Optimization Control on 'Electricity-Hydrogen' Coordination in Active Distribution Network Part One System Modeling

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Abstract. The integration of a large amount of renewable energy into the distribution network brings the severe consumptive problem. Compared to the traditional storage methods, in this paper, we propose a new solution which is to convert electricity into hydrogen by the electrolysis cell. What's more, by methanation we convert hydrogen into methane to provide fuel for the micro-turbine. Thus on the one hand the loss of on-grid renewable energy can be decreased, on the other hand the fuel cost required for the micro-turbine can be curtailed. The main contribution relies on the efficiency model of the electrolysis cell, and the research with the consideration of the network operation constraints in the distribution level is meaningful.

Introduction

Distributed Generators (DG) have been developed rapidly in recent years. Fig. 1 shows the trend of installed capacity of renewable energy[1].

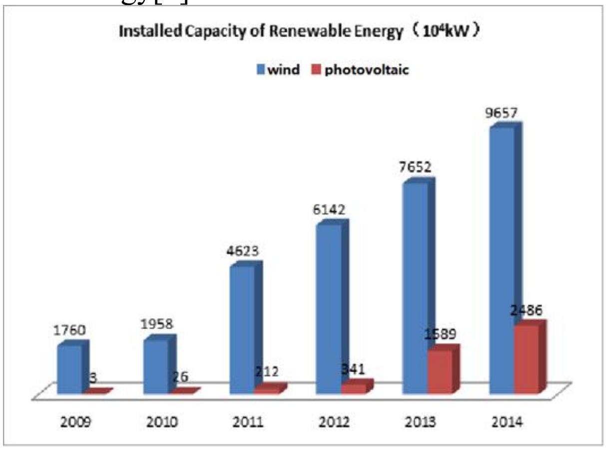

Fig. 1 Installed capacity of renewable energy in recent years

However, with more and more renewable energy accessing to the active distribution network(ADN), the consumption problem is becoming increasingly serious. A storage device is an important scheduling unit in ADN to realize the local consumption of renewable energy. While with the gradual expansion of distribution network and the increase of distributed energy capacity, traditional energy storage methods have been unable to meet the need of ADN[2].

As a kind of energy storage material, hydrogen has high energy density (HHV: 3.54KWh / Nm3, 39.42KWh / kg) and is easy to storage[3,4]. Based on two important energy carriers – electricity and hydrogen, the electrolysis cell can realize large-scale and long-term energy storage, and improve the consumptive capacity of renewable energy in ADN[5].

In the research of the electrolysis cell, literatures [6,7] described electrochemical process of the electrolysis reaction in detail. In the research of the coordinated dispatch of the electrolysis cell with ADN, literatures [8-11] established an isolated micro-grid system consisting of DGs, batteries and the electrolysis cells. Above all, the research level mainly remains on the micro-grid level, basically single point optimization, and regardless of network operation constraints. Our main contribution is

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to realize the ‘Electric-hydrogen’ coordinated dispatch in distribution network with the consideration of the network operation constraints.

The rest of the paper is organized as follows: The second section presents hydrogen efficiency curve which can be used in power system scheduling; the third section establishes the models of active distribution network and the two-level dispatching strategy; The final section draws the conclusions.

Modeling of the Electrolysis Cell

Reaction Principle. The Alkaline the electrolysis cell, which is widely used in the industry, is used for modeling and analysis in this paper. Electrolytes of alkaline electrolytes are generally KOH solutions. The chemical reaction equations are:

$$2H_2O+2e^- \rightarrow H_2(g)+2OH^- \qquad \text{* MERGEFORMAT (1)}$$

$$2OH^-(aq.) \rightarrow \frac{1}{2}O_2(g)+H_2O(l)+2e^- \qquad \text{* MERGEFORMAT (2)}$$

The energy required for electrolysis reaction is:

$$\Delta H=\Delta G+T\Delta S=zF\left[T\left(\frac{\partial U_{rev}}{\partial T}\right)_p-U_{rev}\right] \qquad \text{* MERGEFORMAT (3)}$$

