Addressing Electrical Power Supply System that Enhance the Reliability and Maintain the Continuity of Auxiliary Power Supply to Reactor Coolant Pumps after Grid Collapse due to Natural Disaster or Man Made Threats

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Abstract: ***At nuclear power plant (NPP), reactor core is a heat-producing device through controlled nuclear fission reaction and transfer them by reactor coolant pumps (RCP). Since decay, heat is sufficient to meltdown the reactor core. Therefore RCP serviceable continuously for overlong period after the chain reaction stopped. At this article focus on long-term uninterrupted power supply to the RCP because, lack of grid supply for long period might be concerning with nuclear safety-security issue that we see at Fukushima daiichi NPP accident. Generated electricity of NPP is transfer though grid towers. They are arrange periodically and go far away from NPP substation. After a distance from NPP if, intentionally single tower of all different grid lines breakdown though terrorist attacks then create a major destructive violence. At this situation, NPP's unit generator tripped and longtime auxiliary power supply depend on battery back-up, uninterruptible power supply (UPS) or Emergency Diesel Generator (EDG). Though re-construction of towers are lengthy process and sooth to say EDG, UPS, batteries are not sufficient for longtime continuous power supply without interruption. To overcome this situation, established such a complete small power generation unit along with NPP. Due to several advantages, a diesel engine power plant is best. All single engines are assemble at parallel and capable to maintain the supply continuity to make it almost 100% reliable. Hence, additional diesel plant along with NPP obviously enhance the safety of RCP's electrical power supply system and improving the NPP safety parameter.***

Keywords: Reactor Coolant Pumps, Safety system, Power supply Continuity, peak-load diesel plant

1. Introduction

Terrorists cherishes only one idealism and that is to establish fear in humanity by create a destructive action. Hence, nuclear installation is their first-rate target because make a disturbance at any portion of it provoke huge violence and easily fill up their goals. Therefore, it is most important to ensure, also provide the reliable safety and security at any part of a nuclear plant. In here, we discussed a probable cause that could be originate new era of nuclear violence by attacking electric grid towers though terrorist activities, but we shows a simple solution that provide reactor safety by maintaining continuity of RCP's auxiliary power supply system. In NPP, reactor core is key equipment that produce heat energy through nuclear fission and transfer them to the steam generator. The coolant pumps are to provide forced primary coolant flow to remove and transfer generated heat from the reactor core. There are so many design of primary coolant pumps. Usuallya VVER 1200 (AES 2006) generation3$^+$-design power reactor has four main coolant pump is of the CGNA1391 type. All coolant pump supplies on average 88,000 m^3/hour coolant through reactor vessel with outlet pressure16.02 Mega Pascal (MPa). Each coolant pump consume, hot<5 MWe and cold<6.8 MWe. So, the reactor needed roughly30megawatt electrical (MWe) power for RCPs and that is 2.5% of reactor electrical power[1].Hence, reactor safety depends on cooling system and if we need to maintain safe reactor operation, must be ensure to supply uninterruptible that auxiliary power to RCP's for this large volumetric coolant flow continuously.

From International Atomic Energy Agency (IAEA) data, auxiliary power systems are sub-divided as on-site, off-site and work together as preferred system to provide adequate power in all plant conditions for maintained safe state. Off-site power systems are not plant equipment but they are, nevertheless, essential to the safety of NPP's. It's because, unfortunately all the grid towers that covered NPP collapse due to natural disaster or man-made threats, create difficulty for auxiliary system and then off-site power supply system is also important in the defense in depth concept[4].Although on-side auxiliary supply depends on NPP's self-power or UPS, battery back-up, EDG but there reliability doesn't 100%. Therefore develop such a safety bus, that energize from any other reliable plant that adjacent of NPP and maintain continuity ofRCP's power,as well as provide reactor safety when auxiliary power system at trouble for over long period.

