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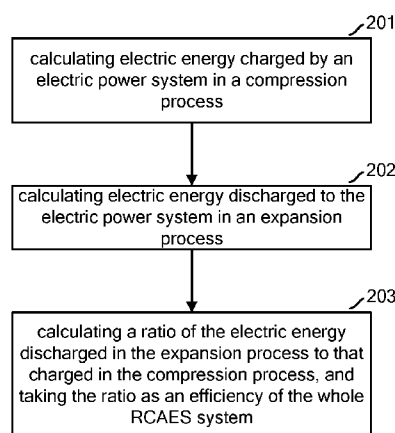
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(54) Title: METHOD AND SYSTEM OF EFFICIENCY EVALUATION OF RCAES SYSTEM

**Figure 2**(57) **Abstract:** An efficiency evaluation method of an RCAES system is disclosed, and the method includes calculating electric energy charged by an electric power system in a compression process (201), calculating electric energy discharged to the electric power system in an expansion process (202), and calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system (203); wherein gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant. A corresponding system is also disclosed.

METHOD AND SYSTEM OF EFFICIENCY EVALUATION OF RCAES SYSTEM

TECHNICAL FIELD

The present disclosure relates to a field of a power generation system, and
5 particularly to a method and a system of efficiency evaluation of a RCAES (Regenerative
Compressed Air Energy Storage) system.

BACKGROUND

Due to the uncertainty and anti-peaking nature, integration of large scale renewable
energy brings great challenges to the operation and dispatch of a power system. CAES
10 (Compressed Air Energy Storage) system provides new ideas to solve this problem as its
characteristics of fast regulating, flexible location and long service life. Especially, the
RCAES system is widely concerned as it can collect a part of heat released in a
compression process and release this part of heat in a work process of air expansion, so
that the energy-conversion efficiency of the whole power system can be improved
15 effectively. At present, few works have been done on efficiency evaluation and analysis of
the RCAES system.

SUMMARY

In an aspect of the present invention, an efficiency evaluation method of an RCAES
system is provided, the RCAES system includes parts of compression, thermal energy
20 storage, compressed air storage vessel (CASV) and expansion; and the method includes
calculating electric energy charged by an electric power system in a compression process,
calculating electric energy discharged to the electric power system in an expansion
process, and calculating a ratio of the electric energy discharged in the expansion process
to that charged in the compression process, and taking the ratio as an efficiency of the
25 whole RCAES system; wherein gas in operation is ideal gas, air mass flow rates in the
compression and expansion processes are known and constant in operation, an isothermal
model is adopted for the CASV of which the temperature is the same with ambient
circumstances, and the temperature and pressure of compressed air after throttling

become constant.

In another aspect of the present invention, an efficiency evaluation system of the RCAES system is provided, and the system includes modules: a first module, for calculating electric energy charged by an electric power system in a compression process;
5 a second module, for calculating electric energy discharged to the electric power system in an expansion process; and a third module, for calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system; wherein gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and
10 constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant.

In another aspect of the present invention, a non-transitory machine-readable storage medium, storing instructions to cause a machine to execute the above method, is
15 provided.

BRIEF DESCRIPTION OF DRAWINGS

Fig.1 is a diagram showing a general structure of a RCAES system in an embodiment of the present invention;

Fig.2 is a flow chart of an efficiency evaluation method of the RCAES system in an
20 embodiment of the present invention;

Fig. 3 is a diagram showing a structure of an efficiency evaluation system of the RCAES system in an embodiment of the present invention;

Fig.4 is a diagram showing a practical structure of a RCAES system in an embodiment of the present invention;

25 Fig.5 is diagram showing operation characteristics of compression in the RCAES system in the embodiment of the present invention;

Fig.6 shows electric energy exchanged in compression and expansion processes of the RCAES system under different values of compression ratio (λ) of each stage

of compressor in the embodiment of the present invention;

Fig.7 shows efficiency of the RCAES system under different values of λ in the embodiment of the present invention;

Fig.8 shows electric energy exchanged in the compression and expansion processes of the RCAES system under different values of exhaust air pressure of throttle (p_{val}) in the embodiment of the present invention;

Fig.9 shows efficiency of the RCAES system under different values of p_{val} in the embodiment of the present invention;

Fig.10 shows electric energy exchanged in the compression and expansion processes of the RCAES system under different values of the maximum working pressure of compressed air storage vessel (p_{stor}^1) in the embodiment of the present invention; and

Fig.11 shows efficiency of the RCAES system under different values of p_{stor}^1 in the embodiment of the present invention.

15 DETAILED DESCRIPTION

Examples will now be described more fully with reference to the accompanying drawings.