Where $\Delta G,\Delta H$ are the Gibbs free energy change and the full enthalpy change. The actual voltage expression for electrolysis reaction is[12]:

$$U_{cell}=U_{rev}+U_{ohm}+U_{act}+U_{con} \qquad \text{* MERGEFORMAT (4)}$$

Where U_{cell} , U_{ohm} , U_{act} , U_{con} are the actual voltage supplied for the electrolysis cell, ohmic overvoltage, activation overvoltage and concentration overvoltage.

The Efficiency Model. The efficiency for the electrolysis cell is:

$$\eta=\frac{U_{tn}}{U_{cell}} \qquad \text{* MERGEFORMAT (5)}$$

Where U_{tn} is thermo-neutral voltage which represents the minimum cell voltage required for isolated operation of electrolysis reaction. The efficiency curve is as Fig. 2.

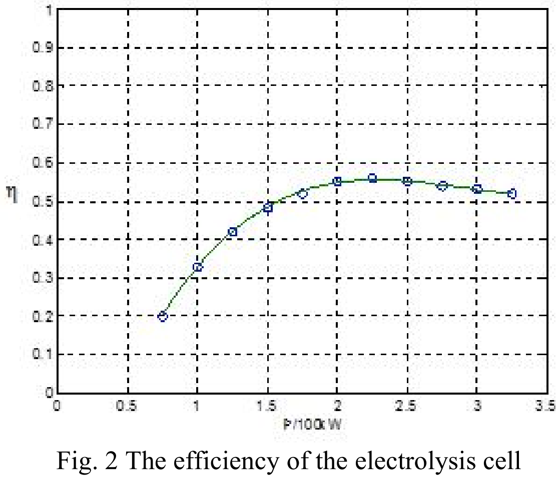

Fig. 2 The efficiency of the electrolysis cell

Modeling of the ADN

Electric Module.

1) the Electrolysis Cell

The external characteristic can be modeled as a PQ node with continuous power generation, controllable decoupling, and the injection power is ($-P_{EL}$, 0), the operation satisfies the upper and lower power constraints:

$$P_{EL,\min} \le P_{EL} \le P_{EL,\max}$$ * MERGEFORMAT (6)

2) Micro-turbine

The external characteristic can be modeled as a PQ node with continuous power generation, decoupling controllability and the injection power is (P_{MT} , Q_{MT}). The operation of micro-turbine needs to meet the upper and lower limits of output constraints and the upper and lower limits of climbing rate constraints.

$$P_{MT,\min} \le P_{MT} \le P_{MT,\max}$$ * MERGEFORMAT (7)

$$Q_{MT,\min} \le Q_{MT} \le Q_{MT,\max}$$ * MERGEFORMAT (8)

$$-R_{pdown}\Delta t \le P_{MT}(t) - P_{MT}(t-1) \le R_{pup}\Delta t$$ * MERGEFORMAT (9)

$$-R_{qdown}\Delta t \le Q_{MT}(t) - Q_{MT}(t-1) \le R_{qup}\Delta t$$ * MERGEFORMAT (10)

3) Wind Turbine

In the MPPT (maximum power point tracking) control mode, the wind turbine can track its maximum power point, its output is related to real-time wind speed and needs to satisfy the upper and lower power constraints:

$$P_{WT,\min} \le P_{WT} \le P_{WT,\max}$$ * MERGEFORMAT (11)

4) Electricity Load

The traditional load in the distribution network load can be modeled as a PQ node with continuous power generation, uncontrollable and the injected power is ($-P_L$, $-Q_L$).

Gas Module.

