Operating algorithm of a small hybrid power plant

The operation of a small size hybrid power plant follows the algorithm presented below. For every calculation time step j the following tasks are executed:

1. Comparison of the total power production from the RES units P_{RES} and the power demand P_d:

   - If $P_{RES} < P_d$, then the total RES power production is provided to the power demand, namely the RES direct power penetration P_{RESp} is equal to the available RES power production: $P_{RESp} = P_{RES}$.
   - If $P_{RES} > P_d$, then the power demand is totally covered by the RES unit, namely the RES direct power penetration P_{RESp} is equal to the power demand: $P_{RESp} = P_d$.

2. Charging level control $b_i(j-1)$ for all the electrochemical battery strings, as configured from the previous time step j-1. The subscript i designates the number for each battery string (i = 1, 2, 3, …). The following sub-cases are distinguished:

   - $P_{RES} < P_d$:

   If there is enough energy stored in the batteries, then the power production deficit is covered by the storage unit: $P_{bat} = P_d - P_{RESp}$. The back-up power production is null.

   The new charging level for each battery string is: $b_i(j) = b_i(j-1) - P_{bati} \cdot t_i$

   where P_{bati} is the discharging power for the battery string i. Obviously it is:

   $$P_{bat} = \sum_{i=1}^{n} P_{bati}$$

   where n is the total battery strings number.

   If there is not enough energy stored, the storage units power production will be restricted by their maximum discharge level. In that occasion it will be:

   $P_{bati} = [\sum b_i(j-1) - b_{dis} \cdot C_{bati}]/t_i$

   where C_{bati} the total storage capacity of the batteries sting i, b_{dis} the batteries maximum discharging percentage (e.g. 60%) and t_i the calculation time step duration.

   The new charging level for all the battery strings will be equal to their minimum required charging level: $b_i(j) = b_{dis} \cdot C_{bati}$.

   The power production deficit P_{def} after the batteries contribution is:

$P_{def} = P_d – P_{RESp} – P_{bat}$.

The next available option for power production is the fuel cell. If $P_{fc\text{-}max}$ is the maximum power production available from the fuel cell device, determined either by its nominal power or by the stored hydrogen, then the power production from the fuel cell device will be:

$P_{fc} = P_{def}$, if $P_{fc\text{-}max} > P_{def}$, or

$P_{fc} = P_{fc\text{-}max}$, if $P_{fc\text{-}max} \leq P_{def}$.

In the second case, the power production remaining deficit will be covered by the main back-up units (diesel generators):

$P_{th} = P_d – P_{RESp} – P_{bat} – P_{fc}$.

The power storage P_{st} will be null, as well as the available power for the electrolysis unit P_{el} and the RES power rejection P_{RESrej}.

- $P_{RES} > P_d$:

If there is enough storage space, all the RES power production surplus will be stored in the battery strings: $P_{st} = P_{RES} – P_{RESp}$. In that occasion, there will be no available power for the electrolysis and the RES power rejection will be null.

The new charging level for the battery strings will be: $b_i(j) = b_i(j\text{-}1) + P_{sti} \cdot t_i$

where P_{sti} is the charging power for the battery string i. Obviously it is:

$$P_{st} = \sum_{i=1}^{n} P_{sti}$$

If there is not enough storage space to store the RES production surplus, then the stored power of each battery string will be restricted by its storage capacity, calculated as follows:

$P_{sti} = [C_{bati} - b_i(j\text{-}1)]/t_i$.

In that occasion, the charging level for the battery strings will be equal to their storage capacity.

The RES power production surplus after the major storage units will be:

$P_{RESav} = P_{RES} – P_{RESp} – P_{st}$.

If the nominal power of the electrolysis device is P_{eln}, then the RES power rejection P_{RESrej} and the absorbed power P_{el} by the electrolysis unit will be either:

$P_{RESrej} = P_{RESav} - P_{eln}$ & $P_{el} = P_{eln}$, if $P_{RESav} > P_{eln}$, or

$P_{RESrej} = 0$ & $P_{el} = P_{RESav}$, if $P_{RESav} \leq P_{eln}$.

In the first case the power provided for the electrolysis unit will be P_{el}, while in the second case it will be P_{RESav}.

The above describe operating algorithm is presented in figure 1.

