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Electricity Model for Energy Security in India

Prof. M. Venkaiah

Principal MNR College of Engineering & Technology, Sangareddy Dt. T.S, India-502294

ABSTRACT

Energy is supplied in the form of electricity, heat or fuels and an energy supply system must guarantee sustainable energy supplies, production and distribution of energy. A system which can be utilized as integrated energy system which can satisfy the electricity needs of the country in appropriate and sustainable manner is developed in this paper. Integrated Energy System for electricity generation is modeled and optimized using LINGO 10.0 software. The objective function targets at minimizing the cost and the constraints take care of various other factors such as demand, potential, reliability and emission. The production and demand for various energy sources in India is estimated with the help of data from various government departments. The electricity optimization model is prepared for the base year i.e. 2004. This model is a top-down optimization which requires energy requirements as a prerequisite. This model can be used to forecast the future energy mix for electricity generation in India. It is found that for the base year, 56.76% of the total demand is met by coal indicating that the country is mostly dependent on coal which is the primary energy resource. Gas meets about 8.21% of the total electricity demand while from nuclear energy only 0.875% of demand is being met. Whereas amongst the renewable energy sources hydro meets 10.61% of the total demand while wind meets 17.33% and biomass 6.2% of the total demand. Oil and Solar PV does not contribute to meeting the energy demand, as the unit cost of electricity generation from these sources is comparatively higher.

Key words: Integrated energy system, optimization model, LINGO 10.0, forecast.

1. INTRODUCTION

The energy requirement in India is steadily increasing and this requirement is being met by both commercial and renewable energy sources. India faces formidable challenges in meeting its energy needs and providing adequate energy of desired quality in various forms to users in a sustainable manner and at reasonable costs. Due to the non-availability of sufficient resources and a considerable amount of emission of pollutants from commercial energy, it is now being felt that renewable energy has to be utilized to a greater extent. India needs to sustain a high economic growth to eradicate poverty and meet its economic & human development goals. Such economic growth would call for increased demand for energy and ensuring access to clean, convenient and reliable energy for all to address human development. To deliver a sustained growth of 8% through 2031, India would, in the very least, need to grow its primary energy supply by 3 to 4 times and electricity supply by 5 to 7 times of today's consumption. A top down optimization model has been developed to determine the optimum allocation of different energy sources, conventional and non-conventional for electricity generation. The aim is to provide energy security by proper utilization of available energy resources and long term sustainability and security.

2. LITERATURE REVIEW

A number of optimization models have been developed for renewable energy allocation at both the macro and micro level of energy planning. Optimization and simulation models have been applied to renewable energy systems modeling. Samarakao *et al.* (1988) demonstrated the use of optimization and embedded simulation to establish the least cost configuration of an isolated wind/PV/diesel system with battery backup [1]. The model was implemented using two different non-linear optimization packages. Hernandez (1997) presented a thermo-economic optimization and cost-benefit balance to sanction the substitution of fossil fuel fed energy systems by renewable energy sources [2]. The model was analysed on economic-environment criteria.

Mourelatos *et al.* examined the impact of CO_2 reduction policy on the strategic planning of the energy sector [3]. The conflicts between economic and environment goals influencing the penetration of renewable energy sources (RES) were studied. In the linear programming model, energy flows were optimized with respect to the system's economic efficiency. Chedid *et al.* (1999) provided a methodology for the optimization of an electrical distribution network when upgraded by renewable energy technologies. A multi-objective linear programming model was used in conjunction with fuzzy logic [4].

Optimization models had been applied by researchers to Indian conditions for modeling renewable energy systems. Sinha and Kandpal (1991) had developed a linear programming model for determining an optimal mix of technologies for domestic cooking in the rural areas of India [5]. A mathematical model involving common sources (including biomass, commercial and solar) and a commercially available technology is formulated along with the detailed techno economics of the different energy conversion routes. Similar exercise has been done for irrigation and lighting. Minimizing cost was chosen as the objective in all cases.

Joshi *et al.* had developed a linear programming model for decentralized energy planning for three Nepalese villages. The model sought to optimize energy sources as a function of energy conversion efficiencies for different end-uses [6].
A linear programming model had been developed for India by Srinivasan and Balachandra, taking into account different energy sources that can provide different end-use services through different end-use devices [7]. This micro-level energy planning model was developed for Bangalore North Taluk.

