Developing a Program for the Design of a Solar Photovoltaic System for Vaccine Storage

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Abstract-*It is observed that at many locations vaccines are damaged because of the non-availability of electricity for longer periods. Government has supplied with electricity operated vaccine storage unit (ILR- Ice Lined Refrigerator) for Public Health Care Centers(PHCs). Annually, nearly 2/3rd of the wasted vaccines are due to spoilage which is, more than the portion of expired vaccines.*

In isolated rural areas, electricity grid extensions are often not economical. Off-grid renewable technologies provide a sustainable and cost-effective alternative. A need was realized to avoid the spoiling of these vaccines because of the lack of electricity. Solar Photo-voltaic system was thought as one of the solutions.

The solar radiation availability and specifications vary from place to place. Hence a Visual Basic program was thought as a useful tool to design such system to calculate required data which varies from place to place, where the parameters such as location, solar constants and the variation of the load, will be the input entered by the user, of which, the output obtained will be the structural design and the equipment specifications of the solar PV system suitable for the particular location. This system will potentially become a viable solution for remote locations.

Keywords:-Vaccine storage unit, PV system, Visual basic program.

I. INTRODUCTION

A. The Vaccine Cold Chain

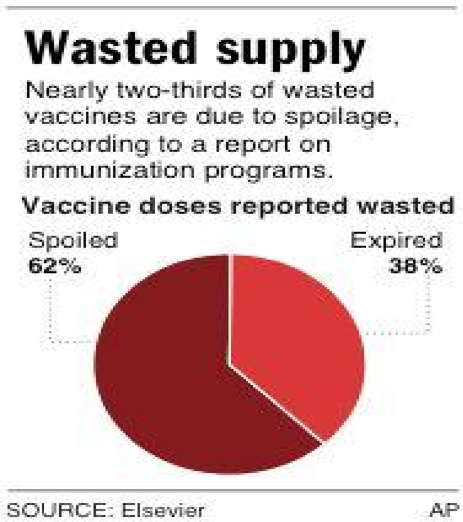
To ensure the optimal viability of vaccines, their storage and handling need careful attention. Vaccines are highly thermo-sensitive biological substances which have a fixed shelf-life and lose viability over time. The loss of viability is irreversible and accelerated if proper storage and temperature conditions are not maintained. A vaccine vial must remain between 2°C to 8°C throughout the entire cold chain system , when it is transported, when it is stored in a refrigerator and when it is used at an immunization session. At higher levels of the cold chain, such as regional or provincial health centers, measles, yellow fever, and oral polio vaccine should be stored in freezers at -25°C to -15°C. Vaccines should be transported in insulated containers with a sufficient number of frozen ice packs to keep vaccines at 0°C to 8°C. In addition to maintaining adequate refrigeration needs, proper handling practices need to be understood and practiced by all personnel along the supply chain.

Monitoring and maintaining the viability of vaccines is important for several reasons:

1. Product efficacy: Vaccine failures caused by administration of compromised vaccines may result in child mortality and the re-emergence or occurrence of preventable infectious diseases.
2. Resource management: Vaccines are expensive and are often in short supply in rural communities with challenging transportation environments.
3. Lost opportunities: Loss of vaccines may result in lost opportunities to immunize on a large scale, especially in hard-to-reach areas and resource-poor settings.[2]

B. Solar PV System

The use of solar refrigerators has been proven to compensate for power supply reliability. Refrigeration systems that use environment-friendly refrigerants provide a sustainability advantage when compared to other refrigerant selections. To minimize environmental impacts associated with refrigeration system operation, it is reasonable to evaluate the prospects of a clean source of energy. From a sustainability perspective, directly using sun as a primary energy source is attractive because of its universal availability, low environmental impact, and low or no ongoing fuel cost. Research has demonstrated that solar energy is an ideal source for low temperature heating applications such as space and domestic hot water heating. Solar heating applications are intuitive since, when solar energy is absorbed on a surface, the surface temperature rises, providing a heating potential.[2]



[1]

Fig. (a)

