

Risk Assessment of Experimental Power Reactor at the Early Stage in Developing Countries: Between Straight Tube and Helical Coil

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ABSTRACT

Research on renewable energy is an appropriate action to accommodate high needs of energy and to maintain economic stability. Experimental Power Reactor is a Hot Temperature Gas Reactor developed in Indonesia that utilizes steam to fulfill needs of electricity in isolated areas. Helical coil is the steam generator component that is needed to produce heat more efficiently compared to straight tube. The problem is that the utilization of the component can be said to be zero in Indonesia due to its general unavailability in markets. The complexity and low demand for helical coil causes the component to become rare. This study is aimed to analyze the risk of investment in renewable energy at the development stage. Reviewing relevant literatures and interviewing the experts have been done to figure out how far the development of renewable energy in Indonesia as well as the following risks. With consideration of efficiency and the projection of renewable energy in the future and without disregarding the development complexity, helical coil needs to be developed and utilized as a component in steam generators.

Keywords: Risk Assessment, Renewable Energy Investment, Steam Generator

1. INTRODUCTION

One of the indications of the increase in economic stability of a country is the movement towards the utilization of renewable energy sources. When needs of energy from sources with low rates of renewability are suppressed but the optimization of industrial processes are maintained, the GDP can then increase. From statistical data of Review of Energy as issued by British Petroleum [1] and the International Renewable Energy Agency (2018), it can be seen that the consumption of primary sources of energy in 2017 increased by 0.7% from the previous year, which is higher than the average per decade energy consumption of 1.7%. With increased needs for energy, the price of production also increases as a result. Oil prices increased by 19.3% in 2017 with an average growth of consumption of 1.8% per annum [1].

The global growth of consumption is caused by the high rate of energy consumption in developed countries, as in China with rates of 50,000 barrels per annum (b/a) for oil

consumption and 31 billion cubic meters (bcm) for natural gas, leading among the consumption by countries in the Middle East and Europe, as well as the United States. The growth of energy consumption in Indonesia in 2017 is 1.9%, exceeding the average growth of energy consumption of Asia-Pacific countries. OECD countries have proven that the increase in development and utilization of renewable sources of energy increased their 2017 GDP by 1% from the previous year.

The power sector still becomes a primary concern in the development of renewable energy. The development of renewable energy in this sector experienced an increase of 2.8% in OECD countries, with wind and solar as the primary generating sources. Locatelli, et al. [2] affirmed that the development of an electrical energy storage system is the most appropriate solution to increasing system flexibility and endurance with electrical power. With consideration of the aspect of limited energy resources, an alternative electrical generator that the government has offered is nuclear power.

The Center for Dissemination and Partnership of National Nuclear Power Agency of Indonesia or NNPAI (2017) reported that the primary reason that nuclear power is considered and can be accepted as an alternative energy source is the stability of electricity supply and its low expense. On the other hand, many people in society have the tendency to reject nuclear power for the reason of safety (78.10%). This research will present the analysis and description of risks in investment for the development on an experimental power reactor at the early development stage.

The Experimental Power Reactor or EPR is a development of nuclear power as a realization of the 2015-2019 Middle-Term Indonesia Development Plan, with strict consideration of the factor of safety. Using the technology of Pebble Bed Reactor (PBR), the EPR is judged to be very safe, functional for cogeneration, flexible in fuel, reliable, competitive in price, multi-use, and able to be developed in all areas of Indonesia to fulfill electrical supply needs. In other words, the development of the EPR is meant to make Indonesia a technology provider for supplying electrical and high heat energy to support the needs of the national industry as well as to be a regional leader. In the long term, the EPR is a milestone of mastery for commercial nuclear power plants that are based on the technology.

The efficiency of developing EPR as an alternative energy source requires consideration of several economic aspects. One of these is the environmental-friendliness of EPR, which becomes the focus of conservationists and even investors who are interested in environmentally friendly technology. On the other hand, when renewable energy is considered as an alternative to primary energy, while in practice renewable energy still requires primary energy, the rise and fall in prices of primary energy will become the key factor in determining the prices of renewable energy. In other words, the presence of renewable energy is inseparable from primary energy [3].

