



Advanced Pumped Storage Hydropower and Ancillary Services Provision

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2017 HydroVision International
June 27–30, 2017

Denver, Colorado

NREL/PR-5D00-68453

Objectives

- Study A-PSH and ancillary services provision.
- Two types of configurations are discussed:
Type 4 and Type 3.
- A small system (250 kW) and a large system (460 MW) are considered.
- Various controls are considered.

Two Common Configurations of A-PSH

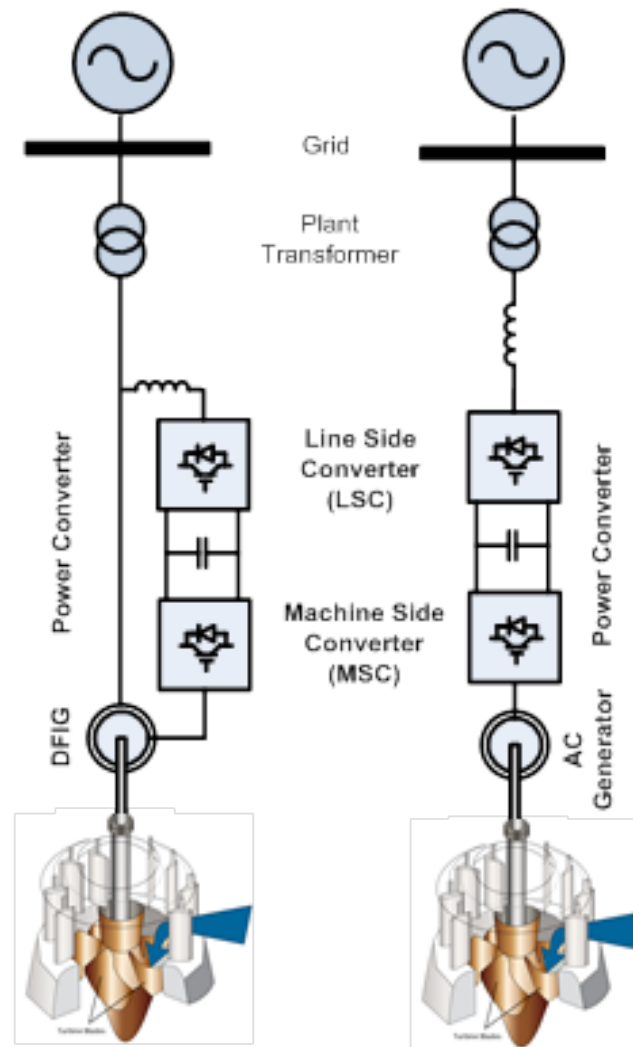


Fig. 1. Diagram of the physical connection of a Type 3 and Type 4 A-PSH. Image from Wikipedia