Embodiments of the present invention provide a method of efficiency evaluation of a RCAES system under basic formulation assumptions based on electrical-mechanical-thermal dynamic processes and measurable parameters of the RCAES system. In the embodiments of the present invention, impacts of key parameters of the RCAES system including compression ratio (CR) of compressor, exhaust air pressure of throttle (EAPT) and/or maximum working pressure (MWP) of compressed air storage vessel (CASV) are considered in efficiency evaluation of the whole system. Hereinafter, Part 1 introduces the basic formulation assumptions of the method of efficiency evaluation of the RCAES system provided in the embodiments of the present invention, Part 2 describes a calculation method of the efficiency of the whole RCAES system, and Part 3 discusses the impacts of the compression ratio of a compressor, the

exhaust air pressure of a throttle and the maximum working pressure of compressed air storage vessel (CASV) on the efficiency of the RCAES system through a practical application case of the present invention.

1 Basic Formulation Assumptions

5 A general structure of the RCAES system in the embodiments of the present invention is shown in Figure 1, including four main parts: compression, thermal energy storage (TES), compressed air storage vessel (CASV) and expansion. Efficiency analysis of the RCAES system in the embodiments of the present invention is based on the following assumptions:

10 1) Gas in operations is ideal gas;

2) The air mass flow rates in compression and expansion processes are known and constant in operation; the compression ratios of all stages of compressor are identical, and the expansion ratios of all stages of turbine are identical;

15 3) An isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances; the air pressure inside the CASV changes along with air inflow of the compressor; and the exhaust air pressure of the last stage of the compressor is kept identical with the air pressure inside the CASV, so the last stage of the compressor is called unsteady stage of compression; and

20 4) The temperature and pressure of compressed air after throttling become constant, and each expansion stage of the turbine is a steady process.

2 Efficiency Evaluation of the whole RCAES System

25 In a conventional efficiency evaluation method for a CAES system, output electric energy and input electric energy is obtained by measurement, and the efficiency is indicated by the ratio of the output electric energy to input electric energy. However, this method is hardly to be extended to be applied in analysis the impacts of the key parameters on the system's efficiency or optimizing the system's key parameters. To cope with the deficiency, an efficiency evaluation method based on energy conversion of compression and expansion processes is provided in the embodiments of the present

invention, which considers the impacts of the key parameters in the compression and expansion processes on the efficiency of the whole system.

2.1 Energy Conversion in Compression Process

In the complicated compression process, the RCAES system is charged with electric power of which one part is stored in high-pressure air as molecular potential energy and the other part is stored in high-temperature water as thermal energy. However, the closely involved electric power and compression work can be illustrated with the compression efficiency defined as follows:

Compression efficiency: the ratio of compression work to electric energy charged in compression process, indicated by η_{com} .

As the compression efficiency is determined by the electric-mechanical power conversion efficiency and adiabatic efficiency of the compressor both being approximately constant from engineering perspective, the compression efficiency of RCAES system can be described as a known parameter when analyzing the system efficiency. Therefore, if the compression work that has been done on the compressed air is obtained, the electric energy charged from the electric power system can be calculated out.

To facilitate description of the energy conversion process, without loss of generality, it is further assumed that:

1) The compression process starts when the pressure of the CASV reaching its minimum value p_{stor}^0 and ends when the pressure reaching its maximum value p_{stor}^1 . Besides, p_{stor}^0 and the EAPT p_{val} are identical.

2) The compressor includes N_c stages. The exhaust air pressure of the penultimate stage N_{cs} , indicated by $p_{N_{cs}}^{com}$, is lower than the minimum working pressure of the CASV, i.e., $p_{N_{cs}}^{com} < p_{stor}^0$, while the last stage is exactly the reverse, i.e., $p_{N_c}^{com} \geq p_{stor}^1$.

Hence, all the stages of the compressor work simultaneously during the system's air compression and energy storage process, where the first $1 \sim N_{cs}$ stages are steady with constant exhaust air pressure and temperature while the last stage is unsteady with

time-variant pressure having the same value with the CASV. Once the above assumptions are not satisfied for a practical RCAES system, the compression process can be formulated in a multi-period way with the same methodology. Furthermore, the assumption that the temperature of the TES can be controlled to keep all stages excluding the first stage of the compressor constant and in the same temperature denoted as T_{inc} , which is common in engineering.

