Empowering India through integrated grid operation A case study

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SYNOPSIS

India has a skewed distribution of natural resources like coal, gas and hydro required for electrical power generation. This necessitates generation of power at one place and its transmission to the load centres. Grid interconnections besides enhancing the reliability of power systems help in transfer of power from surplus areas to deficit areas.

This paper describes the need for interconnections within and across countries, the role they play in bulk transmission of power. A specific case of synchronous interconnection of Northern Regional Grid with Western Regional Grid of India through 765 kV Agra – Gwalior-Bina line (charged at 400kV) is discussed. Sample calculations illustrate the low pay back period and the benefit-cost ratio even without taking into account the benefits of emission reduction.

Our economy is expected to grow @10% every year and capacity addition of over 75000 MW is planned for the XIth Plan. Needless to mention there would be uncertainties in generation expansion. Further, the growth would not be uniform throughout the country causing diversity in power demand. It is the transmission system, which would help in minimizing the uncertainty arising out of these geographical disparities in growth rate. A robust transmission system would ensure economy and efficiency through being able to handle a variety of generation and load despatch scenarios without any congestion. Even if this were the situation for only 10% of the time, the payback period would be less than three years even without taking into account the benefits of emission reduction.

KEYWORDS

Grid interconnection, Economic gains, global warming, Pareto improvement

BACKDROP

Indian Power Sector has experienced phenomenal growth since independence. The installed capacity of power generation in India has increased from a level of 1300 MW at the time of independence to over 1,32,000 MW today. However, even after such an expansion in Generation, the demand for energy has not been met and there is an energy shortage of around 7-8 percent with a peak power shortage of about 13 percent. There has been a similar growth in transmission to match the generation.

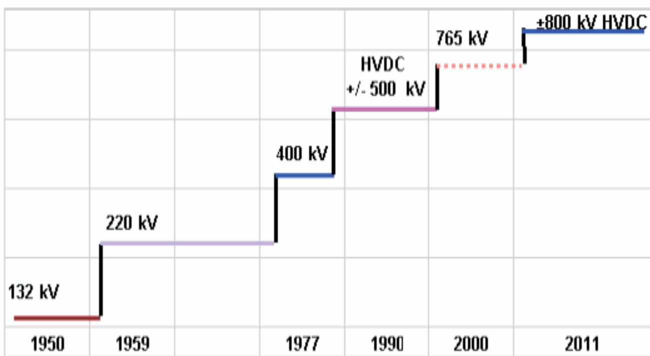

Fig-1: Growth of transmission technology in India

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The transmission network of India is divided into five (5) grids, the East, West, North, South and North-Eastern. Figure-1 depicts the growth of transmission technology in India. The GDP of India is growing @ 9 percent per annum which necessitates growth of power availability of about 10 percent [Integrated Energy Policy]. The 16th Annual Power Survey of Central Electricity Authority projects demand to reach about 2,00,000 MW by the end of 11th Five Year Plan (2012). To meet this demand,Government of India (GoI) has an ambitious plan to add generation capacity of about 1,00,000 MW up to 2012. The matching transmission system should be adequate and reliable to meet evacuation requirement for each station and must provide reliable dispersal to distribution network of each area. The transmission system must be robust enough to meet extreme credible contingencies & take care of long term system needs. Power Grid Corporation of India Ltd, the Central Transmission Utility (CTU) of India is responsible for implementing inter-state, inter-regional and national level transmission schemes in addition to implementation of evacuation schemes for mega independent power projects and Ultra Mega Power Projects and central sector generation projects.

EVOLUTION OF INDIAN ELECTRICITY

The development of Indian Electricity grids has been a long journey starting from 1964 when it was decided to develop the electricity grids in the country on a regional basis as regions were developed on the concept of Regional self sufficiency. The regional grids came into their own in mid 1980s with minimum power exchanges at interregional level in radial mode. The first asynchronous HVDC back to back station connecting the Northern and the Western grids was commissioned in Vindhyachal in 1990. The Eastern and North Eastern synchronization took place through initial radial operation on 132 kV Alipurdwar – Gosaigaon and 220kV Birpara – Salakati, this line was commissioned as early as 1986 as a part of the Chukha (Bhutan) Transmission System but synchronous operation had to wait till 1991. At that time (1991) NER system size was 600 MW while Eastern Region was 6000 MW.