Hydro Turbine Control

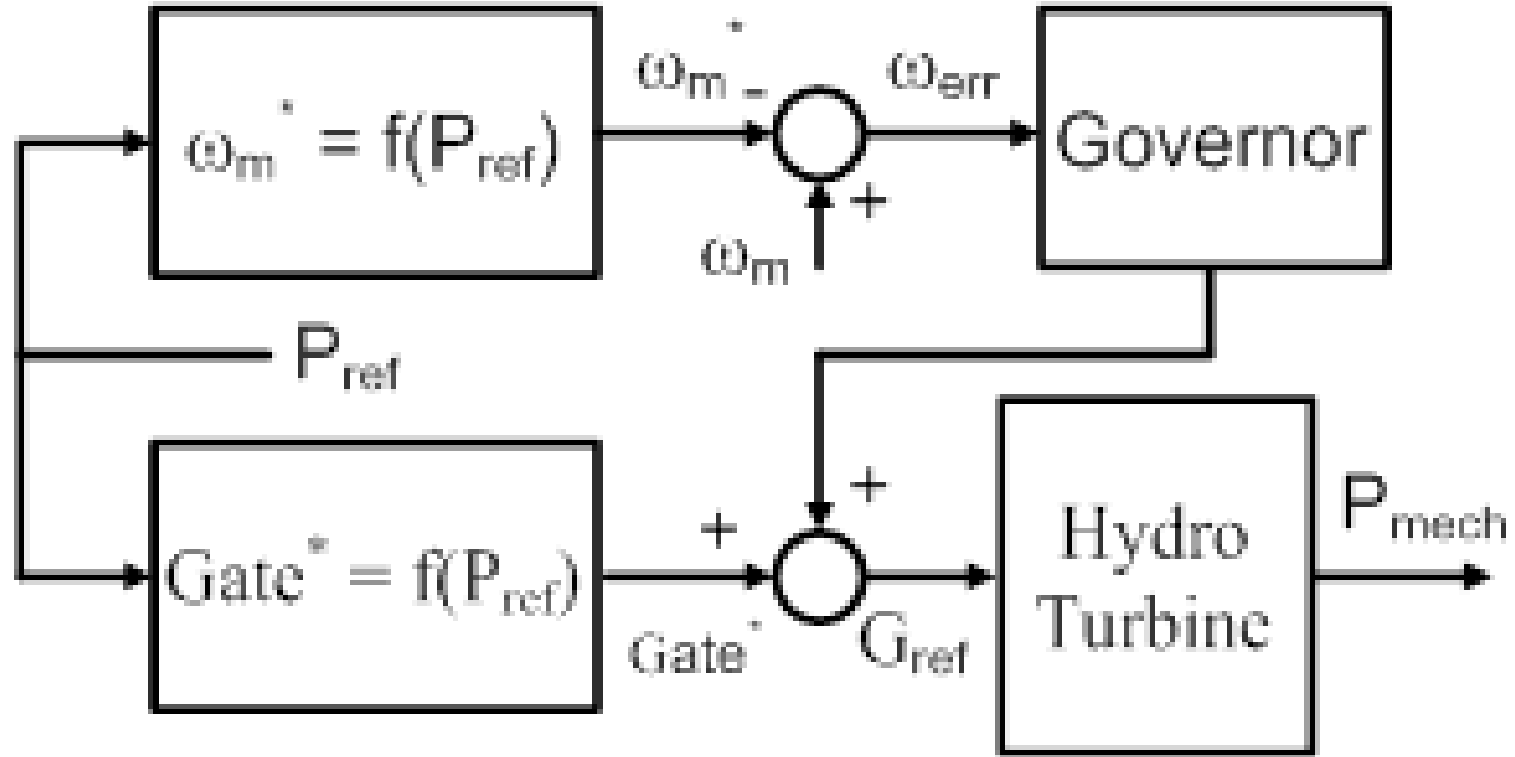


Fig. 2. Simplified diagram of a hydro turbine control