2. Effect of Grid Vulnerable at Power Supply System

Figure 1: 230KV power transmission tower at Bhairab in Kishoreganj broke down due to tornado

A 230KV Ashuganj-Sirajganj transmission tower lashed by tornado at 8:30 PM in May 01, 2017 on the bank of the river Meghna under Bhairab upazila in Bangladesh that crashed into the river and broke the cross-arm of another tower of char-Sonarampur area of Ashuganj upazila. Due to overflow of electricity to make up electricity supply gap from another 230KV line, a 230KV Ghorasal-Ishwardi grid line tripped at about next day 11:20 AM. The breakdown in the power transmission led to shutdown of 25 power plants and left the vast areas of the countrywide without power. Nearly 30 percent consumers experienced power cuts for five hours. As effect of this grid disaster, forced power outage in a number of 38 districts of the country's southern and northern part. After five months, replace of two grid towers in Ashuganj-Sirajganj 230 KV National Grid Line has been complete; also, operation and power supply has started again after five months from their collapse in storm [2-4].

3. Effect of Auxiliary Power Supply Failure at NPP

Nuclear or any other power plants are not self-sufficient in terms of electricity. Most conventional plants, such as coal or gas plants are significantly consume (5-6)% of auxiliary power. However,NPPconsumemaximum10% and between them3% required for RCP. So secure electric power supply is mandatory at NPP for operative the cooling system both running and shutdown condition. Because fission chain reaction of the reactor are stops but a significant amount of decay, heat continuous generated and release from the fission products. The amount of heat is typically so large that continued cooling is necessary to protect the fuel sheath from melting. To protect the reactor core from melting, pumping the coolants by using RCP and remove excess heat from the reactor core. If all the feedback power systems are fail, the cooling system of the reactor will not work due to lack of electricity and the reactors will overheated. Finally inevitably resulting in a total meltdown of the reactor core, radiation as well as radioactive products spread out at local environment and nuclear plant facing a real danger situation [5-7].

4. Description of the Electrical Power System At NPP [8]

All electrical systems are depend on decisions on engineering design that are beyond the scope of this Safety Guide. According to IAEA Safety Guide, nuclear power plant has three major subsystems:

4.1 Off-site power system

The off-site power system is composed of transmission system and switchyard with the grid. The off-site power system provide main generator via auxiliary transformer& grid power supply via the standby transformerto the plant in all modes of operation and in all plant states.

4.2 On-site power system

It is composed of distribution systems that includes the AC and DC power supplies necessary to bring the plant to a controlled state following anticipated operational occurrences or accident conditions and to maintain a safe state, until off-site power supplies can be, restore. The on-site electrical power system sub-divided into three types of electrical power system: standby & alternate AC power source, DC power source i.e. battery and UPS system.

4.3 Preferred power supply

The preferred power supply is normal supply for all plant systems important to safety. It is, if available, always the first and best choice of power supply to the electrical safety power system. Preferred power supply includes parts of both the on-site and off-site systems.

