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RELIEVING THE POWER CRISIS IN THE NORTHEAST BY IMPORTING ELECTRICITY FROM THE MOUNTAIN STATES

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ABSTRACT
The abundance of fossil resources in the Mountain states can help to relieve the electric power shortages in the northeast US, who suffered the largest blackout in the North American history on August 14, 2003. Lack of local generating capacities in these states can be partly attributed to the lack of local energy resources. Following the peak in the 1970s, capacity additions during the period of 1980 to 2000 were very low in three major northeastern states, New York, Michigan and Ohio. Recent power shortages stimulated the rush for building new natural gas plants. The power crisis in this area can only be eased by importing either fossil fuels or electricity. The Mountain states produce most of the low sulfur coal in the US. Environmental concerns encourage the use of coal from this area, resulting in an increased production expected to last through at least 2025. In this study, two HVDC lines are proposed to export electricity from the Powder River Basin in Wyoming to the Northeast. Economic analysis is also presented, which shows very promising results. The proposed HVDC lines are highly reliable.

KEY WORDS
Northeast Blackout, Energy Transfer by HVDC Transmission

1. Introduction

Once again, on August 14, 2003, a major blackout hit the vulnerable northeast US, crippling cities and leaving millions in the dark. The three states mostly involved, namely, New York, Michigan and Ohio, has a combined population of more than 40.7 million – one seventh of the countries total [1]. The explicit reasons for the blackout have been attributed to some technical and operational incidences [2]. But considering the vulnerability of the power system in this area, lack of adequate local generating capacities may play an indirect exacerbating role. In 2002, the per capita retail sales of electricity in this area were about 10 MWhs, 84% of the US average. Local generation was even lower with only 9.9 MWhs per person, no more than 75% of the national average [1], [3]. Obviously, a large amount of electricity needs to be imported to meet the shortfall. In cases of emergencies, such as the loss of a significant power supply from a remote source, the whole system will be seriously compromised because of insufficient local spinning reserves. Adding local generating capacities, however, is not easy. All of the three states are short in energy resources. Even in the existing coal and natural-gas-fired power plants, fuels are largely relied on importation from other states [3]. Similarly, transmission line expansions are also very difficult due to the high population densities in these states and the strong public resistance to build new transmission lines [4]. Consequently, obtaining right-of-ways is both difficult and expensive – as is true for nearly all well-developed areas in North America.

In this paper, the electrical energy situations in these states are studied in details. Few generating capacities were added in this area during the last three decades. High demand of electricity resulted in high electricity prices, which sent a strong signal to power producers and investors to add more capacities. In addition to building more local plants, the paper suggests the possibility of importing power directly from the Rocky Mountain states by High Voltage DC (HVDC) lines. This study shows that this is economically feasible and beneficial. The fact that the fuel prices in the Rocky Mountain states are among the cheapest in the country makes their electricity most suitable for base load and thus freeing up many high-fuel-cost local plants to serve peak loads and increase spinning reserve margins. Existing HVDC lines in the US show that HVDC transmission is highly reliable.

2. Northeast Electrical Energy Situation

The electrical energy situations in the states of New York, Michigan and Ohio can be better understood by a detailed study of their electrical infrastructures. Fig. 1 shows the percentage share of electricity generation from various energy resources in 2002 [3]. The numbers are percentage values with small contributions neglected and not shown. It can be seen that fossil fuels were the primary resources for electricity in these states. New York had the least fossil fuel utilization percentage of 52.4%. As much as 70.9% of Michigan electricity and 91.9% of Ohio electricity was generated from fossil fuels.

