ANALYSIS OF THE FEASIBILITY OF SMALL MODULAR REACTORS

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Abstract

This paper discusses the technical and economic aspects of a Small Modular Reactor (SMRs). The technologies and the designs available at present times are discussed in the beginning, followed by their overall contribution to electricity generation. The issues regarding investment into SMRs and their manufacturing are considered afterwards. Then a comparison between Large-Scale Reactors (LSRs) and SMRs is done on basis of their initial capital costs, terrestrial footprint and power output. The fuel management, safety, and modularity of SMRs are also analyzed. Additional benefits like load following and cogeneration are also mentioned. Social and political aspects of their development are included at the end.

Keywords: *small modular reactors, future nuclear power, clean energy, economic analysis, cogeneration, safe nuclear technology*

Introduction

With the increasing population, the demand for electricity and energy is also increasing. Traditional energy sources like coal and crude oil are facing cynical criticism due to the degradation they are causing to the environment. These resources are also depleting rapidly. Hence, the requirement for clean energy is vital in the coming years. In this paper, we attempt to discuss the feasibility of using nuclear power as the main source of electricity for the future. Currently, nuclear power contributes a mere 11% of the total electricity production. A compact nuclear reactor would make nuclear electricity more accessible by bringing the nuclear reactor to every doorstep. All this is possible, once Small Modular Reactors (SMRs) become feasible and widely available. In the current times, large scales nuclear reactors are still not leading the energy production. Large initial investments and the huge amount of residual waste are a major cause of concern. Majority of the public is still scared of a nuclear meltdown. This paper will also discuss whether investment in research on compact nuclear reactors is economically and environmentally viable or not in the current times. Yet, SMRs are still in their initial phase and need further research and investigation to be a leading electricity producer of the future.

Literary Survey

[1] Very few Small Modular Reactors (SMRs) are developed enough to be used for the production of energy on a commercial scale. Countries like Canada, France, India, Argentina, Japan, Brazil, Republic of Korea, China, Russia, USA, and South Africa are developing and researching SMRs technologies. Numerous concepts and design (including Generation IV designs) are available. Light Water Reactors, Liquid Metal Cooled Reactors, and Gas Cooled Reactors are the main prospects. Supercritical Water Reactors are the least supported. The full-scale commercial performance testing is still pending. SMRs are easier to operate and maintain. The operational temperature of the Reactor Pressure Vessels (RPVs) is lower in SMRs than the Large Scale Reactors (LSRs). Consequently, less heat needs dissipation from the reactor and hence passive cooling systems can be used in them.

[2] A variety of SMR designs help in selecting the best possible design for the commercial production of electricity. Working designs that have some level of industrial involvement are: <A>mPower: The reactors work in groups of two or more, which are buried under the ground. The nuclear steam supply and the once-through steam generators are placed inside the RPV. This ensures safety during a meltdown. <B>NuScale: The steam generator is a helically shaped coil, is placed inside the RPV. The steam leaves from the top and the feedwater comes into the reactor from the bottom. The difference in the density drives the steam upwards. No coolant pumps are present. This removes the mechanical and electrical components of cooling systems. During a meltdown, the SMR is submerged into a water pool. <C> Westinghouse: This SMR borrows many design aspects from the AP-1000 LSR, also by the same company. The core uses the same 89 Robust Fuel Assemblies, available and used worldwide. Most of the coolant components are inside the pressure vessel, making the reactor design modular.

[3]Traditional economics state LSRs are considered more viable compared to SMRs due to the belief in the principle of 'Economy of Scale'. It states the specific capital cost, i.e. currency/MWe of a reactor, decreases with increase in the size of the reactor; as the numerator (currency) increases at a slower rate than the denominator (output). Although, 'Economy of Scale' principle can only be applied if the reactors are similar in design and just differ in size, as it had been the case in the past. This is no longer correct as modern SMRs have distinct designs and characteristics, meaning that the 'Economy of Scale' cannot be applied to the economic analysis of LSR vs SMR. Moreover, the investments in SMRs are also modular due to their small size and short construction time. In particular, SMRs are more flexible and adaptable to the market conditions where the capacity of the plant can be instantaneously decreased or increased according to the demand i.e. market matching. On the contrary, LSRs require a huge amount of time to be manufactured due to which the investment can only be made on the bases of long-term planning and predictions which can be risky.

[4] Reutler and Lohnert (1984), stated that a power plant composed of multiple small modular reactors should be competitive enough to produce electricity on a commercial scale. Taking the example of High-Temperature Gas-Cooled Reactor Pebble-Bed Module (HTR-PM) vs the Pressurized Water Reactor (PWR), it is observed that factor of differentiation between them is the cost of the RPV. This cost gap is almost negligible because the RPV contributes only 2% of the total capital costs of the PWR power plants. Large Nuclear Reactor (LNR) produces 1000 MWs – 1200 MWs whereas, SMRs produce around 250 MWs – 300 MWs. Thus, the future of their construction and maintenance is on their 'economics of scale' (costs which are dependent on the scale of output) and 'economics of experience' (reduction in costs of manufacturing with the help of knowledge gained). In the case of HTR-PM, it was found that 2 x 250 MW is a better option than one 458 MW plant. Even though the 2 x 250 MW costs 5% more than the 458 MW, the technical certainties of the 2 x 250 MW against the 458 MW, making it the economic winner.

