Can Small Modular Nuclear Reactors Provide Realistic Pathways for Clean Energy?

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Abstract

The article discusses the potential of Small Modular Reactors (SMRs) as a sustainable solution for achieving 'Net Zero Emission' goals by 2050, as highlighted in the United Nations Climate Change Conference. SMRs, including 'Generation IV' Reactors, offer advantages such as cost-effectiveness, flexibility, and wider application beyond electricity generation. The article examines various SMR designs and their potential applications, ranging from land-based to marine environments, with countries like Russia and China leading in their development. While SMRs present advantages in terms of construction speed and flexibility, they also pose challenges, including regulatory, legal, and economic issues. Initiatives by organisations like the International Atomic Energy Agency aim to address these challenges and streamline the development of SMRs. India, aiming for clean energy and net-zero emissions by 2070, is considering SMRs as part of its nuclear energy strategy, with plans to involve the private sector in their development. However, the article emphasises the need for a holistic approach to address technical, operational, economic, and legal challenges for the successful commercialisation of SMRs and their integration into the global energy landscape.

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Journal of the United Service Institution of India, Vol. CLIV, No. 636, April-June 2024.

Introduction

Impacts of climate change have been a cause of concern globally, and in the United Nations Climate Change Conference (COP28), for the first-time nuclear energy, especially, the 'Generation IV' Reactors and Small Modular Reactors (SMRs), was discussed as a sustainable solution for achieving the goal of 'Net Zero Emission' by 2050. Already, there are about 440 nuclear power reactors operating in 32 countries plus Taiwan, with a combined capacity of about 390 Giga Watt electric (GWe), and in 2022 these provided 2545 Terra Watt hours about 10 per cent of the world's electricity.[1] Further, 90 power reactors with a total gross capacity of about 90 GWe are planned, and over 300 more are proposed, depending on addressing issues like funding, site proposal approvals, verification, etc, they will be operational in the next 15 years.[2] SMRs will further add to the tally, and increase the scope of nuclear energy, and SMRs will not be limited to electricity generation only, but will have a wider application in major industries.

Nuclear Energy Agency (NEA) Director General Mr Magwood in COP28 had stated that "Advancements in nuclear technology, including the development of SMRs and the launch of such initiatives as the NEA's accelerating SMRs for Net Zero provides realistic pathways to providing the clean energy that countries need to meet this goal".[3] SMRs can be the substitute for 'Diesel Generators'; for mining operations as well as high-temperature heat to replace fossil fuel cogeneration in heavy industries like fertilisers, and marine propulsion to replace heavy fuel oil for merchant shipping.[4] Further, these may become popular due to the flexibility they provide to the user for wider application, particularly, as an alternative to fossil fuel, hence, the construction of SMRs has gained momentum, and there are initiatives being taken globally, to plan the operationalisation of SMRs commercially, and decarbonisation is one of its goals.

What are SMRs?

SMRs are newer generation reactors designed to generate electric power typically up to 300 MW.[5] The name itself suggests that these reactors are small in size where capacity can be anywhere from 30 Mega Watt Electric (MWe) to 300 MWe, with modular facilities, where reactors are made in the factory and transported to the site, and further, they can be installed as a single plant or having multiple modules. The reactor uses nuclear fission technology. Thus, SMRs enhance the range of operations as they can be installed in remote areas, due to their ease of fabrication and offsite transportation facilities, which are lacking in larger power plants.

More than 80 designs are being developed ranging from land-based water-cooled reactors like Pressurised Heavy Water Reactors (PHWRs), Light Water Reactors to Heavy Water Reactors and Boiling Water Reactors. Further, in the marine environment, the water-cooled reactors can also be used as floating units deployed on ships and barges. Russia is the pioneer in this technology and Russia's 'Akademik Lomonosov, the world's first Floating Nuclear Power Plant (FNPP) that began commercial operation in May 2020, is producing energy from two 35 MWe SMRs'.[6] The non-water reactors include the pebble-bed salt-cooled Reactor, molten-salt reactor, Fast Neutron Reactors, etc. The High-Temperature Gas Cooled Reactor Models can be used in industrial applications. World's first HTGR-Pebble-bed Module (HTR-PM) was developed by 'China, in Shandong Province, with the major purpose of HTR-PM, is to co-generate high-temperature steam up to 500! and electricity, making it cost-effective - and to supply steam and electricity for the petrochemical industry to substitute the burning of natural gas and coal'.[7] Further, Micro Reactors are also being developed which are 'Very small SMRs designed to generate electrical power typically up to 10 MW(e), where different types of coolant, including light water, helium, molten salt and liquid metal are adopted by microreactors'.[8] A number of countries are developing SMRs and some of the countries who are in the race are Russia, China, United States (US), Argentina, Canada, and South Korea. India is also considering building SMRs.