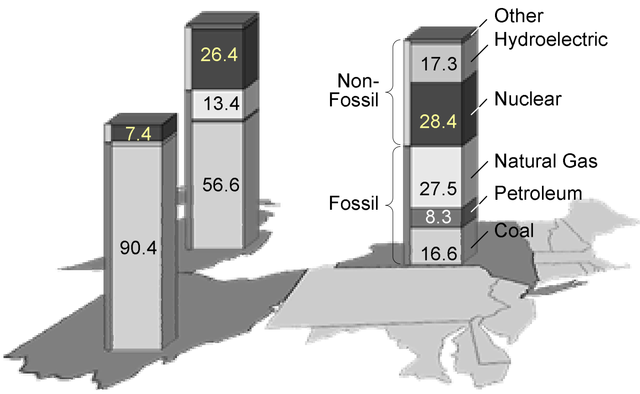

Fig. 1: Percentage Share of Energy Sources in Electricity Generation in Michigan, New York and Ohio

Local fossil fuel reserves, however, are very low. New York and Michigan have no local coal production and rely solely on importation. Ohio's local production of coal was only enough to satisfy about 24% of the demand in its power plants [3]. In the case of natural gas, New York produced a negligible 3.1% of its total consumption in 2002. Michigan's local production was barely enough to meet 28% of its consumption [3]. Local production in Ohio was also very low, but natural gas was not a major resource for electricity generation in this state. Although 8.3% of New York electricity was from petroleum, local petroleum production was negligible.

Electricity price usually has a strong correlation with power plant fuel types. In general, generation cost of coal, nuclear and hydroelectric plants is considerably lower than that of natural gas and petroleum plants. Consequently, the higher the percentage share of generation from natural gas and petroleum, the higher the electricity price is. Since petroleum is a rarely-used fuel in power plants, the percentage share of generation from natural gas alone usually has a strong influence on electricity price. Fig. 2 shows the electricity prices of the states of New York, Michigan, Ohio and the US from 1990 to 2003 [3]. The prices are in nominal values.

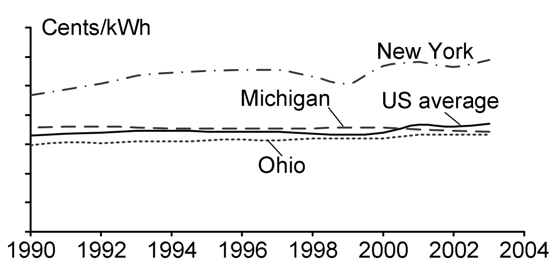

Fig. 2: Electricity Prices of New York, Michigan, Ohio and the US, 1990 – 2003

The electricity price in New York was much higher than the prices of both Michigan and Ohio, which were very close to the US average of 6.92 cents/kWh, averaged over this 14-year period. The New York price was 10.82 cents/kWh, 56% more expensive than the US average, while the prices for Ohio and Michigan were 6.32 and 7.07 cents/kWh, respectively [3]. Obviously, the high percentage share of electricity from natural gas and petroleum put the New York electricity price among the highest in the US. On the other hand, Ohio's electricity price was much lower because of the exclusive use of coal – although mostly imported from other states. It is also noticeable in Fig.2 that the electricity prices of New York in 2000 and 2001 were slightly higher than normal years. Not surprisingly, natural gas prices in these two years happened to be much more expensive than normal [3]. This fluctuation can also be seen in the US average price, where natural gas accounted for about 17.9% of its total generation in 2002. It was not reflected in Michigan and Ohio electricity prices due to their low natural gas use.

3. Generating Capacity Additions

Fig. 3 shows the total retail sales in dashed lines, and net local generation in solid lines, of New York, Michigan and Ohio from 1990 to 2002. It shows a steadily increasing trend in the retail sales of electricity. Michigan, for example, increased from 82.4 million MWhs in 1990 to 107.3 million MWh in 2002, an increase of more than 30% [3]. To meet the ever increasing demand of electricity, power producers can choose either to add new generating capacities or to exploit existing capacities further by squeezing the spinning reserve margins. Unfortunately, most power producers tried to run on their existing capacities instead of building new power plants. This can be seen clearly from Fig. 4, which shows the existing generating capacity additions for the state of New York. Very similar trends also existed for the states of Michigan and Ohio [3].