Suganthi and Samuel had developed a macro level energy planning model which maximized the GNP-energy ratio [8]. It determined the optimum allocation of commercial energy and renewables for emission reduction from commercial energy utilization.

Iniyan and Jagadeesan (1999) had developed a renewable energy optimization model for India. The model considered the allocation of renewable energy sources in different end-uses. It optimized the cost and efficiency of the system [9].

The literature review reveals that the electricity model taken up in this paper which includes allocation of conventional as well as renewable energy sources has not been taken by others till date.

3. THE ENERGY SCENE IN INDIA

India, the seventh largest energy consumer in the world plans for major infrastructure investments to keep pace with the growing demand particularly for the electric power and for the imports of LNG to supply power projects. Oil accounts for about 30% of the total energy consumption. Coal satisfies most of India's energy requirement. India is the third largest coal producer in the world after China and USA. An exponential growth in natural gas utilization is expected. The domestic gas supply is unlikely to keep pace with domestic gas demand. To meet this constantly growing commercial energy demand, India has to depend to a large extent on imports. On the renewable energy front, after the creation of a separate Ministry in 1992, special emphasis was given in the Eighth Plan to the generation of grid quality power from renewable energy sources.

3.1. COAL

Coal is the most important & abundant fossil fuel in India and accounts for 55% of India's energy need. India's industrial heritage was built upon indigenous coal, largely mined in the eastern and the central regions of the country. India is, however, poorly endowed with oil assets and has to depend on crude imports to meet a major share of its needs (around 70 percent). A large population of India in the rural areas depends on traditional sources of energy such as firewood, animal dung and biomass. The usage of such sources of energy is estimated at around 155 mtoe per annum or approximately 47 percent of total primary energy use.

Coal has been recognized as the most important source of energy for electricity generation in India. About 75% of the coal in India is consumed in the power sector. In addition, other industries like steel, cement, fertilizers, chemicals, paper and thousands of medium and small-scale industries are also dependent on coal for their process and energy requirements. In the transport sector, though direct consumption of coal by the Railways is almost negligible on account of phasing out of steam locomotives, the energy requirement for electric traction is still dependent on coal converted into electric power.

The coal reserves of India up to the depth of 1200 m have been estimated by the Geological Survey of India at 247.85 billion tonnes as on January 1, 2005 of which 92 billion tonnes are proven. Hard coal deposits spread over 27 major coalfields are mainly confined to eastern and south central parts of India

The lignite reserves in India are estimated at around 36 billion tonnes, of which 90% occur in the southern State of Tamil Nadu. 4150 million tonnes (mt) spread over 480 sq km is in the Neyveli Lignite fields in Cuddalore District of which around 2360 Mt have been proved. Geological reserves of about 1168 mof lignite have been identified in Jayamkondacholapuram of Trichy District of Tamilnadu. In Mannargudi and East of Veeranam, geological reserves of around 22661.62 Mt and 1342.45 mt of lignite have been estimated respectively. Other states where lignite deposits have been located are Rajasthan, Gujarat, Kerala, Jammu and Kashmir and Union Territory of Pondicherry.

In spite of various policy initiatives to diversify the fuel mix but considering the limited reserve potentiality of petroleum & natural gas, eco-conservation restriction on hydel project and geo-political perception of nuclear power, it is becoming increasingly evident that coal will continue to occupy centre-stage of India's energy scenario. Indian coal offers a fuel source to domestic energy market for the next century & beyond. Based on estimates, the consumption of coal is projected to rise by nearly 40 percent over the next five years and almost to double by 2020.

3.2. OIL

The Indian Petroleum industry is one of the oldest in the world, with oil being struck at Makum near Margherita in Assam in 1867 nine years after Col. Drake's discovery in Titusville. The industry has come a long way since then. For nearly fifty years after independence, the oil sector in India, has seen the growth of giant national oil companies in a sheltered environment. A process of transition of the sector has begun since the mid nineties, from a state of complete protection to the phase of open competition. The move was inevitable if India had to attract funds and technology from abroad into our petroleum sector.