Advantages and Challenges

Firstly, SMRs will be cheaper and more cost-effective as it can reduce a nuclear plant owner's capital investment due to the lower plant capital cost and further, the Modular components and factory fabrication can reduce construction costs and duration.[9] Secondly, the flexibility it provides, by which these can be installed in remote areas, can help in widening the scope of nuclear energy, thereby, managing the depletion of fossil fuels, as well as emission problems, of greenhouse gases. SMRs can help provide electricity to the remotest of villages, and also can be used in factories and industrial areas. The modular build is used in a number of different sectors including civil construction; shipbuilding; chemical process and oil and gas; aerospace; and automotive industries.[10] Thirdly, SMRs are easier to build as per the requirement of the grid and quicker as well. The construction time for larger nuclear plants is longer, compared to the speed with which SMRs can be constructed.

As far as challenges are concerned, there are technical, regulatory, legal and economic challenges. Considering, that there are a number of technologies that are being developed, hence, each design will require safety certifications, which may create regulatory challenges. Currently, most of the regulatory mechanisms including licensing, commissioning, operating issues, etc are customised for larger nuclear power plants and the same is lacking for SMRs. Further, if the nuclear reactors are exported, they may undergo liability issues, considering reactors are not included in the Convention on Nuclear Safety (CNS) Treaty, so in case of accidents, the aspect of insurance will become a sore point between the supplier and the user. Considering so many technologies are being developed, hence, reactor design becomes a significant issue for the safety of SMRs. Additionally, the CNS treaty also does not say anything about the FNPP. Therefore, legally, the CNS treaty needs to be amended, because according to this "Nuclear installation means for each Contracting Party any land-based civil nuclear power plant under its jurisdiction including such storage, handling and treatment facilities for radioactive materials as are on the same site and are directly related to the operation of the nuclear power plant".[11] It includes only land-based installations and is silent on marine installations. Another major challenge will be the disposal of spent fuel and proliferation issues. Thus, the SMR industry is yet to fully develop an operational fabrication facility for large-scale serial manufacturing of SMR components, which necessitates a very large investment, further, technology developers may have challenges in mobilising finance for technology development, licensing and construction of prototype plants.[12]

To address some of these challenges the Department of Nuclear Energy of the International Atomic Energy Agency (IAEA) has been undertaking initiatives from as early as 1990 when a 'Guidance document for preparing a User Requirements Document for SMRs and their application was published'.[13] Further, some of the initiatives included the 'Launch of the Nuclear Harmonisation and Standardisation Initiative in Jun 2022, and the IAEA organised in Aug 2022 a Technical Meeting on Generic User Requirements and Criteria (GURC) of Small Modular Reactor Technologies for Near Term Deployment… to develop high-level GURC'.[14] All these proposals will help streamline many preliminary glitches.

India's Roadmap to SMR

India's aspiration of having clean energy and achieving the goal of net zero by 2070 is through harnessing non-fossil fuel sources, and nuclear energy will become an integral part of this journey. Dr Jitendra Singh, Union Minister, had pointed out that "A number of measures have been taken to promote renewable energy in the country and India today stands at number four in the RE installed capacity across the world after China, Europe and the United States …. and nuclear in terms of baseload power can play a big role in the de-carbonisation strategy".[15] India's Nuclear Power Cooperation of India Limited (NPCIL) and Department of Atomic Energy (DAE) look after the aspects of nuclear power plants. India already has 22 operating reactors, with an installed capacity of 6780 MWe of which eighteen reactors are PHWRs and four are LWRs.[16] Dr Ajit Kumar Mohanty, Chairman, the Atomic Energy Commission and Secretary, DAE, gave a statement at the Nuclear Energy Summit, in Brussels in 2024, where he stated that apart from "Adding two indigenously designed 700 MW PHWR, the Kakrapar Atomic Power Project—— the 'Core Loading' also took place at the first Indigenous Fast Breeder Reactor (500 MWe) and India is also considering steps for the development of SMRs".[17] India has a robust plan for large-sized Nuclear Power plants; however, it can use SMR technology as an add-on to address industrial decarbonisation and achieve the goals of the 'Clean Energy' transition.

