Application of Small Modular Reactors in Modern Microgrids

Md Razibul Islam
University of Ontario Institute of Technology (UOIT), Ontario, Canada
(mdrazibul.islam@uoit.ca)

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Summary

Energy supply is one of the most important concerns of every government, energy authority, and researchers to meet the growing regional energy demands. Microgrids have the potential to solve the problem of conventional power grid and offer sustainable decentralized power system. However, most of the current distributed generation within microgrid doesn't meet future energy demand expectations. SMR could an effective and a viable power generation source for modern microgrids to support future electricity demands. A comprehensive 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.

1. Introduction

With an increasing energy demand and dependency on the main electric grids, there are some risks associated with the use of the centralized power generation. Microgrid is a 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 [1]

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. Solar and wind are good choices as renewable energy sources, however they are not sustainable enough to support base load [2]. Diesel generator, coal fired generation and gas turbines are significant sources of greenhouse gas emissions.

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

2.1 Small Modular Reactor

A Small nuclear plant also referred as Small module reactor (SMR) is new emerging technology which could be compatible as distributed generators. According to the International Atomic Energy Agency (IAEA), a plant having an electrical output power less than 300MWe is defined as small modular reactor (SMR) or small nuclear plant [3].

In nuclear reactor, sustained fission chain reaction is required to generate electricity. Typically, uranium oxide (UO2) is used to form fuel rods which are arranged in the reactor core. Energy generated from the fission reaction is extracted as heat through the coolant which produces steam. The pressurized steam from steam generator drives turbines to produce electric power. The main components include fuel, reactor core, primary heat transport system, steam generator, secondary heat transport system, turbine and generator.

Table 1: Different SMR technology with Particulars

SMR Name	Type	Thermal Capacity	Electrical Capacity	Fuel	Refueling cycle
Westinghouse SMR	PWR	800MWt	225 MWe	<5% Enriched U235	2 years
mPower	PWR	530 MWt	150-180 MWe	<5% enriched U235	4+ years
NuScale	PWR	160 MWt	45 MWe	4.95 % enriched	2 years
IRIS	PWR	300-1000 MWt	100-335 MWe	5% Enriched U235	5 years
Gen4 (Hyperion)	FNR	75MWt	25 MWe	Uranium nitride	10 years(replaced)
4S	LMR	30MWt	10 MWe	19.9 % enrichment	10-30 years

The various size and long term refueling of SMR is the main advantages for the microgrid. Table 1-1 illustrates the main parameter of the various small modular reactor technologies.

2.2 Microgrid with Small Modular Reactor

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.

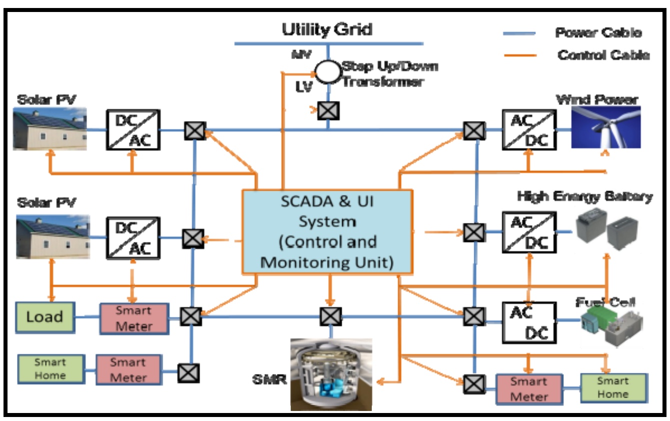

Figure 1: Microgrid with Small Nuclear Plant[1]

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. Evaluate SMR as Potential Energy Source in Microgrids

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 winter (January) season is much lower than a day and in summer (June).

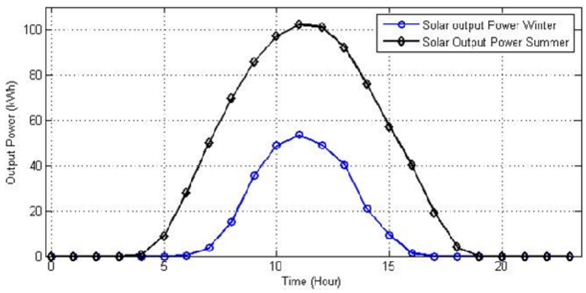

Fig 2. The Weather effect of Hourly soar power output

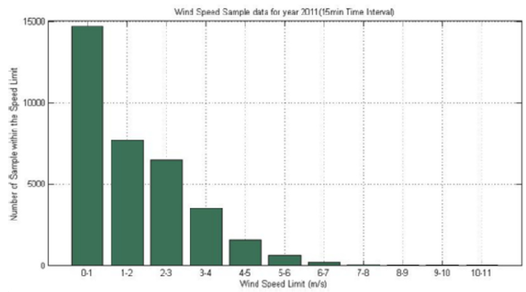

Fig 3. Wind Speed Sample Data for July 2012(UW)