Typical Power Conversion in a A-PSH

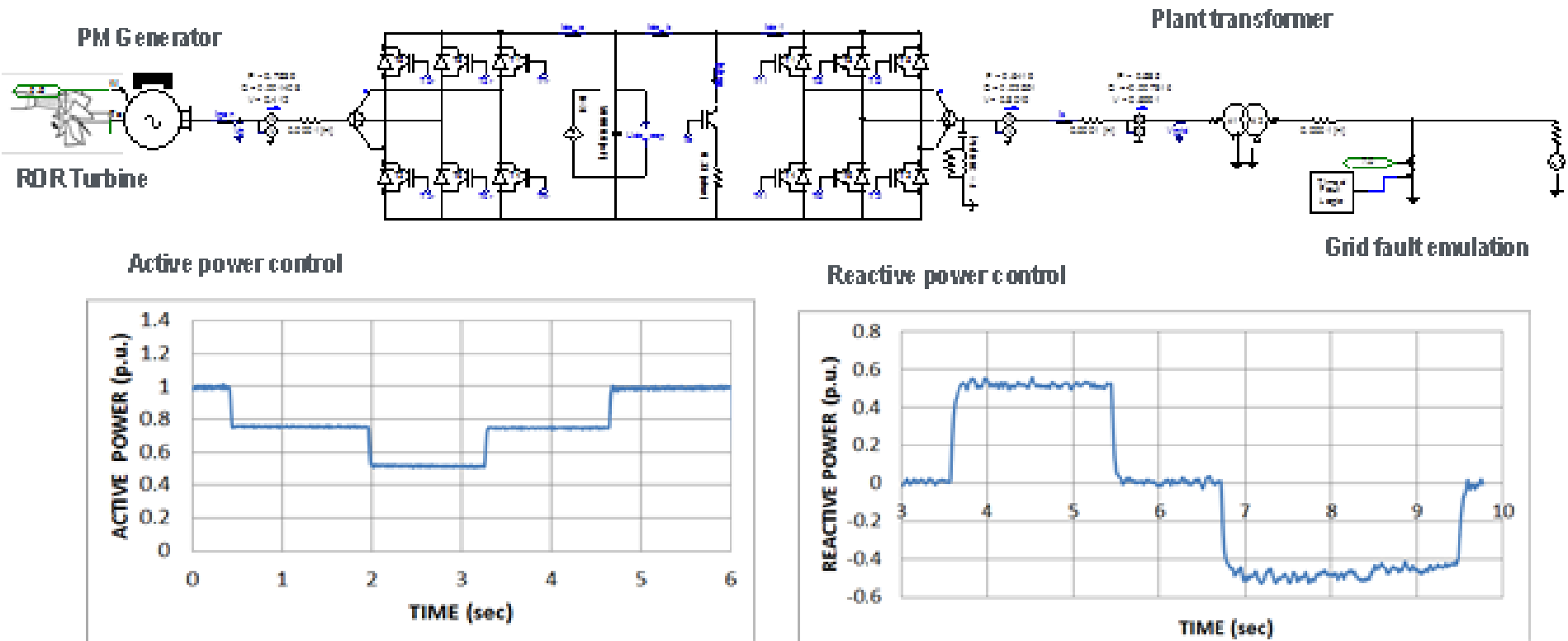
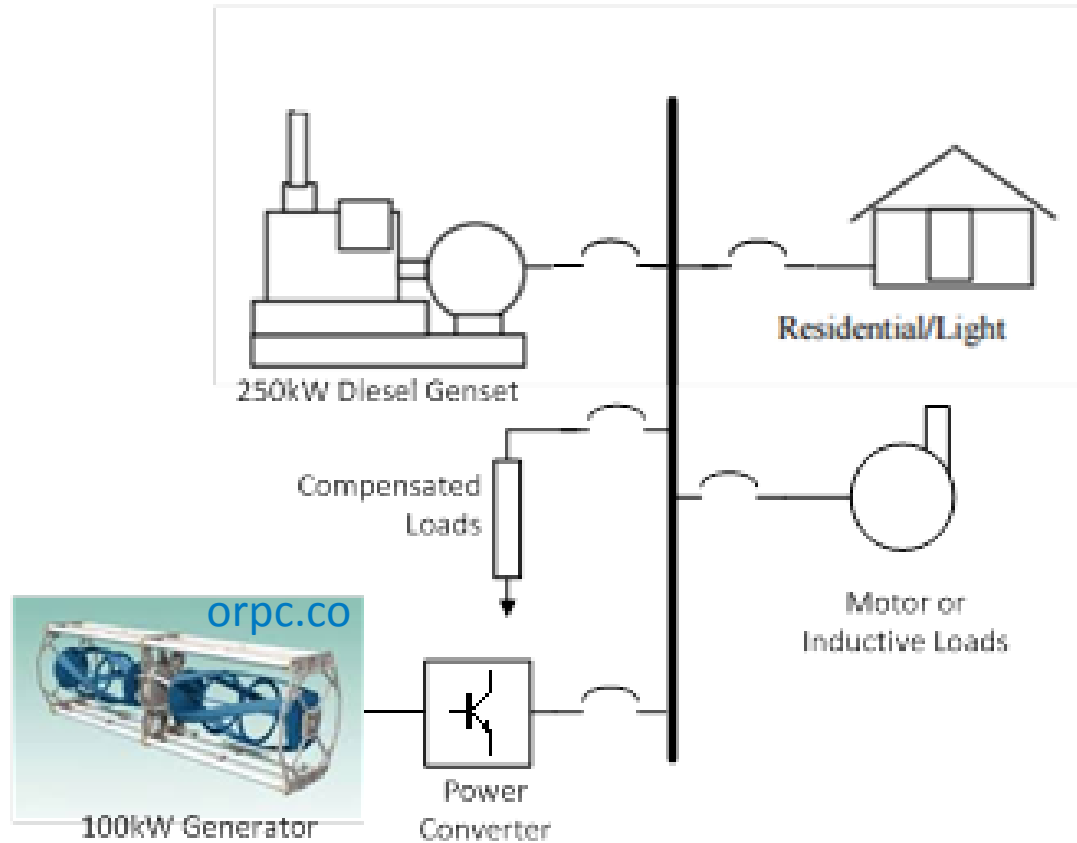