India is looking to develop 300 MW capacity SMRs. There were reports that "Indian Oil is reportedly in preliminary talks with Nuclear Power Corporation to build small nuclear units, seen as a cost-effective alternative to larger plants".[18] This is basically to circumvent the delays faced in the construction of bigger power plants, as SMRs are easier to build. India is also mulling inviting the private sector in this field. "The government is in talks with at least five private firms including Reliance, Tata Power, Adani Power, and Vedanta to invest around $5.30 billion each".[19] All these are positive steps. Considering, India already has experience in constructing nuclear reactors ranging from the larger Kudankulam Nuclear Power Station-1 1000 MWe to the smaller one at 'Rajasthan Atomic Power Station Unit-1 with 100 MWe capacity'.[20] In the military domain, India also has nuclear-powered submarines where small nuclear reactors are used. Therefore, India has experience in constructing nuclear reactors. In order to prevent the overburdening of NPCIL, the route to involve the private sector is encouraging and a viable solution, provided the requisite ecosystem is created.

Ecosystem Required

As of now, NPCIL is responsible for not only designing, and commissioning of nuclear power plants but also all the operational aspects that are controlled and monitored by them. Therefore, for the private sector to get involved, one will require certain structural and legal changes. The nuclear power industry in India has been the forte of the Public Sector mainly the NPCIL, however, companies like Larsen & Toubro have been involved in the manufacturing of "Reactor vessels for PHWRs and Fast Breeder Reactors designed technology and critical equipment and systems for heavy water plants, fuel re-processing plants and plasma reactors".[21] For SMRs, one can also similarly invite the private sector, provided there is clarity as to their role and responsibilities. Whether the private sector will be required at the design, and construction stage or at the operational, stage. The question is how much one needs to decentralise without compromising nuclear safety and security standards. The most challenging issue will be managing the fuel and the disposal of the spent fuel. SMRs may increase the quantity of radioactive waste and the disposal requires well-thought-out processes. Hence, instead of total decentralisation, one option is to partially decentralise, whereby, keeping control of the fuel management, especially, disposal of spent fuel with the government, for security purposes and to prevent proliferation issues. Since this is a new technology for private regulators, hence, they need to be trained in the safety requirements and efficient operational processes, so the whole ecosystem requires cooperation of public-private partnership at a holistic level. Training modules starting from educational institutions to industries are essential to obtain optimal technical manpower. Further, to succeed as a commercial venture regulatory support including licensing support and continuity in the supply chain is essential. Thus, the licensing, safety certification, and legal issues need to be relooked, which may be a long-drawn process. Also, management of public perception is an important aspect, as there are apprehensions about nuclear energy. Even during the construction of nuclear power plants, the initial processes require public awareness. By educating people about the safety mechanisms, local protests could be avoided. So, for SMRs, this requirement is more, as the scope is wider. Thus, it may be concluded that though the feasibility of SMRs is evident, it will take time for SMRs to fructify as a commercial venture, as the ecosystem needs to be developed.

Conclusion

SMRs have emerged as one of the viable tools in addressing the challenges of climate change and achieving the goal of 'Net Zero Emission', but the technology still needs to mature. The ecosystem, whether it is a legal framework, design construction, operational monitoring, waste management, or verification mechanisms are concerned, still needs to be developed in most countries, including India. IAEA on its part has already taken several steps to smoothen the initial glitches and this year also the Technical Meeting on GURC's objective is not only to assess the progress but to 'Present an IAEA's draft guidance document on top-tier GURC for SMR Technology that provides a framework to cover deployable SMR designs and could serve as a reference for utility organisations to develop more detailed GURC'.[22] Thus, for SMRs to succeed commercially, a holistic approach is required, both in terms of public-private partnership and in the creation of an ecosystem, whereby, all technical, operational, economic, and legal issues are addressed

Endnotes

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