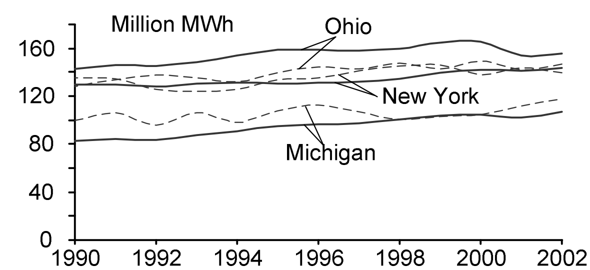

Fig. 3: In-state Electricity Generation and Retail Sales in New York, Michigan and Ohio, 1990 – 2002

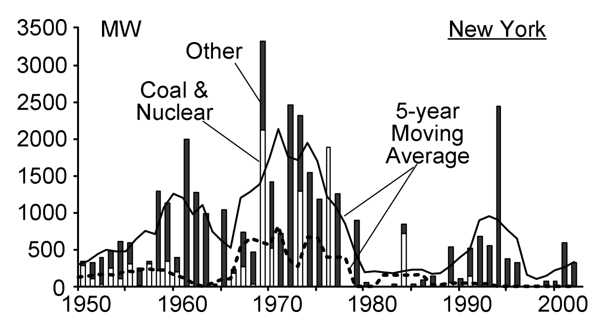

Fig. 4: Existing Generating Capacities in Operation in New York, 2002

Generating units added online before 1950 constituted only a small fraction of total capacities and thus are not shown. The capacities are classified into two categories: coal and nuclear plants and all others. Five-year moving averages are also shown for the combined capacities of coal and nuclear plants and the total capacities.

In the 1970s, generating capacity additions in all three states were in a high tide, which peaked around 1974. The pace slowed down significantly thereafter. Few capacities were added during the 1980s and the 1990s. But the demand of electricity never eased throughout the years, as shown in Fig. 3. Lack of generating capacities will eventually expose its symptoms – either high electricity prices or, even worse, deteriorated system security levels, which put the system in danger of potential blackouts and brownouts. High electricity prices stimulated the rush for more generating facilities in the new century. In 2002, capacity additions in Ohio set a record high; Michigan also saw the second highest additions [3]. This was not only due to the lack of capacity additions in the past two decades but also to the need for replacing retiring units. Even if a very long power plant lifetime of 50 years is assumed, the generating capacities added in the late 1950s and early 1960s are expected to be out of service gradually in the coming decade.

Most capacities added recently were natural-gas-fired. Not only was it true in these states, according to [3], of the total added 187 gigawatts between 2000 and 2003 in the US, 175 gigawatts is natural-gas-fired. Only about five gigawatts of new renewable plants and less than one gigawatt of new coal-fired capacity were added over the same period – almost no coal plant was build in Michigan, New York or Ohio. This was very different from earlier years, when most capacity additions were either coal or nuclear. This pattern is unlikely to change in the near future. According to [3], between 2004 and 2007, the total nameplate capacity additions in the US are 128.2 gigawatts. About 90.5% of the new plants will be fired by natural gas while only 7.5% will use coal. More natural gas plants might potentially raise electricity price in the future. As discussed previously, electricity price has a strong link to the price of natural gas. With its popularity not only in electric utilities, natural gas demand is expected to increase rapidly, so is its projected price. As a result, electricity prices will follow this upward trend.

