Implementation of a bang-bang strategy for PV system connected to the grid

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***Abstract*—This paper presents a bang-bang strategy for PV system connected to the grid. A string PV system coupled to a single stage inverter is described. The inverter presented in this paper utilizes higher order DC filtering and is made of a single stage topology utilizing PI regulators to control the Maximum Power Point (MPP). Additional PI regulators are employed to minimize the Total Harmonic Distorsion (THD) to the minimum. The inverter designed meets all relevant standards requirements.**

I. PV System Model Architecture

Due to PV systems costs, the inverter must be economically designed to reach low price in the market and to accelerate the development of renewable energy power plants. In any case, it must adhere to the standards adopted by various regions [1]-[3] and utility demands for grid interactive inverters.

The inverter model developed is a 1.2kW, transformerless inverter for grid connected PV installation. The use of transformerless inverters has its own advantages and limitations. Its key advantages are higher efficiency, and reduced form factor and weight making it economical compared to topologies where transformers are employed [4].

Fig. 1 shows the architecture used to simulate the PV system. Table 1 describes the processes involved.

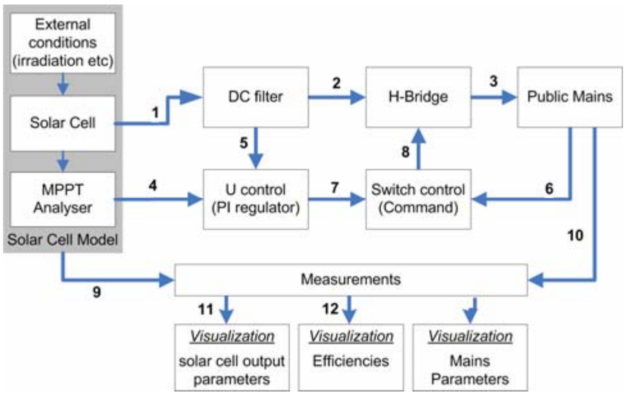


Fig. 1. Synoptic of architecture used to the PV system connected to the grid

A. Command Strategy

The command strategy employed is known as bang-bang control. In this strategy, the desired waveform is set as the control with upper & lower boundary or set-points floating with it [5]. A switching pattern in Fig. 2 is generated for switches S_1 to S_4.

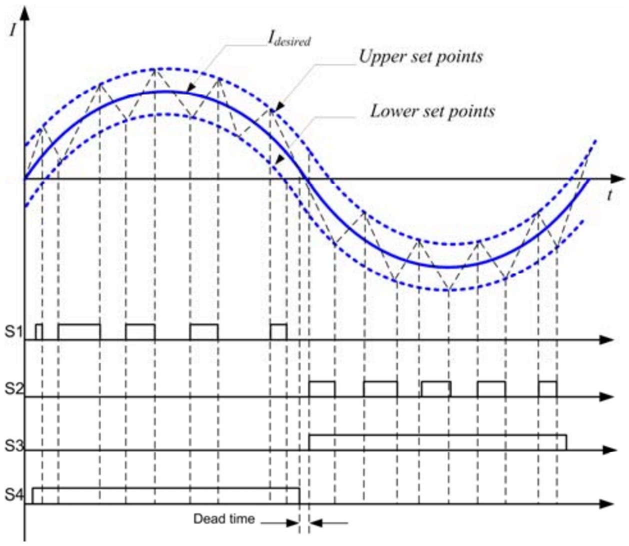


Fig. 2. Illustration of Bang-Bang command scheme

B. Regulator

The output voltage without filter has a variation of 17*V* with a frequency of 100*Hz*. A filter depicted in (2) is designed with a cut-off frequency of 10*Hz*, selected as a trade-off between system speed and desired level of filtering.

$$F(s) = \frac{1}{(1+0.01s)} \quad (2)$$

The set points created by the filter are used to regulate switching to accomplish the inverter output within the threshold stipulated by the relevant standards. The switching regulation is achieved by employing a proportional integrate (PI) regulator. The regulator developed in (3) has a bandwidth of *0.023s* and the integrator time constant T_n= *0.031s*.

$$F(s) = k_p \frac{T_n s+1}{T_n s} = 27.74 \frac{0.031s+1}{s} \quad (3)$$

In addition to this configuration, a THD regulator is designed to keep this parameter within bounds of less than 5% according to [2], [3]. a PI regulator is adopted as depicted in (4). Since the inverter's dead (switching changeover) time is high (due to H-Bridge configuration), the time constant for the regulator is set to *0.05s* for closed loop.