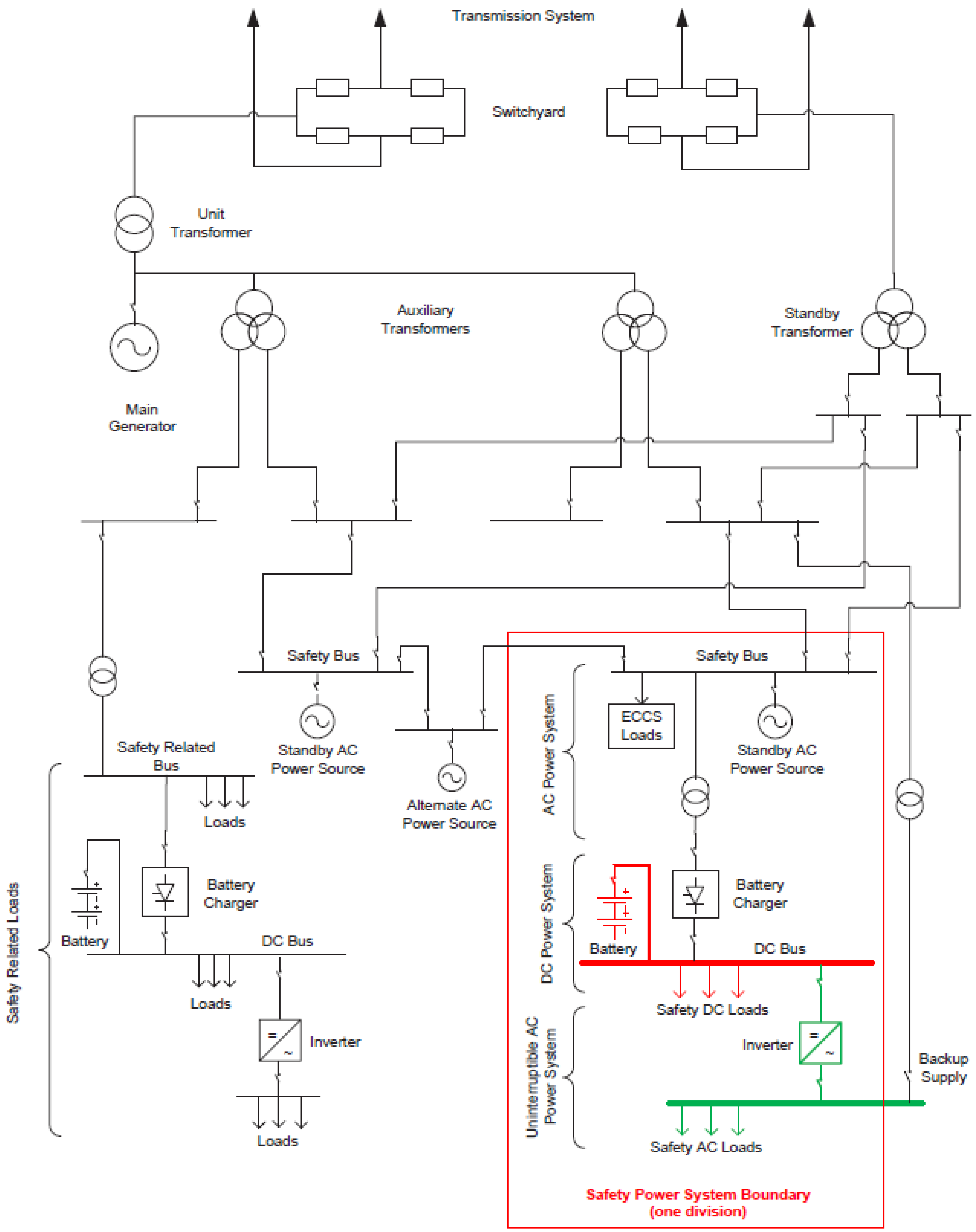
