The contribution of pumped storage schemes to energy generation in SA

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What is a Pumped Storage Scheme?

- The Pumped Storage Scheme (PSS) is a hydro-power generation plant situated typically between two reservoirs (in most cases dams) connected by a large diameter pipelines (penstocks) or underground tunnels.
- The water is pumped from the lower reservoir into elevated upper reservoir serving as an energy storage (i.e. water battery storage)
- Typically 3 to 5 sec of starting time and some 15 sec will get a PSS in a full operation
Pumped storage operation concepts
(PSS is a net consumer of energy, but with significant benefits)

**Pumping power (kW):**
\[ P_p = gr \times Q_p \times H_p \times \text{eff} \]

**Generating power (kW):**
\[ P_g = gr \times Q_g \times H_g \times \text{eff} \]
Benefits having PSS within energy generation industry

• The **upper water storage** serves as ideal **hydraulic energy storage** (*e.g.* storing 1 kWh of hydro-energy requires 10 cub m of water over a drop of 40 m);

• **Peaking requirements** of electricity grid are balanced by installed **PSS capacity** and its reactive capabilities;

• The **excess power** available during **off-peak periods** is used in pumping;

• The availability of **installed pumped storage** increases the **reliability of** the supply grid
Specific benefits having PSS within energy generation industry

- A grid with ample **installed pumped storage** absorbs more **generation inputs** from **intermittent supply**;
- A grid will **cope better** with increasing share of generation from **renewables** *(i.e. wind & solar)*;
- An ample **pumped storage** capacity **limits** a need for large **investment in the grid**;
- **Reduce** the **O&M** costs of other generation facilities;
- A PSS can have more than one purpose *(e.g. Water transfer)*
Pumped storage installed capacity in South Africa

- Total **installed capacity** of PSSs in SA is presently at **2910 MW** (i.e. **some 6% of total electricity generation capacity in SA**);
- There are **four large PSSs operating currently around SA** namely: 1979 **Steenbras** (180 MW); 1981 **Drakensberg** (1000 MW); 1987 **Palmiet** (400 MW) and new 2016 **Ingula** (1332 MW);
- On the **international scale**, Ingula PSS occupies presently **19th** place and **Drakensberg PSS** slipped to **57th** place after extensive development of PSSs around World, but primarily in China;
- At present the **largest PSS** is in USA (**Bath Country at 3 003 MW**), however, **China’s Fenguing PSS under construction** with capacity of **3600 MW will soon be largest in the World**.
Other (conventional) hydropower capacity in SA

Eskom together with DWS generate hydro-electricity from several conventional hydroelectric plants, two on Orange River and others attached to the dams on the perennial rivers in the Eastern Cape. These installations do not have the same function as the PSSs, but can provide for a peak demand.

(i) Eskom’s Eastern Cape Province total installed conventional hydropower capacity is at present some 61 MW;
(ii) DWS/Eskom’s total conventional hydropower capacity installed on the Orange River at the Gariep and Vanderkloof dams is 400 MW;

NB: There are several small scale hydropower installations (all <10 MW) owned by the private owners. The Department of Energy’s REI4Ps programme allowed for development of a few recently built small scale hydropower plants (e.g. Stortemelk and Neusberg) and others are in planning stages. Most viable prospects for development of small scale (<10MW) hydropower in SA is extensive primary water supply infrastructure as are medium and large dams mainly in the State’s ownership.
## Summary stats on SA’s pumped storages

<table>
<thead>
<tr>
<th>PSS (owner)</th>
<th>Total peaking capacity (MW)</th>
<th>Average gen. head (m)</th>
<th>Upper/lower reservoirs</th>
<th>Active storage (mill. m cub)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steenbras (CTCC)</td>
<td>4 units @ 45 MW = 180</td>
<td>286</td>
<td>Upper Steenbras</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Steenbras</td>
<td>3</td>
</tr>
<tr>
<td>Drakensberg (Eskom)</td>
<td>4 units @ 250 MW = 1000</td>
<td>430</td>
<td>Driekloof (upper)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kilburn (lower)</td>
<td>29</td>
</tr>
<tr>
<td>Palmiet (Eskom)</td>
<td>2 units @ 200 MW = 400</td>
<td>265</td>
<td>Rockview (upper)</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kogelberg (lower)</td>
<td>15</td>
</tr>
<tr>
<td>Ingula (Eskom)</td>
<td>4 units @ 333 MW = 1332</td>
<td>450</td>
<td>Bedford (upper)</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Braamhoek (lower)</td>
<td>26</td>
</tr>
</tbody>
</table>

**NB:** All installations are furnished by the Francis reversible pump/turbine units. The plants of Drakensberg and Palmiet PSS are also serving as the Water Transfer Schemes between either primary or secondary river basins. The Palmiet PSS is connected to Steenbras. Ingula PSS is built for energy generation only.
Steenbras and Palmiet Pumped Storage Schemes