One of the main components that powers the generator turbine in the EPR is the steam generator, which is commonly in the form of a straight tube. With consideration of efficiency of resources, the straight tube is starting to be replaced by a component in the form of a multi-concentric roll (helical coil), thus being able to provide several advantages [4], because the size of the diameter can be reduced. Helical coil in the steam generator pressure vessel of the EPR is an integrated part in the reactor that is used to produce steam with high pressure that powers the electrical power generator. DeLlano-Paz, et al. [5] presented results of portfolio analysis of investment costs in renewable energy that showed that nuclear power is the best technology with the lowest risk and portfolio costs. What becomes interesting to be discussed with the several advantages gained from the utilization of helical coil is whether the development of EPR can be more efficient and whether it may be able to confer advantages for end users.

This research provides an analysis of the difference of usage of straight tube and helical coil in steam generators. The usage of straight tube and helical coil in steam

generators has merits and demerits in the planning, development, construction preparation, construction, and maintenance stages. The complexity of development and construction of steam generators with helical coil leads to efficiency in construction and maintenance fees, but the risk of failure due to component scarcity becomes a primary issue that needs to be resolved.

The remainder of this study is structured in the following manner. Chapter 2 describes the risks reviewed related to the utilization of straight tube and helical coil in steam generators. Chapter 3 explains the methods that applied to the conducting of this study. Chapter 4 encompasses the findings and discussion. Finally, conclusion, implications, and suggestions for future research are covered in Chapter 5.

2. LITERATURE REVIEW

2.1 Risks on Renewable Nuclear Energy Investment

The utilization of different sources of energy in the development of renewable energy presents different risks and advantages. Nuclear as a primary source in the development of renewable energy possesses the greatest risks in the safety aspect or accidents or leaks of the nuclear reactor (Center for Dissemination and Partnership of National Nuclear Power Agency of Indonesia (NNPAI), 2017). What becomes a concern of society regarding the development of energy systems is whether the sources of power are sufficiently safe to be developed and utilized. Nuclear power produces waste in the form of radioactive materials. The effects of the accident that occurred at the Fukushima Daiichi nuclear power plant indicated that protection from nuclear radiation in the waste is very important to be developed for the management of waste from energy sources [6]. NNPAI has taken initiatives to develop nuclear energy with a strict safety aspect by developing an Experimental Power Reactor (EPR) in accordance with Presidential Regulation Number 2 of Year 2015 on the 2015-2019 Middle-Term Indonesia Development Plan.

The risk of development and utilization of renewable energy differs according to the source of power. In general, the risks of development and utilization of nuclear are the general risk of accidents, location of development, management of waste processing, and system deactivation (IAEA, 2009) [7]. Lazo and Kaufer [8] classified the risks of development and utilization of nuclear power as the anticipation of the possibility for nuclear accidents, namely nuclear safety management and radiation exposure risk management, and including emergency condition handling plans, preparedness and management, and provision of effective communication for accidents that may occur. In the perspective of economics, nuclear power is competitively priced in comparison to other sources of electrical power, including fuel costs, but more elements are involved in capital fees, including development area preparation fees, construction fees, and post-construction fees. Koomey and Hultman [9] analyzed research and policies that evaluated the potential for nuclear power in the future and concluded that

the designs of nuclear reactors are expected to become safer and reduced in terms of cost.

Previously conducted research on the risk analysis of nuclear power tend to be focused on the safety aspect, from planning, preparation, construction, and post-construction. Through analysis of previously conducted research and adjustments with differences in usage of the straight tube and helical coil components in steam generators, the possible risks that are considered to be present are explained in Table 1. Public support, complexity of permit-obtaining processes, transportation, damage due to natural disasters, legality, and market risk are disregarded in this research, because their effects toward and differences in the usage of the two components are the same.