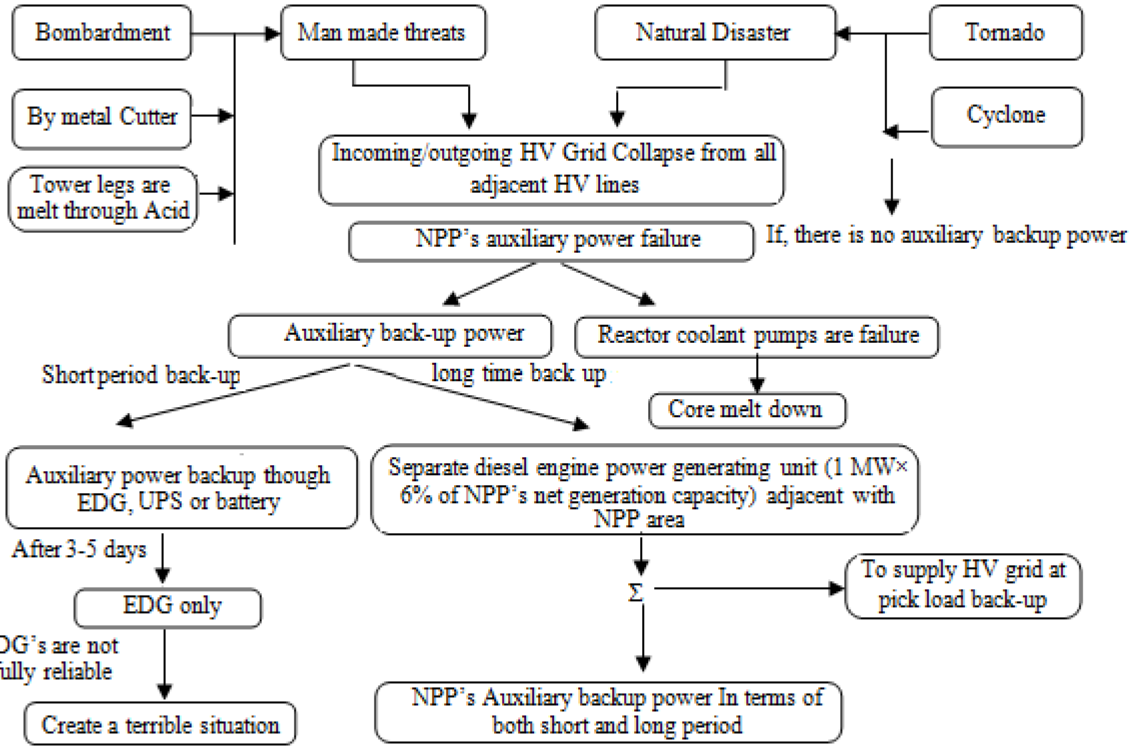


