Performance Study of Grid Connected Solar-PV System

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Abstract -- **Renewable energy generation and distribution led to the idea of injecting solar-photovoltaic power into utility grid. Inverters connected to grid evolved over a period of time, with high diversity. Inverter parameters like reliability, size, efficiency and weight, reliability etc. improved significantly via development of innovative design, reducing cost of production.**

Recent technological developments of grid-connected photovoltaic systems (GCPVS) are reviewed in this paper. In areas, with high penetration of distributed generation resources, GCPVS cause unwanted stress on the electrical grid. Techniques to address technical challenges caused due to growing number of GCPVS are presented.

Keywords: Grid connected power system, Maximum power point tracking system, Solar tracking,Total harmonic distortion

I. INTRODUCTION

DEPENDENCE on fossil fuel combustion for generation of electricity is affecting climate change due to greenhouse gas emissions. For meeting energy needs, renewable energy is being given top priority [1]. Considerable research has been conducted in electricity generated from solar cells, owing to clean and unlimited source of energy. For better utilization, interconnection of photo-voltaic (PV) system with grid is needed. Accordingly, PV power disbursal to the utility grid attracted attention of policy makers [2].

In contrast with off-grid PV systems, grid-connected photovoltaic systems (GCPVS) operate in parallel with the electric utility grid, requiring no storage systems. GCPVS feed power to the grid when generated power exceeds local load demand. This helps to offset greenhouse gas emissions. As a result, during peak solar hours fewer conventional generation plants are needed. Moreover, GCPVS reduce Transmission and Distribution (T&D) losses which jump during peak hours [3]. Locating DG assets close to loads partially mitigates these losses.

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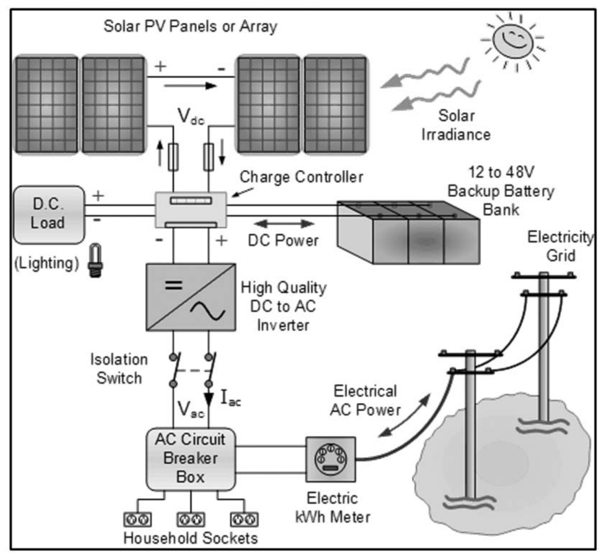

Figure 1. A typical solar PV system.

Standards governing safe installation, operation and maintenance of GCPVS, and methods of improving efficiency of PV systems are given. Inverter design using transformer-less and soft-switching lead to high efficiency, low cost, and compact structure. Inverters having ability to support electric grid ancillary services will be preferred.

II. STANDARDS AND SPECIFICATIONS OF GRID-CONNECTED PV INVERTER

For GCPVS to be operated safely and reliably, standards must be adopted, to build electricity consumer's trust, reducing costs and nurture R&D. Standards on the subject have been evolved by International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE) and National Electrical Code (NEC).

Basically, these standards fix the limits for variations in inverter voltage and operating frequency besides power factor, harmonics produced and DC current injected into grid to prevent transformer saturation [5]. They also address grounding issue. IEEE 1373 standard lays down practice for field test methods and procedures for GCPV system. The standards recommended by IEC are: (*a*) IEC 61683: procedure for measuring efficiency; (*b*) IEC 61173: guidance on overvoltage protection; (*c*) IEC 62116: procedure of islanding prevention measures.

III. GCPV SYSTEMS TRENDS

Manufacturing cost of mono-crystalline silicon PV modules reduced from over \$100 per watt in the 1970s to less than \$0.5/W in 2021. Continued technological improvement of power converter technologies and governmental incentives are expected to boost PV industry. According to the Rocky Mountain Institute, grid parity will be achievable by 2030 [6]. Argonne National Lab Scientists argued that this may happen by 2025. International Energy Agency survey found that of the total installed PV systems, over 99% are grid-connected. Large systems are beginning to make up for predominant share of the PV market.

TABLE 1 – PERFORMANCE PARAMETERS

Performance parameters	Definition
Reference yield	$Y_r = I_{POA}/G_O$(kWh/kW$_P$)
Array yield	$Y_a = E_{DC}/P_O$(kWh/kW$_P$)
Final yield	$Y_f = E_{AC}/P_O$(kWh/kW$_P$)
Corrected reference yield	$Y_{CR} = Y_R(1 - \gamma(T_C - T_0))$
Performance ratio	$PR = Y_f/Y_r$(%)
System losses	$L_S = Y_a - Y_f$(kWh/kW$_P$)
Array capture losses	$L_C = Y_r - Y_a$(kWh/kW$_P$)
Miscellaneous capture losses	$L_{cm} = Y_{CR} - Y_A$(h/d)
Thermal capture losses	$L_{tc} = Y_R - Y_{CR}$(h/d)
Array efficiency	$\eta_{pv} = 100 \times E_{DC}/I_{POA} \times A_a$(%)
System efficiency	$\eta_{sys} = 100 \times E_{AC}/I_{POA} \times A_a$(%)
Inverter efficiency	$\eta_{inv} = 100 \times E_{AC}/E_{DC}$(%)
Capacity factor	$CF = E_{AC}/(P_O \times 24 \times 365) = Y_f/8760$

IV. ISSUES IN GRID-CONNECTED PV SYSTEMS

GCPVS feature long working life (25–30 years), low operations and maintenance costs and environmental advantages over fossil-fuel power plants, still they have their own set of challenges. Large scale adoption of GCPVS could create enormous stress on the electric grid.

