Viability Analysis on Photovoltaic Configurations

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Abstract - **Energy research is basis for wealth creation that leads to successful societal transformation. PV systems play important role in sun energy extraction process. The different PV system configurations are compared on the basis of operational difficulties in the life long energy recovery processes of the module with a view of efficiency improvement and cost reduction. Significance of grid-connected PV Systems in the sun energy extraction process is presented.**

Index Terms— **Batteries, Inverters, Photovoltaic power systems, solar energy**

I. Introduction

The societal transformation will primarily be centered on education, healthcare, agriculture and governance. This transformation will encompass higher employment generation, higher industrial growth, higher national efficiency & productivity, higher empowerment of women, creation of a truly transparent society and generation of significant rural prosperity.

All above centered at economic development, this will depend upon its ability to generate wealth. The ultimate aim of any society is to add value to make human life more comfortable. In the long run each society develops an environment, culture, customs and practices based on its native strengths like natural resources and skills, ingenuity, imagination and civilization strengths of its people.

Entire society wealth creation is the process of energy generation and utilization. The per capita energy consumption is used to indicate standard of living in any country. Thus energy research is basis for in the societal transformation

There are only two types of primary energy sources that have energy potentials and the durability sufficient to match mankind's future needs.

1. Nuclear energy (fission and fusion)
2. Sun derived energy

The pros and cons of first are well known.

II. SUN DERIVED ENERGY

Solar energy can be used (i) directly such as solar thermal, PV systems (ii) indirectly through its effects on generating wind, rain or vegetation growth (Bio mass) (iii) Fossil fuel such as petroleum, coal and etc. Fossil fuel such as petroleum, coal and etc was sun derived energy of historical times. If we calculate the efficiency from the historical point of view the efficiency was very poor because it consists of sunshine of several thousand years. At present also steam engines are operating at very poor efficiency and high co_2 production and so on.

Thus by doing this of type analysis the PV system with 10% efficiency can be proved as highly efficient energy plant.

III. UNIQUE QUALITIES OF PV SYSTEM IN ENERGY EXTRACTION PROCESS FROM THE SUN

The sun can be described as an enormous fusion reactor that sends huge amounts of energy into space. A tiny part of that energy but still an enormous amount, compared to our needs, reaches the earth all the time. Each day more solar energy falls on Earth than the total amount of energy our world's 5.9 billion populations would consume in 27 years (based on 1995 levels).

Photovoltaic, generating electricity from sunlight is a clean, affordable and available technology. Photovoltaic (PV), or solar cells as they are often referred to, are semiconductor devices that convert sunlight into direct-current (DC) electricity. PV systems have several advantages such as low maintenance, unattended operation, reliable long life, no fuel and no fumes, easy to install, low recurrent costs, system is modular and closely matched to need.

The amount of current generated by a PV cell depends on its efficiency, its size (surface area) and the intensity of sunlight striking the surface. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of about 25 square inches will produce about 2 watts peak power. If the sunlight intensity were 40% of peak, this cell would produce about 0.8 watts of power. Being a solid state device, it has a life span of 20 to 25 years.[1]

Photovoltaic cells are connected electrically in series and or parallel circuits to produce higher voltages and/or currents. *Photovoltaic modules* consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of the complete PV generating unit. *Photovoltaic panels* include more than one PV module assembled as a pre-wired, field installable unit. A *Photovoltaic array* is the complete power-generating unit, consisting of a number of PV panels.

IV. PV SYSTEM CONFIGURATIONS

Photovoltaic-based systems are generally classified according to their functional and operational requirements, their component configuration, and how the equipment is connected to the other power sources and electrical loads (appliances). The two principle classifications are

(i) Stand Alone PV Systems.
(ii) Grid-Connected PV Systems.

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Stand Alone Systems can be further classified as

(a) Stand-alone PV systems with batteries
(b) Direct- coupled Stand-alone PV systems

V. STAND-ALONE PV SYSTEMS WITH BATTERIES

This system is very simple and consists of PV module, a maximum power point tracker (MPPT), charge controller and battery. Normally system is used to store energy in batteries during the day time and the battery service the load during night. The inverter is required in the system when the battery has to service ac load

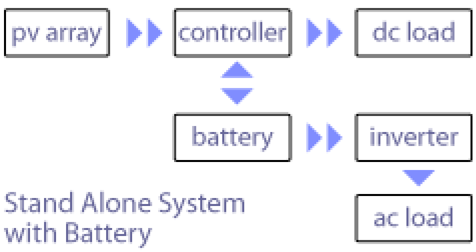

Fig. 1 Standalone PV Systems

A. Problems of Battery in the System

While batteries may seem like a good idea, they have a number of disadvantages. The type of lead-acid battery suitable for PV systems is a deep-cycle battery, which is different from one used for automobiles, and it is more expensive and not widely available. Battery lifetime in PV systems is typically three to eight years, but this reduces to typically two to six years in hot climate since high ambient temperature dramatically increases the rate of internal corrosion. Batteries also require regular maintenance and will degrade very rapidly if the electrolyte is not topped up and the charge is not maintained. They reduce the efficiency of the overall system due to power loss during charging and discharging. Typical battery efficiency is around 85% but could go below 75% in hot climate. [2]