4. A Solution from the Mountain States

For the states of New York, Michigan and Ohio, building natural-gas-fired plants might appear to be the only choice. Local hydroelectric power has long been utilized fully; nuclear plants are strongly objected by the public due to safety concerns; renewable plants are either too expensive to build or restricted by technologies to be a reliable workhorse at the present time; the capital cost of coal plants is more expensive. However, in the long run, importing electricity from some resource-rich areas might be another choice. HVDC transmission lines can reliably transmit power over a long distance. Presently, there are five long distance HVDC lines in operation in the US, totaling 8,520 MW. The Quebec-New England line brings Canadian electricity to the Boston area in Massachusetts; the Pacific Intertie and the Intermountain lines terminated in the Los Angeles area, California; and the CU and the Square Butte projects send North Dakota's power to Minnesota. Three of these five lines transmit electricity from coal-fired power plants. Importing electricity has at least the following benefits:

1. Relieve the pressure for building more local plants, whose fuels must be imported.
2. Expand the markets for the energy-exporting areas.
3. Better utilization of the energy resources of the energy- rich states.
4. Supply of cheaper electricity to the load centers.
5. Strengthen inter-grid links.
6. Take advantage of time and climate differences and reduce the need for peak load capacities.
7. Easier capacity expansion.
8. Relieve the transportation systems for coal or natural gas.

The Mountain states have very rich fossil fuel reserves, particularly coal. Coal from this area is well known for its low-sulfur content. Phase II of the Clean Air Act Amendments of 1990 mandated maximum sulfur emissions of 1.2 pounds of sulfur dioxide per million Btu. Among all major coal producing areas in the US, the central Appalachian Basin in the eastern states and the Powder River Basin in the Mountain states are the primary sources of low-sulfur coal: only about 30% of central Appalachian Basin coal and 90% of Powder River Basin coal meets the standards [5].

In addition, most coal in this area is minable from the surface. Extraction cost is thus much lower than most other areas. For instance, the average open market price of coal in Wyoming, a major coal-producing Mountain state, was only \$6.37 per short ton in 2002, while the national average was \$17.98 per short ton [3].

With both high quality and low price, the coal production in the Mountain states is skyrocketing. Fig. 5 shows the historical coal production in the eastern and western regions from 1970-2002 with projections to 2025 [3]. The majority of the western coal is produced in the Mountain states. It can be seen that the production in the eastern states remained essentially constant over the years – only declined slightly after 1997, which clearly reflected the effect of the Clean Air Act. The production of the western states increased almost linearly over the same period. It passed the eastern states in 1999 with a production of 571 million short tons, 12.7 times of its production in 1970. The projected production will continue to increase through at least 2025 [3].

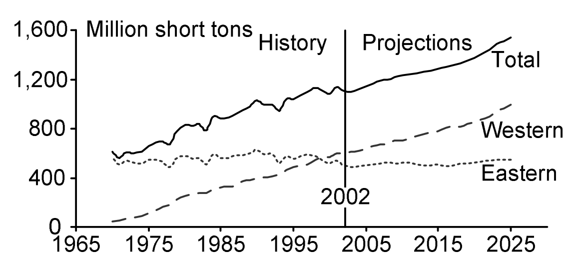

Fig. 5: Coal Production by Region, 1970-2025

Despite the public preference of the environmentally-friendly natural gas and renewable energy plants, it is the coal plants that produce by far the largest amount of electricity in the US. In 2002, about 1.933 billion MWhs of electricity was generated in coal plants, 50.1% of total generation. As a comparison, electricity generated from nuclear, natural gas and hydroelectric were 20.2%, 17.9% and 6.6%, respectively [3]. As much as 91.6% of the coal produced was used for electricity generation [3].

Following the recent surge of capacity additions of natural gas plants, more coal plants will likely be added soon afterwards. Coal-fired power plants are expected to remain the primary source of electricity generation through 2025 with an expected output of 3.029 billion MWhs per year by then. That would be 52% of the total electricity generation, an increase of nearly 2% from the 2002 level [3].

However, most Mountain states are lightly populated with very small demand for electricity. Only a small amount of coal is used locally; nearly all of the remaining coal goes to power plants in other states by railroad. As the production continues to increase, exportation will increase proportionally and put more pressure to the already heavily burdened railroad system. It is, therefore, of great interest to study the possibilities of increasing local utilization of coal in the Mountain states.