Fig. 3. Detailed transient model of a permanent magnet synchronous generator—full converter topology

A Small System Case Study



<https://www.pinterest.com/source/orpc.co/>

Fig. 4. A small system to showcase the ancillary services provision

A Small System Case Study

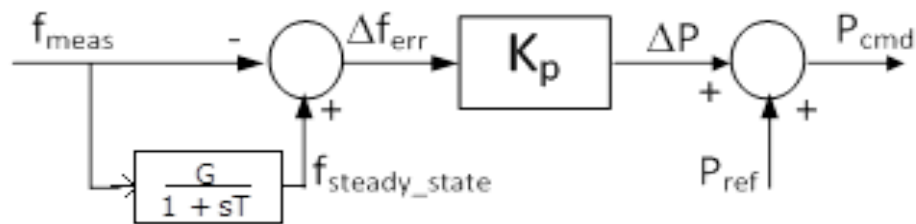


Fig. 6. Control block diagram to assist in frequency regulation of the diesel genset

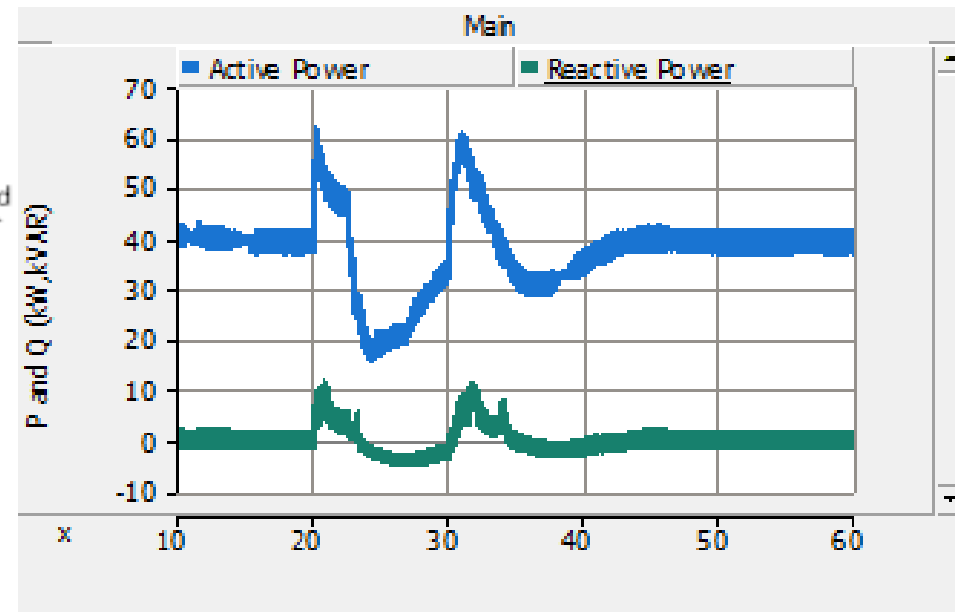
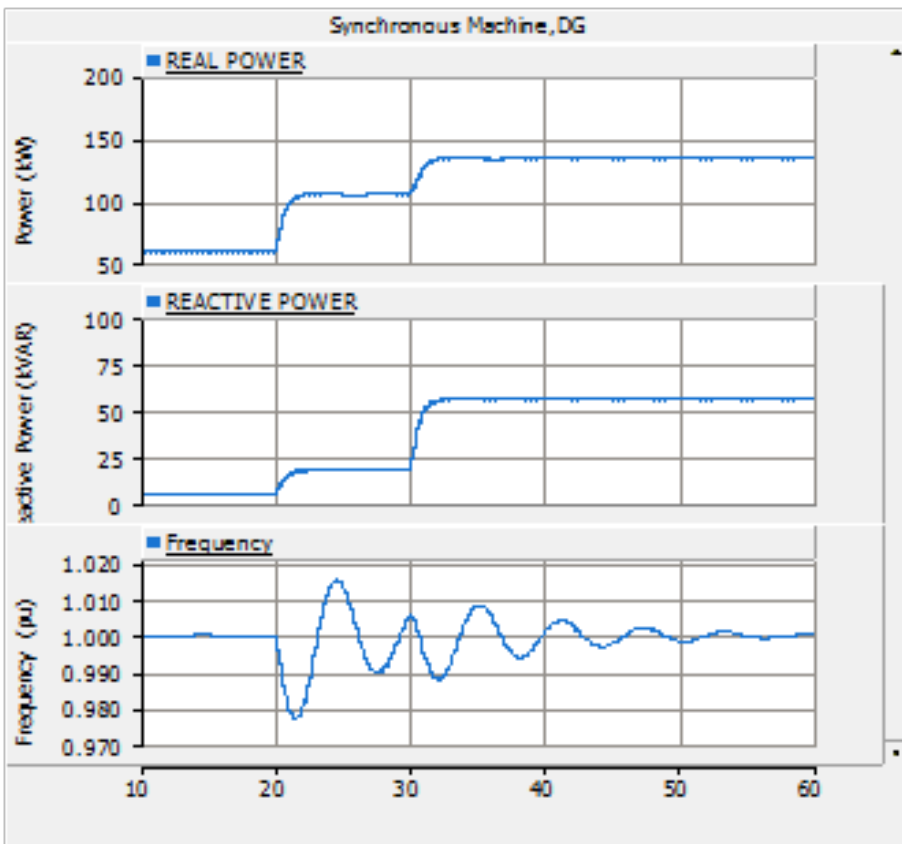
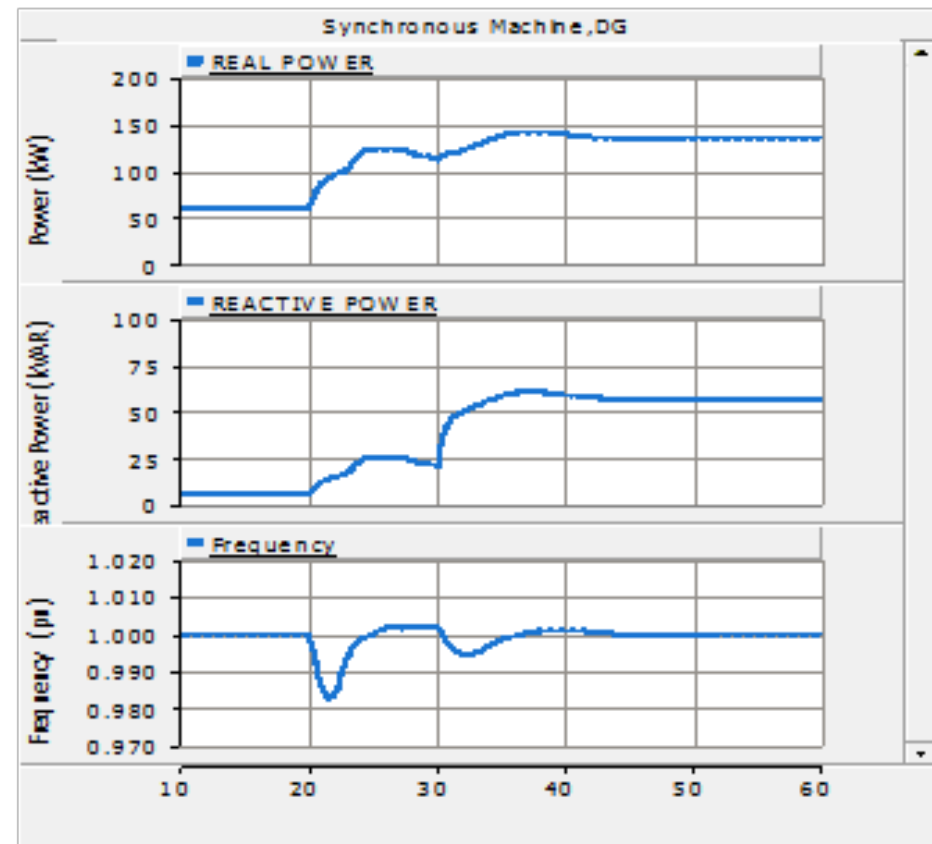