Table 1. Risks in Differences of Usage of Straight Tube and Helical Coil Components

| Risk Type | Description | Entity/ Executor (Agent of Risk) |
|---|--|---|
| 1.Strategic/ Business Risk | | |
| a.Risk of insufficient finances/expertise, or unskilled management [10] | Risk caused by scarcity of capital (such as due to debt) and/or insufficient investor skills and/or unskilled management that results in losses | Loan provider/ investor/ developer |
| b.Risk of technology and innovation [11] | Risk caused by: 1.Inaccuracy of early planning in relation to resource evaluation 2.Availability of technology for renewable energy 3.Innovation that causes inefficiency, obsolescence, or unsuitability of technology in line with insufficient public (political) support that causes potential for change that is | Developer/ supplier/ stakeholder |

| Risk Type | Description | Entity/ Executor (Agent of Risk) |
|--|---|---|
| | detrimental to the policy support schema and causes revenue to be lower than expectations | |
| 2.Operation/ Maintenance | | |
| a.Risk of general process and maintenance [10][11][13][14] | Risk caused by damage to physical assets due to negligence, accident, usage, and depreciation, and/or the unplanned possibility of termination/replacement of processes and/or unsuitable renewable energy technology that causes losses (confer Risk 1b) | Manpower/ supplier/ developer |
| b.Damage due to sustained losses [15] | Risk caused by faults in the component/tube that cause losses | Supplier |
| c.Losses due to business disruption [16] | Risk caused by disruption of potential business that causes losses | Manpower/s upplier/oper ator/nature/ developer |
| 3.Counterparty Risk | | |
| a.Supplier of O&M services [16] | Risk caused by the low quality of partnership which causes losses | Supplier |
| b.Risk from power purchase agreement (PPA) partner [16] | Risk caused by the low quality of partnership which causes losses | Power purchaser |

3. METHODS

This research constitutes a synthesis that is based on the results of data triangulation. To analyze the risk of investment in EPR development, this research utilizes primary data collected from interviews with the developer of a prototype steam generator with helical coil from the National Nuclear Power Agency of Indonesia (NNPAI), secondary data taken from results of steam generator development by NNPAI from 2017, as well as review of literature on prior research and development on renewable energy from nuclear sources.

Interview with the developer is meant to obtain a picture of the development process of a steam generator with helical coil from the planning stage to the current stage of early development. Analysis of developer needs that become references in planning development can be done through the normative, practical (developer), and empirical aspects. The risks faced during the processes of planning and development can also be obtained from interview results with the developer, which are adjusted to the criteria of nuclear power investment risks in Table 1.

The comparison of straight tube and helical coil in steam generators is conducted by analyzing the existing untabulated results of testing for the development of the two kinds of components based on the experts and by an empirical overview based on relevant research that have been previously conducted. The comparison is conducted not only based on the performance of components, but also from the standpoint of optimizing investment for each component.

4. RESULTS AND DISCUSSIONS

4.1. Risks on Utilizing Straight Tube and Helical Coil in Steam Generators

4.1.1. Strategic or Business Risk

This research focused the analysis on two business/strategy risks, which are the risk of insufficiency of funds or skills or unskilled management [10], and the risk of technology and innovation [11]. The straight tube has been very commonly utilized as a component of steam generators, particularly for the EPR in Indonesia, and thus the procurement of the straight tube is rather easy. Most of the straight tubes in Indonesia are obtained from Japan, because no manufacturing companies in Indonesia have been able to produce this particular component (seamless). However, investors of straight tubes to be used in the Experimental Power Reactor (EPR) are still limited because of the relationship with nuclear, and thus if straight tubes become necessary to obtain, this will become the first procurement for nuclear power plants in Indonesia.

The funding to be conducted for the development of the EPR in Indonesia still faces a level of uncertainty because this is inescapable from political will. The government can be said to support normatively. However, based on the 2015-2019 Middle-Term Indonesia Development Plan, nuclear power

plants are not alternative sources for supplying electrical energy in Indonesia. As a result, there will be rejections from many parties over the construction of nuclear power plants, of which most are for the reason of the risk of radiation when disasters or failures occur. Germany had once widely developed and commercialized a high-temperature gas-cooled reactor (HTGR) named THTR, but was not operated again due to rejections from environmental NGOs, and so the government of Germany decided to deactivate the THTR reactor after 432 days in operation [12].

