Role of Fusion Energy in India

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The growth in demand of electricity is increasing relentlessly in India. The growth rate of installed electricity generation for the past two decades is found to be above 8 % and is much higher than the growth of any other sector in India. The realization of commercial fusion power reactor will take at least another fifty years. Hence, in the first half of this century, it is expected that the nuclear fission reactors will play a major role in reducing the greenhouse gas emissions. The Indian fusion program is focused to achieve a commercial reactor by 2060 and sustain its growth there after. The contribution of fusion reactors to electricity generation by 2100 is expected to be 5 % of total installed capacity with a conservative growth rate and 10 % with an accelerated program.

Keywords: DEMO,fusion,energy,tokamak

1. INTRODUCTION

The population growth of India is expected to stabilize by 2050 and the total population could reach around 1.5 billion even with moderate growth rate[1]. The population growth and the sustained economic growth of India will make it to consume huge amounts of energy. The average growth rate of installed electricity generation capacity is found to be more than 8 % [2] for the past three decades and is substantially higher than other forms of energy[3]. The earlier study[4] has predicted the electricity demand and the contributions from various technologies up to 2100 by keeping the carbon emission level below 550 ppm. This has used consumption model for predicting the electricity demand. The electricity demand predicted for 2050 by this model is considerably low compared to that of installed capacity prediction[3]. The prediction based on installed capacity will give the realistic energy scenario for India and this prediciton has to be extended up to 2100.

It is expected to develop various fusion technologies before realizing a commercial fusion reactor. The crucial technologies needed are : development of reactor grade materials, blanket technology, fuel system to handle huge amount of tritium, efficient remote handling system to enhance the availability of the reactor, plasma facing components for high heat flux, superconducting magnets, etc.. The fusion technologies may require fifty years from now to mature enough to achieve a fusion power reactor[5]. For the Indian scenario, the contribution of electricity from fusion power reactors is expected mostly in the second-half of this century.

In this paper, the growth of installed electricity capacity has been predicted using a growth model similar to that of the developed nations[6]. The prediction will depend on this model and the sensitivity with this growth model will be discussed. This study will present two cases in terms of contribution of electricity from fusion power reactors namely low and medium. In section II, the present energy scenario of India along with proposed schemes without fusion will be discussed. Section III describes the Indian fusion programme. The method to predict the electricity demand beyond 2050 will be discussed in section IV. Section V describes the sustainment of energy scenario with various level of contributions from nuclear fusion.

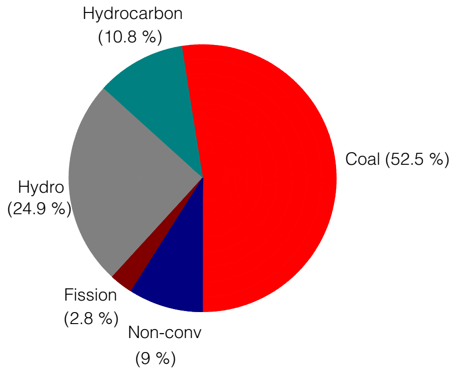

FIG. 1: Pie-chart of installed capacities from various energy schemes

2. PRESENT ENERGY SCENARIO OF INDIA

The installed capacity of electricity has grown from 45 GW in 1985 to 147 GW by 2008[7]. As on 31 December 2008, the total installed capacity is about 147 GW and is given in the executive summary report of Central Electricity Authority, Ministry of Power[7]. The coal and the hydrocarbon has contributed 52.5 % and 10.8 % of the total power respectively. The remaining is provided by the hydro, non-conventional renewable energy sources and nuclear fission reactors. Fig.1 shows the pie-chart of the present scenario of installed capacity in India. The

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contribution from coal and hydrocarbon is dominant and has to be minimized in the future. It is expected that the growth rate of electricity demand will be high and the contributions from alternative schemes like fission, fusion should be enhanced considerably.

A three-stage nuclear power programme has been envisaged by the Department of Atomic Energy for the utilization of indigenous nuclear resources of modest Uranium and abundant Thorium[3, 8, 9]. In this programme, the spent fuel of one stage is reprocessed to produce fuel for the next stage. It is expected that the installed nuclear capacity will be of 30 GWe by the year 2020 and 275 GWe by 2050 [3]. This indigenous effort of producing electricity through nuclear fission reactors can be accelerated further with the help of international support.

