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Feasibility Study on Small Modular Reactorsfor ModernMicrogrids

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ABSTRACT - Microgrid isa solution of conventional power grid problem and offer sustainable decentralized power system. Microgrid with modern distributed energy resources (DER) could play an important role to alleviate dependency on the main electricity grid. Distributed energy resource comprises wind turbine, solar photovoltaic, diesel generator, gas engine, micro turbine, fuel cells, etc.Due to the gap between typical loads and supply within microgrid, larger scale energy generation could provide a possible solution to balance power demand and supply. Feasibility study of Small Nuclear Power Plant, such as Small Modular reactor (SMR), within microgrids could be achieved via different cases. To achieve the target,acomprehensive feasibility study is conducted on microgrid with SMR through electricity generation profiles, geographical and environmental assessment, as well as cost analysis using simulation practices and data analysis.Also potency of SMRs is analyzed. Parameters and Key Performance Indicators (KPIs) could be analyzedto achieve feasible solution of microgrids with small modular reactor (SMR) to improvethe overall microgrid performance.The study shows that SMR could be a feasible solution if microgrid parameters are selected properly.

1. Introduction

Energy performanceis one of the most important concerns of Government, Energy Authority, and researchers. Their target is to ensure lower carbon-dioxide emissions, sustainable, efficient, and cost effective energy solutions. After the blackout of northeastern USAin 2003, Governments started focusing on developing Microgrids to reduce dependency on the main grid and replace centralized generation with decentralized ones.Solar and wind are good choices as renewable energy sources, however they are not sustainable enough to support base load[1]. Diesel generator, coal fired generation and gas turbinesare significant sources of greenhouse gas emissions.
Small nuclear power plants, which are also called small module reactors (SMRs), are emerging technology. SMRs would come into attention as flexible, reliable and cost effective electric power source for future world. Near future, SMRs might be most reliable distributed generator within microgrid.

2. Small Modular Reactor in Modern Microgrid

Modern Microgrid architecture is an aggregation of Distributed Generation, the Storage system and load operating as a single system providing both electric power and heat.

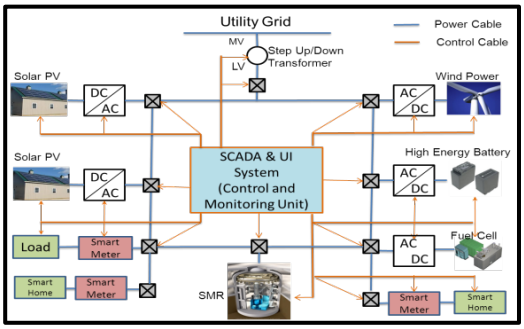


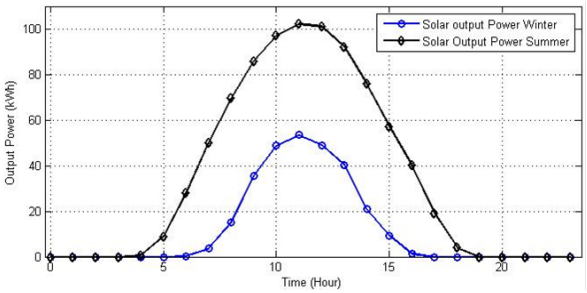
Fig 1. Microgrid with Small Nuclear Plant

One of the objectives of microgrid is to alleviate dependency of centralized generation and serve as independent small grid. Fig 1 shows the proposed microgrid topology where a small nuclear plant could be an effective power generation to support base load within microgrid.

There are varieties of size and technology of small modular reactor (SMR) which might be an alternative solution for independent microgrid.Light water reactor (LWR), fast neutron reactor (FNR) and graphite moderator reactor (GMR) are the main category of small modular reactors and the size could be vary from 10MWe to 300MWe.

3. Feasibility Analysis Result

Solar power is one of the promising technologies as renewable energy resources. It's a clean energy supply technique which has almost no greenhouse gas emission. But the output power of solar energy depends on number of sunshine hour which vary with season and weather condition. Fig 2 illustrated the output power of the solar power which shows the variation in different season. Output power of a day in winterseason is much lower than a day and in summer.



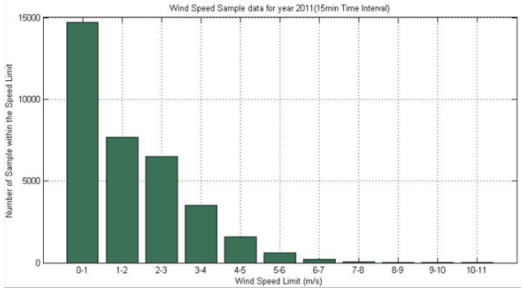
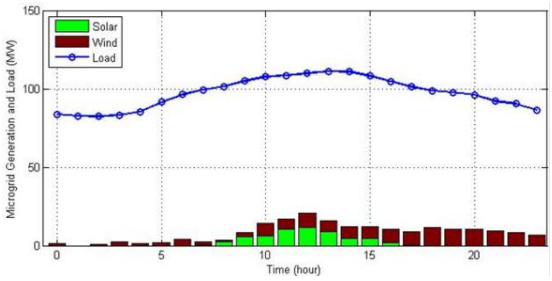


Fig 2. The Weather effect of Hourly soar power outputFig 3. Wind Speed Sample Data for July 2012(UW)

Wind power could contribute to reduce the dependency of fossil fuel power sources, and it is a good choice as clean and greenhouse emission free. One of the main parameter of output wind power is wind speeds which highly vary with time. To generate electricity from wind turbine, the wind speed must be greater than minimum speed. Figure 3 showing data from the University of Waterloo weather station for the year 2011 with 15-min time interval. In the year 2011 total counted sample were 34935 where the first bar showing 14693 samples for speed limit 0-1 m/sec. And the total sample for the speed limit 0-3m/sec is 28864 which are around 80 percent of total sample. So if we consider cut in speed as 3, eighty percent of the time power would not be generated and output power is very much fluctuating [3].



