Potential for New Pumped Storage Schemes in South Africa

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Abstract—**On the South African grid, pump storage schemes offer a range of benefits. They improve grid flexibility and service peak demand, while also increasing the base load utilization level for thermal plants. Financially they potentially offer higher returns compared to alternative peak generation options that use relatively high cost fuel. The Integrated Resource Plan for South Africa currently proposes adding gas turbines and batteries to the future grid for peaking capacity and increased flexibility, with no added pump storage. This paper investigates the costs, services and contributions of pumped storage on the grid, the history of this technology and its potential future role. Within the South African context the paper aims to address the possible misconception of limited pump storage scheme site availability by providing an overview of site feasibility studies conducted in the last ten years, including estimated cost projections. Ultimately the paper argues that there is still potential for additional pumped storage on the future grid, and that further research should be done in order to analyze and better inform the energy modelling inputs and assumptions which are currently being used.**

Keywords— Pumped storage, ancillary services, variable renewable energy, gas turbine, flexible generation

I. INTRODUCTION

Eskom, South Africa's national power utility, has the following flexible resources based on a 2017 study: 2.7 GW Pumped Storage (PS), 3 GW Open Cycle Gas Turbines (OCGT) running on diesel fuel, 14 GW of fast-ramping capacity from coal fired plants and meaningful quantities of Demand Response Resources [1]. The overall energy generation capacity of South Africa is currently increasing with 9.5 GW from two large coal-fired power stations, Medupi and Kusile, which are nearing completion, and with more than 20 GW of renewable energy by 2030 [2].

Coal fired plants are considered as base-load stations as far as generation is concerned and previously their production was supported by additional peaking capacity to allow for constant production and reduced ramping. Looking into the next 15 years, Eskom's coal fired generation is still the dominant supplier of energy. However, these coal stations will most likely be under-utilized with the increasing penetration of renewable energy generation. Furthermore, the additional variable renewable generation will most likely result in an increased requirement for flexibility from Eskom's fleet [1]. Utility-scale storage can provide a solution for grid flexibility and increase the baseload plants' utilization factors.

The South African Integrated Resource Plan (IRP) released in 2019 [2] proposes gas turbines and batteries as the new flexible generation technologies to manage peaking capacity and the variability associated with increased renewables. The significant planned future dependence of the South African power system on market-based gas exposes the economy to a number of potential risks [3].

In this paper, PS is proposed as an alternative technology to gas turbines and batteries for peaking and flexible generation. In section II the paper provides a review of PS technology internationally and of future PS predicted costs and trends. In section 3 it then focuses on the history of PS schemes in South Africa, and on how and why PS was incorporated into South African IRPs over the years. A common misconception, of the limited PS scheme site availability in South Africa, is also addressed by providing an overview of studies conducted in the last ten years for potential PS scheme sites and their estimated cost projections. The final section concludes the paper.

II. PUMPED STORAGE INTERNATIONALLY

A. International history and trends

PS technology development started after World War II when populations increased and rapid economic growth reshaped demand curves by increasing the peak to baseload ratio and creating more distinctive seasonal peaks [4].

By the 1960s thermal generators were designed for constant high output to optimize efficiency and to reduce equipment stress and lower maintenance cost. Dramatic increases in the price of oil and natural gas led to the Powerplant and Industrial Fuel Use Act limiting options to provide load-following and peaking services from gas turbines [5].

Within this context, along with the development of nuclear energy, many PS projects were built between 1960 and 1980 to absorb surplus power and generate peaking capacity. PS's capability to balance the load allowed nuclear and coal to operate at peak efficiencies, resulting in PS being evaluated as an alternative to fossil-fueled intermediate load and peaking units. Other services provided by the technology were largely ignored during this time [5].

PS scheme project development declined from the 1990's in Europe, United States and Japan, in part due to the decline in nuclear growth, market deregulation (previously PS schemes were almost exclusively built by state-owned entities), and the repeal of the Powerplant and Industrial Fuel Use Act in 1987 [4] [5]. The dramatic drop in natural gas price also played a role: in the 1970s combined-cycle gas turbines

(CCGT) and PS schemes were similar in costs, however by the 2000s PS schemes was estimated to cost twice as much as CCGT, thereby limiting its economic competitiveness. However, in countries with rapid economic development, such as China, PS was seen as beneficial for grid reliability and for bridging the gap between on and off peak demand, and was regarded as a way to aid renewable energy integration [5].

