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## THE BOTTOM LINE

Development of power transmission networks requires long lead times and substantial capital. Optimization of investment is especially critical in fast-growing economies such as India's, where there are competing demands on financial resources, and utilities need to maintain adequate cash flow to expand electricity service for economic growth and poverty reduction. As shown by examples from Andhra Pradesh and West Bengal, integrated, iterative planning of transmission and distribution using appropriate software can provide the necessary optimization while meeting the objectives of expanding grid capacity, maintaining system stability, and improving efficiency.



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# Improving Transmission Planning: Examples from Andhra Pradesh and West Bengal

## Why is this issue important?

**Coordinated planning of transmission and distribution networks is needed to ensure that the power system meets demand efficiently, safely, and reliably**

In most Indian states transmission planning is done by the state transmission utility based on the utility's identification of system constraints and on load growth data provided by distribution utilities. Although a software tool is used, network mapping is limited to the transmission network, with the distribution network being modeled as a lumped load at a few locations on the transmission grid. As a consequence, the five-year transmission plans of some states do not represent an optimal path toward the objectives of grid stability, capacity expansion, and system efficiency.

In some states, moreover, transmission planning has been guided primarily by removal of immediate system constraints through peak loading of transmission lines and power transformers. Limited use has been made of information about downstream distribution networks, geographic load distribution, and growth over time in supply and demand.

To test whether in-state planning could be improved, an integrated transmission and distribution planning process was recently undertaken for West Bengal and Andhra Pradesh, two fast-growing states with effective utilities. The iterative process made use of Siemens' PSS/E software, which is used for transmission planning at the central and state levels.<sup>1</sup> It also took generation planning into account.

The success of the process, which suggested ways to reduce technical losses and create transmission assets, is evident from

the fact that it, triggered changes in West Bengal. In addition to incorporating changes in its transmission investment plan, the state asked the World Bank to help prepare distribution planning criteria as a ready reference for its planning department. The state of Andhra Pradesh, where technical loss reduction is a primary objective, requested a detailed load-flow analysis of the distribution network of two high-growth districts to further optimize its transmission investment plan.

This kind of exercise gives utilities an opportunity to engage in integrated and holistic planning to optimize their transmission investments while continuing to maintain a robust and efficient power system.

## What are the challenges to transmission planning in India?

**The components of India's large and complex grid are growing, creating the need for integrated, iterative planning**

India has a multilayered national grid consisting of five synchronously connected regions, with 400kV as the main backbone layer.<sup>2</sup> The uppermost layer is a 765 kV system (with 500 kV and 800 kV HVDC

<sup>1</sup> The Power System Simulator for Engineering (PSS/E) model is a system of computer programs designed to simulate power system performance using numerical algorithms. It consists of three main modules: (i) PSS/E Power Flow for steady-state analysis; (ii) PSS/E Balanced or Unbalanced Fault Analysis; and (iii) PSS/E Dynamic Simulation.

<sup>2</sup> The regions are: Eastern, Western, Northern, Southern, and North-Eastern. Since the end of 2013, the five have operated as a single synchronous system, one of the largest in the world.

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links) that provides interregional connectivity. The robust interstate transmission network is planned, built, and managed by Powergrid in its role as the central transmission utility. Within states, the transmission network is planned by the concerned state transmission utility.

The transmission network is a complex web of generating stations (sources of electricity) and grid substations (large sinks into which electricity flows and is dispatched to consumers at lower voltages through distribution substations and lines). At any given time, adequate capacity should be available in the transmission network to ensure that the load connected to the grid is served in accordance with established operating criteria. Those criteria include, among others, thermal limits to avoid overloading lines or equipment under normal and contingency conditions; voltage limits; frequency variation limits; and various other criteria to ensure that power quality, system stability, and efficiency are maintained.

A strongly interconnected power system with high-capacity transmission corridors across regions offers the benefit of balancing supply (generation) and demand (load) within the grid to accommodate routine disparities in the timing of peak loads and in power surpluses and deficits between subregions, as well as unexpected disturbances such as a steep and sudden change in connected load or generating capacity. If the grid is not dynamically balanced (within specified limits), such steep changes may cause grid instability (disturbance in frequency and voltage). In extreme cases they may lead to local or widespread blackouts.