Fig. 7. Power converter output to assist the diesel genset governor in controlling the grid frequency

A Small System Case Study



No frequency compensation by hydropower



The frequency compensation of the hydropower is implemented on the power converter.

Fig. 8. Real and reactive power output and the corresponding frequency of the diesel genset output.

A-PSH Provides Constant Output Power

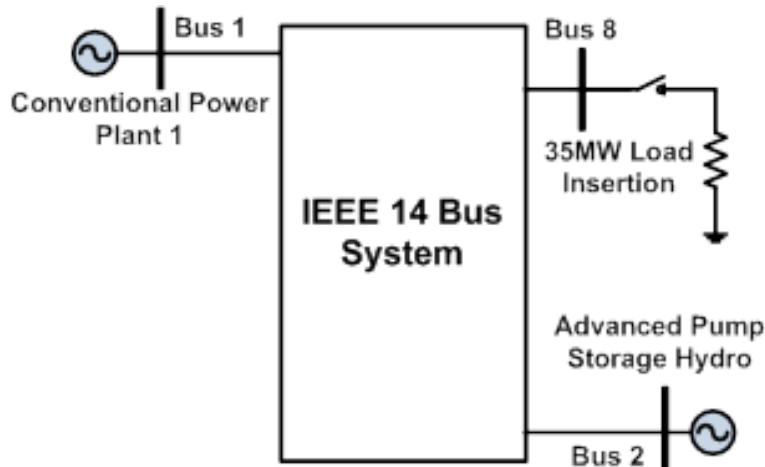


Fig. 9. Simplified diagram of the IEEE 14-bus system with the A-PSH connected at Bus2 and the load connected at Bus 8.

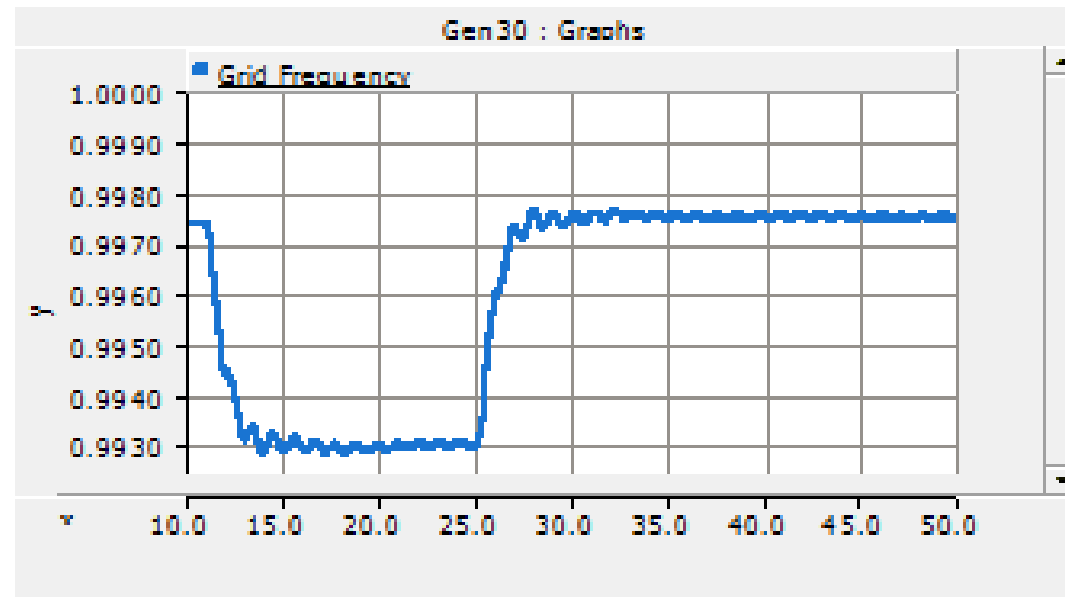


Fig. 10. Grid frequency as the 35-MW load is inserted into the grid at 11 s and the load is removed from the grid at 25 s. A-PSH is set to generate constant power at 45 MW.