[5] A Monte Carlo evaluation was done on the economics of a medium scale reactor, a combined cycle gas turbine and a coal power plant using probabilistic analysis. The results show that coal tax plays a major role in deciding the feasibility of SMRs. If the current taxes levied on coal remain the same, SMRs will not have a considerable impact in the coming years. But if the governments are vigilant enough and increase the coal tax, it could jumpstart the SMR economy. By creating a portfolio of designs and trying to reach higher flexibility we can minimize risks and increase revenue for the investors. Costs which are lost to make a nuclear reactor smaller are recovered by making it modular, i.e. parts manufactured on an industrial scale and assembled on site.

[6] SMRs due to their simpler designs are much safer compared to LSRs. SMRs can incorporate passive systems based on natural laws, like gravity and natural circulation for, decay heat removal and emergency core cooling. Some SMRs like CAREM-25 of Argentina, NuScale of the USA and ABV-6M of Russia use natural circulation for cooling in normal operation mode and avoid coolant circulation pumps. Natural circulation system uses the difference in density between single liquid coming downward in the annulus of the reactor vessel and the two-phase mixture going upward in the core. This is made possible by increasing the volume of water in the vessel and by adding chimney above a shorter core, as most of the SMRs have a shorter core, the required buoyant force can be easily established. Other passive systems include the Nuclear Steam Supply System (NSSS) and Engineered Safety Features (ESF). The NSSS module removes external coolant loop piping, which eliminates large-break loss-of-coolant accident. The passive ESFs eliminates the need for external power under accident conditions.

[7] It is impossible to set up LSRs in countries with geographical constraints and weak economy due to natural barriers and insufficient technical infrastructure. These regions don't have proper grid capacity. Thus, SMRs are the perfect solution which can be tailored to tackle a particular set of problems which cannot be addressed by LSRs. Their small size makes them much suitable for smaller grids with low capacity, for areas with low population and low energy demand. Due to their modularity, they can be manufactured completely in the factory and can be delivered and installed module by module. This is simpler especially in cases where onsite manufacturing is impossible due to geographic barriers.

[8] Renewable energy power plants like wind and solar are highly variable in energy production. This is a major problem for electricity grid managers. Incorporating SMRs along with solar and wind can solve the problem of the fluctuating energy production in the power plants. This will ensure constant electricity supply to the grid and saving fuel and costs as well. This is achieved by using multi-module SMRs which increase their electric production when less electricity is generated by the solar and wind power plants. LSRs can also be used but they offer no fuel or cost saving due to the substantially fixed nature of input raw material. This form of load following is different from the one used in developed nations, like Germany and France, where the time of increase in demand is known. This is better for developing countries, where solar and wind are increasing rapidly, and where timings of the increase in demand for energy are still unknown.

[9] SMRs are extremely suitable for setting up cogeneration plants. <A> Biorefinery mainly produces biofuel out of biomass, electrical energy, and thermal energy. Biofuel includes biodiesel, ethanol, biogas, and bio-jet fuel. If SMRs are set up along with a biorefinery then, 50% of the energy produced by the SMRs should be directed towards the biorefinery, when it is working in load following mode. <B> Water desalination can be done by using the membrane method or the thermal method. Membrane method mainly uses electricity, whereas thermal energy is used in the thermal method. The start time of a desalination plant is not fixed. The plant can start and stop at any moment and keep working properly. Load following SMRs can be integrated with this cogeneration plant. <C> Another possible cogeneration technique is to heat a group of buildings or a district in a subpolar or polar region using numerous SMRs placed at proper locations.

[10] Lower costs, higher safety, and less waste are the main reasons why SMRs are advocated so strongly by the pro-nuclear public. But it is seen, the available SMR designs are not perfect. Practical designs have to make choices in between the three and trade one for the other. Lower cost and higher safety never seem to fit together into a single design. Example, the HTR-PM operates at

higher temperatures because it uses small pebbles (balls) with the unique coating as its fuel. This provides higher security and safety but costs are increased due to the requirement to manufacture the special fuel. Safety is also sacrificed when fast neutron reactors are used, which generate less quantity of radioactive waste. Another factor opposing SMRs is the proliferation of nuclear weapons by the different nations developing SMRs. Almost all the general public is still afraid of nuclear technology due to the horrors of WW2 and the various nuclear meltdowns over the years.

Findings

Due to the small size, modularity and simplicity SMRs show a diversity of unique advantages which cannot be replicated in LSRs. SMRs provide increased safety. The risks of a reactor meltdown are also reduced while using lower capacity reactors. They are cleaner than the LSRs as SMRs are more fuel efficient and produce less radioactive waste. Their operability is not limited by geography or location. Few SMRs are commercially active and are still to produce electricity on an industrial scale. A large variety of SMR designs provide options to the investors and governments. SMRs can be incorporated into cogeneration plants. These can be highly efficient and provide additional services. Remote countries in demand of a clean and stable energy source, which are unable to set up LSRs can benefit from SMRs. Their small size makes them much suitable for smaller grids. Due to their modularity, they can be factory made and shipped to these regions. In terms of economic, they still need to reduce their manufacturing costs as compared to LSRs for the same amount of electricity output.

Conclusion

Individuals advocating for development and deployment of SMRs on a large scale suggest this new alternative form of nuclear power can rectify all major problems that we are facing with nuclear power today. Still, there are significant technical and social gaps to be covered. Research should be focused on better passive cooling systems for RPVs. Traditional nuclear fuel rods need to be replaced. 96% of the traditions fuel gets wasted and is stored underground and not used again. More efficient fuel layouts and materials are coming up, but more research is needed before their commercialization. Modularization of RPV and reactor simplification is required. It is important to make people aware of nuclear energy so that the people in power can make educated decisions; even if they are against this technology. Concerned authorities should invest in SMR development as it goes one step further in securing the future of humankind. By 2050, 11 billion humans will need electricity supply and clean water, Small Modular Reactors might just be the answer.

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