GCPVS inadequately contribute to the grid when demand increases in the hours following sunset.

Solution is as follows. Generation plants capable of fast ramping, like gas reciprocating engines and simple-cycle combustion turbines, can help mitigate the effects of the stress on the grid. But such new investments will take considerable time to plan and design besides dependence on fossil fuels. A preferred solution is to couple GCPVS with storage systems that extend their operation by an extra hour or two after the sunset. This would negate the need for rapid ramping of reserves.

V. TOPOLOGIES OF GRID CONNECTED PV INVERTERS

For connection to grid, DC power of PV array is converted to AC with proper voltage, frequency and phase. This task is achieved by an inverter. Configurations are shown in Fig. 2.

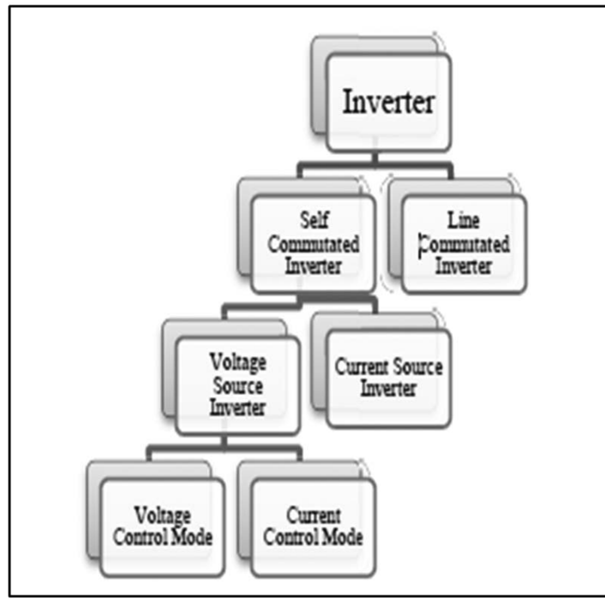

Figure 2. Classification of inverter types.

Self-commutated inverters may be voltage source inverter (VSI) or current source inverter (CSI) based on voltage or current waveforms at their input DC side [7]. For limiting current flow from the inverter to the grid, a tie line inductor is used along with VSI. The input DC side terminals of a VSI are connected in parallel with a large capacitor that resembles a voltage source.

In CSI, where input side is a DC current source, CSI is connected in series with a large inductor that maintains the current continuity.

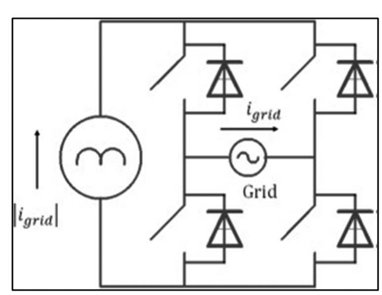

Figure 3*a*. Line-commutated grid PV inverter configuration.

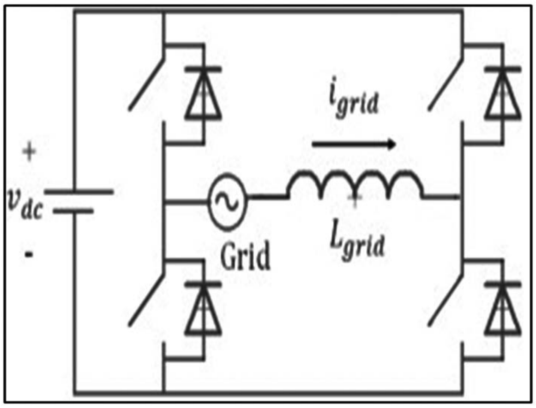

Figure 3*b*. Self-commutated grid PV inverter configuration.

Figure 3 shows configurations of line-commutated and self-commutated inverters.

Current control mode inverter offers two advantages:

- high power factor can be obtained by a simple control circuit
- suppression of transient current in case of grid disturbances.

VI. CONCLUSION

Although solar PV market has experienced astronomical levels of growth and cost reductions in recent years, there are many technical challenges and economic realities that need to be reconciled for DG resources like GCPVS to be at parity with conventional generation. For successful mass adoption of GCPVs, new technologies must be developed that will allow the inverter to do more than just provide DC/AC conversions. Modern grid interactive inverters will need to provide Volt/VAR control (power factor and voltage stabilization), frequency regulation, enable storage and utilize modern communications protocols, all at a reasonable cost. This new generation of inverters has been rightly termed "smart inverters".

GCPVS design will embrace smart inverters with capability to monitor, react and adjust their output based on instantaneous feedback from the grid. They will have features to capture and share data with the facility management system for maintenance, leading to a more reliable grid.

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