In the early 1990s the Southern (~16 GW) and Western (~20 GW)grids were synchronized through 400 kV Chandrapur (WR) – Ramagundam (SR) double circuit line. Maintaining the tie-line flows between the two regions was a difficult task, particularly due to the absence of proper Data Acquisition and communication systems at the RLDCs. Therefore, this option was not pursued further and only radial mode of operation continued till the commissioning of HVDC back-to-back station at Bhadrawati in 1996.

In 2002 the interconnection between East and North was done through radial operation of 400 kV double circuit Biharshariff – Sarnath line. The east and the west systems were synchronized on 2nd March 2003 with the help of 400 kV double circuit Raipur – Rourkela and 220 kV triple circuits of Budhipadar – Korba. Thereafter, several other inter-regional HVDC back-to back links at Gazuwaka (East and South) and Pusauli (East and North) were commissioned which provided asynchronous interconnection between the regional grids. The next major milestone was the synchronization of Northern grid with the North East – East -West grid on 26th August 2006 over the 400 kV Muzaffarpur-Gorakhpur D/C line to form the NEW Grid.

Advantages of interconnected systems

1. Optimal Utilisation of unevenly distributed natural resources

In India, major Hydro resources are in North Eastern Region & Northern Region whereas coal reserves are mostly in eastern states of Bihar/ Orissa/ West Bengal. There is not much hydro potential in West & South and not much coal potential in North & West. Transmission of bulk electrical power is cheaper than transporting natural resources. Thus interconnection of grids provides an attractive option for optimal utilization of unevenly distributed natural resources. After interconnection, the least costly generating units within the interconnected area can be dispatched first, providing an overall cost savings that can be shared among the operating systems.

2. Exploitation of Regional Diversity

The regional grids are spread over large geographical areas with diversity in time, weather, crop pattern, industrialization, population density, economic growth etc. This leads to diversity in the power requirements. Grid interconnections help in sharing the available generation capacity in different regions and thus reducing the requirement for installed capacity in each region. Interconnections help to achieve the economies of scale and thus provide the opportunity to invest in generating units of higher capacity and better efficiency. The diversity available across such a vast interconnection [Fig-2] brings with it energy security also.

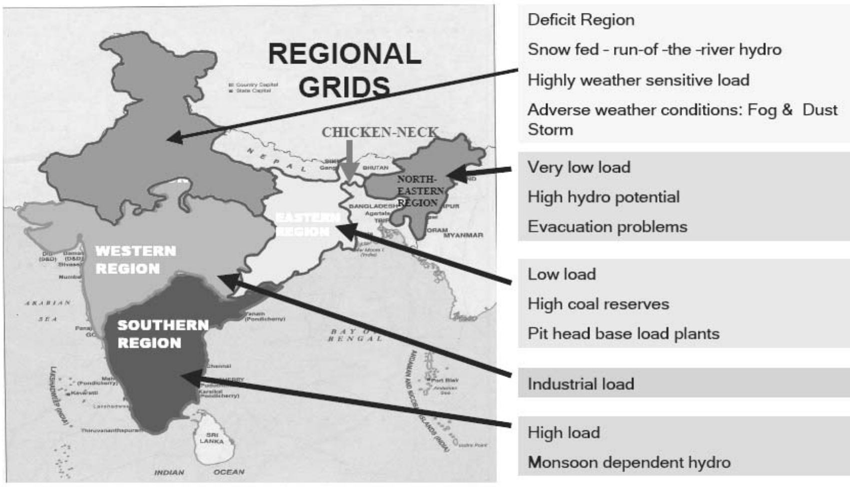

Figure 2: Regional Peculiarities in different parts of India

3. Improvement in the plant load factor (PLF)

Grid interconnections facilitates transfer of power from surplus to deficit areas resulting in greater utilization of installed generation capacity and thus improved Plant Load Factor for generating Stations.