Figure 2: Schematic diagram of electrical power supplies for a nuclear power plant [4]

5. Probabilistic Algorithm of Grid Collaspe & Failure Probability of RCP'S



6. Add A Safety Busat NPP Auxiliary Power System for Long Time Grid Failure

At any nuclear power station, engineers are design the electric grid (from other units or from the grid) for a safe and tight secure power grid system for the safety of nuclear plants both under normal operations and in a shutdown state. Therefore, the site selection for NPP's must chose that the power grid have multiple feeders from different and independent (geo graphically separate) sources. At fig. 03, a geographic map of under constructed first nuclear power plant (NPP) and connected transmission grid lines named Rooppur NPP, situated in Bangladesh. It has one 132 KV and four 400 KV double circuit grid line. As, on grid power of Rooppur NPP depends on geologically separated five double circuit grid system.We have seen at this local map that the incoming or outgoing grid lines from NPP to the other sub-station is very far distance and these distances are almost unprotected. The probable problem is that unprotected grid lines are possible to destroy without any difficulty by the terrorists.

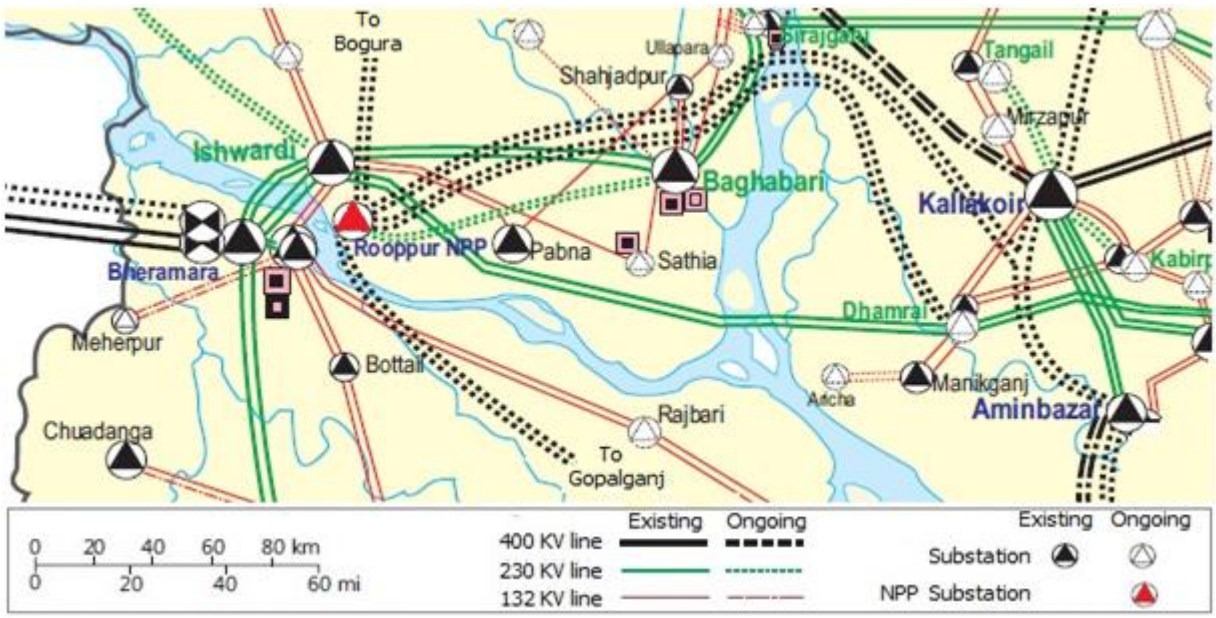


Figure 3: Geo-graphical site map of Rooppur NPP [9]

As for example at figure 03, Rooppur NPP connected other five sub-stations are far miles away and if only five grid towers be destroyed at any suitable unprotected places then NPP's on-grid power will get stuck for long shut down, also power generation of NPP remain closed. As a result, NPP's auxiliary power depends on off grid system like as EDG, batteries or UPS. However, towers re-constructions are lengthy process and sooth to say that EDG, UPS or batteries are reliable but not 100%. In engineering point of view, 30 MWe power supply through batteries and UPS up to 6 month is quite ridiculous and without interruption auxiliary power supply continuity rely only from EDG is to be risky because EDG suitable for emergency backup and designed to maintain short-term power generation, not for continuous reliable run up to 6 month without interruption.

