$$V_d = \sqrt{2}\, V_a$$

$$I_d = I_a$$

DC power per conductor $P_d = V_d\, I_d$

AC power per conductor $P_a = V_a\, I_a \operatorname{Cos} \phi$

$$\frac{P_d}{P_a} = \frac{\sqrt{2}}{\operatorname{Cos} \varphi}$$

It mean that P_d = 1.414 P_a at Cos ϕ = 1, and 1.768 P_a at Cos ϕ = 0.8. Required conductor cross section ratio for I_d versus I_a is 0.5 at Cos ϕ = 1 and 0.32 at Cos ϕ = 0.8.

3.3. Comparison with Rail Transport

Cost comparison between HVDC system and railway transport mode done by M Bahrman from ABB Power Company's team resulting that HVDC system is cheaper[4]. The 3000 MW HVDC transmission of 750 miles distance with discount rate 7% and 12% appear costs of \$6.44 per MWh and \$9.89 per MWh respectively. While Coal Transport that undergo 900 miles with cost rate of \$30 per ton and \$50 per ton appear costs of \$15.00 per MWh and \$25.00 per MWh respectively (Table 1).

Table 1: Capital cost comparisons of DC Transmission and Rail Transport[4]

	Transmission – 750 miles		Coal Rail Transport – 900 miles	
	Rate 7%	Rate 12%	Rate per ton $30	Rate per ton $50
- Total Cost per Year	$143,837,937	$220,934,280	$335,070,000	$558,450,000
- Cost per kW-yr	$47.95	$73.64	$111.69	$186.15
- Cost per MWh @ 85% load factor	$6.44	$9.89	$15.00	$25
- Capacity	Firm (Note 1)		Subject to congestion	
- Price	Fixed		Subject to congestion	
- Integration of renewable	Yes		No	

3.4. HVDC Transmission Cost Estimation

Cost of transmission line includes the investment and operation costs that contain fixed and variable components. The investment includes land acquisition, tower, and wire line transmission. Commonly seabed transmission line free of land acquisition, although the seabed cable more expensive than overhead line. The Table 2 is listing of some HVDC transmission line cost estimation of several projects.

The following are recent example of overhead transmission line project cost. The cost involved voltage system of 345 kV, 500 kV and 765 kV for given distance as follow[5]:

- American electric power Co.: 765 kV line from Wyoming, V.Va. to Jackson Ferry, Va., 90 Mile @ estimated cost of $287 M or $3.2 M/mi, capacity ~ 2200 MW – Cost per kW-yr = $16.52.
- American Transmission Co.LLC: 345 kV line from Duluth, Minn. To Wausau, Wis., 220 mile @ estimated cost of $396 or $1.8 M/mi, capacity ~ 300 MW – Cost per kW-yr = $165.87.
- Bonneville Power Administration 500 kV Scultz-Wautoma line, 64 mile @ cost of 175 M or $2.7 M/mi, capacity – 1200 MW – cost per kW-yr = $18.38.

Table 2. HVDC Transmission Line Cost Estimation of Several Projects[9]

	Location	MW	Length (km)	Cost (Euro M)	Year
Galatina-Arachthos	Ita/Gre	500	165	240	2001
Cross-Sound Cable	USA	350	50	110	2002
Basslink	Australia	480	350	484	2005
Moyle	Scot/NI	2*250	63	180	2001

Source: Cost and Risk Analysis for a Norway-Netherlands HVDC Interconnector

Table 3. Comparison of DC and AC Transmission Capital Cost[4]

Relative Cost	2000 MW DC Transmission	2000 MW AC Transmission
Land	50%	100%
Line	33%	100%
Tower	30%	100%

The breakeven distance depends on some factors, as transmission medium (cable or OH line), different local aspects (permits, cost of local labour etc.). When comparing high voltage AC with HVDC transmission, it is important to compare a bipolar HVDC transmission using two lines to a double-circuit high voltage AC transmission using six lines in their route, especially when availability and reliability is considered[2]. This comparison is involving technical, economic and environmental aspects.

Table 3 shows the capital costs comparison between DC and AC system transmission involving land, line and tower along route of the transmission for 2000 MW of power.

Table 4 is estimated cost of $ per kilowatt for the HVDC Converter Station. The option consists of back to back, monopole, and bi-pole system. Among those systems normally just monopole and bi-pole system transmitting the power only, while back to back to adjust the frequency only.

Modern HVDC systems are designed to operate unmanned. This feature is particularly important in situations or countries where skilled people are few, and these few people can operate several HVDC links from one central location[8].