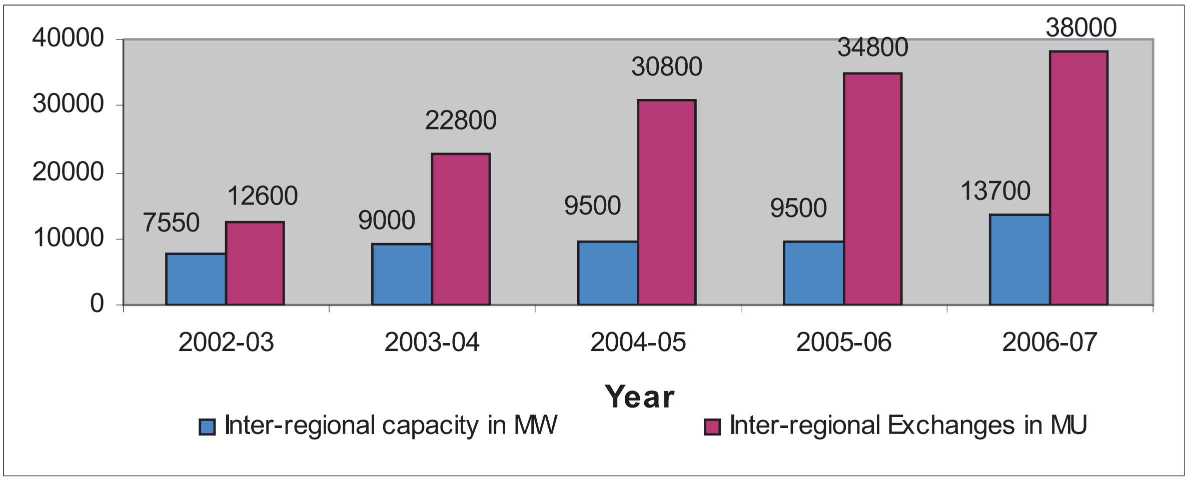

Fig 3: Increase in inter-regional power exchanges

If the grids having peak demands at different times of the day are interconnected, then base load generation plants having low fuel cost per unit of electricity produced can run continuously and result in savings on account of fuel and efficient operation. As when plants are run near their full capacity losses are reduced and efficiency increases. This had been the case particularly with Eastern Region thermal stations which before March 2003 had to be backed down to contain high frequency. The all India plant load factor has improved from 69.97% in 2001-02 to 77.03% in 2006-07 (CEA: Thermal Performance Review 2001-02 and 2006-07 highlights). This seven percent rise has been possible to a large extent on account of interconnection of regional grids in 2003 and 2006 besides the Renovation and Modernization (R&M) projects.

4. Improved reliability

Any interconnection invariably increases the reliability of the whole system and the load demand can be met with a greater certainty. Further, interconnections in general provide flexibility to meet unforeseen energy demand; hence support each other under contingencies.

5. Increased economic efficiency in system operation

With cross-border exchange, the generation of each of the interconnected countries has access to a larger market. This results in merit order operation on large scale and extends opportunity to promote operation of efficient power plants as far as possible, to achieve overall economic efficiency in system operation.

6. Reduced environmental damage

Apart from improving economic matters, sharing of resources through cross border interconnection also improves environmental issues as renewable or “clean” energy like hydro power can be used more than other polluting sources. Thus optimization in new capacity and optimum utilization of existing capacities would help in minimizing the adverse impact on the environment. The efficiency improvements on account of large efficient fossil fuel fired plants would enable retiring the older and inefficient units which would also bring about 40% reduction in CO2 emissions (as derived from the specific CO2 emission data for new 500 MW unit plants and old sub-100 MW capacity coal fired units-Dec 2007 report available on CEA’s website)

CASE STUDY:

Benefits accrued with commissioning of “inter-regional Agra – Gwalior transmission line” between western and northern grid of India