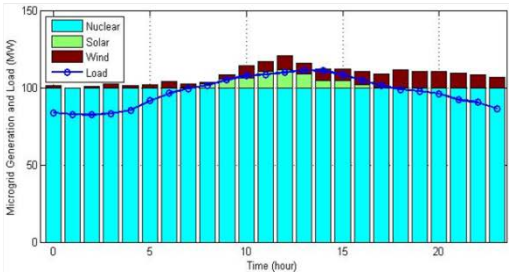


Fig 4. MG generation and load Profile without SMRFig 5. MG generation and load Profile without SMR

The fig 4, illustrated that because of limited and fluctuating generation profile of renewable energy conventional generations are not sufficient and reliable to support the microgrid (MG)load. So the rest of the load has to support from the main grid. The generation profile of proposed MG is illustrated in fig. 5 where small modular reactor supporting base load in MG. Other small generation sources and renewable energy might support peak load. We can define the performance indicator as Microgrid Generation Reliability Factor (MGRF). MGRF is defined as a percentage of microgrid power generation to support connected load.In fig 4 the MGRF is close to zero where as in fig 5 the MGRF is one means fully reliable and independent.

Some of the distributed generators have environmental effect.Table 1-1illustrated the average carbon dioxide emission in grams per kilowatt hour for a different type of electricity sources. Coal, oil and

gas power plants have huge direct emission from burning whereas hydro, solar PV, wind and nuclear have no direct emission.

Table 1-1: Green House Gas Emission from Different Sources [3]

CO2 equivalent g/KWh	Coal	Gasoline	Hydro	Solar PV	Wind	Nuclear
Direct Emission	903	468	0	0	0	0
In direct Emission	232	95	120	190	29	15

Technology evolution and design process of small modular reactors are ongoing in many countries and the technologies are very diverse. Light water reactor (LWR), fast neutron reactor (FNR) and graphite moderator reactor (GMR) are the main category of small modular reactors [4].

Current Nuclear Plant Safety System	Small Modular Reactor (SMR) Safety System
High pressure and low pressure injection system is required	Core cooling is maintained with passive safety system
For safety related system emergency sump and associated net positive suction head (NPSH)	For accident mitigation no safety related pump is required, so no need sump and supply suction protection
Emergency diesel generators are required for core cooling	Passive safety system design doesnot required emergency AC power for core cooling
Active containment heat system and spray system required	Not required because of passive heat rejection out of containment also containment spray system not required
Significant amount of online testing required for complex ECCS and I&C systems which contributes to plant unreliability and challenges of safety systems with inadvertent initiations	Less testing is required for passive and simpler safety system, system doesnot lead to accidental initiation
Condensate storage tanks, Emergency feedwater system and associated emergency cooling water supplies required	Without an emergency feedwater system, core heat removal is possible which is a significant safety enhancement

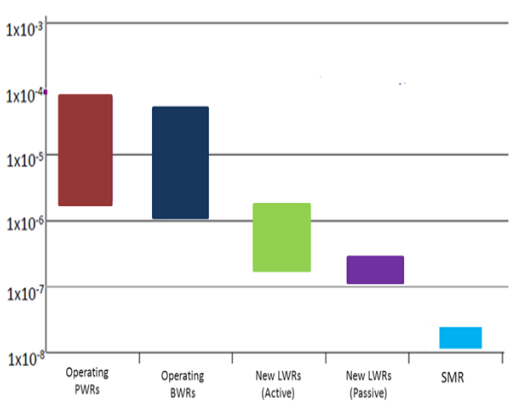


Fig 6. Comparison ofSMR and the conventional Nuclear PlantFig 7. Core Damage Frequency of various NPP[4]

Small modular reactors offer various flexible size and technologies. Advantages of modular reactors include plant manufactured and transportable to site, less onsite construction, less construction time, more easier and efficient containment. These factors allow SMR to provide a flexible, simple and cost effective energy alternative. Fig 6,illustratesthe enhancement of the safety system over conventional nuclear plant.Compact design and safety systems offer the lowest core damage frequency (CDF) among various type nuclear plants shown in fig 7.

4. Conclusions

To address the global electricity challenges, there is no obvious “silver bullet”. We have to include all possible technological diversification to meet future energy requirements. Besides, policy maker and investors are concerned about global warming, carbon dioxide emission from coal fired generation.
As the base load category, small modular reactor could offer significant and feasible solution to cover regional power needs. Key success factors of utilizing SMR’s include simplicity, passive safety, modularity, speed of construction, and reduced financial risk. This could be a viable and possible energy solution for developing countries. Nuclear energy, e.g. SMR, can offer viable and promising energy solution to meet base load requirements within microgrids.

5. References

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