Different weather effect of solar power output is significant. The output power of a cloudy day is significantly lower than sunny day. And in rainy day the output power could be near to zero.

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 [4].

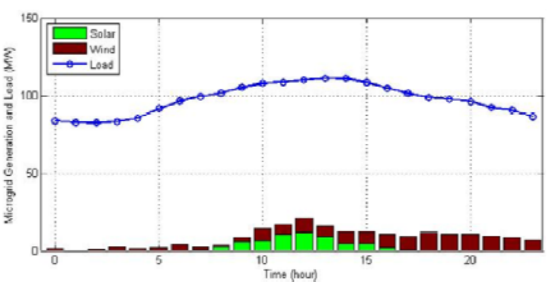

Fig 4. MG generation and load Profile without SMR

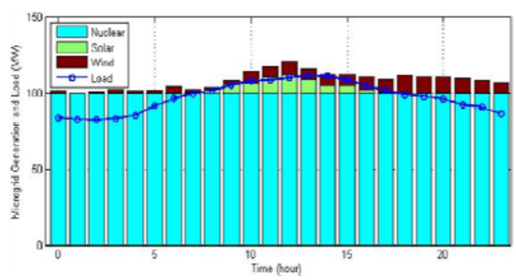

Fig 5. MG generation and load Profile without SMR

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 whereas in fig 5 the MGRF is one means fully reliable and independent.

Table 2: Green House Gas Emission from Different Sources [4]

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

Some of the distributed generators have environmental effect. Table 2 illustrated 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 3: Electricity Generation Cost for different case of 100MWh Microgrid [1]

	Generation Capacity (MWh)	Levelized Cost of electricity (2010 USD/MWh)	Levelized Cost of electricity per(2010 USD)
Nuclear (0%)	0	112.7	0
Wind (80%)	80	330.6	26448
Solar (20%)	20	156.9	3138
	MG Cost with No SMR		**29586**
Nuclear (50%)	50	112.7	5635
Wind (40%)	40	330.6	13224
Solar (10%)	10	156.9	1569
	MG Cost with 50% SMR		**20428**
Nuclear (100%)	100	112.7	11270
Wind (0%)	0	330.6	0
Solar (0%)	0	156.9	0
	MG Cost with 100% SMR		**11270**

Table 3 illustrates the three different case of microgrid cost for 100MW generation capacity. Solar, wind and SMR are defined the generation sources in microgrid. In the first case, cost is calculated where solar and wind power cover all load and no other generation source used. Second case, 50 percent is covered by SMR and rest of the generation from solar and wind power. In the case three, no solar and wind power and all generation capacity covered from the SMR. From the table it is illustrates that total cost without SMR is maximum and total cost would be minimum when 100 percent generation capacity covered from the SMR.

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 [5].

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

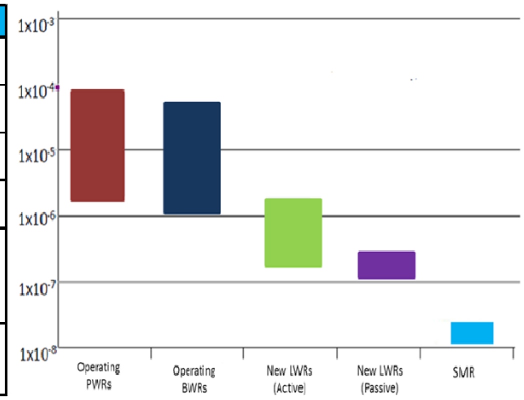

Fig 6. Comparison of SMR and the conventional Nuclear Plant

Fig 7. Core Damage Frequency of various NPP[5]

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, illustrates the 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. Conclusion

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. Nuclear energy, e.g. SMR, can offer viable and promising energy solution to meet base load requirements within microgrids as well as energy solution for developing countries.

5. References

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