5. A Proposed Transmission Scheme

The largest coal reserve and producing area in the Mountain states is the Powder River Basin in northeast Wyoming and southeast Montana. The mine mouth prices are among the cheapest in the US while the sulfur and ash contents are among the lowest. According to [6], only two power plants appeared on the top 25 best coal-fired plant list in the following three categories: lowest production cost, lowest NOx emissions and lowest SO_2 emissions. Laramie River plant in Wyoming, which uses the Powder River Basin coal, was one of them. It was built more than twenty years ago in 1981.

To export electricity, more generating capacities are needed in the Mountain states. At the current stage of study, it is assumed that the new power plants will be sited in the Powder River Basin area to achieve the lowest fuel prices. The HVDC transmission lines will start from this area consequently. Michigan and New York are proposed to be the market of the exported electricity. The proposed transmission lines are shown in Fig. 6 as solid lines. Major coal beds in the US are also shown in the same figure [5]. Ohio is not selected to be a targeted market both because of its relatively low electricity price and its closeness to the central Appalachian coal mines. In an accompanying study, another two HVDC lines are also proposed, sending power to California and Texas. These two lines are shown as dashed lines in Fig. 6.

It can be seen that, these transmission lines will cross four time zones by linking three separate power grids. The time and climate differences of the targeted states can be easily utilized to help satisfy their respective peak demands. A brief summary of the involved states are listed in Table I [3], [7]. According to [3], about 64% of the electricity price is made up of the generation component. The estimated generation prices for each state in Table I are the prices calculated by using this percentage number and respective state retail prices. It should be noted that the retail sales and sales prices were 5-year state average from August, 1998 to July, 2002.

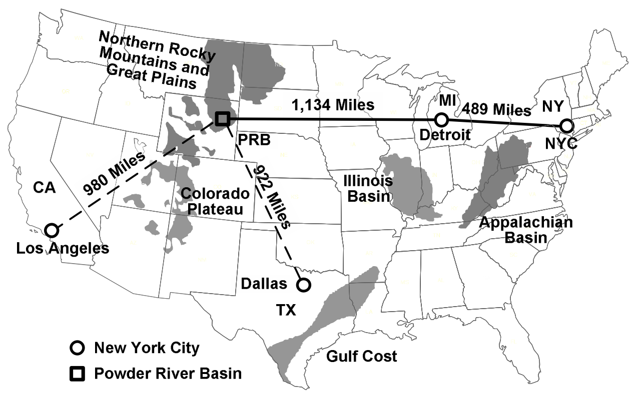

Fig. 6: Proposed Transmission Lines

Table I: Targeted Markets of Wyoming Electricity

State	Retail sales (GWh)	Retail price (¢/kWh)	Generation price (¢/kWh)	Distance to PRB (Miles)
Michigan	105,152	7.05	4.51	1,134
New York	143,170	10.96	7.01	1,623
Wyoming	12,555	4.47	2.86	-

It can be seen that electricity consumptions in both Michigan and New York are an order of magnitude higher than that of Wyoming while the retail prices are much higher.

6. Economic and Reliability Analysis

One of the major advantages of HVDC transmission over high voltage AC (HVAC) transmission is its ability to support long transmission distances. The proposed transmission lines to Michigan and New York are both over 1,000 miles long, a distance not practical for HVAC transmission – even without considering the difficulties of linking two different power grids. The economic analysis in this study is a broad overview without considering any issues specific to the proposed transmission lines. Generally accepted industrial average values for cost estimation are assumed. It is also assumed that each of the proposed transmission lines is rated 2,000 MW at a voltage level of ±500 kV, the same voltage level as the 846-miles-long Pacific Intertie. The actual transmission distances will be considered 10% longer than the direct distances. The approximate capital costs of the proposed two lines are listed in Table II [8]-[10]. The transmission efficiencies are found by assuming that a bundle of four ACSR type "Bittern" conductors per pole will be used. The theoretical transmission efficiencies are also given in Table II. It should be noted that converter losses of 1.4% have been added to give the overall efficiencies [11].