A-PSH Provides Ancillary Services (Inertial Response)

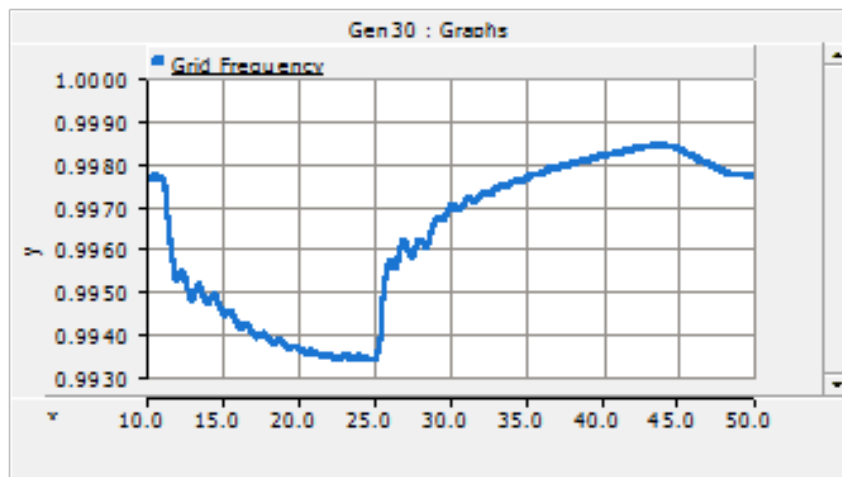
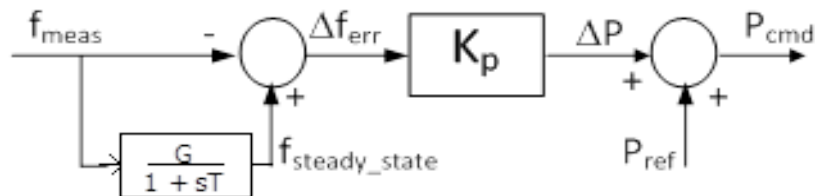


Fig. 11. Grid frequency as the load is inserted into the grid at 11 s and the load is removed from the grid at 25 s.

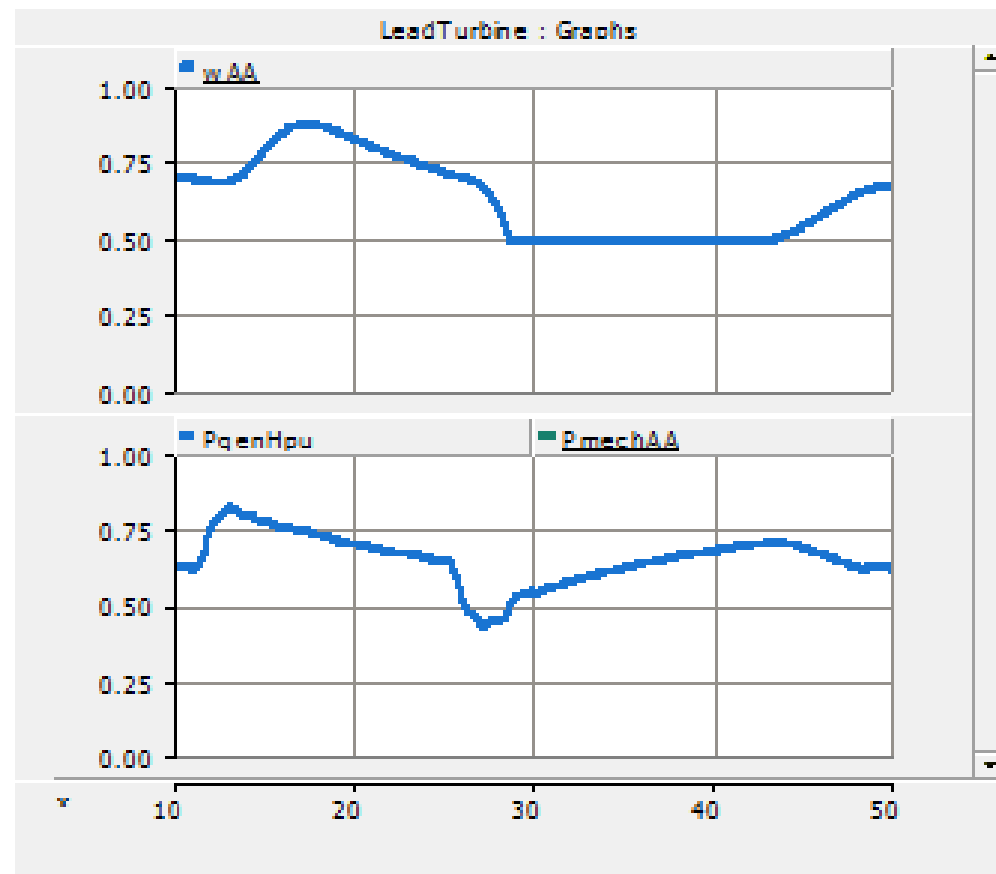


Fig. 12. Rotational speed (top) and output power (bottom) of the A-PSH as the load is inserted into the grid at 11 s and the load is removed from the grid at 25 s.

