Design of Solar Energy System to Back up the Emergency Power Supply in Nuclear Reactors

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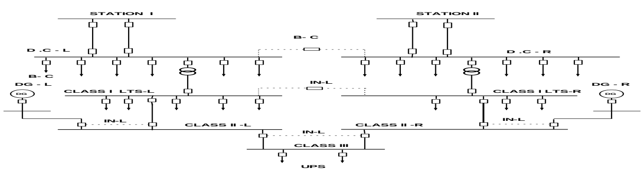
ABSTRACT: This paper focuses on providing a solar photovoltaic (PV) system as a backup source of secondary power for a nuclear reactor facility in the event of a power failure at the nuclear reactors. In similar events, loss of all normal power supply, diesel emergency supply, the batteries are the only electrical stored energy source available. The solar PV facility is connected to the electrical network of the reactor through direct connection. If the reactor electrical system is failed the solar PV system will be connected aromatically to backup power as an emergency system.

INTRODUCTION

Safety of nuclear reactors has the highest priority to ensure the global protection of public and environment. A nuclear reactors key safety feature is continuously running its emergency system in order to transfer the generated heat and to verify the main safety functions. So, the electrical emergency system must be active during normal operation and shutdown. As we know, while the plant shut down and loss of normal power supply, emergency system(diesel generator), the reactor releases decay heat, which can sufficiently melt down the reactor. If the system suspects, even slightly, that the reactor's chain reaction may have stopped and thus failed to continue operation, the reactor coolant pumps begin operating by grid supply, an emergency diesel generator, or a battery backup's power. If the normal power supply and emergency diesel generator backup systems fail, then the solar battery backup is the last source for servicing the emergency system. But battery backups can provide power in emergency periods only during certain hours. Solar power supplied by a PV cell is a common, reliable source.. This paper focuses on providing a solar photovoltaic (PV) facility with optimal sizing and design as a source of secondary power (natural and reliable source) for a nuclear reactor (ETRR2) facility in the event of a power failure. In the event of a loss of all normal, backup and diesel emergency supply, the batteries are the only electrical stored energy source available in this case.

REACTOR SYSTEMS

Egyptian second testing research reactor (ETRR-2) is an open pool type reactor, its thermal power is 22 MW (maximum power), at average thermal flux 8.1*1013nv and maximum thermal flux 2.7*1014nv, which use a plate-type 19.7% enriched uranium with aluminum cladding of fuel, the neutron flux is moderated by light water and reflected by beryllium. The ETRR-2 electrical system design follows conventional practice for industrial plants except that extra reliability requirement for nuclear reactor is provided. The basic structure of the electrical system design is shown in figure 1. It has been chosen to provide simple bus arrangement for MW (maximum power), at average thermal flux 8.1*1013nv and maximum thermal flux 2.7*1014nv, which use a plate-type 19.7% enriched uranium with aluminum cladding of fuel, the neutron flux is moderated by light water and reflected by beryllium. The ETRR-2 electrical system design follows conventional practice for industrial plants except that extra reliability requirement for nuclear reactor is provided. The basic structure of the electrical system design is shown in figure 1. It has been chosen to provide simple bus arrangement for easy, safety, and flexibility in operation The ETRR-2 is fed from the outside by two medium voltages lines (11 KV), L1 and L2 (Class "C" supply). These lines feed two transformers identified as T1 and T2. The electric loads have been classified according to the following categories:



Basic structure of the electrical system design.

Hybrid Solar Systems Description

A hybrid solar system, also known as "on-grid solar with battery storage," generates power in the same way as a typical grid-connected solar system but has the ability to store the solar energy. The advantages of hybrid solar systems are the following:

- Storing and saving solar or cheaper off-peak energy
- Allowing the use of solar energy during peak times (self-use or load-shifting)
- Providing power during a grid outage or blackout
- Enabling energy independence Hybrid solar systems' disadvantages include
- Having a higher cost than on-grid solar; the cost increase is primarily due to the batteries
- Requiring more room and having a greater installation cost due to their generally larger, more complex installation

MODULES CALCULATION

Depending on the module technology selected for the PV plant the total number of PV panels required in the system will vary as well as the area needed for the implementation of the PV plant will also differ depending on that parameter. For calculating the required number of PV panels, *NPV*, the following equation is used: PV modules quantity calculation: We choose, module watt-peak = 300Wp.

Total input energy for loads/day = 120 KW×3 hrs = 360 KWH- Multiply load daily input energy times 1.3 (the energy lost in the system) to determine DC energy, which must be provided by the solar panels Solar panel-supplied energy/day for loads = 360 KWH × 1.3 = 468 KWH

$$G_f = \frac{Total\ load}{PV\ generated\ Energy} = \frac{Service\ time\ in\ hours}{Generated\ sun\ light\ hours} \quad (1)$$

$$N_{PV} = \frac{P_{load\ KWH}}{G_f \times PV_m} \quad (2)$$

$$Battery\ capacity\ _{WH} = \frac{Total\ Load\ _{WH} \times Atunomy\ time}{DD \times B_l \times V_B} \quad (3)$$

$$BP_l = \frac{Battery\ capacity\ _{WH}}{B_{AH}} \quad (4)$$

Where: DD: depth of discharge, B_l: Battery losses. , V_B: Nominal battery voltage

BP_l: Battery parallel lines, B_{AH}: Battery capacity Ah Choose a 75% deep-cycle battery and a battery loss of 0.85. Consider an 800-volt battery (25 quantity 32- volt 936 Ah batteries connect in series). For safety of operation in cloudy or less sunny weather, choose days of autonomy as 1.3 (the number of days that we need the system to operate when there is no power produced by PV panels).