Currently the world has 161 GW of PS plants and this is expected to increase by another 78 GW before 2030 [4]. The historic and expected future growth in PS worldwide is shown in Figure 1 and Figure 2 below.

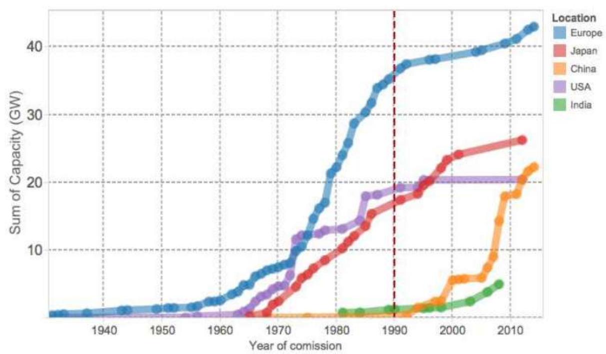

Figure 1. PS worldwide yearly increased capacity [4].

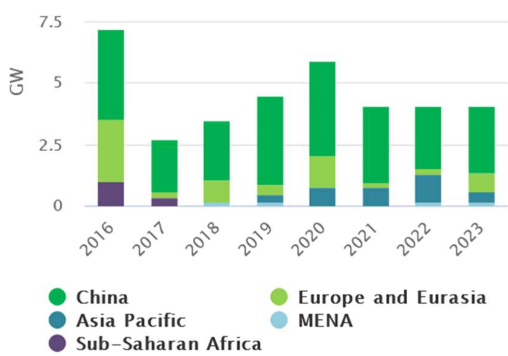

Figure 2. Annual PS capacity additions by region [6]

There have been studies which state that with the current growth in renewables the number of new PS schemes internationally have begun to increase again, driven by the need for increased flexibility and for reduced curtailment of wind and solar PV, especially in China, Europe and Asia-Pacific as shown in Figure 2.

B. PS schemes in vertically integrated, liberalized and unbundled markets

There is however also evidence to the contrary: in Germany, considered a leader in renewables, PS scheme proposals were abandoned and in 2014 several PS schemes were mothballed. Solar generated electricity reduced the price of daytime energy, and thereby the viability of PS which was previously used to discharge during this time. PS schemes with variable (asynchronous) generators received revenue from not just providing peak capacity but also ancillary services for voltage support, frequency regulation and black start services [4]. Revenue streams based solely on time-shifting energy have become a risk as dramatic market changes can occur from one year to the next.

The uncertainty of revenue with PS has also caused Switzerland to suspend two new large PS schemes in preliminary stages of construction. Switzerland typically uses PS to exploit market prices in neighboring countries and makes particular use of France's low-cost nuclear electricity for charging [4].

A study reasoned that the attenuation of PS in Europe was due to the unfavorable market conditions where spot prices are depressed, and the markets are unbundled and liberalized [4].

In comparison, vertically integrated companies or state-owned utilities with transmission and distribution (T&D) infrastructure which used PS schemes as a T&D asset were increasing capacity. They valued the technology highly for its benefits in stabilizing the power grid, providing peaking power, improving power supply quality and ensuring safe grid operation.

The largest PS schemes development has occurred in countries with substantial capacity expansion plans and no overcapacity, either for supply or flexibility. The issues with PS in the US was also highlighted where PS competes in the Day-Ahead market and costs for charging or discharging are unknown, putting the technology at a risk of making a loss. A study showed the US does not use the value of PS to assist with lowering overall energy costs, and neither has the mechanisms to reward PS for its benefits / allow more stable revenue streams for PS [5].

Unbundled and liberalized markets have a divided incentive problem to promote PS scheme investment as they are typically focused in one market segment. Vertically integrated utilities in comparison can accrue the benefits of PS throughout the network value chain resulting in lower risk premiums and therefore lower capital cost. Of the total 171 GW PS schemes installed or currently been constructed, only 4.9 GW were shown to be developed in unbundled and liberalized markets [4].