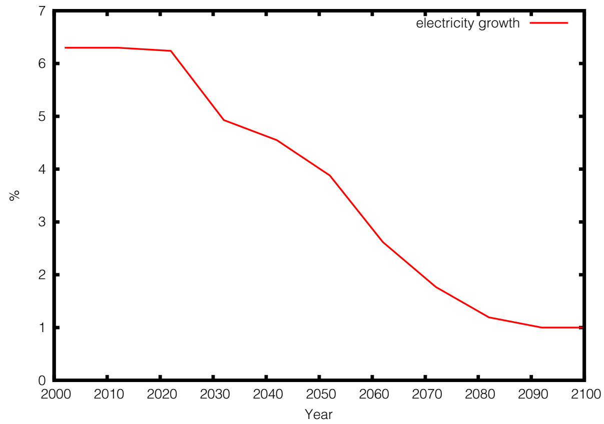

FIG. 2: Electricity growth rate up to 2100

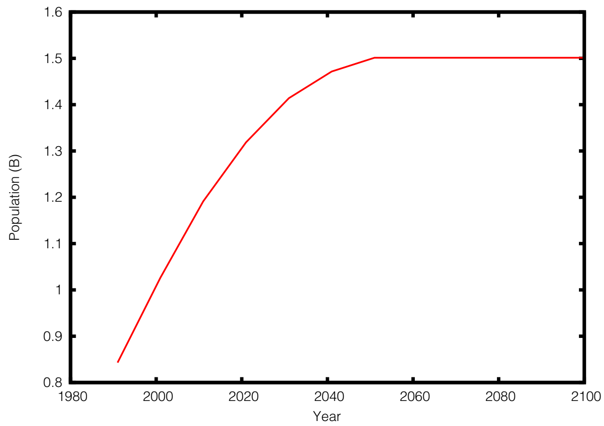

FIG. 3: Growth of population in India for medium-variant

3. INDIAN FUSION PROGRAMME

The first steady state tokamak (SST-1)[10, 11] is being built to address various issues relevant to fusion reactors based on tokamak concept. This device will have the capability of producing single- and double-null plasmas in steady state to answer its suitability for the reactor operation. With the upgradation of divertor system and auxiliary system, it will be possible to study various advanced configurations in steady state with various stabilization mechanisms. For the fusion reactor, the design and operational experience of D-T plasma is essential. Hence, India is participating in the design, construction and operation of ITER[12] which is the large sized D-T tokamak reactor. India is providing just 10 % of the components needed for this machine. The technological activities related to remaining components have to be achieved to realize the indigenous fusion reactor.

It is planned to develop nuclear fusion technologies relevant to fusion reactor in the next two decades. An intermediate fusion reactor will be realized so that the integral testing of indigenously developed reactor components can be performed. This device will also provide facility to demonstrate technological capabilities beyond ITER for realizing DEMO reactor. In the mid of this century, a DEMO reactor with reasonable plant availability will be realized[5]. The Indian fusion program is aimed to achieve a commercial fusion power plant at least by 2060.

The contribution to Indian energy scenario from fusion reactor will be expected only beyond 2060. It will be desirable if this program can be accelerated so that fusion reactors can be realized well before 2050.

4. ENERGY SCENARIO BEYOND 2050

India is on a road to rapid growth in economy and the GDP is growing at a faster rate in the recent past. The population is another key element and is expected to stabilize by 2050. This eventually drives the growth of electricity demand well beyond 2050. The earlier study[3] has shown the projection of installed electricity capacity up to 2050. The energy intensity is expected to fall beyond 2022 with a constant fall of 1.2 %/yr[13]. This study has projected the requirement of electricity will be of 1300 GWe by 2050. As it is mentioned in the earlier section, fusion can impact India's energy scenario only in the second-half of this century. To see the effect, the projection has to be estimated up to 2100.