1) the Electrolysis Cell

$$n_{H_2} = \frac{P_{EL}\eta_{EL}\Delta t}{LHV_{H_2}}, \quad LHV_{H_2} = 240MJ/kmol$$ * MERGEFORMAT (12)

2) Methanation

$$n_{JWH} = \frac{1}{4} n_{H_2}$$ * MERGEFORMAT (13)

3) Gas Load

$$n_L = \frac{P_{MT}\Delta t}{\eta_{MT} HHV_{CH_4}}$$ * MERGEFORMAT (14)

Operation Constraints of ADN. A typical distribution network tree topology is shown in Fig. 3:

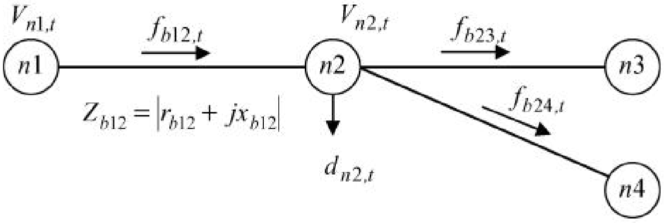

Fig. 3 Tree topology of ADN

Ignore the network loss of ADN, the relationship between branch current and node current is:

$$f_{bij,t} = d_{j,t} + \sum_{k \in j, k \neq j} f_{bjk,t}$$ * MERGEFORMAT (15)

Using the road-branch association matrix, (15) can be written as follows:

$$f_{b,t} = T^T d_t$$ * MERGEFORMAT (16)

$$d_t = \frac{P_t + jQ_t}{V_N}$$ * MERGEFORMAT (17)

The elements in the road-branch association matrix (T) are defined as follows[13]:

$$t_{ik} = \begin{cases} 1 & k \in i \\ 0 & k \notin i \end{cases}$$ * MERGEFORMAT (18)

For that the difference between phase angle of the node voltage in the distribution network is very small, so it can be approximated as follows[14,15]:

$$\Delta V_{ij,t} = V_{i,t} - V_{j,t} = Z_{ij} f_{bij,t}$$ * MERGEFORMAT (19)

$$Z_{ij} = | r_{ij} + jx_{ij} |$$ * MERGEFORMAT (20)

On this basis, the constraints of the power flow in th distribution network are as follows:

$$f_{bij,t,\min} \le f_{bij,t} \le f_{bij,t,\max}$$ * MERGEFORMAT (21)

$$V_{i,t,\min} \le V_{i,t} \le V_{i,t,\max}$$ * MERGEFORMAT (22)

Dispatch Model. After establishing the model of components and operation constraints in ADN, a two-level dispatch approach is modeled[16], the specific content is shown in Fig. 4:

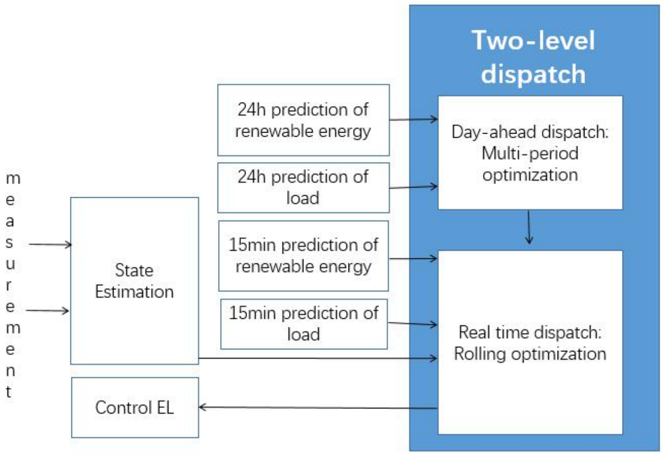

Fig. 4 The two-level dispatch in ADN

Conclusion

In this paper, a new solution which is to convert electricity into hydrogen by the electrolysis cell was presented in order to store the renewable energy.This paper put emphasis on the ‘electric-hydrogen’ coordinated dispatch in ADN basing on the proposed efficiency model of the electrolysis cell. As the first part of the parper, the model of the electrolysis cell and the ADN were presented. In the second part of the paper, the optimal model and case study will be presented.

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