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Operating algorithm of hybrid power plant of a wind park and a Pumped Hydro Storage system aiming at 100% R.E.S. penetration

The wind powered PHS hybrid plant can be introduced in power systems of small and medium size to approach the 100% RES penetration. The corresponding operation algorithm is analysed below:

1. For each time calculation step, the total available power production from the RES unit P_{RES} and the current power demand P_d are introduced. Additionally, a maximum RES direct penetration percentage versus the power demand p_{max} is defined (usually around 30%).

2. The RES direct penetration P_{RESp} is calculated from the following relationships:

   a. If $P_{RES} \geq p_{max} \cdot P_d$, then $P_{RESp} = p_{max} \cdot P_d$.
   b. If $P_{RES} < p_{max} \cdot P_d$, then $P_{RESp} = P_{RES}$.

3. If P_p is the nominal power of the storage units (pumps), then the potential power storage P_{st} is calculated as follows:

   a. If $P_{RES} - P_{RESp} > P_p$, then $P_{st} = P_p$.
   b. If $P_{RES} - P_{RESp} \leq P_p$, then $P_{st} = P_{RES} - P_{RESp}$.

4. The water volume V_p that must be stored in the PHS upper reservoir to achieve power storage P_{st} for a time calculation step with duration t is calculated:

   $$V_p = P_{st} \cdot t \cdot \eta_p / \gamma \cdot H_p$$

   where H_p is the available head of the pumping penstock, γ the water specific weight and η_P the pumps overall efficiency for the current operation conditions.

5. The water volume V_h that must be removed from the PHS upper reservoir to achieve a hydro turbines power production of $P_d - P_{RESp}$ for a time calculation step of duration t is calculated:

   $$V_h = (P_d - P_{RESp}) \cdot t / \eta_h \cdot \gamma \cdot H_T$$

   where H_T is the available head of the falling penstock and η_h the hydro turbines overall efficiency for the current operation conditions.

6. The water volume $V_{st}(j)$ remaining in the PHS upper reservoir after the current calculation time step j is calculated as:

$V_{st}(j) = V_{st}(j\text{-}1) + V_p - V_h$

where $V_{st}(j\text{-}1)$ is the water volume remaining in the PHS upper reservoir from the previous calculation time step.

7. The capacity V_{max} of the PHS upper reservoir to store the potential water volume remaining after the current time calculation step is examined:

   a. If $V_{st}(j) > V_{max}$, then:
      $P_{st} = 0$
      $P_{rej} = P_{RES} - P_{RESp}$
      $V_{st}(j) = V_{st}(j\text{-}1) - V_h$.

   b. If $V_{st}(j) \leq V_{max}$, then:
      $P_{st} = P_p$ or $P_{st} = P_{RES} - P_{RESp}$
      $P_{rej} = P_{RES} - P_{RESp} - P_{st}$
      $V_{st}(j) = V_{st}(j\text{-}1) + V_p - V_h$

   where P_{rej} is the RES power rejection.

8. Additionally, the adequacy of stored water volume to support the required hydro turbines power production during the current calculation time step is examined (V_{min} the minimum possible water volume stored in the PHS upper reservoir):

   a. If $V_{st}(j) < V_{min}$, then:
      $P_h = 0$
      $P_{th} = P_d - P_{RESp}$
      $V_{st}(j) = V_{st}(j\text{-}1) + V_p$.

   b. If $V_{st}(j) \geq V_{min}$, then:
      $P_h = P_d - P_{RESp}$
      $P_{th} = 0$
      $V_{st}(j) = V_{st}(j\text{-}1) + V_p - V_h$.

The above described operation algorithm is depicted in figure 1.

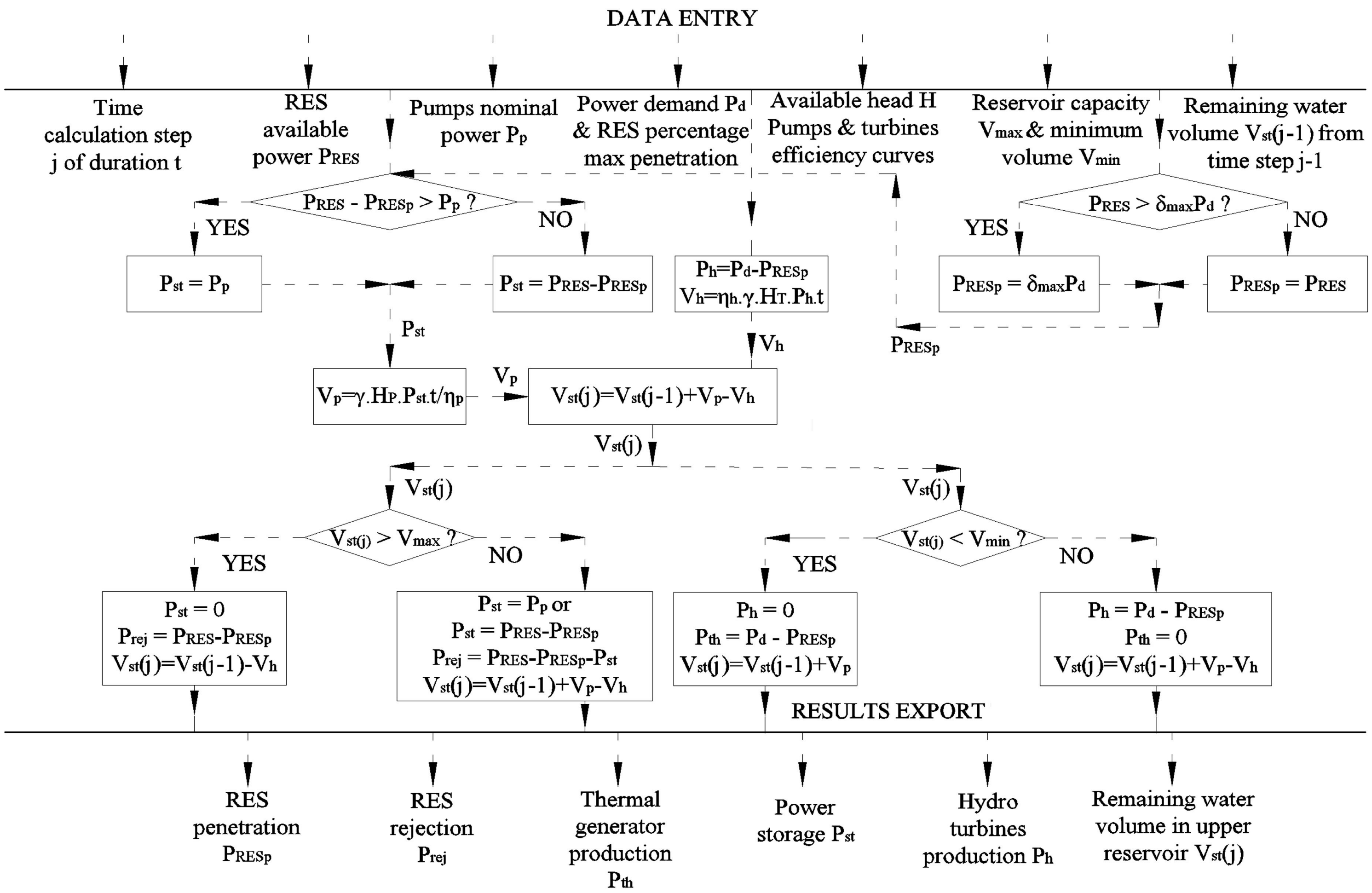

***Figure 1**: Operation algorithm of a wind park – PHS hybrid power plant aiming to 100% RES penetration.*