Because electricity flows along paths of least resistance, the direction and quantity of power flowing across any network element is decided by the equivalent resistance offered by alternative paths in the network. As the number of elements in the network grows, the problem of estimating looped power flow along various branches increases exponentially, creating a need for load-flow analysis using simulation software. Such software provides an accurate estimate of the quantity and direction of power flow across various network elements and can be used to identify constraints in the network. The accuracy of the software’s output depends to a large extent on how accurately and extensively the power system network is represented in the model. When superimposed with anticipated year-on-year load growth and additions to generation

capacity, it is possible to identify transmission investments that will keep the network parameters within prescribed limits, thereby resulting in optimal system operation. In India, all state and central entities use Siemens’s PSS/E software to perform load-flow analysis and design their transmission networks.

Given economic and financial constraints, right-of-way limitations, and various other risks (among which climate-related risks are becoming increasingly important), the process of planning investments has become an iterative process that must be integrated with various other processes and programs. In India, a new investment proposal in a state has a major impact on the system in the vicinity of the investment (and a lesser impact on remote locations) owing to variations in load growth across the state. Any new investment that may have been considered under initial assumptions may become redundant when all the new investment proposals are simulated simultaneously.

### What specific planning problems have been identified—and how are they being solved?

#### As an alternative to piecemeal planning of transmission investments, an integrated approach was tested in Andhra Pradesh and West Bengal

The following issues in state-level transmission planning have been noted:

- Network planning is focused on removal of immediate system constraints, with little focus on future load growth across the network. This leaves many areas deprived of adequate transmission capacity to support power flows. Bottlenecks in some state systems constrain the delivery of electricity and hamper development.
- When load growth is taken into account, it is often done on a lumped basis at a few locations on the grid, depending on the size of the state. This does not provide a very clear picture of future constraints.

“The World Bank has advocated an integrated transmission and distribution investment planning approach. This approach was tried as a “proof of concept” in the states of Andhra Pradesh and West Bengal, where the utilities perform well.”

- Schemes to strengthen transmission networks are generally derived from inputs provided by distribution utility officials. Too often they do not take into account the physical locations of upstream grid substations or prevailing system parameters at those substations. As a result, the locations of new distribution substations are disconnected from the economics of loss reduction in the transmission system.
- Transmission investment planning is guided by peak loading of the transmission lines, feeders, and power transformers. This approach is well suited for a radial power system. However, the power network at extra high voltage (EHV) is meshed—that is, it comprises several loops. Therefore, a reliable software is needed to simulate power flows under varying conditions so as to identify existing and future constraints.

The World Bank has advocated an integrated transmission and distribution investment planning approach that would include the following:

- More-detailed mapping of the transmission network, preferably down to the 11 kV feed-in point at distribution substations
- Optimization of the location of new distribution substations in coordination with the transmission utility (with load shifting if required)
- Performing iterations to arrive at an optimized investment plan that takes into account actual load growth.

This approach was tried as a “proof of concept” in the states of Andhra Pradesh and West Bengal, where the utilities perform well, through a nonlending technical assistance project funded by a trust fund of the UK Department for International Development. Andhra Pradesh was chosen because of a new transmission and distribution project being prepared under the state’s ambitious 24x7 Power for All Program. West Bengal was chosen because the Bank had provided nonlending technical assistance to the state in 2007–08, when the state’s power sector was unbundled and corporatized. West Bengal was the only state in which the public sector utilities were profitable for several years after unbundling and corporatization.

**Table 1.** Key facts on the transmission and distribution networks of Andhra Pradesh and West Bengal

Voltage level (kV)	Number of substations	Total length (CKM)	Number of substations	Total length (CKM)
	Andhra Pradesh		West Bengal	
400	6	2,635	4	1,645
220	71	8,541	21	2,917
132	169	8,859	76	6,953
66	0	0	8	315
33	2,633	24,431	517	13,926
11	0	190,453	0	150,946
0.40	0	295,550	0	291,092