A-PSH Provides Ancillary Services (Transient and Steady-State)

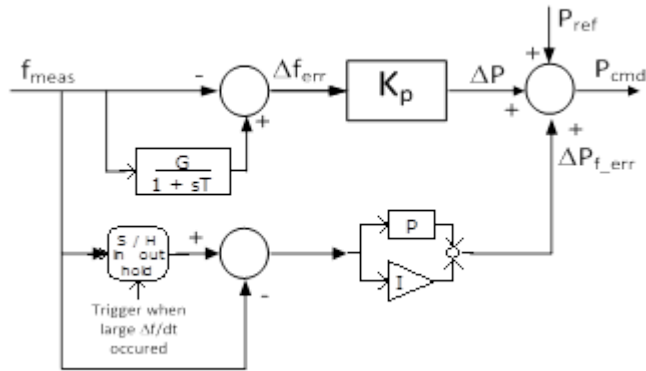


Fig. 14. Modified controller to include frequency regulation from the A-PSH, thus combining the inertial response at the beginning of the transient and the frequency restoration at the end.

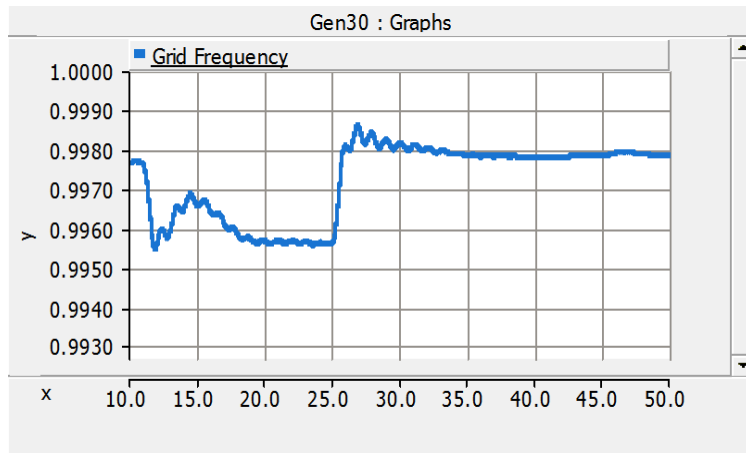


Fig. 11. Grid frequency with modified controller as the load is inserted into the grid at 11 s and the load is removed from the grid at 25 s.