Table 4 Turnkey Cost of HVDC Station[6]

	Back to Back		Monopole	Bi-pole		
	200 MW (%)	500 MW (%)	500 kV, 500 MW (%)	±500 kV, 1000 MW (%)	±500 kV, 2000 MW (%)	±600 kV, 3000 MW (%)
Valve groups	19	19	21	21	22	22
Converter transformers	22.5	22.5	21	22	22	22
DC switchyard and filtering	3	3	6	6	6	6
AC switchyard and filtering	11	11	10	9.5	9	9
Control/prot./communic..	8.5	8.5	8	8	8	8
Civil/mech..works	13	13	14	14	13.5	13.5
Aux. power	2	2	2.5	2.5	2.5	2.5
Project eng. and admin.	21	21	17.5	17	17	17
Total	100	100	100	100	100	100
Total per kW	$130	$90	$180	$170	$145	$150

3.5 HVDC Transmission Possibility from Bangka-Belitung to Java Island

Bangka-Belitung Province is located at east side of Sumatra Island that facing to the South Sumatra Province. Although the province does not significant amount of energy resources, the island acquire advantages from very stable bedrock in Indonesia. The other benefit is that the island has a close distance to load centre of Sumatra. The most economic transmission from the nearest coastal of Bangka Island to Java Island is 496 km, consisting of 43 km sea path and 453 km land path to the Balaraja in Banten Province on Java. Based on the previous data of several projects, HVDC Transmission estimated costs from Bangka to Java range from US$634 million to US$1654 million. The cost consists of US$533 million to US$1150 million for overhead transmission line and US$101 million to US$304 million for submarine cable. These costs do not include converter station that range from US$440 million to US$600 million for power of 4000 MWe. Therefore, total cost of HVDC system (transmission and station) for such power range from US$1.07 to US$2.25 billion.

The type transmission options have to suit to power capacity, environment protection program and economic aspects, choosing monopole or bi-pole system. The costs can be decreased according to how more power capacity transmitted and the selected technology option.

4. CONCLUSION

1. HVDC transmission system is the most efficient to transport energy from one region to another one region. No limits in transmitted distance, valid for both overhead lines and submarine or underground cables.

2. HVDC allows fast control of power flow, which implies stability improvements, not only for the HVDC link but also for the surrounding AC system. Direction of power flow can be changed very quickly (bi-directionality).
3. An HVDC link has no increase the short-circuit power in the connecting point. This means that it will not be necessary to change the circuit breakers in the existing network. HVDC can carry more power for a given size of conductor. For the same transmitted power, the need for ROW (Right Of Way) is much smaller for HVDC than for HVAC. Therefore environmental impact is smaller with HVDC.
4. In the economic aspect the HVDC capital costs for the transmission options comprise estimates of the cost to design, purchase and construct new HVDC transmission components.
5. Operating and maintenance costs for HVDC assets are including the replacement existing submarine cables, overhead transmission lines and HVDC substation assets. The total cost of the HVDC system is able to compensate high converter station costs according to break even distance requirement for HVDC transmission system to apply.
6. As an archipelago country, Indonesia needs to consider HVDC transmission system in the near future to distribute electricity energy generated to many regions or islands separated by long distances and by a lot of wide seas, according to the Indonesia's region condition. With HVDC system it is expected that there are not separated region. Evenly of energy resources can be efficiently distributed using HVDC instead of barge, ship and train transport as well as supporting nuclear power development program in Indonesia.
7. The most efficient transmission system from Bangka to Java Island is combined system of overhead and submarine cable. The total estimated cost of HVDC system range from US$1.07 to US$2.25 billion including a pair of converter for power of 4000 MWe.

REFERENCE

[1] PT PLN (Persero), Statistik PLN 2007, 2008.

[2] ROBERTO RUDERVALL (ABB Power Systems Sweden), J.P. Charpentier (World Bank United States), Raghuveer Sharma, (ABB Financial Services, Sweden), High Voltage Direct Current (HVDC) Transmission Systems Technology, Review Paper, http://www.trec-uk.org.uk/elec_eng /world_ bank_hvdc.pdf, September 20, 2009

[3] LARS STENDIUS & KJELL ERIKSSON, HVDC Light - An excellent tool for City Center Infeed, ABB Power Systems, SE-771 80 Ludvika, Sweden, lars.stendius@se.abb .com, kjell.eriksson@ se.abb.com, http:// library.abb.com /global/scot/scot221.nsf /veritydisplay/ 176e923dadc8c622c1256fda004c8ca4/ $File/ powergen2.pdf, September 21, 2009

[4] MIKE BAHRMAN, Economic of Mine-Mouth Generation with HVDC Transmission Relative to Coal Transport, ABB Power Company, March 30, 2006. wwww.abb.com/hvdc

[5] ANONYMOUS, HVDC Inter-Island Link Upgrade Project Investment Proposal, Part IV – Cost Benefit Analysis, © TRANSPOWER NEW ZEALAND LIMITED 2005.

[6] CHAN-KI KIM, VIJAY K. SOOD, GIL-SOO JANG, SEONG-JOO LIM, and SEOK-JIN LEE, HVDC Transmission: Power Conversion Applications in Power Systems, John Wiley and Sons, (Asia) Pte Ltd, 2 Clementi Loop, # 02 01, Singapore, 129809, Copy Right 2009.

[7] ISSARACHAI NGAMROO, Ph.D., FACTS & HVDC Controllers, Training Workshop on FACTS Application, Energy, AIT, Sirindhorn International Institute of Technology,

Thammasat University, December 16, 2004, http://www.scribd .com/doc/15250510/Presentation-3-FACTS-HVDC-Controllers, September 20, 2009.

[8] JOHAN SETR´EUS, (Graduate Student Member, IEEE), and LINA BERTLING, (Member, IEEE), Introduction to HVDC Technology for Reliable, Electrical Power Systems

[9] ANONYMOUS, Cost and Risk Analysis for a Norway-Netherlands HVDC, Interconnector, Tabor Caramanis & Associates, © 2004, Tabors Caramanis & Assoc.