Compatibility Analysis of Grid-connected Pico-hydro Systems using Conventional Photovoltaic Inverters

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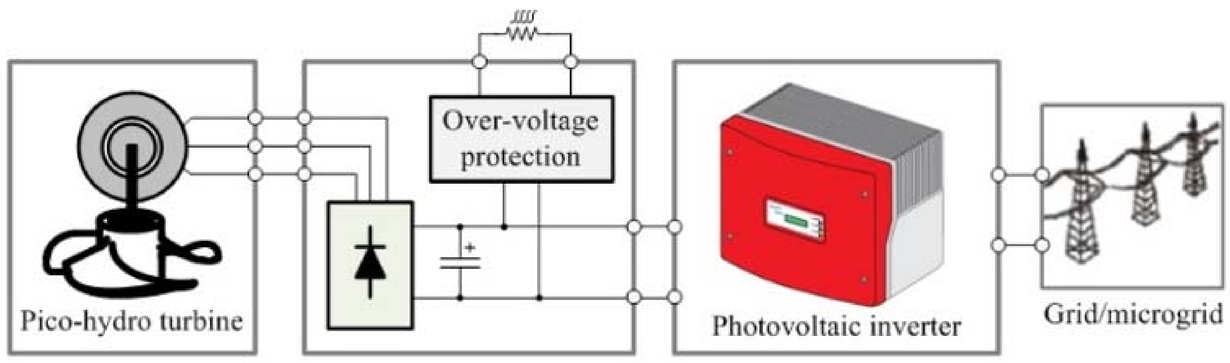
Introduction

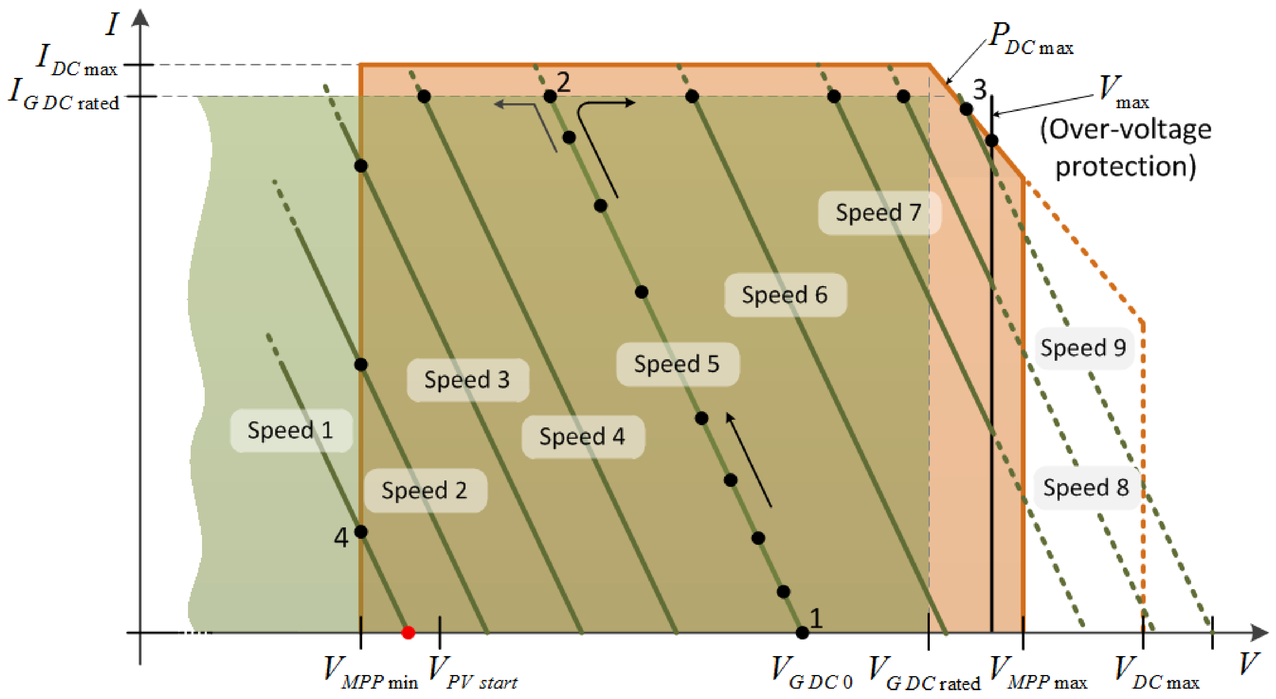
Small scale hydropower has a considerable untapped potential, able to contribute to the increased energy demand.
The integration of these systems into microgrids is an emerging solution for the electrification of remote areas and for self-sustainable power systems.
Taking into account variability of heads and the water flow seasonal variation, the efficiency of pico-hydro power plants is greatly improved if they may work at variable speed, enabling increased energy capture.
This work is devoted to the design and compatibility analysis of variable speed grid-connected pico-hydro systems using conventional photovoltaic inverters, which provides cost effective solutions able to explore a large amount of feasible sites.
In order to corroborate the proposed design procedure, experimental tests of the proposed innovative topology with two inverters and selected generators are presented, evaluating the performance in steady state and dynamic conditions.