765 kV Agra-Gwalior line had been envisaged as a part of the super power highway comprising of 765 kV Sipat (WR)-Seoni (WR)-Bina (WR)-Gwalior (WR)-Agra (NR)-Fatehpur (NR)-Sasaram (NR)-North Karanpura (ER)-Sipat (WR) 765 kV Agra-Gwalior-Bina (operated at 400kV) was commissioned on 31st March 2007 and provided a synchronous inter-regional link between the Northern and Western regional Grid This has been a major step in the progression of the power system in the country. Since the synchronous links between Northern Grid and Eastern Grid as well as between Western Grid and Eastern Grid are already operational by August 2006, the energization of 765 kV Agra- Gwalior (operated at 400 kV) closed the mega loop between the Northern, Western and Eastern grid allowing a free flow of large quantum of power between regions in a truly integrated manner. The integrated operation has led to multidisciplinary benefits enumerated below

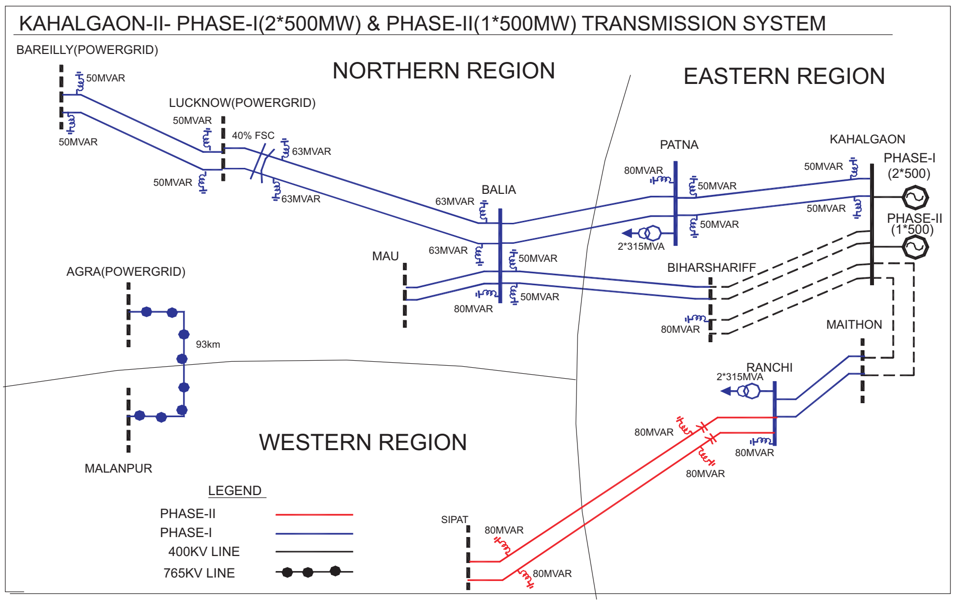

Figure 4: Interconnecting North – Eastern – Western Grid:

Technical benefits

1. 400 kV Agra –Gwalior interconnection has enhanced system stability and reliability of the synchronous North-West-East-Northeast Grids having installed capacity of around 88 GW and peak met of 60 GW.

2. The commissioning of the Agra-Gwalior line has facilitated the rejuvenation of the 220 kV Auraiya-Malanpur and 220 kV Auraiya – Mehgaon lines on a continuous basis. These lines constructed by Madhya Pradesh were relatively dormant. Parallel operation of this link was not feasible as this would have been a very weak link between two large 25000 MW (Northern and Western) systems and was used only under emergency conditions. With the commissioning of 765kV Bina-Gwalior-Agra line, these lines could be put in closed loop mode. Thus, old dormant assets have now been put into full operation with benefits to both regions.

3. The commissioning of this link has constituted a Pareto improvement by strengthening the system and improving the voltage profile of power consumers in the areas near and about Gwalior & Malanpur. The Gwalior/Malanpur substations are located at the remote end of the Western region and used to have low voltage conditions. With the commissioning the Agra-Gwalior line the voltage profile of the Gwalior area has improved substantially. A typical voltage profile over a period of a day is shown in Figure 5. A project is said to constitute a Pareto improvement if it improves the quality of life for some people, but does not make anybody worse off. Gwalior-Malanpur loads are fed from both Western and Northern regions thereby improving the reliability of power supply. It has also resulted in reliability of the evacuation system from Auraiya power station of NTPC.