In normal operation of a storage battery there are four major reasons for the ageing process:

- deep discharge (this gives irreversible sulphation)
- overcharge (this increases the corrosion velocity)
- low electrolyte level exposing the electrodes to air (this reduces the capacity permanently and increases the corrosion velocity)
- high battery temperature (this increases the corrosion velocity)

As an example the battery life is shortened dramatically if the battery is left in a deeply discharged condition for a long time (more than few days). This situation can occur if the load is too large compared to the energy from the photovoltaic module and the controller does not have a low state of charge warning or disconnect function. In such an instance the battery shall be completely disconnected from the load or recharged by other means if possible until the battery is fully charged again.

For all those reasons, experienced PV system designers avoid batteries whenever possible.

Hence this model of stand-alone PV systems with batteries can be used for theoretical study purpose but not for efficient sun energy extraction.

VI. DIRECT- COUPLED STAND-ALONE PV SYSTEMS

In Direct- coupled Stand-alone PV systems, PV array is directly connected to the load through a maximum power point tracker (MPPT).

Water pumping is a major application for Direct- coupled Stand-alone PV systems. [3] Typically, these systems include a ground-mounted array (with or without an optional mechanical tracking device), a pump controller, an inverter for AC pump motors, and the pump/motor assembly operating with either DC or AC. Water is pumped only during daylight hours and is usually stored in a water tank to cover periods of bad weather..

Fig.2 Direct-coupled Stand Alone Systems

Building integrated PV (BIPV) systems is also a direct-coupled stand-alone PV systems but one has to know how the PV system meets the hourly building load.

This, of course, requires knowing not only the hourly output of the PV system but also the hourly detail of the building electrical load.

A. Effectiveness Of The Load Connected Systems

To calculate the effectiveness of the load connected systems, let us consider the example of calculators supplied with PV cells. Suppose this type of calculators is being used in 24 hour supermarkets, they can be used all the 24 hours with the light availability.

But the actual load utilization hours may be in the order of 50% even in busiest markets.

Because of this type of low utilization problem, the direct-coupled stand-alone PV systems become ornamental in nature rather than supplying energy during full life time of the system.

VII. GRID-CONNECTED PV SYSTEMS

Grid-connected photovoltaic (PV) systems feed electricity directly to the electrical network, operating parallel to the conventional electric source. This is also called Photovoltaic power systems. The simplest grid-connected system, such one with low-voltage for residential use, contains a PV array and an inverter unit. In high-voltage applications, the system requires transformers and appropriate power switching and protection devices. Grid-connected PV systems generate clean electricity near the point of use, without transmission and distribution losses. [4]

Their performance depends on local climate, the orientation and inclination of the PV array, and inverter performance. The output of a grid-connected PV system depends on the PV / inverter sizing ratio defined as the ratio of PV array capacity at standard test conditions to the inverter's rated input capacity [6]. Properly matching PV and inverter rated capacities improves grid-connected system performance.

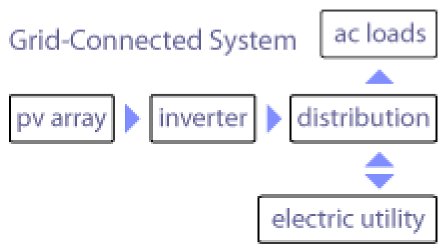

Fig. 3 Grid-Connected System

Optimal sizing depends on local climate, surface orientation and inclination, inverter performance, and the PV/inverter cost ratio (T). Under low isolation (incident solar power), a PV array generates power below its rated capacity, leading to inverter operation at partial load. Inverter efficiency drops with part-load operation: it also becomes sub-optimal when a significantly undersized inverter is made to operate mainly in conditions of overload, which result in energy loss. [6]

The inverter accounts for 10-20% of the initial system cost. Inverters generally need to be replaced every 5-10 years, whereas modules and other system components have a life of 25 years or more. Investment in a new inverter is required 3-5 times over the life of a PV system.

A. Feed-In Tariff Subsidy

The ever starving electrical grid is the correct load match for ever shining sun.

Further for the grid connected PV systems many countries offer the feed-in tariff subsidy payment and this enables the system owner to get regular income to meet the above inverter cost replacements.

VIII. VIABILITY ANALYSIS

Sun is continuously pouring the energy on the earth and it is our duty to utilize it. The unutilized sun energy is always loss to mankind.