The sector in recent years has been characterized by rising consumption of oil products, declining crude production and low reserve accretion. India remains one of the least-explored countries in the world, with a well density among the lowest in the world. With demand for 100 million tone, India is the fourth largest oil consumption zone in Asia, even though on a per capita basis the consumption is a mere 0.1 tone, the lowest in the region- This makes the prospects of the Indian Oil industry even more exciting.

The years since independence have, however, seen the rapid growth of the upstream and downstream oil sectors. There has been optimal use of resources for exploration activities and increasing refining capacity as well as the creation of a vast marketing infrastructure and a pool of highly trained and skilled manpower. Indigenous crude production has risen to 35 million tonnes per year, an addition of fourteen refineries, an installed capacity of 69 million tonnes per year and a network of 5000 km of pipelines.

But with the consumption of hydrocarbons said to increase manifold in the coming decades (155mmtpa by the end of the 10th plan) the liberalization, deregulation and reforms in the petroleum sector is essential for the health and overall growth of our economy. India remains one of the least explored regions in the world with a well density of 20 per $10000km^2$. Of the 26 sedimentary basins, only 6 have been explored so far. The Oil and Natural Gas Corporation (ONGC) and the Oil India Limited (OIL) - the two upstream public sector oil companies- in 1981/82 had taken their search to previously unexplored areas. Number of wells drilled as well as the meterage increased. However current reserve accretion continues to be low.

3.3. GAS

Natural Gas currently accounts for 8% of the energy consumption in the country. The current demand is 89 mcmd with domestic availability lagging behind at 63mcmd. The total gas consumption in 1996/97 was 19bcm with power and fertilizer sectors accounting for more than 80% of the consumption.

The gap between demand and supply is set to widen unless major gas discoveries are made. India is also looking at pipeline gas and LNG imports from neighboring countries as well as countries from Iran, Oman, Central and South East Asia. The growths of the gas/ LNG imports are very closely intertwined with the power sector, and the competition, and perhaps to an extent the replacement of coal as the preferred fuel. The setting up of Natural Gas import infrastructure would depend to a large extent on the ability of the power sector to pay for gas as against the cheaper coal, or an alternative fuel.

The aggregate consumption of petroleum products during 1997/98 was 90mt. In the period 1992-98, LPG and HSD registered the largest demand growth rate of 9.2% and 8.6% respectively. The Transport (38%), residential (26%) and industrial (24%) sectors are the largest consumers of petroleum products. The total production of petroleum products during 1997/98 was 61mt (MoPNG 1998). India's self sufficiency in petroleum products has declined to 34% in 1997/98 from 60% in 1985/86 resulting in a substantial growth in the import bill.

3.4. NUCLEAR ENERGY

India has consciously proceeded to explore the possibility of tapping nuclear energy for the purpose of power generation and the Atomic Energy Act was framed and implemented with the set objectives of using two naturally occurring elements Uranium and Thorium having good potential to be utilized as nuclear fuel in Indian Nuclear Power Reactors.

The estimated natural deposits of these elements in India are:

- Natural Uranium deposits - ~70,000 tonnes
- Thorium deposits - ~ 3,60,000 tonnes

India has at present 14 operating nuclear reactors – 2 Boiling Water Reactors (BWR) and 12 Pressurized Heavy Water Reactors – with a total installed capacity of 2770 MWe. Nuclear Power Corporation of India Ltd. (NPCIL), a wholly owned enterprise of Government of India under the administrative control of Department of Atomic Energy (DAE) operates these plants.

3.5. RENEWABLES

The oil shocks of 1970s led to spiraling crude oil prices in the world market which prompted planners to view energy security as an issue of national strategic importance. Energy security has an important bearing on achieving national economic development goals and improving the quality of life of the people. India's dependence on crude oil will continue for most part of the 21st century but the continued dependence on crude oil is loaded against it with inherent price volatility linked to finite global reserves. In addition, global warming, caused largely by greenhouse gas emissions from fossil fuel energy generating systems, is also a major concern. India needs to develop alternate fuels considering the aforesaid two concerns.