C. Photovoltaic Operated Refrigeration Cycle

Photovoltaics (PV) involve the direct conversion of solar radiation to direct current (dc) electricity using semiconducting materials. In concept, the operation of a PV-powered solar refrigeration cycle is simple. Solar photovoltaic panels produce dc electrical power that can be used to operate a dc motor, which is coupled to the compressor of a vapor compression refrigeration system. The major considerations in designing a PV-refrigeration cycle involve appropriately matching the electrical characteristics of the motor driving the compressor with the available current and voltage being produced by the PV array.[3]

II.RESEARCH

GUIDELINES TO BE CONSIDERED BEFORE DESIGNING OF SYSTEM:

- The cold chain system: Storage and transport of vaccines at a low temperature from the manufacturer to the actual vaccination site.
- POLIO: Most sensitive to heat has to be maintained at -20 degree Celsius.
- Freezer compartment vaccines: Polio, Yellow fever.
- Cold temperature vaccines which are not allowed to freeze: Typhoid, DPT, tetanus toxoid, DT, BCG etc.
- The vaccines must be protected from sunlight and prevented from contact with any other chemicals like antiseptics.
- At health centers most of the vaccines except polio can be stored up to 5 weeks (max) if maintained at 2-5 degree Celsius. [4]

Ice Lined Refrigerator:

Manufacturer :Vestfrost (made in Denmark)
Model: MK144
Effective (Gross) Volume: 94L
Rated Voltage : 220-240V~
Rated Frequency: 50Hz
Power Consumption: 120W
Temperature Classification: T
Refrigerant: R134 a 140g

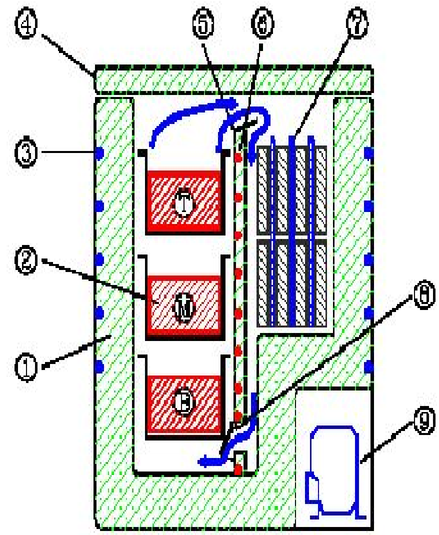


Fig. (b) [5]

III. STUDIES AND FINDINGS

To design a solar PV system for vaccine storage we have to follow three steps[6][7] (Utility of program will be demonstrated at the time of presentation.)

1. Load Estimation (or specified load), power convertor rating and system voltage:

The load refers to any appliance that needs to be powered by the PV system. In this step, one needs to estimate how much energy is required for the operation of the load.

CFL – 14 Watt
No. Of Hours Used- 12
Total Watt-Hour – 168 Wh
ILR- 120Watt
No. of Hours Used- 24
Total Watt-Hour- 2880Wh

- Determining the inverter rating: It can be estimated based on the total load connected to the inverter and converter. In this case, total load connected to the inverter is 134 Watt. In actual implementation one should find an inverter from the market close to this rating. Total Watt-hour-3048 Wh.

- Daily energy supplied to inverter: In this example daily energy used by the load is 3048Wh. This energy is supplied by the battery through the inverter. In the inverter, energy conversion takes place from DC to AC. This process will have its own efficiency of conversion. In most cases the inverter efficiency is reasonably high, at least 85%. Let us consider it as 90%, then the energy supplied by the battery to inverter input is, 3386.66Wh

- Deciding the system voltage: It should be noted that the voltage and current in a PV system after the inverter are in AC but before the inverter, from PV module to inverter input, the voltage and current are DC. The output voltage of the inverter is decided by the voltage at which load operates. In this it is 24V.

2. Sizing of Batteries:

In the previous step we have estimated that 3386.66Wh of energy is required to be supplied by the battery. Also that the terminal voltage of the Battery bank should be 24V.For this condition, how many batteries and of what size of batteries are required?

- Determine the battery capacity for a given load: In the solar PV normally the deep discharge batteries are used with DoD in the range of 60% to 80%. In this case it is 70%. This means that out of 100Ah battery capacity only 100*0.70= 70Ah is the usable capacity.

