New possibilities for reducing the cost of pumped storage backup for intermittent wind and solar power

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Traditionally pumped storage has been used for peak shaving, i.e. the electrical motors pumped water up a mountain towards a storage dam at the top for prolonged periods of low power demand over weekends, where after the stored hydro energy was retrieved over the course of the following five week days to supplement the supply of power demand peaks by allowing the water to flow down the mountain to drive a power generation turbine.

This long timeframe demanded large storage dams, or, for a given dam size, small turbine capacities. The introduction of intermittent wind and solar PV power is changing the need to short-term pumping when the wind is blowing or the sun is shining and short-term power production when clouds move in front of the sun or the wind suddenly stops blowing. Since wind and PV-solar will create multiple opportunities to refill the dam in a typical day, more turbine-pumps can be coupled to a given dam, which will reduce capital cost. Since pumped storage has virtually zero variable costs, the multiple extra pumping and power production sessions will come at virtually zero additional cost. Relatively new variable speed pump-turbine technology adds the possibility to do ultra-short-term frequency control by varying the power consumption of the pump or the power production of the turbine in real time in order to match the ultra-short term variations in power output of wind turbines as the wind is gusting.

Variable versus fixed-speed pumped hydro storage

The need for pumped storage

Due to very sharp drops in cost, wind and solar photo-voltaic (solar-PV) power has in a few years changed from the most expensive to the cheapest readily available sources of new power in South Africa. These sources are also more flexible as they can be deployed much faster than traditional base-load power sources such as nuclear and coal. With price out of the way, there remain only one stumbling block that currently prevents the large scale deployment of wind and solar-PV power, namely its intermittency. As the wind speed is exceedingly intermittent and the sun can disappear behand clouds for days a combination of wind and solar-PV power is substantially unreliable, unless a reliable source of backup can be added to it. In the US the current glut of cheap shale gas is used to fuel gas turbines as cheap back-up for wind and solar-PV. However, since South Africa has not yet been able to confirm large amounts of shale gas that can be mined affordably in for instance the Karoo, one solution would be to import liquefied natural gas (LNG) from e.g. the US, gasify it here and use it to fuel gas turbines as backup. However imported LNG is much more expensive than locally mined shale gas and therefore the gas option is much less attractive in South Africa than in the US. Also shale gas mining creates pollution and release of relatively small amounts of methane gas. Since methane is a 22 times as strong greenhouse gas as CO_2, this released of methane creates a substantial global warming cost, even though still substantially less than that of coal. Importation of large amounts of LNG will also put further pressure on the balance of payments of the South-African economy, which is likely to weaken the rand further. Such imports also create strategic risks for South Africa, such as the risk of economic boycotts or disruption of supply terrorist attacks on importation lines. All of these factors create scope for a local clean, sustainable and virtually CO_2-free storage technology, such as pumped hydro storage.

The potential of variable-speed pumped storage for very short term frequency stabilisation

Traditionally pumped storage in has been used for peak shaving, i.e. the electrical motors pump the water up a mountain at a constant speed and power towards a storage dam at the top. This happens for prolonged durations of low power demand over weekends. It thus takes several days of pumping to fill the dams. (Pumping also takes place during the hours around midnight during weekdays.) Thereafter this stored hydro energy is withdrawn to supplement the supply of peak demand, mainly during the large evening demand peak of each of the five week days. This is done by allowing the water to flow down the mountain to drive a power generation turbine, at a constant speed and power. The operational cycle from fully filling the dam at the top to fully emptying it was thus typically a week. This deployment strategy was typically designed for a grid with low intermittency, but with regular sharp demand peaks that must be supplied, as was until recently the case for the mainly coal power-supplied South African grid. Globally this picture is changing rapidly as large generation capacities of intermittent wind and solar PV power are added to the grid. Times of oversupply and shortage are thus becoming increasingly erratic as solar-PV power will cause oversupply around midday on sunny days and the wind power during random periods of the day when the wind might blow strongly. These times of oversupply can rapidly change into times of shortage if the sun were to disappear behind clouds or the wind were to die down, which it is wont to do. This means that a new potential role for pumped storage is busy opening up, namely very short term frequency stabilisation by rapidly increasing the rate at which power is consumed to drive the electric pumps during times of oversupply and then rapidly switching to producing varying amounts of power from the hydro turbines when power shortages were to occur, or when the output of the wind or solar plants were to simply fluctuate or oscillate, as they regularly do.