The search for alternative fuels that would ensure sustainable development on the one hand and energy security on the other began in the 1970s itself. Consequently, new and renewable sources of energy have emerged as an option. Ministry of Non- Conventional Energy Sources (MNES) supports the implementation of a large broad- spectrum of programmes covering the entire range of new and renewable energies. The programme broadly seeks to, inter-alia, supplement conventional fossil fuel- based power; reach renewable energy, including electricity to remote rural areas for a variety of applications like water pumping for irrigation and drinking water purposes, drying farm produce, improved chulhas and biogas plants, energy recovery from the urban, municipal and industrial wastes. In addition, exploitation of hydrogen energy, geothermal energy, tidal energy and bio-fuels for power generation and automotive applications is also envisaged.

The Electricity Act 2003 contains several provisions to promote the accelerated development of power generation from non- conventional sources. The Electricity Act 2003 provides that co-generation and generation of electricity for renewable sources would be promoted by the SERCs by providing suitable measures for connectivity with grid and sale of electricity to any person and also by specifying, for purchase of electricity for such sources, a %age of the total consumption of electricity in the area of a distribution licensee.

Efforts are being made to reduce the capital cost of projects based on non- conventional and renewable sources of energy, reduce cost of energy by promoting competition within such projects and at the same time, taking adequate promotional measures for development of technologies and a sustained growth of these sources.

The efforts to increase the share of renewables in the total power generation capacity of the country have yielded results. The share has been continually rising. Renewables presently contribute about 4800 MW, which represents over 4.5% of the total installed capacity. The power generation capacity established so far has largely come about through private investments. Wind power contributes about 2483 MW, while biomass power and cogeneration account for 613 MW and the share of small hydro power is 1603 MW.

4. INDIA'S ENERGY SECURITY

India's energy security, at its broadest level, has to do with the continuous availability of primary commercial energy at an affordable price. Reducing energy requirement and increasing energy use efficiency and augmenting the domestic energy resource base are the most important measures to increase energy security. However, it is still necessary to recognize that India's growing dependence on energy imports increases uncertainty regarding availability of energy at affordable prices.

Long-term projections for energy requirements depend on assumptions of growth of the economy, growth of population, the pace at which "non-commercial energy" is replaced by "commercial energy", the progress of energy conservation, increase in energy efficiency as well as societal and lifestyle changes. No wonder the various available projections differ widely.

The strategies to meet the energy requirement are constrained by country's energy resources and import possibilities. Unfortunately, India is not well-endowed with them. Reserves of oil, gas and uranium are meager though we have large reserves of thorium. While coal is abundant, it is with low calorie and high ash content, though with low sulphur content and regionally concentrated. The extractable reserves, based on current extraction technology remain limited. Hydro potential is significant, but small compared to our needs and its contribution in terms of energy is likely to remain small. Further, the need to mitigate hydro environmental and social impact, often delays its development.

5. ASSESSMENT OF ENERGY PRODUCTION AND DEMAND

The production or supply of various energy sources is shown in **Table 1**. It shows that the major portion, 927852 GWh, of energy supply comes from coal followed by oil 333360 GWh and natural gas 302802 GWh. The energy supply with the nuclear energy is comparatively very less. Amongst the renewable energy sources, solar PV has the highest potential of 754290.4 GWh followed by wind, hydro and biomass. The total electricity demand in India in the year 2004 which is taken as the base year in this project was 667782 GWh which is calculated on the basis of data provided by International Energy Agency (IEA). The unit energy costs have been calculated using standard procedures described by [10] and is based on Capital cost of Installed capacity, O&M costs, life of plants, etc. used for calculation for each resource. The results as reported in **Table 2** show that the unit cost of energy from different resources has been found as Rs. 4.13 for coal, 8.13 for oil, 6.1 for natural gas, 4.5 for nuclear, 2.50 for hydro, 3.10 for biomass, 3.50 for wind and Rs 15.27 per unit for solar PV.

Table 1: Production and Direct use of energy sources

Energy Source	Production GWh	Direct Use GWh
Coal	927852	136600
Oil	333360	90099
Natural Gas	302802	111130.5
Nuclear	9972	NA
Hydro	111366	NA
Wind	162000	NA
Biomass	61200	NA
Solar PV	754290	NA

Source: IEA, 2004

Table 2: Unit cost of energy sources

Energy Source	Unit Cost Rs/KWh
Coal	4.13
Oil	8.13
Natural Gas	6.1
Nuclear	4.5
Hydro	2.5
Wind	3.5
Biomass	3.1
Solar PV	15.27

The energy needs of the country have been identified as residential, industrial, commercial and transportation [11]. The reliability and emission factors are also calculated on the basis of certain assumed parameters. Both reliability and emission factors are calculated on the relative basis. **Table 3** shows the emission factors and reliability factors for different energy sources.