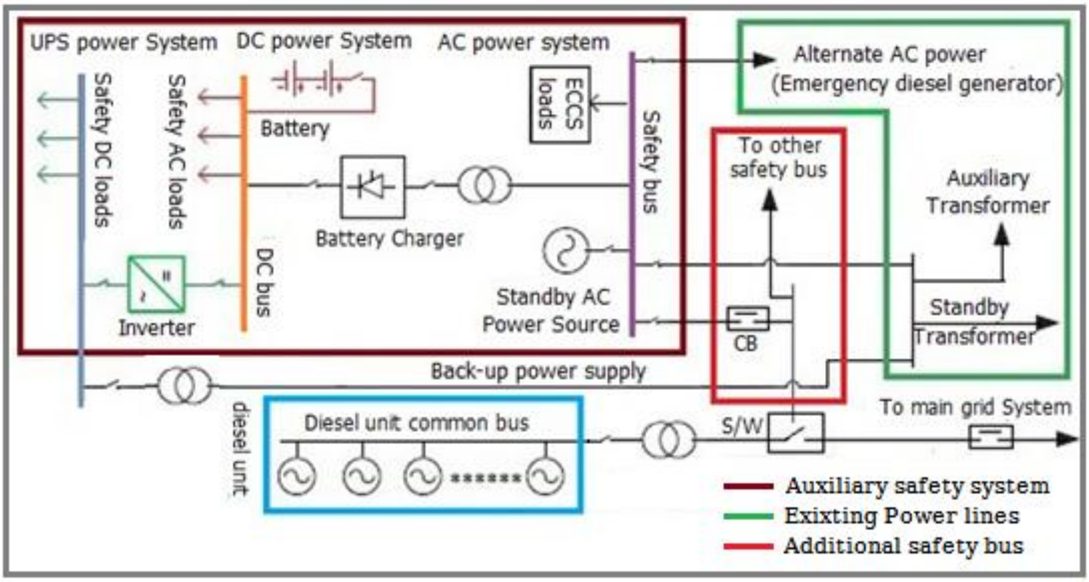


Figure 4: Connection of diesel based plant with safety bus system &grid at NPP

Hence, to avoid such that situation add an independent power generation source with an extra auxiliary supply safety bus adjacent with NPP that satisfied the RCP's capacity. This independent diesel generating unit and a special safety bus add with NPP's main power supply system that seen at figure 4.Worldwide so many diesel plants are in service and if installed one plant along with NPP, that must be enhance the power supply reliability and also backup the emergency moments when incoming power failure due to grid disaster.

7. Mathematical Data Calculation

Auxiliary power calculation[1]

A VVER (AES 2006)generation 3^+ reactor power1200 MWe and total # of coolant pumps 4.

1 (one) coolant pump consume = hot<5 MWe & cold<6.8MWe

∴VVER (AES 2006) generation 3^+ reactor 4 coolant pumps max^m consume = 6.8×4 = 27.2 ≈ 30 MWe

Coolant pumps % consume = $(\frac{30}{1200} \times 100)$ % = 2.5% of reactor gross power

If, consider safety factor 2:

Then electrical power required of all coolant pumps become = 2.5% × 2 = 5% of reactor gross power

∴ VVER (AES 2006)generation 3^+ reactor RCP's safety margin power = $(\frac{5}{100} \times 1200)$ = 60 MWe

Land area comparison

A 1200 MWe NPP's land = $\frac{1100}{2}$ acres = 650 acres [17]

A 60 MWe diesel plant needs = $(\frac{60}{50} \times 2.5)$ = 3 acres [18]

∴ % land need for 60 MWe diesel power plant w.r.t. 1200 MWe NPP = $(\frac{3}{650} \times 100)$ = 0.857 %

Cost comparison

A (1200 MWe×2) VVER generation 3^+ reactor total cost = 12.65 billion USD [17]

∴1200 MWe single unit required cost = $\frac{12.65}{2}$ = 6.33 billion USD

A 50 MWe diesel plant cost =$(\frac{60}{50} \times 44)$ = 52.8 million USD[18]

∴ % cost need for 60 MWe diesel power plant w.r.t. 1200 MWe NPP = $(\frac{52.8\text{million}}{6.33\text{ billion}} \times 100)$ = 0.834 %

8. Scope and Opportunity of Diesel Based Back-Up Generating Unit

Generally, a country use different and multiple sources of fuel energyfor power generation due to avoid single fuel dependency and reduces the risk, if singular fuel crises then power production may be not interrupted from the rest energy sources.

Table 1: Worldwide percentage use of multiple fuel sources [13-16]

Source	Coal	Natural gas	Hydro	Nuclear	Petroleum/ Bio	Renewable/ others
Bangladesh	1.84	64.99	1.7	On-going	27.04	4.43
USA	30.1	31.7	7.6	20	2.1	8.5
World-wide	39.3	22.9	16	10.6	4.1	7.1

At table-01, different sources of energy usage in worldwide and observe that, USA uses about 2% petroleum, 20% nuclear energy for power generation. As we discuss before, the reactor coolant pump requires max^m 2.5% of generated electricity. Therefore, in USA requires more or less 0.5% diesel-powered engines to fulfill the demand of auxiliary power supply of 20% of nuclear power sources. Hence, Power Sector Master Plan(PSMP) in Bangladesh involves gas coal, oil, nuclear energy, renewable sources for fuel balancing. For this diversity inBangladesh,45 oil-based power plants with capacity 3,805 MW become approved in year 2017 [14-15] and a two unit with 2400 MWe capacity nuclear plant named Rooppur NPP has under constructed.