Design Procedure of Grid-connected Pico-hydro Systems



- Fixed-blade propeller water turbine
- PM synchronous generator
- Power rectifier bridge
- Over-voltage protection circuit
- PV inverter

Integration Procedure



Superposition of the operating areas of the inverter and the generator

1 $0.4P_{DC\,max} \le P_{G\,rated} \le P_{DC\,max}$

2 For the speed range of the application:

$$V_{DC\,min} \le V_{G\,DC} \le V_{DC\,max}$$

3 Compatibility between the inverter and the generator:

$$P_{DC}/V_{DC\,min} \le I_{G\,DC\,rated} \le I_{DC\,max}$$

4 Over-voltage protection: $V_{max} < V_{DC\,max}$

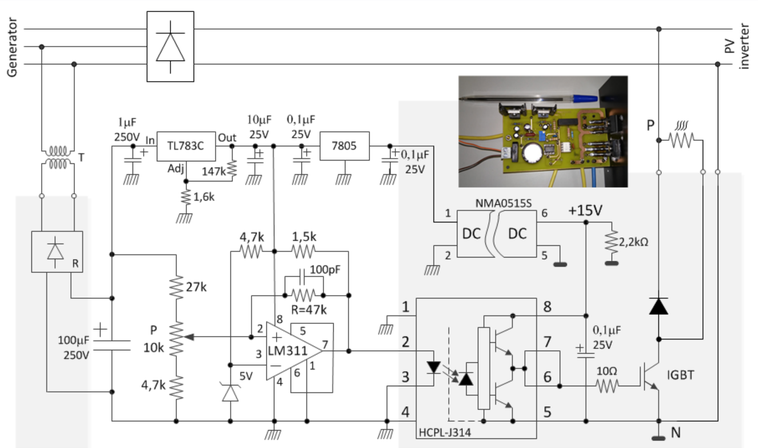
5 For the initial speed: $V_{G\,DC\,0} > V_{PV\,start}$

6 Dynamics of the generator should be compliant with the tracking period of the MPPT algorithm

The maximum admissible current may be set by $I_{DC\,max}$ of the inverter, or through the internal impedance of the generator, from which the voltage drop superimposes an incremental current variation in finding the MPP.
Usually, this situation occurs near the generator rated current, preventing critical overloads.

Over-voltage Protection Circuit

Controls the power flow to an auxiliary power resistor to reduce the generator speed and thus the over-voltage in the event of surpassing a DC voltage limit.



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Experimental Analysis

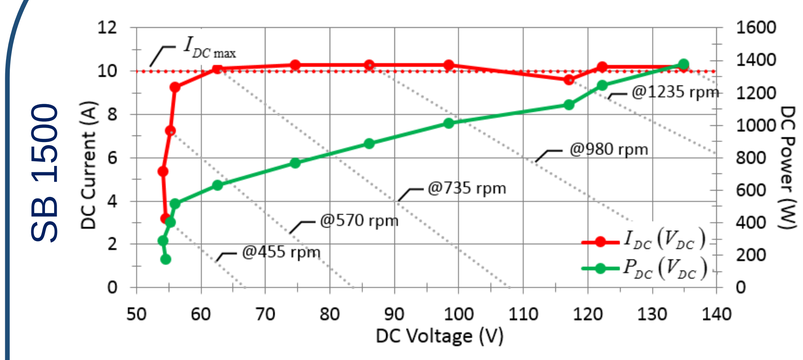
To validate the proposed design topology, the overall system has been tested with two standard PV inverters and selected PM synchronous generators.

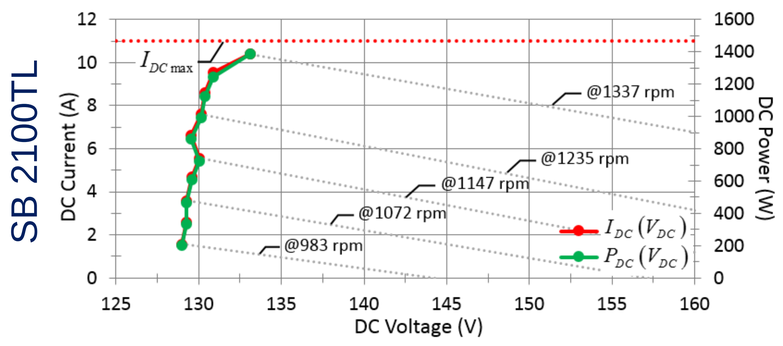
Generator (winding)	V/rpm	W/rpm	@ 1500 rpm			
			$V_{DC\,0}$ (V)	V_{DC} (V)	I_{DC} (A)	P_{DC} (W)
1	0.15	0.86	219	150	8.6	1297
2a (star)	0.25	0.87	381	266	4.9	1300
2b (delta)	0.15	0.83	223	148	8.4	1245