From the above analysis it is revealed that, as in the case of the wind – PV – batteries hybrid power plant, the simultaneous power production and storage from and to the electrochemical batteries is required. To ensure this option, given that a battery string can not be charged and discharged simultaneously, at least two separate battery strings must be introduced, with appropriate dimensions (number and nominal capacity of involved batteries units, total string voltage). Depending on the size of the power demand, more battery strings may be required, as indicated in the case studies presented below.

Another crucial point is the charging and discharging order of the battery strings. To maintain a balance between the charging levels of the battery strings, for every calculation time step the battery strings with the highest charging level should be discharged first, while the battery strings with the lowest charging level should be charged prior to the rest.

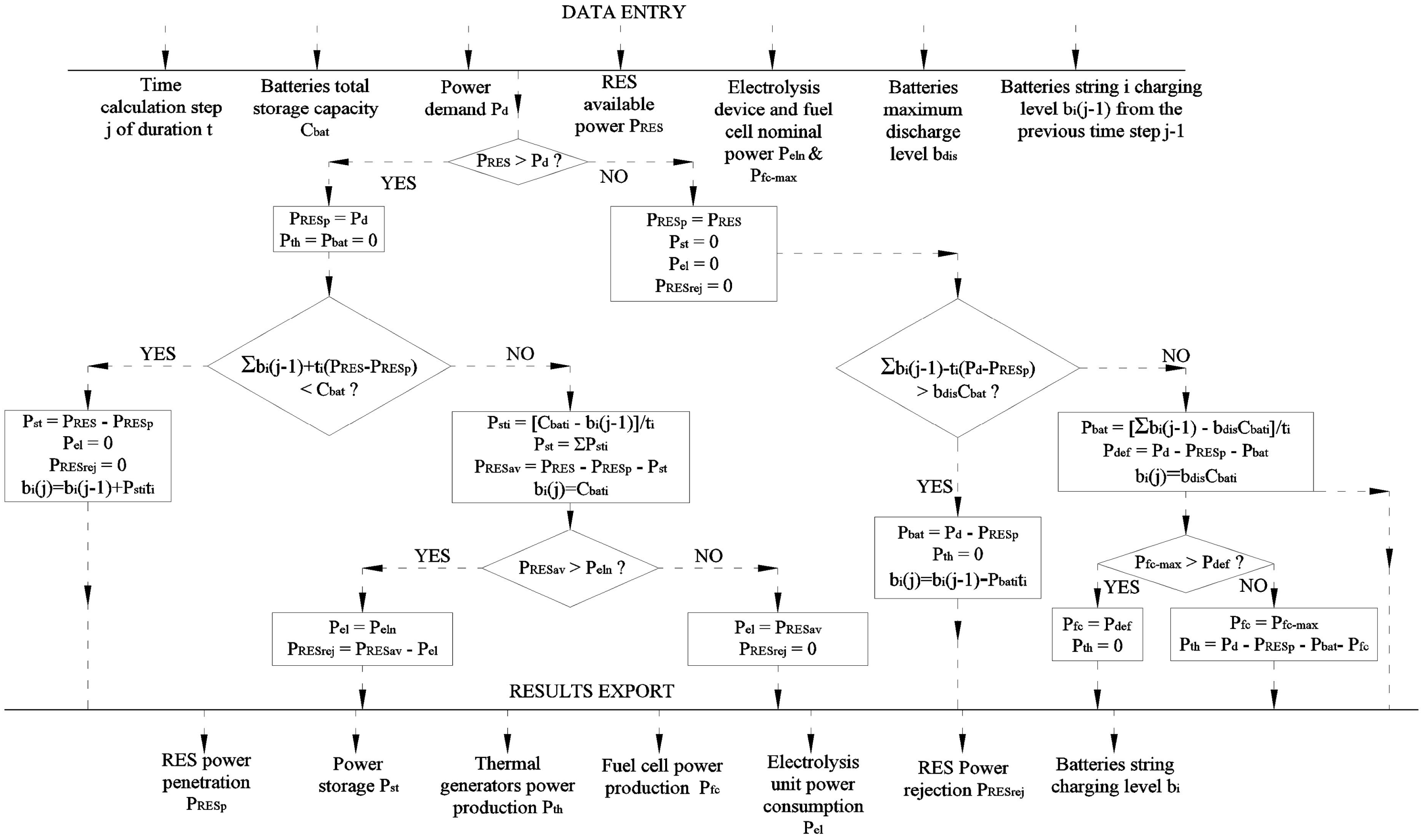

***Figure 1**: Operation algorithm of a wind – PV – electrochemical batteries hybrid power plant of small size.*