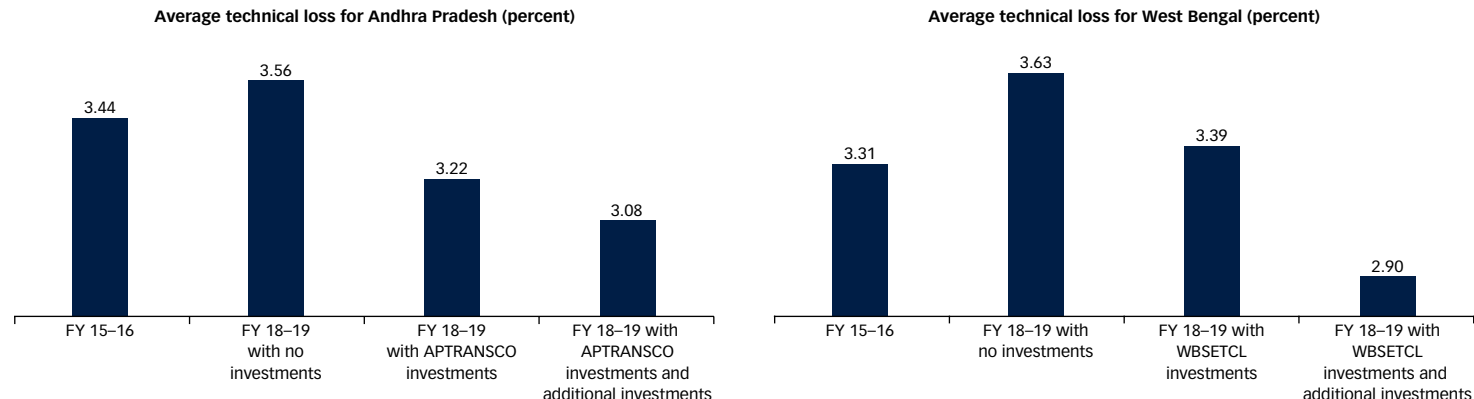
*Note:* CKM = circuit kilometers. The peak load of Andhra Pradesh during FY 2015–16 was 7,622 MW; for West Bengal, 7,988 MW.

*Source:* Central Electricity Authority’s Load Growth and Balancing Report, FY 2015–16.

Key facts about the transmission and distribution networks of these states are provided in table 1.

The project began by modeling the existing transmission network of West Bengal and Andhra Pradesh using the PSS/E software, from the highest voltage level in the states (400 kV in both cases) up to the 11 kV point at distribution substations. Load-flow analyses of the base-case network were carried out to identify network elements in which steady-state voltage and loading exceeded the allowed margins. The base-case network thus modeled was validated by both utilities with respect to network interconnections, prevailing constraints, and technical parameters. Revisions were made as required.

Ideally, the next step should have been to arrive at an optimized investment by adopting the iterative, integrated planning approach described above. However, because investments for the next three to five years had already been approved, the utilities were not keen to reopen the entire planning process. The investments already approved were therefore modeled on a year-on-year basis and iterations run to identify additional network constraints that, if addressed, would further improve the technical parameters and provide economic benefits, including reduction of technical losses.

**Figure 1.** Trend in technical loss reduction based on load-flow analysis in Andhra Pradesh and West Bengal

Note: APTRANSCO and WBSETCL are the transmission utilities in Andhra Pradesh and West Bengal.

“Not anticipating the surprising results of the integrated approach to planning transmission and distribution, the states were initially reluctant to reopen their planning process and revise their investments. However, once the benefits of integrated planning were demonstrated, the utilities quickly realized that reopening the process would help them optimize their investment plans and improve their operations and cash flow.”

The exercise led to several findings. In one specific case, the date of construction of a substation and associated transmission lines differed by a year or two in some locations. Such a scenario would have resulted in stranded capacities, delaying benefits from the investments. There were other cases in which it was possible to defer planned investments by a year or two. The final results are reported in table 2. The trend in technical loss reduction based on load-flow analysis is shown in figure 1.

Both states have proceeded to incorporate the additional investments proposed in their investment plans. The expected results are reported in table 3.

Andhra Pradesh has asked the World Bank to carry out an analysis of the distribution network in the two districts where the highest load growth is expected over the next five years (Tirupati and Vishakhapatnam) so as to assess whether load shifting (relocation of distribution substations) in these districts can further reduce technical losses in the transmission system. This exercise is presently under way and is likely to increase the returns from transmission and distribution investments.

### Was the integrated planning approach successful?

**The results from Andhra Pradesh and West Bengal show how transmission and distribution utilities in fast-growing economies can optimize their investments**

Not anticipating the surprising results of the integrated approach to planning transmission and distribution, the states were initially reluctant to reopen their planning process and revise their investments. However, once the benefits of integrated planning were demonstrated, the utilities quickly realized that reopening the process would help them optimize their investment plans and improve their operations and cash flow. They further decided on additional changes in their planning practices and sought assistance on reconfiguring their transmission networks. This kind of exercise provides an opportunity for utilities, in India as well as across the developing world, to undertake integrated and holistic planning to build a robust and efficient power grid in a cost-effective manner.