Table 3: Emission factor and Reliability factor

Energy Source	Emission Factor	Reliability Factor
Coal	1.67	0.8
Oil	1.43	0.45
Natural Gas	1.53	0.55
Nuclear	1.11	0.65
Hydro	1.1	0.7
Wind	1.05	0.75
Biomass	1.18	0.8
Solar PV	1.08	0.75

6. MODELING OF INTEGRATED ENERGY SYSTEM

The challenge in designing a reliable energy system is to find a combination of technologies where the pros of some types balanced out the cons of the others. A reserve capacity is necessary as a backup for fluctuating sources, especially in the electrical system [12]. Designing a combination of technologies where fluctuations in production match a varying demand, such that any fluctuations in supply never lead to electrical production that cannot meet the demand, can minimize this capacity. The model requires the assessment of the energy share of each of the supply inputs with the objective of achieving a minimum cost of energy generation.

An integrated energy model has been constructed for the major end uses. The general model can be formulated on basis of Linear Programming (LP) as

Objective function:

Minimize $$\sum_{i=1}^{8} C_i X_i$$

Constraints:

Demand $$\sum_{i=1}^{8} X_i \geq D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{1 constraint}$$

Supply $$\sum_{j=1}^{8} \left[\sum_{i=1}^{1} X_i \leq P_i - E_i \right] \quad \ldots\ldots\ldots\ldots \text{8 constraints}$$

Reliability $$\sum_{j=1}^{8} \left[(1/R_j) \sum_{i=1}^{1} X_i \leq P_i - E_i \right] \quad \ldots \text{8 constraints}$$

Emission $$\sum_{j=1}^{8} \left[\epsilon_j \sum_{i=1}^{1} X_i \leq P_i - E_i \right] \quad \ldots\ldots \text{8 constraints}$$

Where: ***i*** denote the different energy systems,
j denotes the number of energy systems,
C is the cost of the system,
X the quantity of energy,
D the energy demand in a particular year,
P the production in that particular year,
E the end use of the energy source for that year,
R is the reliability factor,
Є is the emission factor.
P – E denotes the amount of energy which remains after the direct or end use

Note: E=0 for the nuclear energy and renewable energy sources (hydro, wind, biomass, solar) as they are directly converted to electricity without any end use.

7. OPTIMIZATION OF INTEGRATED ENERGY SYSTEM

Various optimization techniques for Integrated Energy Systems have been reported in the literature like: (i) linear programming (LP) [13]; (ii) geometric programming (GMP); (iii) integer programming (IP) [14]; (iv) dynamic programming (DP); (v) stochastic programming (St P) (Dantzig and Charnes and Cooper (1955, 1959)]; (vi) quadratic programming (QP); (vii) separable programming (Se P); (viii) multi objective programming (MOP); (ix) goal programming (GP); (x) HOMER; (xi) VIPOR; and (xii) Hybrid 2, etc.

Presently, the software available for optimization are LINDO, LINDO API, LINGO, HOMER, VIPOR, TORA, etc., out of which LINGO 10.0 [15] version has been reported to be the most traditional package for solving linear, integer and quadratic optimization models. The software offers the most comprehensive tools for studying the inner workings of the revised Simplex Method used to solve linear optimization models [16]. Its unique features are its goal programming, parametric analysis and efficient solution of quadratic programs.