Inverter	$P_{DC\,max}$ (W)	$I_{DC\,max}$ (A)	$V_{DC\,min}$ (V)	$V_{DC\,max}$ (V)	$V_{MPP\,range}$ (V)	$V_{PV\,start}$ (V)
SB 1500	1600	10	50	600	160-500	80
SB 2100TL	2200	11	125	600	125-480	150

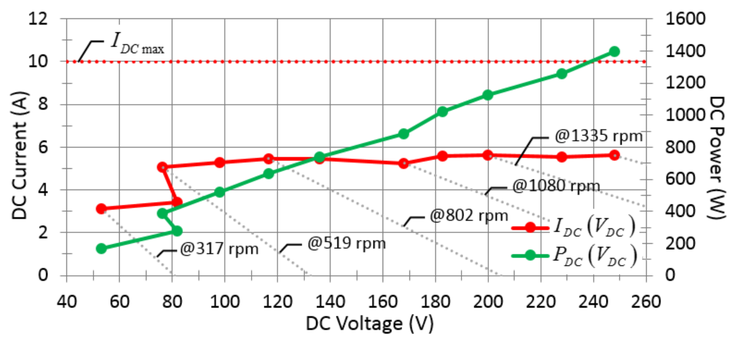
Steady State Operation

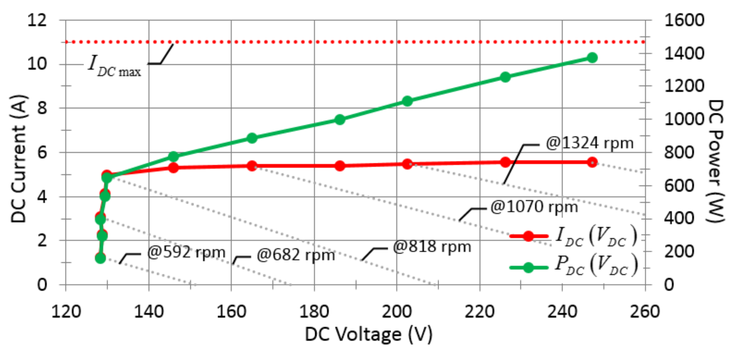
Generator 1



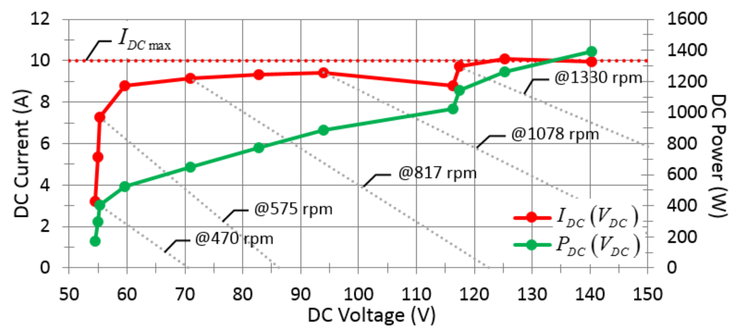


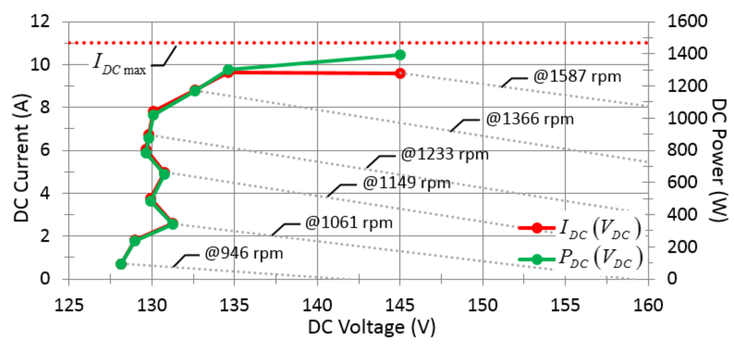
Generator 2a





Generator 2b



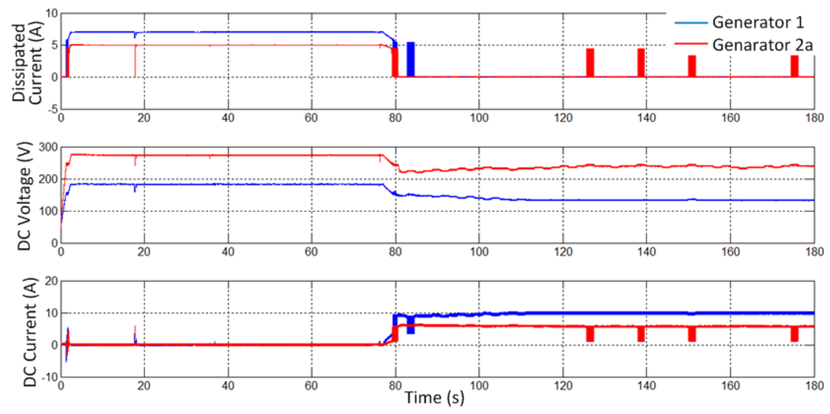


Operating points of the generators are within the SOA of the inverters without surpassing their rated quantities in a critical extent, provided that the reference mechanical power is kept in the power range of the generators and the compatibility conditions are verified.