Rockview Dam (Palmiet PSS) & Upper Steenbras Dam
Tugela-Vaal Water Transfer Scheme (WTS) operating by means of **Drakensberg PSS**
Eskom’s foremost pumped storages
1332 MW Ingula Pumped Storage Scheme (presently 19th PSS on international scale)
Planning and design criteria adopted in developing PSSs in South Africa

(i) a large PSS site should have static head between **100 and 700 m**
(ii) a **gradient of 1:10** between upper and lower dam would be **ideal**
(iii) water **availability**, its **losses and evaporation** must be **assessed**
(iv) the **pump/turbine** assembly to be placed at least **25 m below** water level of lower reservoir
(v) key cost components are **land configuration** and **pumping head**
(vi) if a **lower reservoir** already **exists**, such **site has a priority** in choice
(vii) a **peaking and stand-by capacity** of PSSs are main purposes
(viii) most of PSS’s **infrastructure** is either buried or excavated underground
  (there are **no environmental effects during operation** of a PSS)
(ix) SA’s **pumped storages** are build for more than one purpose (**generation + water transfer**)
(x) key **shareholders** in developing PSSs in SA are **DoE/Eskom and DWS**
Examples of electricity production from SA’s generation mix (GWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>Base-load generation</th>
<th>Peaking and stand-by generation</th>
<th>Intermittent gen.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal-fired</td>
<td>Nuclear</td>
<td>Hydros</td>
</tr>
<tr>
<td>2009/10</td>
<td>215 940</td>
<td>12 806</td>
<td>1 274</td>
</tr>
<tr>
<td>2010/11</td>
<td>220 219</td>
<td>12 099</td>
<td>1 960</td>
</tr>
<tr>
<td>2011/12</td>
<td>218 212</td>
<td>13 502</td>
<td>1 904</td>
</tr>
<tr>
<td>2012/13</td>
<td>214 807</td>
<td>11 954</td>
<td>1 077</td>
</tr>
<tr>
<td>2013/14</td>
<td>209 483</td>
<td>14 106</td>
<td>1 036</td>
</tr>
<tr>
<td>2014/15</td>
<td>204 838</td>
<td>13 794</td>
<td>851</td>
</tr>
<tr>
<td>2015/16</td>
<td>199 888</td>
<td>12 237</td>
<td>688</td>
</tr>
<tr>
<td>2016/17</td>
<td>200 893</td>
<td>15 026</td>
<td>579</td>
</tr>
</tbody>
</table>

NB: * PSSs needed on average 30% more energy for pumping than production. ** Eskom paid to the REI4Ps plants R 9,5 and R 15,4 billion in 2014/15 and 2015/16 respectively for energy supplied. The generation from diesel/gas plants peaked in 2015/16 and is being minimized as per recent records.
Location of renewable power generation plants within national grid

Location of REI4Ps generation plants around SA (four windows)  Layout of national electricity grid infrastructure
Function of existing PSSs since national grid absorbing renewable power generation

- Maintaining a **balance between demand and production** is essential to any electricity grid, such grid needs energy for **rapid balancing** (i.e. against so-called ramping effects);
- **Eskom’s pumped storages** (Drakensberg and Palmiet) were designed to be **weekly balanced** (i.e. the upper dams can be pumped full over the weekends);
- The national grid is at present in a conundrum of the electricity **demand outstripping base-line production** and existing **PSSs are required** to generate far more frequently - thus **shifting from weekly to daily balanced** systems;
- At the same time the **grid needs to mitigate** the impacts of **increased intermittent** renewable power plant production
What would be viable solutions in mitigating a need for a rapid-response energy generation?

- **Using available peaking capacity more efficiently** avoiding as much as possible the open cycle gas turbine generation – the priority in generation should be given to PSSs against OCGT;
- **Increasing macro capacity of existing pumped storages** – either by extending capacities of various PSS components or by external battery storage;
- Installing **new pumped storage** after the Ingula PSS – to go ahead with **development of Tubatse PSS** using existing De Hoop Dam as lower storage and to enable for water transfer to the Nebo plateau;
- **Improving electricity transmission network between Lesotho and RSA** to have access to peaking generation of Kobong PSS
Location of planned Tubatse PSS
Eskom and DWS next logical choice

Location of feasible pumped storages after Ingula PSS

Location showing De Hoop Dam and Nebo plateau
Lesotho’s existing hydropower plant at Muela (72 MW) and planned **Kobong PSS of 1200 MW** in capacity with **Lesotho using 200 MW domestically** (max static head at 600 m)
The contribution of pumped storage schemes to energy generation in South Africa

Concluding remarks

• a pumped storage scheme is effectively a large energy storage battery (energy is stored in the form of water during off-peak periods and released during the peak electricity demands),

• a PSS using reversible pump/turbine assembly is so far most effective way to store electrical energy at acceptable costs,

• a PSS is the source of energy that can deliver positive or negative reserve to the grid for balancing intermittent resources such as wind and solar,

• a PSS can provide energy for a rapid balancing of a grid, and

• new pumped storage installations benefit from the technological achievements of the recent past in the development of hydraulic and electrical machines and progresses in automatisation

THANK YOU