  Dividing the energy to be supplied by the system voltage would give us the required charge capacity of the Battery. Thus, Required charge capacity = 141.11Ah. Therefore number of batteries required would be: No. of Batteries = 8.063 therefore we need 8 batteries of 100Ah capacity.

- Battery Autonomy: 4 days battery autonomy means the battery should be able to supply the energy to the where there is no sunshine for 4 days. Therefore Total charge that needs to be supplied to battery bank – 705.55 Ah.

3. Sizing of PV modules:

- Daily energy supplied PV modules: For this, energy supply at the output terminal of the battery bank, the energy supplied to the input terminal of battery bank from a PV panel, should be higher. This is because the batteries will have less than 100% efficiency of charge-discharge cycle. The efficiency of battery depends on the type of battery. Normally, the battery efficiency will be between 80% to 90%. In this case it is 90%. Therefore energy supplied at the input of battery terminal should be 3762.95 Wh. The energy to the input terminal of the battery bank is supplied through controller electronics. The efficiency of controller circuit is quite high. In this case it is 90%. Therefore energy supplied by PV panels at the input of controller circuit is 4181.061 Wh.

- Solar Radiation, capacity and number of panels: To calculate this at particular location we have to implement certain equations and constants. For ex, Pune

  a – 0.31
  b - 0.43
  Day of the year (n) -19
  Latitude- 18.5203
  Average Sunshine Hours –2900/365=7.94 hrs
  (https://www.currentresults.com/Weather/India/annual-sunshine.php)
  Isc –1353 w/m^2 day

Declination angle:

$$\delta = 23.45 \sin\left(\frac{360}{365}(284+n)\right)$$

δ= -20.5695^0

Sunset/sunrise angle & Peak Sunshine Hours-

$$\omega_s = \omega_{st} = cos^{-1}(-\tan(\emptyset - s)\tan\delta)$$

$$t_d = \frac{2\ \omega_{st}}{15}$$

ω_s= 88.68^0, $t_{d=}$ 11.824hr

The Monthly average solar radiation-

$$H_0 = \frac{24}{\pi} I_{sc} \left[\left\{1 + 0.033\cos\left(\frac{360\, n}{365}\right)\right\}\left\{\cos\emptyset\cos\delta\sin\omega_s + \left(\frac{2\pi\omega_s}{360}\right)\sin\emptyset\sin\delta\right\}\right]$$

H_{o} = 7399.79 w/m^2 day

Peak Power rating-

$$H_{avg} = H_0\left(a + b\,\frac{\overline{n}}{N}\right)$$

H_{avg}= 4430.64 w/m^2 day

In order to charge batteries, the PV panels need to supply the energy to the battery bank at 24V. Therefore,

Total Ah generated by panels=174.211Ah.

Total Amperes that should be produced by PV module=21.9409A.

No. Of modules=7.8639which is approximately equal to 8.

IV. PEER REVIEWED

- Procedure should be developed for multiple locations.
- Some comments about the other methods of vaccine storage methods are required

V. IMPROVEMENT AS PER REVIEWER COMMENTS

- A program has been developed which can be executed for multiple locations.
- It was observed that certain techniques such as triple fluid with vapor absorption system will be more useful for locations where electrically operated vapor compression cycle based ILR is not purchased. This kind of comparative study can be done separately.

VI. CONCLUSION

i. The program can calculate the size of the PV system required for the given location.
ii. For case study, numbers of PV modules required were 4.
iii. A device is required to be developed which will prioritize the power consumption by ILR.

APPENDIX

- ILR: Ice Lined Refrigerator
- Inverter Rating: It is required load energy supplied from battery bank through an inverter (AC loads) or converter (DC loads).
- Monthly average solar radiation: It is the monthly average of daily extra-terrestrial radiation on inclined surface.
- Battery Autonomy: The autonomy is defined as the number of days the battery should be able to supply the energy to load even when there is no sunshine.
- DoD (Depth of discharge): It is used to describe how deeply the battery is discharged. .

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