C. Value and cost of PS schemes internationally

As an energy storage technology, PS supports various aspects of power system operations. However, determining the value of PS schemes and their many services and contributions to the system is a challenge. The United States Department of Energy (US DoE) has recognized this challenge and are in the process of developing a guide to assess the value of PS schemes and their contributions to the power system [7]. The analysis is investigating the following aspects:

- value of bulk power capacity and energy arbitrage,
- value of PS ancillary services,
- power system stability benefits,
- PS impacts on reducing system cycling and ramping costs,
- reduction of system production costs, and
- PS transmission and non-energy benefits.

The international estimated costs for PS technologies differ widely as shown in Table 1, highlighting the dependency of such costs on site availability, risk premiums and storage time.

TABLE 1. *PS SCHEME COST COMPARISON*

PS scheme Cost Comparison		
Study reference	***Hour storage***	***$/kW***
Blakers et al. 2017[8]	-	560
Voith 2018 (1400 MW) [9]	10	1290
Entura 2018 (6 hrs) [8]	6	1036
PHES (48 hrs) [8]	48	1925
Enel 2018 [5]	-	2000
US Department of Energy [10]	-	2638

III. PUMPED STORAGE IN SOUTH AFRICA

A. *History of PS schemes in South Africa*

South Africa does not have an abundance of hydropower potential. The development of macro hydropower in this country has been historically associated with the development of primary water supply infrastructure and inter-basin transfers (e.g. Drakensberg PS scheme, Palmiet PS scheme and Gariep and Vanderkloof hydropower schemes) [16]. The current total installed pumped storage schemes in South Africa is approximately 2912 MW which consists of the plants shown in Table 2.

TABLE 2. *CURRENT PS SCHEMES IN SOUTH AFRICA [16]*

PS schemes in South Africa		
Scheme	***Commissioned year***	***Capacity (MW)***
Steenbras	1979	180
Drakensberg	1982	1000
Palmiet	1987	400
Ingula	2017	1332

Steenbras PS scheme is the municipal asset of the City of Cape Town, and the other three plants are owned by the national entity, Eskom.

B. *Cost of PS schemes in South Africa*

The most recently completed Ingula 1332 MW PS scheme is typically used for South African PS scheme cost estimates. The project was originally estimated at $1 billion and was finally completed in 2017 at a cost of $2.24 billion [20]. This translates to roughly $1682/kW.

The project start date was in 2005 but the project faced many challenges, delays and cost overruns. PS scheme average construction time is usually 7-8 years - the challenges faced by the project however increased the construction time to 12 years, driving up the construction cost significantly. The following contributing factors for price increase and cost overruns for Ingula PS scheme are known [19]:

- Scope creep of the civil works, mainly due to unforeseen geotechnical conditions - this was approximately 10-15% of the civil costs.
- An underground accident during the grouting process of the steel inclined shaft. This delayed the project by about 1.5 years and without this incident the cost was estimated to be $1140/kW.
- Further claims from interactions between (mainly) the civil and electro-mechanical contractors.
- The cost for contract acceleration.
- Weakening of the Rand exchange rate.
- $36 million over budget for the turbines.

C. *The role of PS in South African long-term resource plans*

PS used to feature strongly in South Africa's capacity expansion plans with a predicted 7.3 GW required from 2008 to 2030 as shown in Table 3. However, interest in PS has declined in South Africa since 2008. In essence capacity expansion models since 2010 saw no economic justification to install PS, rather increasing Open Cycle Gas Turbine (OCGT) capacity. A comparison of South African new build plans over the past 10 years is shown in TABLE 3 below.

The IRP 2010 stipulated 4.9 GW peaking capacity which could be PS or OCGT, however gas turbines were assumed [15].

TABLE 3. *SUMMARY OF SOUTH AFRICAN CAPACITY EXPANSION PLANS [2] [12] [13] [14] [15]*

Energy Sources	***2008 Plan***	***IRP 2010***	***IRP 2016***	***IRP 2018***	***IRP 2019***
New Capacity for 2030	***MW***	***MW***	***MW***	***MW***	***MW***
Coal	21924	16 383	6250	6732	7232
OCGT	–	4930	3910	8100	3000
CCGT	–	2370	2370		-
Pumped storage	7268	1332	–	-	-
Battery Storage	-	-	-	-	2088
Nuclear	19741	9600	9600	-	1860
Imported hydropower	–	2659	2609	2500	2500
Wind	1603	9200	8400	9462	15762
CSP		1200	1000	300	300
PV		8400	8400	6484	6814
SHP, biomass, landfill, etc.		465	–	2600	4000
Total	50536	56 539	42 539	35878	43556

A possible misconception with energy modelers is that there are limited sites available for PS schemes in South Africa, potentially leading to high implementation costs for these schemes. The next section provides an overview of studies conducted in the last ten years for potential PS scheme sites in South Africa, and their estimated cost projections.