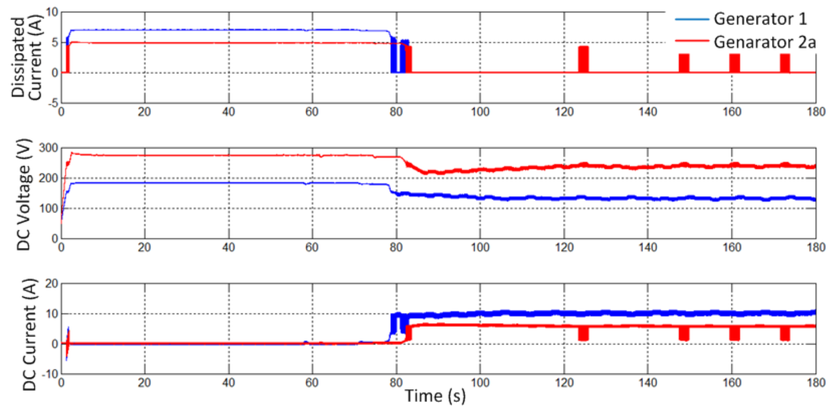
Dynamic Operation

Synchronization with the utility grid

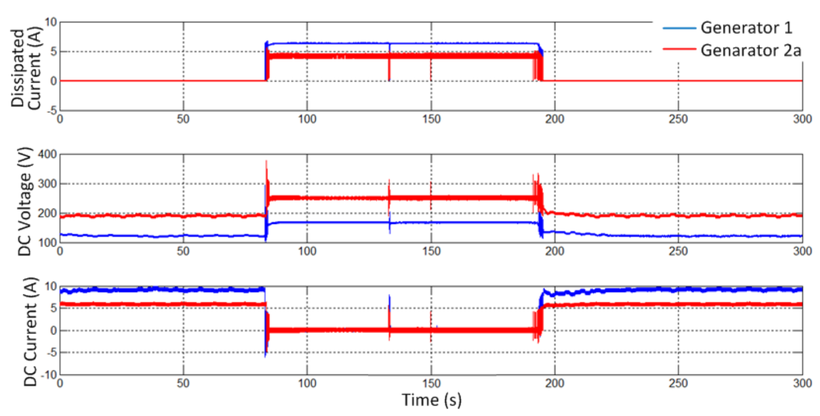
SB 1500

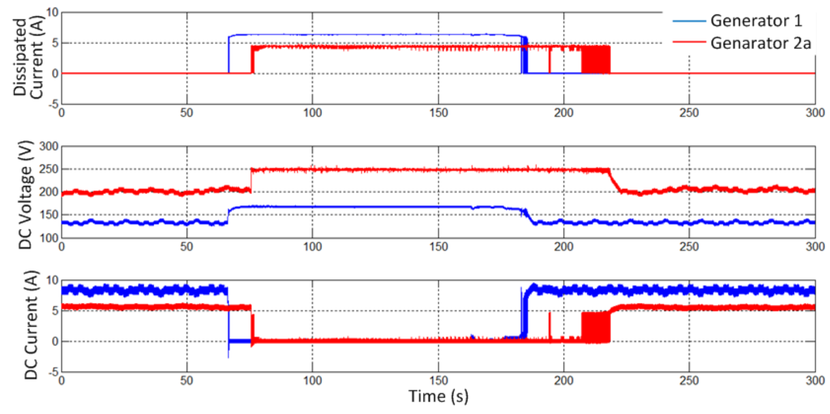


SB 2100TL



Grid failure





Conclusion

The proposed topology allows a variable speed operation mode whereas a MPP tracking is provided by the PV inverter.
An over-voltage protection circuit was designed in order to protect both the generator and inverter against special states, such as sudden relieving of the inverter due to grid failure.
Steady state and dynamic performances of the proposed approach have been experimentally tested under power control by using a turbine emulation system.

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