Moreover, several power sources, a standard diesel-generating unit become perfect for back-up power supply due to its remarkable characteristic and has 100% plant reliability by parallel combination of engines. Although hydro, coal and gas turbines are most economical sources but these are base load plant with large size capacity. This plant has higher installation, maintenance cost and important thing is that these sources are not use as a back-up power plant. While in many places, gas turbine used as peaking plant with smaller capacity but continuous half a year endless reliable run is so tough. Rather then, reciprocating engines use diesel, HFO, gas fuel sources are peaking load plant and has several advantages. A simple compares between diesel engine, gas engine and nuclear plants are shows at table 02:

Table 2: compares of diesel, gas and nuclear plants with several factors[19]

Power plants	Total Capital Cost	Fuel Price	Cost of Energy	Capacity Factor
Units	($/kW)	($/MMBtu)	($/MWh)	(%)
Diesel Engine	$500 – $800	$18.23	$197 – $281	95% – 10%
Natural Gas Engine	$650-$1,100	$5.50	$68 – $106	95% – 30%
Nuclear	$6,500-$11,800	$0.85	$112 – $183 $	90%

Here at table-02 we see that, per KW diesel engine capital cost roughly 8% w.r.t. NPP. If, supply6% back-up auxiliary power from an independent peak load diesel fuel power plant that requires only 0.834% extra cost of NPP installed budget. On the other hand, a diesel plant require very less space and simply placed adjacent with NPP because 2400 MWe NPP's area around 1100 acres[17] where 50 MW capacity diesel plant needs 2.5 acres only (9080 square meter)[18], which is less than 1% of NPP's total area. Another key advantage is the availability of diesel fuel at everywhere and its storage process so simple. Also a diesel power generating unit easy to operate in both isolation or grid connected mode, less component and less maintenance required, quick start-up at any situation. Therefore, without doubt, an effective running diesel plant is more reliable, that serves long time uninterrupted power supply to the coolant pumps at emergency period after grid collapse.

9. Future Recommendation

- NPP's grids should kept under live camera monitoring up to next substation.
- Installed object sensor at tower that identify human presence and send a message to proper authority.

10. Conclusion

Nuclear power is the inevitable result of human civilization and development of science but once accident occurs, it creates a large-scale destructive disaster. Therefore, for the safety of nuclear installations, security related all small issues should considered seriously. By analyzing the reasons from the past accident, the safety of the reactor also depends on reactor coolant pumps, so all steps must be taken to keep it operational and functional both running or shutdown condition of the reactor. This is a potential risk but not impossible, so it should not overlooked. It may thought that there is sufficient EDG, but the question is, with the entire generator, how long they can supply 3% of the reactor electrical power continuously. It is more reasonable and trusting to rely on a pick-load diesel power plant, unlike the EDG, because EDG is isolated from main supply system and being lazy almost all the time. However, the pick-load diesel power plant system is more convenient to use for its 100% plant reliability by parallel combination of all diesel engine-generators. Therefore, if trouble at a single set, then it is possible to ensure the supply continuity from the rest, and get the opportunity to make the trouble set serviceable again. Every day at peak-load hour it supplies electrical power to national grid makes the unit always operative. On the other hand, generated electricity meets a small portion of electricity demand at peak load hour and cover-up its investment by selling electric energy to the consumers. So, from the lesson & learn of Fukushimadaiichi nuclear accident, we should take action to manage and accept all the loyal procedure to prevent the power loss of RCP and resist core meltdown of NPP's reactor. Just initially invest approximate 0.834% of total NPP budget, it is possible to ensure the continuity of RCP's power supply for overlong period after grid disaster and that safety investment returns after few years by selling its energy. obviously this procedure might be improve, also upgrade the safety of NPP that intercept the probability of LOCA through maintain the continuity of NPP's auxiliary power after terrorist attacking and collapse its grid towers.

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