A. Site availability and cost for future proposed PS schemes

Eskom's Integrated Strategic Electricity Plan identified the need for a number of PS schemes in the future. A comprehensive search was started in the mid-1980s. In this process, ninety potential sites were identified, investigated and systematically reduced to two, Ingula and Lima [16], of which Ingula was completed in 2017. Since then a further two sites have been proposed to Eskom; Kobong and Ceres. Figure 3 shows the location of these potential PS scheme sites.

1) Lima (Tubatse) PS scheme

Since the 1990's Eskom had been planning the construction of a large pumped storage scheme along the escarpment between the Nebo Plateau and the Steelpoort River valley, in the Limpopo Province. A feasibility study of a scheme of 1000 MW rated capacity, conducted by Eskom, was completed in November 2000. The project was named Lima PS scheme, which later became known as Tubatse PS scheme.

A detailed design study conducted in 2007 proposed a capacity of the scheme of 1500 MW, consisting of four variable speed turbine units of 375 MW each operating with a net head of 629 m [12]. The feasibility report from March 2008 [12] estimated the construction cost at $1,28 billion resulting in $1023/kW and a Levelised Cost of Energy of $67,4/MWh. Eskom applied to the National Energy Regulator of South Africa for a license to operate the scheme and expected the plant to come on stream by 2014. The water would be secured through an off-take from De Hoop Dam. As part of the agreement Eskom would also supply 400 000 people with water through the Olifants River Water Resource Development project.

The highlighted advantages of the project were that the lower dam, De Hoop Dam shown in Figure 4, has been constructed, there was a high head with a short penstock in good rock with granites, the Record of Decision had already been granted, Environmental Impact Assessment completed and the land for the scheme was already owned by Eskom [12].

The Eskom Board approve the business case and the investment decision for Tubatse in 2008. However, the project was put on hold due to the financial crisis in 2008 [19] when development finance became expensive and forecast of future peak energy demand more uncertain. Eskom therefore decided to stop further development of Tubatse. The economic crisis did have a substantial effect on peak demand, and Eskom's interest in additional PS decreased. Eskom's main focus was then on the already committed base load supply coal power stations of Medupi and Kusile, and the Ingula PS scheme [19].

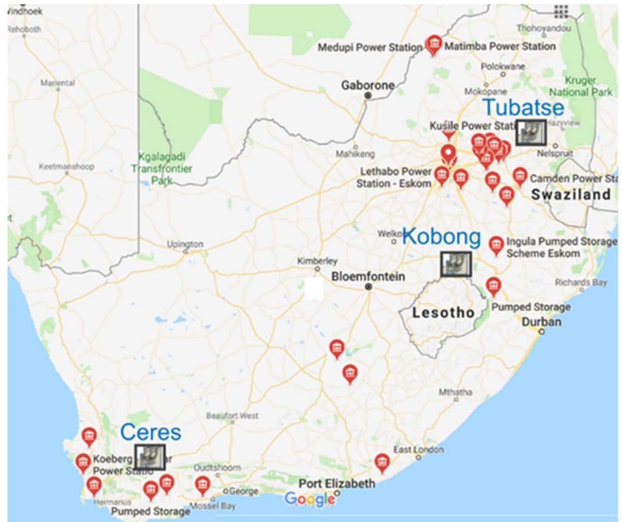

Figure 3. Potential PS scheme locations in South Africa [12], [17], [18] (red marks indicates current power plants)

Figure 4. Lima (Tubatse) PS scheme project layout [12]

2) Kobong PS scheme

Kobong PS scheme was meant to be part of Phase II of the Lesotho Highlands Water Project (LWHP) agreement. Katse Dam, the lower dam, was previously constructed during Phase I. Construction costs were estimated at $0.78 billion [17] and this was assumed to be financed from a concessional loan from the World Bank.

A capacity of 1200 MW was assumed, with a construction time of seven years. In 2014 a feasibility study [17] for Kobong indicated that the project was technically feasible, but only economically feasible subject to a series of assumptions: a market for the peaking power, a price differential between the buying and selling rates, project capital cost, interest rates, availability of funding, agreeing a PPA with South Africa, and integration of the PS scheme into the Lesotho and South African grid.