The population stabilization and the improvement in energy efficiency will reduce the growth rate of electricity demand. In the case of USA[6], the growth rate was about 9 % in 1950 and reduced to < 2.5 % by 1990. This is about 3.25 percent reduction over 40 years. It is further reached to 1.1 % from 2000 to 2007 and expected to remain at 1 % there after. A similar approach is adopted for predicting the energy scenario beyond 2050. Fig. 2 shows the growth rate model for this study. The growth rate is falling by 3.25 % from 2050 to 2080 and clamped at 1 % there after. The sensitivity of the projection depends on this growth model and any further increase in the growth rate will enhance the electricity demand. Fig. 3 shows the population growth as used in Ref.[3]. Fig. 4

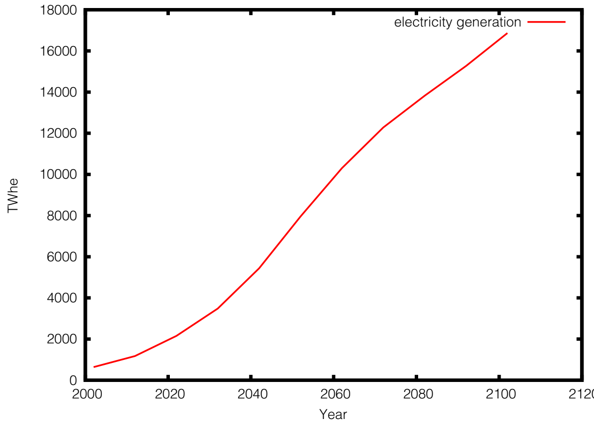

FIG. 4: India's electricity demand up to 2100

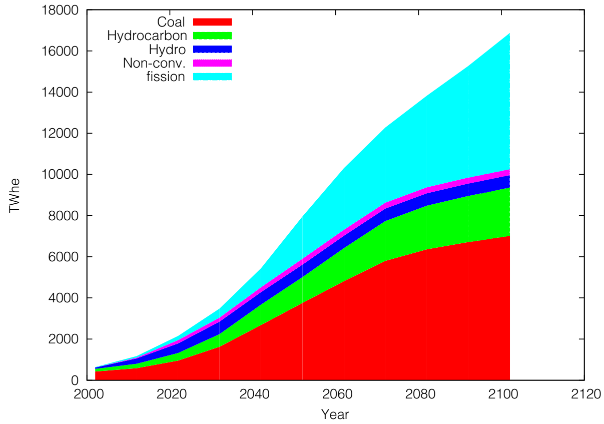

FIG. 5: Electricity generation without contribution from fusion

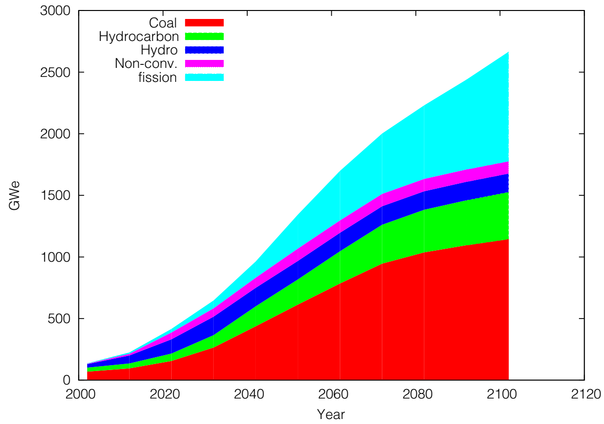

FIG. 6: Installed capacities projection without contribution from fusion

shows the installed electricity growth up to 2100.

The projection of contribution from fusion reactor will mainly depend on the availability of tritium. It is assumed that the fusion reactor of 1 GWe with a tritium breeding ratio (TBR) of 1.1 should be available by 2060. This will produce the required tritium for the next reactor after 10 FPY (full power year). If the plant availability is assumed to be 60 %, then the total number of years needed for this is about 15 years. The half-life of tritium is 12.3 years and hence, the storage of tritium should be optimized to maximize the utilization. If 5 reactors are operational after 10 FPY, each one will be provided with 20 % of bred tritium and will have sufficient tritium at least for 2 FPY. The fusion reactors will be multiplied in a similar way to enhance the electricity production. The contribution from fusion reactors to sustain the demand will be discussed in the next section.