Although the technology for variable speed pump-turbines is already well established [1], it has not yet been adopted widely as it is more expensive than the standard constant speed pumps and turbines and since there was little need for variable speed pumps before intermittent renewables penetrated global grids on a large scale. However, for a Spain-like grid which contains a high penetration of intermittent wind and solar-PV, using variable speed pump-turbines to do frequency control is twice as profitable as using constant speed pump-turbines to do merely peak shaving [1]. [2] also showed variable speed pump-turbines to be profitable in the Spanish power market. However, repeating these analyses for the South-African power grid will required detailed grid stability studies which fall outside the scope of the present study and therefore it is referred to a follow-up study.

The technology for variable-speed pumped storage

Variable speed pumps are driven by synchronous motors and therefore their rotation speed is fixed by the frequency of their AC power supply. The AC frequency is then modified by means of a frequency converter, which gives the operator control over the frequency and thus over the speed and thus the power consumption at which the motor will drive the pump. Variable speed control in the turbine mode is achieved by means of short-circuiting the water flow to the turbine [2]. The disadvantages are that variable speed pump-turbines are more expensive than constant speed ones and that short-circuiting the water flow to the turbine reduces the efficiency. However, in view of its potential to do affordable frequency control in intermittent grids, the advantages outweigh the disadvantages and therefore it is recommended that Eskom/DOE should seriously investigate this technology for South Africa.
[3] also showed that adding a second turbine to a pumped storage scheme is substantially cheaper than the costs of the first one, as the first one has to also pay for the construction of the dam and the civil works. For instance, adding as second 1 GW turbine to an existing 1 GW scheme reduces the average capital cost of the two turbines to 72% of that of the first one. However, it should be noted that there is a possibility that for some of the currently operating pumped storage schemes, the civil works are nod adequate to handle the switch from fixed to variable speed pump-turbines or to handle the suggested additional pump-turbines.

The economics of variable-speed pumped storage

As pumped storage schemes have practically zero variable costs, the levellised cost of electricity (LCOE) of storage is inversely proportional to the load factor. In the absence of intermittent renewables, these load factors are typically quite low, for instance the Draft 2016 IRP Base Case [4] estimates it at only 22%. If the presence of intermittent renewables were to double this load factor to 44%, the LCOE for storage would half from the current R1,20 to R0,60/kWh. Since the round trip efficiency is only 78%, due to frictional losses, storage and retrieval will add an additional 28% to the LCOE of the original power, over and above the said LCOE of the storage scheme. This means that if wind or solar-PV power, obtained at the currently expected cost of about R0,60/kWh, the total LCOE of the retrieved power at a 44% load factor would amount to R1,39/kWh. This is substantially more than the LCOE for imported LNG fuelled combined cycle gas turbines (CCGT) of approximately R1,00/kWh, which can be obtained by increasing the load factor to above 60% [4: Fig. 5]. However, it is much lower than the LCOE for LNG fuelled open cycle gas turbines (OCGT) power of between R2,00/kWh and R3,00/kWh (depending on the load factor). Replacing South Africa’s planned fleet of OCGTs with pumped storage schemes will also substantially reduce the strategic risk associated with SA’s dependence on imported LNG. The exact figures can only be obtained accurately by doing detailed calculations that would supply the load factors and capital costs for all these options. Such calculations falls outside the scope of the present study. However, it is clear from these preliminary results that it would probably be profitable for South Africa to replace most its intended OCGTs with pumped storage, so that the grid will then be stabilised by a combination of CCGTs and pumped storage schemes.

Research showed that the profitability of doing frequency control for intermittent wind and solar-PV with variable-speed pump-turbines can be improved even further if the output of the wind turbines are constrained when there is too much over production and if demand is moved away from periods of power shortage to periods of oversupply by means of dynamic demand response (DDR). This suggests that if all these features were to be added to the CSIR’s simulated strategy of stabilising the output of wind and solar-PV my means of only output curtailments and gas turbines, the LCOE of the dispatchable output could be reduced below the R1,00/kWh estimated by the CSIR.

Conclusions

- While it has been shown that more calculations are needed, it can be concluded from the current preliminary analysis that variable-speed pumped storage may present a cheaper, cleaner, and more sustainable form of back-up for intermittent wind and solar-PV power than the currently planned fleet of LNG fuelled open cycle gas turbines.

- If variable-speed pumped storage can be combined with the fuel efficient LNG-fuelled open cycle gas turbines the combination could provide backup that is on average reasonably affordable, clean and sustainable.
- Such a backup scheme, which is currently lacking in the South-African power grid, could substantially increase the scope for deploying large generation capacities of cheap new intermittent wind and solar-PV power.
- The combined effect could be to substantially lower South Africa's greenhouse gas emissions at an affordable cost.

References

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