Photovoltaic module is solid state device without any moving part and has long life of 20 to 25 years. So long life and less troublesome PV configuration is the required one. The following table gives the details.

TABLE I Comparative Analysis

PVconfiguration	Advantages	Dis advantages	Viability
Stand-alone PV systems with batteries	Suitable for use of solar energy during night	Short battery life	1.Frequent battery failure results in poor reliability 2. High cost of battery replacement makes the system unviable.
Direct-coupled Stand-alone PV systems	Suitable for specific low energy loads	1.Continouly managing the load poses problem 2. Failure of loads leads to total failure of the system.	Since maximum of 10 to 20% of energy can be extracted, it is unviable.
Grid-Connected PV Systems	Eligible for Feed-in-tariff subsidy	Since minimum size is specified by grid authorities needs very high investment	Even though invertors and other electronic components need replacement periodically the system becomes viable with feed in tariff subsidy payment

From the above discussions, it can be seen that the grid connected PV systems are most significantly differ from other PV configurations in the energy extraction process.

IX. NUMERICAL EXAMPLE

Several types of economic analysis are available in literature. [5]

In this analysis the maximum energy extraction from the given PV panel is our objective. The cost / kilo Watt hour (kWh) of electrical energy from the various PV configurations calculated to get the idea on viability.

The rating of the plant is one kilo Watt peak (kWp) in this example. Annual production of electricity of the PV system is estimated at 38,704 kWh/year for 30.6 kWp PV system capacity. [7].

The annual production of 1kWp plant is 1265 kWh and daily production is 4.2 kWh for 300 days (allowing seasonal variation with absence of sun light). During the life time period of 25 years, 1kWp PV panel may produce 31625 kWh.

A. Stand-alone PV systems with batteries

Cost of one kWp PV panels with accessories like MPPT, charge controllers etc = Rs 2.5 lakh. For one kWp PV panel energy output/ day is 4200 Wh and it needs 4200 Wh /12v = 350 Ah battery approx 3* 100 Ah battery cost Rs 8.000*3 =Rs24,000. The life time of battery is of maximum 5 years and it needs 5 replacements and cost of battery Rs 24,000* 5 =Rs.1,20,000. Cost of inverters =Rs 50,000 with life time of 8 years and needs 3 replacements and hence the cost is Rs 1,50,000 Total cost of system with 25 year life time = Rs.5,20,000

Total energy of output of system 1265 kWh *0.8 for battery efficiency 1012 kWh /year for 25 year life time= 25,300 kWh

Cost / kWh = Rs.5,20,000/25,300 kWh = Rs 20.55

B. Direct- coupled Stand-alone PV systems

The solar water pump is considered as load.

Cost of one kWp PV panels with accessories like MPPT etc = Rs 2.5 lakh. Cost the pump =Rs75000 with 80% efficiency and 10 years life time. So for 25 years of PV panel life time 2.5 replacements are required. So the cost of pump (Rs 75000* 2.5) = Rs 1,87,500. Total cost of system with 25 year life time = Rs.4,37,500. Total energy of output of system (31,625 * 0.8 = 25,300 kWh.) = 25,300 kWh.

Cost / kWh = Rs.4,37,500/25,300 kWh = Rs 17.30

C. Grid-Connected PV Systems

As per Government of India, Ministry of New and Renewable Energy Order no: No.32/61/ 2007-08/PVSE to achieve reduction in the cost of the grid connected PV solar systems, Grid interactive solar PV Power Generation plants of a minimum installed capacity of one MWp per plant at a single location will be eligible for generation based incentive. The Ministry may provide, through IREDA, a generation-based incentive of a maximum of Rs. 12 per kWh to the eligible projects which are commissioned by 31st December, 2009, after taking in account the power purchase rate (per kWh) provided by the State Electricity Regulatory Commission or utility for that project. (Notional amount of incentive Rs. 15 per kWh. – inclusive of power purchase rate)

The calculation for our example as follows:

Cost of one kWp PV panels with accessories like MPPT, etc = Rs 2.5 lakh and for 1 MWp = Rs2,50,000*1000 = Rs 25,00,00,000 = 25 crore. Cost of inverters and accessories - 5.0 crore with the life time of 8 years and needs 3 replacements and hence the cost is = 15 crore. Total cost of 1 MWp plant with 25 year life time = 40 crore.

So the investment cost of 40 crore is a major constraint is in this regard.

For our analysis cost of one kWp grid connected PV system = Rs 4,00,000.

Total energy of output of system for 25 year life time = 31,625 kWh.

Cost / kWh = Rs.4,00,000/31625 kWh = Rs 12.65

The maximum subsidy payment = Rs 15.00

Returns / kWh = Rs 2.35

X. CONCLUSION

Since this type of analysis brings out relative merit of various PV configurations, it may be very useful to make right type of viable investment on PV systems.

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BIOGRAPHIES

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