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Debabrata Chattopadhyay.

Live Wire 2015/48.  
“Supporting Transmission and Distribution Projects: World Bank Investments since 2010,” by Samuel Oguah, Debabrata Chattopadhyay, and Morgan Bazilian.

**Table 2.** Changes to planned investments in Andhra Pradesh and West Bengal as a result of integrated planning

### Andhra Pradesh

#### Transmission lines

Voltage level (kV)	Route length in km	
	Original proposal	Additional proposed
400	5,874	—
220	5,206	5.6
132	4,398	15

#### Substations

Transformation ratio (kV)	Capacity (MVA)	
	Original proposal	Additional proposed
400/220	5,040	—
400/132	7,040	—
220/132	4,800	100

### West Bengal

#### Transmission and distribution lines

Voltage level (kV)	Route length in km	
	Original proposal	Additional proposed
400	1,103	111
220	426	76
132	1,999	186
33	60,289	5,265

#### Substations

Transformation ratio (kV)	Capacity (MVA)	
	Original proposal	Additional proposed
400/220	3,150	315
400/132	1,000	400
220/132	5,280	960
220/33	320	0
132/33	4,401	1,197
33/11	30,389	2,73

**Table 3.** Anticipated results of additional investments proposed after integrated planning

	West Bengal	Andhra Pradesh
Total additional proposed capital expenditure (US\$ million)	100.24	6.82
Reduction in average transmission loss (%)	0.49	0.15
Average power purchase cost (U.S. cents/unit)	5.01	5.29
Energy savings per year (MUs) <sup>a</sup>	249.18	70.88
Cost savings per year (US\$ million)	12.48	3.75
Total savings over useful life of asset (US\$ million)	312.00	93.74

a. Total energy in FY16 according to Central Electricity Authority's Load Growth Balancing Report: Andhra Pradesh, 48,216 MUs; West Bengal, 51,367 MUs.



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**Tracking Progress Toward Providing Sustainable Energy for All in Eastern Europe and Central Asia**

Why is this important?  
Tracking regional trends is critical to monitoring the progress of the Sustainable Energy for All (SE4ALL) initiative.

In declaring 2012 the "International Year of Sustainable Energy for All," the UN General Assembly established three global objectives: to double the 2010 share of renewable energy in the global energy mix, and to provide the global population with access to modern energy services, to double the 2010 share of renewable energy in energy efficiency relative to the period 1990-2010 (SE4ALL 2012).

The SE4ALL objectives are global, with individual countries setting their own national targets in a way that is consistent with the overall goal of the initiative. Because countries differ greatly in their ability to pursue the three objectives, work will make more rapid progress in one area while others will need elsewhere, depending on their respective starting points and comparative advantages as well as on the resources and support that they are able to mobilize.

To sustain momentum for the achievement of the SE4ALL objectives, a means of charting global progress to 2030 is needed. The World Bank and the International Energy Agency led a consortium of 15 international agencies to establish the SE4ALL Global Tracking Framework (GTF), which provides a system for regular global reporting, based on "figures"—yet practical, given available databases—technical measures. This report is based on that framework (World Bank 2014). SE4ALL will publish an updated version of the GTF in 2015.

The primary indicators and data sources that the GTF uses to track progress toward the three SE4ALL goals are summarized below. Energy access. Access to modern energy services is measured by the percentage of the population with access to electricity. These data are collected using household surveys and reported in the World Bank's Digital Identification Database and the World Bank's Global Infrastructure Database.

Renewable energy. The share of renewable energy in the energy mix is measured by the percentage of total final energy consumption that is derived from renewable energy resources. Data used in this indicator are obtained from energy balances published annually by the International Energy Agency and the United Nations.

Energy efficiency. The rate of improvement of energy efficiency is measured by the compound annual growth rate (CAGR) of energy intensity, where energy intensity is the ratio of total primary energy consumption to gross domestic product (GDP) measured in purchasing power parity (PPP) terms. Data used to calculate energy intensity are obtained from energy balances published by the International Energy Agency and the United Nations.

This report uses data from the GTF to provide a regional and country perspective on the three pillars of SE4ALL, for eastern Europe and central Asia.