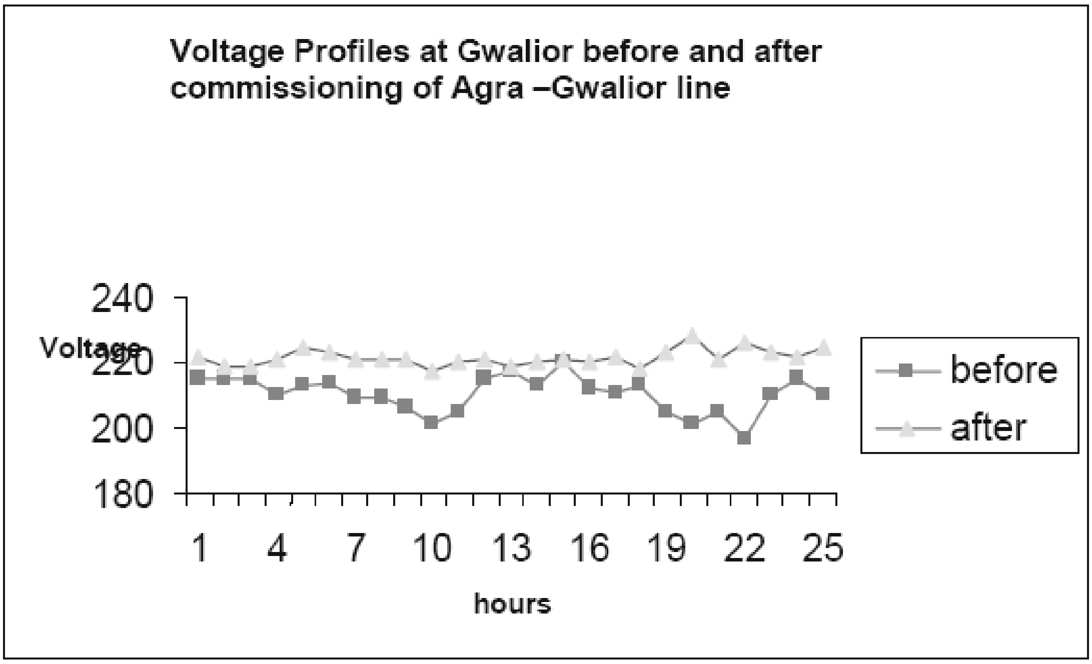

Figure 5: Voltage Profile pre and post commissioning Agra – Gwalior line

It is now possible to exploit the diversity between the Northern and Western regions in a more optimum manner. This diversity is reflected in the flows on the Agra-Gwalior line which have touched 1000 MW in either direction [Fig-6] depending on the season. The hourly load flow on a typical day is shown below. Both Western and Northern regions are benefiting from the diversity. In the absence of the Agra-Gwalior link this power would have been routed through the Eastern region thereby increasing the losses. In other words this line is the balancing link between the Northern and Western regions.

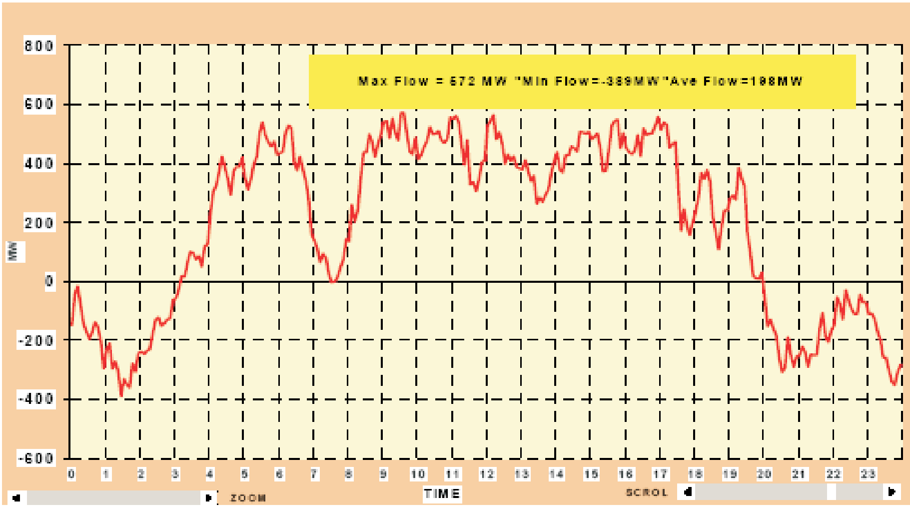

Figure 6: Load flow of a typical day on Agra-Gwalior line

4. Agra-Gwalior interconnection Line has reduced the electrical distance between the large coherent group of generators located in the Singrauli/Rihand/Anpara/Obra complex in the Northern region and the Vindhyachal/Korba complex in the Western region. Thus the interconnection has improved the stability of the integrated system.