5. WAYS TO SUSTAIN THE DEMAND

To sustain the electricity demand, various generation schemes have to be considered. The contributions from fission increases from 2 % in 2002 to 20-30 % of the total power in 2050. The growth rate of fission produced electricity is assumed to fall beyond 2050 and will be sustained at around 2 % till 2100. Any further increase from this assumed growth of fission contribution is advantageous. The maximum contributions from hydro and non-conventional renewable energy are found to be 150 GWe and 100 GWe[3]. This will be achieved by 2050 and no further growth in this sector beyond 2050 is considered. The gap between the demand and the generation from these schemes (hydro,non-conv. and nuclear) has to be sustained by coal and hydrocarbons. As it is seen earlier, the main contributions come from coal and hydrocarbons and will remain till the end of this century. As in Ref.[3], it is assumed around 80 % is produced by coal and the rest by hydrocarbons. There is a possibility of interchanging these ratios depending upon the availability and requirement.

A. without contribution from fusion

In this case, fusion is not considered and this is simply the extension of the earlier study by R. B. Grover et al. with our proposed growth model for electricity demand and for the nuclear fission contribution beyond 2050. This has predicted the installed capacity of 2660 GWe by 2100. The nuclear fission is expected to produce 890 GWe which is about 34 % of the total requirement. Figs. 5 and 6 show the projected electricity generation and the installed capacities. The growth of coal and hydrocarbon contribution exists even near the year 2100.

B. with 5 % contribution from fusion

If a fusion reactor with 1 GWe is realized by 2060 and fusion reactors are multiplied as mentioned earlier, it will be possible to achieve 125 GWe by 2100. Figs. 7 and 8

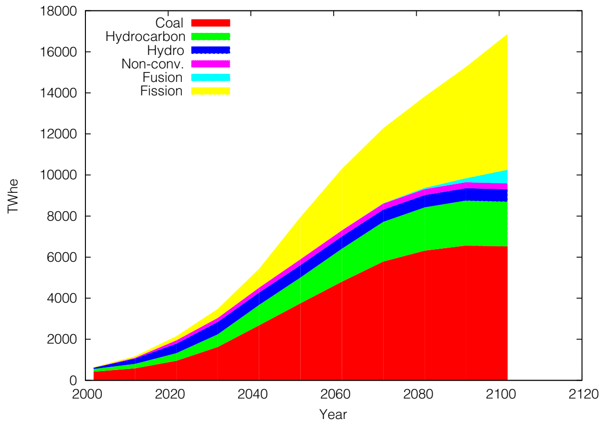

FIG. 7: Electricity generation with 5 % contribution from fusion

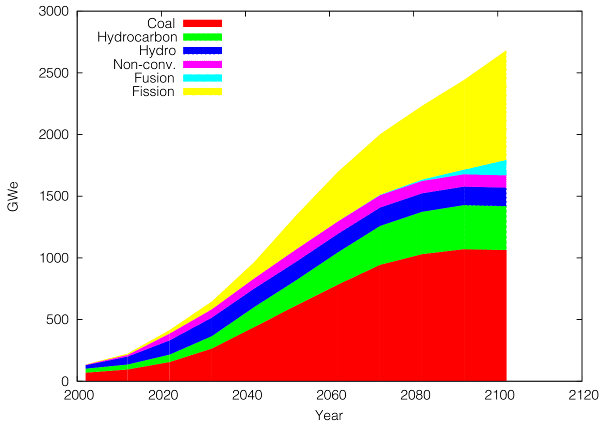

FIG. 8: Installed capacities projection with 5 % contribution from fusion

show the projected scenario for this case. The stabilization of contribution from coal and hydrocarbon started to occur near the year 2100. This clearly shows the impact due to fusion contribution even with conservative growth.