A different issue is faced regarding the usage of helical coils as components of steam generators. The greatest risk is regarding the mastery of the helical coil technology itself. The helical coil is not yet popular in Indonesia and several other developing countries, and thus procurement of this component still very much depends on countries that have developed and constructed HTGRs, such as Japan and China. The currently developing countries are Indonesia, Poland, and Jordan. Currently active HTGRs are present in China (HTR 10) and Japan (HTTR). In addition, staff with expertise related to helical coils are also limited. The limited usage causes investors to become uninterested in the development of helical coils as components of steam generators.

The choice to use straight tubes in steam generators is based on the general usage of straight tubes in steam generators for electricity in Indonesia; consequently, investors will consider it as a safe investment in the field of energy. This is also because of the ease of the process of constructing the component. As such, it can be said that investors and vendors of straight tube steam generators are already plentiful.

Construction of steam generators using straight tubes must consider the attributes of the straight tube itself. For example, for an EPR with 10 MWt, this requires a straight tube with a length of 33 meters, which will affect other infrastructure. In relation to this, steam generators with straight tubes will require more helium gas to transfer heat from the core reactor to the steam generator, while helium gas has smaller crystal lattices and therefore has a greater infiltration capability into materials, and accordingly this increases the potential for material failure in straight tubes. The infrastructure size of steam generators that use straight tubes also leads to efficiency of heat transfer compared to helical coils. On the other hand, procuring either straight tube or helical coil still depends on suppliers from other countries, depending on the facility and the material being used (Inconel 625/Incoloy 800).

In contrast to straight tube, helical coil has a greater efficiency in heat transfer. This is possible because the height of a steam generator with helical coil is only 5 meters; hence, the helical coil construction fee is cheaper and this tends to be safer compared to straight tube (because heat transfer with helical coil goes through a much shorter distance). However, funding for development and construction of a steam generator with helical coil is quite difficult with the consideration that this component is not commonly used. As well, the process of creating the component is relatively

difficult. Countries that have thus far used this component are China, Argentina, the United States, Russia, and India, with the same materials as for straight tubes. In addition, maintenance of steam generators with helical coils tend to be more difficult than for those with straight tubes.

3.1.2. Operation and Maintenance

Risks of operation and maintenance that are considered and related to the usage of the straight tube and helical coil components are general and maintenance risks [11, 13, 14]; damage due to component faults that cause sustained losses [15]; and losses due to potential business disruptions [16]. These risks are related to developers and suppliers. Beck and Pincock [12] explained the negligence of developers and/or human resources that are relevant to the development, construction and maintenance processes, which include licensed operator error, testing activity error, maintenance or repair activity error, installation activity error, radiation protection activity error, and other activity errors.

Damage to steam generators will cause the system to shut down in its entirety. Steam generators function to create steam that is channeled to the turbine, which then continues to the electrical power generator. Damage that occurs to the steam generator includes pitting corrosion of the steam generator material due to the process of cavitation, excess or incorrect usage of inhibitor that causes damage to layers of material followed by corrosion, and imperfect water purification that causes many oxidants to remain in the water, causing corrosion.

The safety aspect of steam generators with helical coil becomes very important because this is directly related to the combustion chamber, which contains the fuel source for the reactor (uranium). The combustion chamber of the reactor contains high radiation, which means that the construction of a steam generator needs to consider construction safety and operation safety, including the processes of construction, connection, and commissioning. Commissioning after construction involves testing for operational usage/feasibility to check whether the instrument is safe to be used, in the sense of whether it has fulfilled the requirements for operation.