The model is entered in the LINGO 10.0 software as:

```
Min = 4.13*@pow(10,6)*coal  +  8.13*@pow(10,6)*oil  +
      6.10*@pow(10,6)*gas   +  4.50*@pow(10,6)*nuc  +
      2.50*@pow(10,6)*hydro +  3.50*@pow(10,6)*wind +
      3.10*@pow(10,6)*bio   + 15.27*@pow(10,6)*solar;

coal + oil + gas + nuc + hydro + wind + bio + solar >=
667782;
coal/.8   * 1.67  <= (927852-136600);
oil/.45   * 1.43  <= (333360-90099);
gas/.55   * 1.53  <= (302802-111130.5);
nuc/.65   * 1.11  <= 9972;
hydro/.7  * 1.10  <= 111366;
wind/.75  * 1.05  <= 162000;
bio/.8    * 1.18  <= 61200;
```

8. RESULT ANALYSIS AND DISCUSSION

The LINGO 10.0 software is being run for the base year 2004. The result shows that 56.76% of the total demand is met by coal indicating that the country is mostly dependent on coal which is the primary energy resource. Gas meets about 8.21% of the total electricity demand while from nuclear energy only 0.875% of demand is being met. Whereas amongst the renewable energy sources hydro meets 10.61% of the total demand while wind meets 17.33% and biomass 6.2% of the total demand. ***Fig.1*** shows the percentage wise allocation of different energy sources for energy generation resulting from the optimization model.

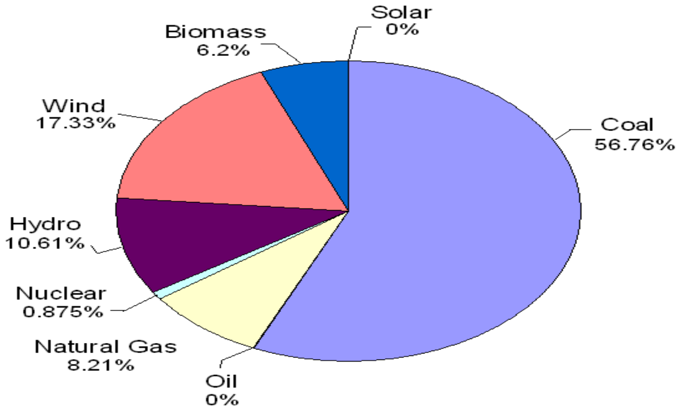

Fig. 1: Percentage allocation of energy sources

Oil and Solar PV does contribute to meeting the energy demand, as the unit cost of electricity generation from these sources is comparatively higher. The software optimizes the cost with considering the other factors like reliability and emission.

The optimum cost comes out to be Rs. 2.636952 x 10^{12}.

The values returned by the software are as follows:

Variable	Value
COAL	379042.9
OIL	0.000000
GAS	54824.58
NUC	5839.459
HYDRO	70869.27
WIND	115714.3
BIO	41491.53
SOLAR	0.000000

Objective value: 0.2636952E+13

The Integrated Energy System thus formulated can also be used for forecasting the energy scenario for the coming years. For this the demand has to be multiplied by growth rate with which the electricity demand increases which will provide the demand (D) for that particular year. The production (P) for that particular year will also have to be calculated taking into consideration the reserves and the potential. The unit cost (C) of energy sources will also change in the coming years. With technological developments the cost of renewable energy sources may decrease and owing to the exhausting reserves of conventional energy sources, their costs are likely to increase.

In the present model the software did not consider solar PV due to high cost. But 50 years hence the cost of generation with solar PV will decrease and at the same time the production of coal, oil and gas will be less. This will lead to shifting more and more towards renewable energy sources.

9. CONCLUSION

The result obtained from the modeling of Integrated Energy System gives an optimum mix of energy sources to fulfill electricity demand. The cost of electricity generation corresponding to demand is minimized. Along with the cost, preference is given to the energy source having more reliability and less emission. If the reliability of the sources is improved it will be found that the renewable energy utilization will be more. The optimum cost comes out to be Rs. 2.636952 x 10^{12} for a demand of 667782 GWh. This cost can be further decreased with the upcoming new renewable energy technologies. The model also suggests that for ensuring long term energy sustainability and security, the renewable energy would be a key player. The study could aid energy planners and policy makers in visualizing the future energy scenario.

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AUTHOR

Dr. M. Venkaiah, received B.Tech and M. Tech in Mechanical Engineering from KLU and IIT Delhi respectively. He got PhD from PtRS University, Raipur on the topic Economic efficiency, Energy security and Environment protection. He is now working as principal in MNR College of Engineering and Technology, Sagareddy, T.S., India.