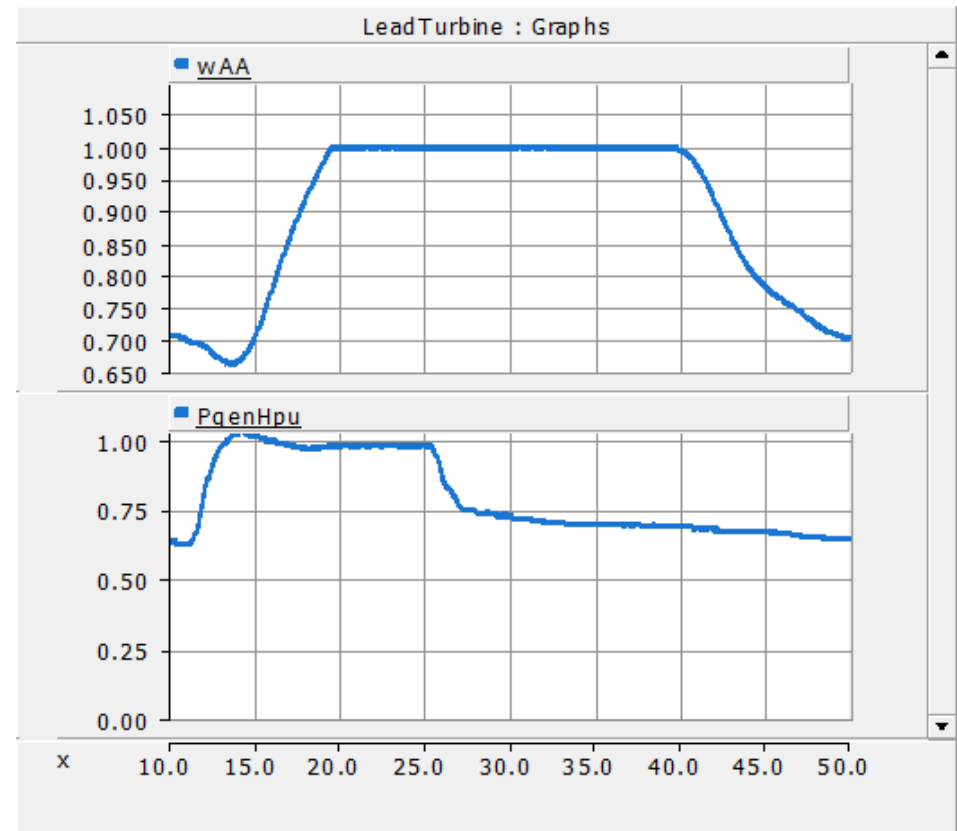
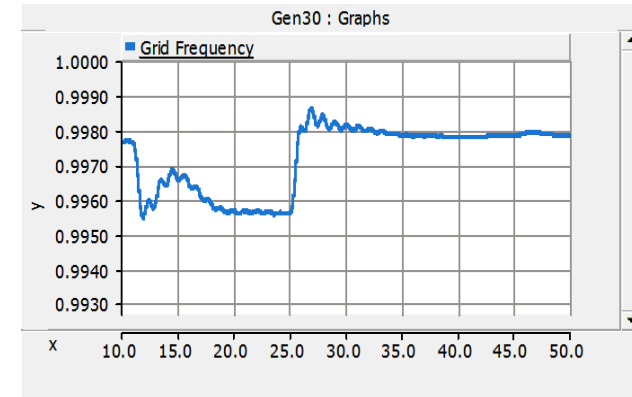
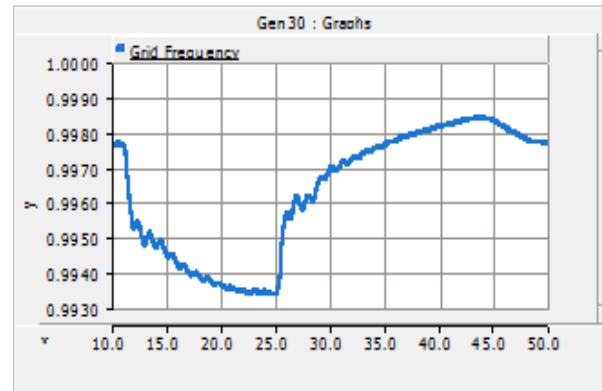
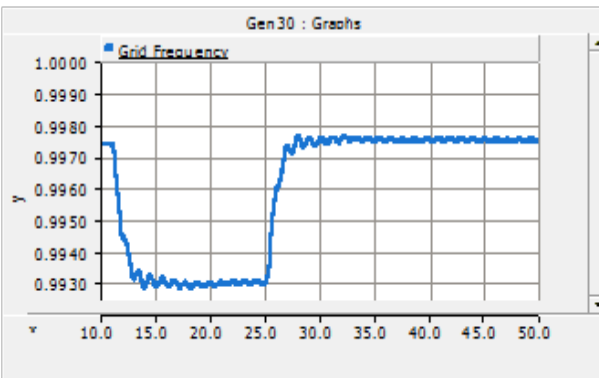
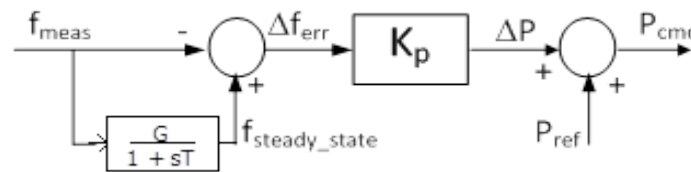


Fig. 15. Rotational speed (top) and output power (bottom) of the A-PSH with modified controller implemented.

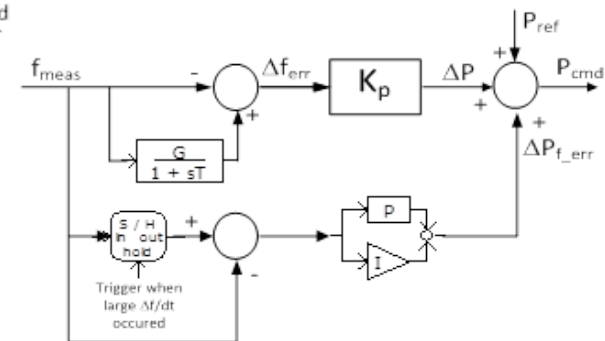
Comparison of Three Different Controls of A-PSH



**A-PSH at constant power
45 MW (constant).**



**A-PSH provides transient
power support
(inertial response).**



**A-PSH provides transient
power support
(inertial response)
and maintained zero
steady-state error.**

Conclusions

- A-PSH is commonly operated in variable speed and equipped with a power converter to control the generator and to control the grid interface.
- The power converter is able to control the real and reactive power instantaneously and independently.
- A-PSH is suitable to provide ancillary services to the grid because of the flexibility of the power converter control.
- A-PSH is not only a power plant but also can be considered an active storage capable of adjusting output power very quickly and is suitable to balance out the renewable power plant.

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