5. The commissioning of the link has increased the resilience of combined grid in the event of the tripping of any of the inter-regional links as can be seen from an incident that occurred on 11th May 2007 at 15:48 hrs, when the 400 kV Raipur-Rourkela D/C lines tripped on transient fault. Prefault import on these lines was 800 MW whereas the import from Northern Region through Agra- Gwalior was 150 MW and Auraiya-Malanpur D/C was 250 MW. The N-E-W grid frequency was about 49.6 Hz. After the tripping the import from NR to WR increased to 460 MW on Agra - Gwalior and 315 MW on Auraiya -Malanpur thereby continuing synchronized operation of N-E-W grid and averting a possible separation of the WR grid.

Economic benefits

8. A simulation of the grid (size 60,000MW) with and without the 400 kV Agra-Gwalior line in service has shown a reduction of losses to the extent of 75 MW to 90 MW on a line flow of 600 MW on the Agra-Gwalior. This is graphically illustrated in Fig. 9 below. Considering an average reduction of 40 MW in transmission losses,

Savings on account of transmission losses= 40 MW x 8760 hours = 350.4 Gwh.

Again considering an energy cost saving of Rs. 4.50/-kwh, monetary savings = 4.5 x 350.4 which is approximately Rs. 1580 million or Rs. 158 crores.

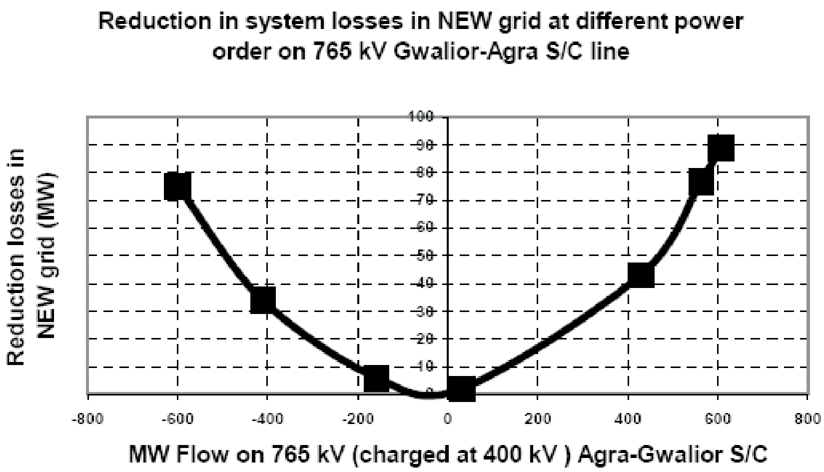

Figure 7: Reduction in transmission losses

9. This link has facilitated exploitation of the all India diversity to the fullest extent. The peak demand in the North occurs during July – September, in the West during October – December and in the South between January – March. The diversity in terms of weather, occupation, culture and lifestyle has an effect on the load pattern in the different regional grids. These present immense possibilities of opportunity power transfers as can be seen from the following illustration:

a. **April-June**: Load crash in Northern region due to dust storms. Typical frequency would be once in four days or say 30 days or 720 hours in a year. Out of this NR would be exporting heavily for nearly 40% of the time or say 300 hours. During this period an additional 600 MW can be safely exported to the Western Region/Southern region on account of the AC links.
Energy exported to WR/SR = 600 MW x 300 hours= 180 GWh.

b. **July-September:** Northern Region is expected to face heavy demand conditions in case of failure of the South West monsoon. The other parts of the country are expected to have a good monsoon resulting in surplus power availability. There is a 50% chance of having this scenario. Availability of the WR-NR AC links is expected to facilitate additional 600 MW import by NR and the
Additional energy imported by NR= 600 MW x 45 days x 24 hours x load factor of 0.7 which is approximately 450 Gwh.