3) Ceres PS scheme

In 2018 a feasibility study by Ceres Hydro Electrical [18] for a PS scheme of 1000 MW with variable turbines, in the Western Cape, was started. The estimated cost for the project is currently $0.4billion with a construction time of 5 years, but the study is still in progress. The higher dam containing

17 million m³ of water is already constructed and the lower dam will be 16 million m³, with a head of 240 m. The lower dam will provide irrigation (36 million m³ per annum) for agricultural use allowing for land reform and providing water security and food security for one thousand farms.

The project could feed into the grid, providing improved flexible generation through variable turbines, but network strengthening will be required. A relatively simple Environmental and Social Impact Assessment is required as only two property owners are involved; the Witzenberg municipality and the University of Cape Town. The proposed scheme would be an Independent Power Producer and would also require a Power Purchase Agreement with Eskom [18].

B. *Future PS outlook in South Africa*

As shown in the previous section, increased capacity for PS currently does not feature in the future South African grid. The alternatives to PS that do feature presently are OCGT and battery storage.

The likely reasons why PS have not featured in the past ten years' capacity expansion plans include the high cost presumed with this storage technology versus gas-based OCGT for peaking generation.

PS scheme cost estimates used in modelling were solely based on the high cost of the Ingula PS scheme project. In addition, gas based OCGT costings were based on the assumption of adequate gas distribution and storage infrastructure, which South Africa currently does not have. There is a risk that the volume requirement for gas would be too low to motivate development of this gas infrastructure. Therefore diesel might have to be used instead as fuel for peaking and flexible generation, driving up the cost of electricity generation in South Africa (OCGT run off diesel costs $50c/kWh compared to coal which ranges between $0.9c/kWh to $3c/kWh, while the current marginal cost for pumped storage is around $2.9c/kWh which is based on the cost of coal [23] [12]).

Furthermore capacity expansion planning tools may not be able to capture the full benefits to the grid of PS accurately in the modelling process, especially in calculating the impact of PS on the overall system energy costs.

PS has a role to play in a diversified energy mix, as has gas turbines, but the risk of sole investment in a gas industry for flexible generation could have detrimental effects on the South African economy if substantial local economic gas reserves are not found [2]. Incorporating new PS schemes for dispatchable power could reduce exposure to international markets from large imports of gas and could allow more cost conservative operation of the OCGT generation.

Previously Eskom and the South African Department of Energy (DoE) have made it clear that there was no requirement for additional PS capacity in the foreseeable future [21]. However the DoE have subsequently included 2.1 GW of new storage as a requirement before 2030 in the latest IRP 2019 [2] as shown in Table 3. It is known that 360 MW of electro-chemical batteries are been considered in South Africa as a World Bank requirement for funding the Medupi and Kusile coal fired power plants [22]. The recommended 2.1 GW storage has been suggested to be battery storage [2], however for such a large storage capacity requirement PS might be the more cost-effective option.

IV. CONCLUSION

As an energy storage technology, PS supports a wide variety of power system operations. Some of the benefits PS provide include flexibility (inertia, frequency response, ramping support, etc.), improved system utilization (increased utilization factor of coal fired power plants and reduced curtailment of variable renewables) and peaking support. The value of these benefits is expected to increase in the future with the potential of higher penetration of wind and solar generation in the system.

This paper highlighted that South Africa currently has several potential PS scheme sites in advanced stages of feasibility analysis, which compare favorably to international PS schemes in terms of cost.

In terms of benefits to the grid, literature highlighted that the value of PS is most accurately captured in vertically integrated utilities like South Africa's Eskom, and that the largest PS scheme developments internationally occurred in contexts of substantial capacity expansion plans and no overcapacity, again like in South Africa. Eskom's potential unbundling might further increase the valuation of ancillary services that PS can provide.

Based on these conclusion, PS in South Africa has been shown to still be a potentially valuable technology to support the future power system. The fact that current capacity expansion planning modelling for South Africa does not allocate any future PS capacity might indicate that further research is required to accurately inform the inputs, assumptions and methodologies used in these models.

Ultimately there is a need to better understand the costs, value and sensitivities of flexible technologies like PS, OCGT and batteries in future power systems, not only in South Africa but internationally.

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