Table II: Construction Costs of the WY-MI and WY-NY HVDC Lines

	WY – MI	WY – NY
Transmission distance	1,247 miles	1,785 miles
Line construction	$0.4 million/mile $498.8 million total	$0.4 million/mile $714 million total
Right-of-Way	$0.125 million/mile $155.9 million total	$0.125 million/mile $223.1 million total
Two converter stations	$125/kW $250 million total	$125/kW $250 million total
Total capital cost	$904.7 million	$1,187.1 million
Efficiency	89.4%	85.9%

Other assumptions for the economic analysis are listed as follows [8], [11], [12]:

- Operation and maintenance (O&M) costs equal to 3% per year of the investment costs for the transmission lines and terminal stations.
- 35 years lifetime for the HVDC transmission lines.
- High interest rate: 80% debt at a cost of 11.54%, 20% equity at a cost of 20%.
- Low interest rate: 80% debt at a cost of 8%, 20% equity at a cost of 16%.
- Tax rate 35%.
- Modified Accelerated Cost Recovery System (MACRS) 20-year class life is assumed with a depreciation factor of 0.44242.

The main analysis results are listed in Table III.

Table III: Transmission Costs of the WY-MI and WY-NY HVDC Lines

		High interest rate				Low interest rate			
		WY-MI		WY-NY		WY-MI		WY-NY	
		BT	AT	BT	AT	BT	AT	BT	AT
I	65% c.f.	11.91	14.18	16.27	19.36	8.89	10.98	12.14	14.99
	75% c.f.	10.32	12.29	14.10	16.78	7.70	9.51	10.52	12.99
	85% c.f.	9.11	10.84	12.44	14.80	6.80	8.39	9.28	11.46
II	65% c.f.	0.00	-2.20	0.00	-3.00	0.00	-2.04	0.00	-2.78
	75% c.f.	0.00	-1.90	0.00	-2.60	0.00	-1.76	0.00	-2.41
	85% c.f.	0.00	-1.68	0.00	-2.29	0.00	-1.56	0.00	-2.13
III	65% c.f.	2.67	2.67	3.64	3.64	2.67	2.67	3.64	3.64
	75% c.f.	2.31	2.31	3.16	3.16	2.31	2.31	3.16	3.16
	85% c.f.	2.04	2.04	2.78	2.78	2.04	2.04	2.78	2.78
IV	Any c.f.	3.39	3.39	4.69	4.69	3.39	3.39	4.69	4.69
V	65% c.f.	**17.97**	**18.04**	**24.60**	**24.70**	**14.95**	**15.00**	**20.47**	**20.54**
	75% c.f.	**16.03**	**16.09**	**21.95**	**22.03**	**13.41**	**13.45**	**18.37**	**18.43**
	85% c.f.	**14.54**	**14.59**	**19.92**	**19.99**	**12.23**	**12.27**	**16.76**	**16.81**

Abbreviations and symbols used in Table III:
BT – Before tax case, AT – After tax case, c.f. – Capacity factor
I – Capital cost, Million $/MWh
II – Depreciation tax shield, Million $/MWh
III – Operating and maintenance cost, Million $/MWh
IV – Losses, Million $/MWh
V – Total levelized transmission cost, Million $/MWh

From Table III, the transmission cost for WY-MI scheme, for example, is $17.97/MWh at 65% capacity factor, high interest rate and before tax: $11.91 for capital, $2.67 for operation and maintenance and $3.39 for losses. The total levelized costs at various line lengths are shown in Fig. 7. The solid lines are for high interest rate and the dashed lines are for low interest rate. It can be seen that the total transmission cost is almost linear with respect to the transmission distance. The total overall cost of the Powder River Basin's electricity at the receiving end can be found simply by adding the cost of generation.