COST EVALUATION

The LCOE of solar PV is reviewed and clarified and a correct methodology is demonstrated for a case study in Egypt, where few LCOE calculations have been done for solar PV when considering energy management strategies [13, 14]. Calculating the LCOE requires considering the cost of the energy generating system and the energy generated over its lifetime to provide a cost in$/kWh . Many have noted that LCOE methodology is very sensitive to the input assumptions, such that it is customary to perform a sensitivity analysis to account for any uncertainty. The general calculation method for LCOE is expressed by Equations. (5) – (7) [15, 16, and 17] while more complicated expressions can be pursued in Darling et al. [17] and Short et al. [16].

$$\sum_{t=0}^{T}\left(\frac{LCOE_t}{(1+r)^t} \times E_t\right) = \sum_{t=0}^{T}\frac{C_t}{(1+r)^t} \quad (5)$$

Rearranging, the LCOE can be found explicitly assuming a constant value per year in

$$LCOE = \frac{\sum_{t=0}^{T} C_t/(1+r)^t}{\sum_{t=0}^{T} E_t/(1+r)^t}$$

$$LCOE = \frac{\sum_{t=0}^{T}(I_t+O_t+M_t+F_t)/(1+r)^t}{\sum_{t=0}^{T}E_t/(1+r)^t} = \frac{\sum_{t=0}^{T}(I_t+O_t+M_t+F_t)/(1+r)^t}{\sum_{t=0}^{T}S_t(1-d)^t/(1+r)^t}$$

Table : Levelized cost of solar PV in the system

Levelized cost of solar PV in the system

Types	Units	Solar PV
Construction cost	$/kW	3800
Lifetime	year	20
Interest rate	%	0.07
Capital recovery factor (CRF)		0.094
Annualized const. cost	$/kW	359
Capacity factor	%	10
Annual power generation	kWh/kW	876
Fixed O&M cost	$/kW	25.73
Construction cost in levelized cost	$/kWh	0.409
Fixed O&M cost in levelized cost	$/kWh	0.029
Variable O&M cost	$/kWh	0
Fuel cost in levelized cost	$/kWh	
Variable O&M cost in levelized cost	$/kWh	0.000
Levelized power gen. cost (breakdown)	Solar PV	
Construction cost	$/kWh	0.409
Fixed O&M cost	$/kWh	0.029
Fuel cost	$/kWh	0.000
Variable O&M cost	$/kWh	0.000
Total	$/kWh	0.439

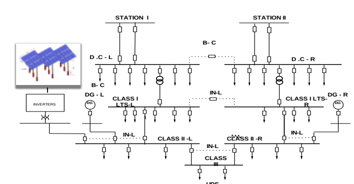
Land Evaluation

The land required for establishing 120 KW nuclear power plants is 1000 acres (1.56 km2) [20].But our highly efficient, high peak wattage solar panels require a maximum of 450 acres for a 120 KW solar plant designed for 100% plant capacity by using storage batteries. The main challenges in installing a PV solar system relate to land management. We have many options, though. The surrounding area of a nuclear power plant has too many evacuation zones, and such land is effectively useless. The estimate for the required land thus becomes: 25 solar panels' required area (8×5.3) ≈ 42.4 m² as in equation 8. Figure 2 shows a PV array design.

$$Total\ area == \frac{468 \times 42.8\ sq.m}{25} = 793.7\ sq.m.$$

The estimate for the required land thus becomes: 25 solar panels required area (8×5.3)

If the grid system and emergency diesel generator backup systems fail. But battery backups can provide power in emergency periods only during certain hours Now, there is a solution: if the battery were charged continuously by any reliable external source, it could be used to provide reactor emergency system for longer periods of time. Solar power supplied by a PV cell is a common, reliable source.



PV system connection with basic structure of the electrical system

CONCLUSION: Reliability of the nuclear power plants is a target for the operating organization and the end users, it is an essential and necessary to meet the future demands. On the other hand the safety is the most considerable factor in operation, maintenance and during shutdown. The loss of auxiliary power supply backup by a solar array to verify the main safety function and guarantee the cooling and confinement. In this paper a solar array is designed to backup the existing emergency system of the reactor to enhance the continuity of safety functions. The designed solar system overcomes the design basic and beyond accidents and enhance the availability of safety and safety related instrumentation monitoring systems. The proposed solar system designed to backup the emergency system shows the benefits of renewable energy, which feeds and supply the reactor emergency systems and save the cost and enhance the global warm. Solar energy successful to backup the emergency power supply in nuclear reactor. Technically, we recommend to use a typical solar plant requires small space, as emergency system with only 2.5% of total used power. So, these demands for emergency system is easily met by solar plants, and much unused land surrounds nuclear reactor as evacuation zones, which can be used for solar plants.