Steam generators are linked to the generator combustion chamber, and in the case of a HTGR, what enters the steam generator is hot helium gas and the nature of helium gas is penetrating the crystal lattice of materials; because of this, when there is pitting corrosion or welding faults, leaks will occur in the steam generator. When leaks occur, radiation will escape through the feed water. The steam generator becomes vital, because in the function of generating electrical power, the primary source of energy other than heat is the steam that turns the turbine and the generator. By using a straight tube, the replacement system is easier when failure occurs and because the component is commonly used. Helical coil is more complex in its construction and is not commonly used. Because of the complex process of creation, the potential for failure in the installation is also high. However, this may be avoided by selecting good materials. The advantage is that the

helical coil can provide a high rate of heat transfer and does not occupy much space.

3.1.3. Counterparty Risks

The procurement of the straight tube and helical coil components is one of the determinants for success of development and construction of a steam generator. Procurement of the component is highly related to the quality of vendor or partner. Even so, according to [16], counterparty risk includes the risk caused by the low quality of partners, as the suppliers of both construction and maintenance, as well as the agreements that bind them.

The primary issue that is often faced with straight tube suppliers is when inflation occurs; most of the suppliers of straight tubes for steam power plants are local investors with limited amounts of capital, so when inflation occurs, they tend to default on their contracts.

Failure in the procurement of helical coils is usually because the helical coil creation process is more difficult and requires more time, and experts that specialize in the field of helical coil are still limited. Investors of this component tend to be from other countries or a combination of local and international investors, which leads to less risk of failure in procurement. This combination of local and international investors may be considered as one way to minimize risks related to the low quality of partners [12]. Further, Beck and Pincock [12] suggested that suppliers should be involved in the system design planning to provide evaluation that may prevent related accidents from occurring [17].

3.2. Risks at the Early Stage of Nuclear Power Plant Construction

The increased acceptance of the people over the past 7 years toward the utilization of nuclear power as a source of energy (Center for Dissemination and Partnership of National Nuclear Power Agency of Indonesia (NNPAI), 2017) becomes the motivation for the development of an electrical power plant design that utilizes nuclear power. NNPAI has taken the initial steps for mastery of the pebble-based reactor (PBR) technology through the Experimental Power Reactor (EPR) program since 2014. In 2015, NNPAI had started the pre-project stage of the EPR in cooperation with a collective of consultants from inside and outside the country. The pre-project stage have resulted in important documents for the EPR, among them the conceptual design document for the EPR, the Front-End-Engineering-Design (FEED), and the Safety Analysis Report (SAR).

NNPAI has possessed the EPR site permit from the Nuclear Power Supervisory Agency in early 2017, which has gone through the evaluation stage up to the end of 2016. In addition, in 2016 NNPAI had begun to compose the early draft for the documents required for the next stage, which are design approval and construction permit. In particular, one of the documents that have been revised by NNPAI is the Accident Analysis Report for the EPR, which have been

adjusted to national regulations. The Revised SAR document and the Conceptual Design of the EPR have been studied by the IAEA Consultant Team and received suggestions for revisions. As part of the continuation of the EPR program, in 2017, the level of the EPR concept design document was elevated to a Basic Engineering Design Package (BEDP). NNPAI has conducted development of the EPR Basic Design and successfully launched the design on September 2017. In 2018, the EPR Detailed Design was produced.

The current process of technological development does not begin from something that is truly novel, although the technology being developed in the country is a technology that has not existed prior. The first matter to be considered is the technology that currently applies at the international scale, including how the latest model and system are developed and applied, as well as all risks that apply. For the aspect of safety that becomes the primary consideration in developing nuclear power, though this aspect has been a primary consideration from the Dragon – the first HTR developed by the UK – to the commercialized 30 MWth HTTR by Japan and 10 MWth HTR by China, the requirements of safety are relatively the same for the processes of planning, development, installation, and maintenance [18][12].

In general, there are three phases that apply for a process of technological development; the first involves responses of rejection from the public and parties that care about the survival of the environment. In the next phase, due to the demands and needs to develop technology, in this case the EPR, decision makers and engineers begin to realize the development of the technology. However, when faced with the success of a development, the early design becomes important, as is performing continuous revisions of the design. Data from the technological design and its revisions can reduce technical risks, which can also make the risk management system more effective [12]. Along with the development process and the revisions to the prototype of the technology, the analysis of the safety aspect will begin to view the development in a positive manner, but with the same bases as safety risk management, the expended costs will not measure up to results of field inspection. As such, in the third phase, there needs to be a cultural restructuring of the risk management system [18].