C. with 10 % contribution from fusion

This needs an accelerated fusion program. If fusion reactor of 2 GWe is achieved by 2060, it can multiply to provide 10 % of the total power by 2100. Figs.9 and 10 show the projection and the turn around in the growth of contributions from coal and hydrocarbon can be seen. The desirable energy scenario in terms of severe carbon emission restriction is shown in Ref.[4] and such scenario is faraway from this case. To achieve the desirable scenario, the contributions from all the schemes other than coal and hydrocarbon have to be enhanced. The contribution from fission has to be enhanced well before 2050 as the fusion reactor starts contributing beyond 2060. This clearly indicates to propose an accelerated program

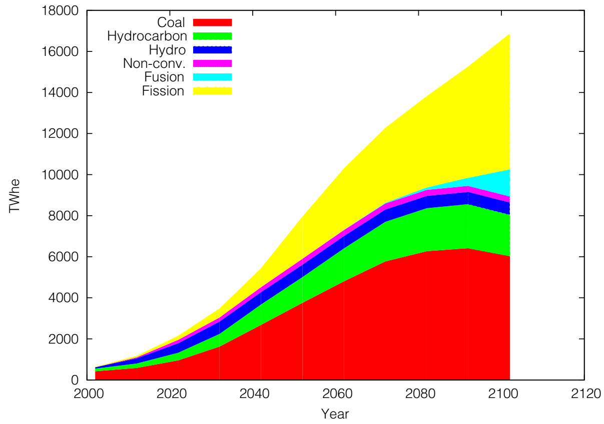

FIG. 9: Electricity generation with 10 % contribution from fusion

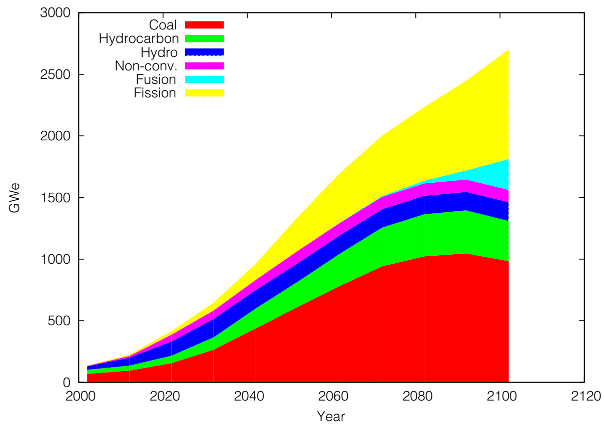

FIG. 10: Installed capacities projection with 10 % contribution from fusion

for the alternative energy schemes to sustain the future electricty needs.

6. CONCLUSION

The projection of India's electricity demand is estimated up to 2100. The requirement is found to be 2600 GWe by 2100. The possible ways to sustain this demand is studied with various generation schemes. The fission has major role to play in the first half of this century to reduce the carbon emission. If the fusion power reactor can be realized well before 2050, the impact of fusion on India's energy scenario will be considerable. This will depend on the development of various fusion technologies and an accelerated fusion program has to be visualized to achieve this.

[1] International Institute for Applied System Analysis (IIASA), 1996. World Population: Major Trends-A Study by United nations (www.iiasa.ac.at/Research/LUC/Papers/gkh1/chap1.htm).

[2] Shah RKD, 1998, Strategies for Growth of Thermal Power. Energy for Growth and Sustainability, Indian National Academy of Engineering, 1998.

[3] R. B. Grover, Subhash Chandra, Energy Policy **34** (2006) 2834.

[4] T. Hamacher, R. P. Shukla, A. J. Seebregts, Fusion Engineering Design **69** (2003) 733.

[5] R. Srinivasan, S. P. Deshpande and the Indian DEMO Team, Fusion Engineering Design **83** (2008) 889.

[6] http://www.eia.doe.gov/oiaf/aeo/electricity.html, accessed on October 17, 2009.

[7] http://www.cea.nic.in/power_sec_reports/executive_summary/20 accessed on November 16, 2009.

[8] A. Kakodkar, International Conference on Innovative Technologies for Nuclear fuel Cycles and Nuclear Power, June 2003, IAEA, Vienna.

[9] www.npcil.nic.in/pdf/nuclear power- an alternative.pdf, accessed on November 17, 2009.

[10] Y. C. Saxena and SST-1 Team, Nuclear Fusion **40** (2000) 1069.

[11] S. Pradhan and SST-1 Team, APFA-2009.

[12] M. Shimada, D. J. Campbell, V. Mukhovatov et al., Nuclear Fusion, **47** (2007) S1.

[13] International Energy Agency (IEA), 2002. World Energy Outlook 2002 Highlights p. 32.