c. **October-November:** Post Diwali, the demand in NR would be low for around 3 days.
Additional energy exported to WR/SR= 600 MW x 72 hours x load factor of 0.7 which is approximately 30 Gwh.

d. **December-February:** During heavy fog conditions in Northern region when there are multiple line trippings, there is a need to back down generation in Northern Region and reduce load in Punjab/Haryana/Delhi to avoid a cascading failure. Availability of WR-NR AC links would result in less backing down in NR and more load could be met in WR/SR.
Additional energy that could be met in WR/SR during fog conditions in NR = 600 MW x 12 fog days x 10 hours per day (2300-0900 hrs daily)= 72 Gwh.

e. December-March (winter rains in NR): 4 days a season
Additional energy exported to WR/SR= 100 hours x 600 MW x load factor of 0.7= 42Gwh.

Additional economy energy transfers (a to e) = 774 GWh. In case the winter rains occur between 15th to 20th Dec, the possibility of fog related trippings at 2d would be remote. Nevertheless in the winter of 2006-07 the rains came only in mid-Feb 2007 and we had both the cases of fog related trippings as well as load crash on account of winter rains**.**

Considering that the above energy transfers would basically replace RLNG/naphtha in North/West/Southern region and saving a cost differential of Rs.4.50/- per kwh, the **Energy Saving on account of economy interchange= 4.50 x 774 = Rs. 3483 million or say Rs. 350 crores.**

10. A system separation could typically result in 2000 MW load interrupted for a period of say 3 hours, if no further cascade tripping takes place and all sub-systems survive. This works out to energy not served of the order of 6 GWhs and taking the Value of Lost load (VOLL) as Rs 20/- per unit on a conservative basis, this works out to Rs 120 Millions for each separation averted. Taking a conservative approach and assuming it is able to avert two grid disturbances in an year, the savings accrued on account of improvement in System Reliability will be **Rs 240 Millions.**

11. **Table 1** summarizes the benefits and costs associated with this transmission system:

S No.	Benefits	Amount in INR Billion		Costs	Amount in INR Billion
1	Economy Interchange of energy due to diversity	3.48		400 kV Agra-Gwalior line with bays	2.29
2	Improvement in System Reliability	0.24		400 kV Bina-Gwalior	3.87
3	Reduction in transmission losses	1.58		400/220 kV Gwalior substation	0.74
4	**TOTAL BENEFITS (annual)**	**5.30**		**Total cost**	**6.90**

Table 1: Benefits and cost related to Agra – Gwalior-Bina line

The annual tariff for this transmission system is expected to be of the order of Rs. 105 crores or Rs, 1.05 billion.

Thus the savings accrued annually on account of this project is Rs 5.30 Billions, whereas the cost for the system is Rs 6.90 Billions. The payback period is thus slightly over a year while the benefit cost ratio is expected to be five (5) even on a conservative basis. The benefits do not take into account the reduction in CO2 emissions that would come about by utilizing the off peak hydro surplus of South, West and Eastern region in Northern Region. This would displace either coal or gas based generation in Northern Region having a specific CO2 emission rate of 1.5 tonne per MWh (coal based old stations of state utilities) or 0.5 tonne per MWh (for combined cycle plant).as per the December 2007 report of the Central Electricity Authority (CEA) on baseline emission data.

Conclusion

Transmission systems have a force multiplier effect on the electricity sector. Apart from increasing reliability of the electricity grids, they help in harnessing the diversity available over the vast interconnection on account of weather, festivals, culture, lifestyle, growth disparities etc. This diversity helps in economy exchanges of electricity leading to very low payback periods (less than three years) on investment as well as a high benefit-cost ratio even without considering its impact on emissions. Strong cross-border international connections would further help in reaping the benefit of this diversity. Further the enlargement of the grid also increases the interdependence between regions and calls for building of institutions, increasing professionalism and exploiting technology at the international, national and regional level to cope with the increased complexity of grid operation.

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