The process of EPR development in Indonesia has reached the second phase, where experts in the nuclear field have begun to conduct development of the design, which is adjusted to standards and legal regulations. Development of the Experimental Power Reactor (EPR) with the HTGR technology was initiated by NNPAI in 2017, since the first time the idea of building a nuclear power plant was conceived at the end of the 1970s and construction plans were made at the end of the 1990s in Jepara, Central Java. This development has been based on the latest HTGR technology of generation 2 or 3. In 2014, Russia offered an EPR with technology of Generation 3++. [12] have even claimed that the Next Generation Nuclear Plant (NGNP) currently being developed at the Idaho National Laboratory in the United States is a technology that approaches generation 4, with the

benefits of a very efficient production of electricity and production of nuclear power hydrogen at a high level of safety.

The next issue after being able to reduce rejection from the people is the uncertainty of costs that must be expended. Cost efficiency becomes another primary concern, because the construction process of nuclear power plants that have been conducted in developed countries have experienced cost overruns 2 or 3 times greater than planned costs. For example, the Olkiluoto 3 power plant in Finland, which was planned to be constructed with a budget of \$4.1 billion, escalated to \$11 billion. This was due to delays of completion of the preparation stage upon entering the construction process; the period between the two phases can last for several years, which may quite significantly affect prices. The research conducted by [9] still leaves the question – considering the cost overrun in the construction process, which is not the final process in the development of a nuclear power plant – of whether the nuclear industry is able to assume the great costs when the nuclear power plant technology being developed has become more advanced (generations 3 and 4).

Ruuska [20] analyzed the Olkiluoto 3 (Finland) and Flamanville 3 (France) nuclear power plant projects and suggested that the management of large multi-firm projects that rely on markets, hierarchy, or a hybrid (combined) form is thought to be inappropriate. However, analysis conducted on plans of procurement of the straight tube and helical coil components have shown that a hybrid system for funding is considered to be more appropriate to reduce the risk of failure. This is due to the factor of economic stability that tends to be low. In other words, energy development planning also requires a cost and risk portfolio, so that the existing differences of combinations of costs and risks are expected to lead to the optimization of costs and minimization of risks [5]. This is even more so considering projects of nuclear development that have had little development over several decades and could not be completed over the period and with the costs that have been planned [21][19].

Among the factors that affect costs and revenues of a project are the capacity being developed, technical attributes, and issues related to investment, whether the size of funding or any problems with funding. By using a helical coil in the steam generator, the capacity of EPR development can be increased. When evaluated from the performance of each component, without ignoring the complexity of the development process, helical coil increases the coefficient of heat transfer with the aid of component structure [22]. The electrical needs of end consumers become the determinants of output from capacity and the cost of the nuclear power plant being constructed [23]. Therefore, differences in the heat transfer component in the steam generator can affect the energy volume output and the costs expended.

5. CONCLUSION

The risks of the early stage of EPR development may be minimized by developing a design that is appropriate to needs, standards, and legal regulations. Analysis of risk

management and the quantitative aspect of risks is very important to be carried out, in particular related to prior EPR development or construction and the rate of acceptance and availability of markets. By considering the height of costs and the risk of failure, it would be better if the planning and development process refers to technology that have been utilized to today, as well as to communicate all developments to the people to obtain their support (minimize rejection).

Regarding the development of new technology, to avoid or reduce the risks of technology, the selection of good-quality components from the appropriate suppliers can lead to efficiency, considering the required length of time for development and continued operations of advanced technology. Meanwhile, to avoid the risk of poor partners and technical risks, suppliers may be positioned as part of the planning and development project, and selected based on their history and reputation. Next, to reduce the risk of delays in the development and construction processes, design planning or construction must be reinforced. This research only utilized qualitative data in the synthesis process; risk evaluation in a quantitative manner needs to be conducted.

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