$$F(s) = 0.4 \frac{0.2s+1}{s} \quad (4)$$

II. Simulation Results

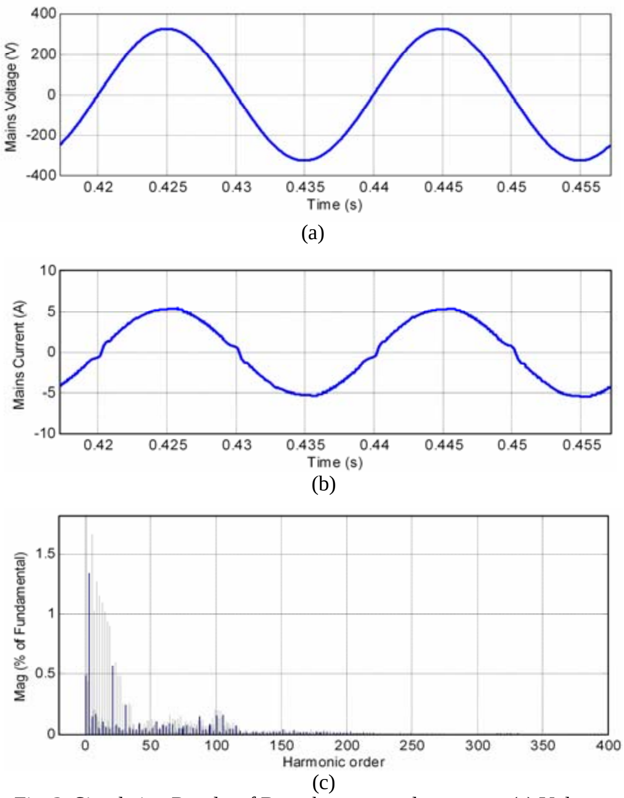
Results are shown on Fig. 3. The harmonics is evaluated using the built-in function of SimPowerSystem which easily generates the harmonics report from the output current waveform.

The single-stage self-commutated H-bridge inverter designed clearly meets all standards requirements for grid connection. Fig. 3(c) shows the harmonics up to order 400th (with fundamental frequency equal to 50*Hz*).

Using the PI regulator, two main processes were established simultaneously by using the H-Bridge; harnessing maximum power from the PV module through the DC filter with setpoints created by MPPT algorithm, and generating the mains current and voltage waveform at the mains frequency.

The main switch command (PI) and the sub regulator, the THD regulator is designed using system's step response and does not consider the transient behavior.

As it can be seen in Fig. 3(b), the zero-crossing contributed to an increase in THD. This zero-crossing distortion is mainly due to dead time when all switches in the H-Bridge are off (dead-time). Introducing THD, PI regulator decreased the THD only by 0.5% but DC component also reduced quite significantly to 0.15%. In comparison to the standard particularly IEC 6172, which regulates inverters with power up to 10kW, the maximum current THD allowed to be injected into the mains is 5% and DC injection must be less than 1%. Thus, the inverter meets these minimum standards fairly well.



(a)

(b)

(c)

Fig. 2. Simulation Results of Bang-bang control strategy – (a) Voltage (reference), (b) current, (c) Harmonics in current

TABLE I.
Summary of Simulated Results.

Characteristic	**Results**
Solar Cell Efficiency ($\eta_{Solar} = P_{AC} / P_{DC}$)	11.49%
Inverter Efficiency ($\eta_{Inverter} = P_{AC} / P_{DC}$)	95%
Adaptation Efficiency ($\eta_{Adapt} = P_{DC} / P_{Max.DC}$)	99%
Static efficiency ($\eta_{Static} = \eta_{Inverter} \cdot \eta_{Adapt}$)	94%
Total system efficiency ($\eta_{System} = \eta_{Solar} \cdot \eta_{Static}$)	10.8%
THD	3.80%
DC component	0.15 %
Transient time	0.075s
Mains Voltage (rms)	230V
Mains Current (rms)	3.78A
Simulation Time step	10 μs.
Simulation Time	10s

Overall, the system performed quite well in all areas as summarized in Table II. The crystalline silicon PV module has efficiencies typically comprise between 9-13.5% and comparative inverters in the market have efficiencies over 90% according to [5].

III. Conclusion

In this paper, a single stage H-Bridge inverter is designed. The full grid connected PV system is simulated to study the effect of bang-bang switching command on the mains power, particularly focusing on the current. All real life parameters like switching, dead time, insulations conditions and grid influences have been taken into account.

Notwithstanding of losses in components, results show that the inverter designed meets all relevant standards requirements. The PI regulators works fairly well at the maximum irradiation of 1000 W/m^2. Like many controllers for other physical systems, it is possible now to simulate fairly accurately the performance of a model PV inverter in a software PV model before going on to realize the actual device for further analysis of component loss etc. With rapid development process, this inverter is fully realized as software model first to study the effect of topology selected for the system.

References

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[5] G. Hagmann, *Leistungselektronik*, 2nd ed, Aula Verlag, Wiesbaden 1998.