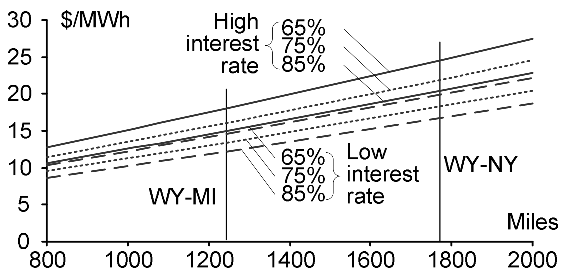

Fig. 7 Total Levelized Transmission Cost

The gross profits per year are also calculated for various capacity factors. Because of the difference in transmission efficiencies at various lengths, the receiving end power for each scheme is different. The results are given in Tables IV. The total gross profit per year for the WY-NY line is much better than that of the WY-MI line. At high interest rate, 65% utilization factor, the gross profit per year for the WY-MI line is even negative. For the WY-NY line, the yearly gross profit after tax ranges from $164.7 to $316.3 million depending on interest rates and capacity factors.

Table IV: Gross Profits per Year of the WY-MI and WY-NY HVDC Lines

	High interest rate				Low interest rate			
	WY-MI		WY-NY		WY-MI		WY-NY	
	BT	AT	BT	AT	BT	AT	BT	AT
65% c.f.	-14.85	-15.56	165.7	164.7	15.91	15.40	206.0	205.4
75% c.f.	5.69	4.99	221.1	220.2	36.46	35.95	261.5	260.8
85% c.f.	26.24	25.53	276.6	275.6	57.01	56.50	316.9	316.3

Abbreviations are same as in Table III. Values are in Million $/MWh.

The profit values are only general approximations because many variables may influence the analysis result significantly. Some major variables are listed as follows:

1. Electricity generating prices.
2. Purchasing prices at the targeted markets.
3. Right-of-way acquisition and costs.

Despite these variations, exporting electricity from the Mountain states might be a promising solution for the power shortages in the northeastern states, especially when their electricity prices are high.

It has been 50 years since the first commercial HVDC transmission in the world was commissioned in 1954. Nearly 100 HVDC projects have been built. Past operating experiences show that HVDC transmission is highly reliable. The proposed HVDC lines to Michigan and New York could improve the reliability of electricity supply considerably. References [13]-[15] indicated that the availability of an HVDC system is consistently over 90% or higher. The locally- operated stations have an average availability of 96.5% [13]. The most recent projects have even better performance. The Intermountain project and the pacific intertie project in the US, for example, have a force outage capacity availability of over 99.7% guaranteed. The forced outage rate of bipole is no more than once every five years [15].

The economic analysis shows that the higher the utilization factor, the higher the profit. According to [13], increasing utilization does not apparently reduce availability. So it is preferable to utilize the proposed HVDC lines heavily, or taking base load. In addition to the economic benefit, it also improves power grid reliability by freeing some local capacities to increase spinning reserve margins. HVDC also has built-in overload control and can be fully loaded without increasing the risk of cascaded line tripping. In case of an emergency, HVDC lines could be run overloaded to help the system survive a potential blackout.

7. Conclusion

The major blackout in the northeast US and Canada in 2003 suggests shortage of electrical power in these states. Because of lack of local energy resource, these states import most of their fuels. In the last two decades, not much capacity was added, which resulted in the recent surge of building natural-gas-fired plants. In the long run, more stable cost effective supply of electricity is needed in these states.

The Mountain states are rich in coal reserves and are the largest coal producers in the US. The importance of coal in power generation is unlikely to decline in the next twenty years. Exporting electricity from the Mountain states can both help increase local coal utilization and relieve the power shortages in the northeastern states.

HVDC transmission lines to Michigan and New York are proposed. Economic analysis indicates very good returns on investment. Despite its longer distance, the WY-NY line could be more profitable than the WY-MI line based on the assumptions made in the study. HVDC is a proved and highly reliable technology for power transmission. The proposed HVDC lines could deliver base load and help increase the spinning reserve margins. In case of emergencies, an HVDC line can be overloaded for hours, which can help maintain system integrity.

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