2.1.1 Compression Time

According to the assumptions in Part 1, the CASV adopts the isothermal model, and according to the state equation of ideal gas, $p_{stor}V_{stor} = mR_gT_{stor}$, the following formula can be obtained by differentiating both sides:

$$\begin{aligned} V_{stor} \frac{dp_{stor}}{dt} &= \frac{dm}{dt} R_g T_{stor} \\ &= q_{com} R_g T_{stor} \end{aligned} \quad (1)$$

where $p_{stor}, V_{stor}, T_{stor}$ are the pressure, volume and temperature of the CASV; m is the mass of air; q_{com} is the exhaust air rate of compressor; R_g is the gas constant.

Thus, the operation time of the compression process can be illustrated as follows:

$$t = \frac{V_{stor}(p_{stor} - p_{stor}^0)}{q_{com} R_g T_{stor}} \quad (2)$$

where p_{stor}^0 is the minimum working pressure of the CASV.

2.1.2 Compression Work of Steady Stages

In the compression process, the compression powers of stages $1 \sim N_{cs}$ remains unchanged and can be expressed as follows:

$$P_{N_{cs}}^W = \sum_{i=1}^{N_{cs}} \left\{ \frac{q_{com} R_g T_{in,i}^{com} K_i}{K_i - 1} \left[\lambda^{\frac{K_i-1}{K_i}} - 1 \right] \right\} \quad (3)$$

where λ is the ratio of each stage of the compressor satisfying $\lambda = \frac{p_{out,i}^{com}}{p_{in,i}^{com}} > 1$ in which $p_{in,i}^{com}, p_{out,i}^{com}$ are inlet and exhaust air pressures of the i^{th} stage; K_i is the polytropic exponent of each stage of the compressor, and $T_{in,i}^{com}$ is inlet temperature of the i^{th} stage of the compressor.

- 5 The polytropic exponent K_i of each stage is approximately identical in engineering which can be expressed as γ , and the inlet air temperature of each stage except the first stage of the compressor can be kept as T_{inc} by the heat exchanger. Thus, formula (3) can be converted into the following expression:

$$P_{N_{cs}}^W = \frac{q_{com} R_g \gamma}{\gamma - 1} (\lambda^{\frac{\gamma-1}{\gamma}} - 1) [T_{in,1}^{com} + (N_{cs} - 1) T_{inc}] \quad (4)$$

- 10 The compression work of steady stages can then be illustrated as follows after the multiplication of formulas (2) and (4):

$$\begin{aligned} W_{N_{cs}}(p_{stor}) &= P_{N_{cs}}^W t \\ &= \frac{V_{stor} \gamma (p_{stor} - p_{stor}^0) (\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor} (\gamma - 1)} [T_{in,1}^{com} + (N_{cs} - 1) T_{inc}] \end{aligned} \quad (5)$$

2.1.3 Compression Work of the Unsteady Stage

The last stage of the compressor is unsteady of which the exhaust air pressure is the same as the CASV's and the compression power of the last stage can be expressed as:

$$P_{N_c}^W(p_{stor}) = \frac{q_{com} R_g T_{inc} \gamma}{\gamma - 1} \left[\left(\frac{p_{stor}}{p_{in,N_c}^{com}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \quad (6)$$

- 15 Furthermore, the compression work can be obtained after integrating the compression power on time basis as follows:

$$\begin{aligned}
W_{N_c}(p_{stor}) &= \int P_{N_c}^W dt \\
&= \int \frac{P_{N_c}^W}{q_{com} T_{stor} R_g} dp \\
&= \alpha_1 \left[\left(\frac{p_{stor}}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor} - p_{stor}^0)
\end{aligned} \tag{7}$$

where $\alpha_1 = \frac{T_{inc} V_{stor} \gamma^2 \lambda^{N_{cs}} p_{in,1}^{com}}{T_{stor} (2\gamma-1)(\gamma-1)}$, $\alpha_2 = \frac{T_{inc} V_{stor} \gamma}{T_{stor} (\gamma-1)}$.

In summary, the compression power and work can be expressed as a function of p_{stor} :

$$\begin{aligned}
P_{com}^W(p_{stor}) &= P_{N_{cs}}^W + P_{N_c}^W(p_{stor}) \\
W_{com}(p_{stor}) &= W_{N_{cs}}(p_{stor}) + W_{N_c}(p_{stor})
\end{aligned} \tag{8}$$

Then, the electric energy charged during the compression process can be expressed as:

$$E_{com} = \frac{W_{com}(p_{stor}^1)}{\eta_{com}} \tag{9}$$

2.2 Energy Conversion in Expansion Process

In the expansion process, the high-pressure air from the CAVS changes into constant-temperature and isopiestic air after throttling, and then drives the turbine to generate electric power after exchanging heat with the TES system. Similar to the compression process, the relationship of expansion work and electric energy can be illustrated by the expansion efficiency defined as follows:

Expansion efficiency: the ratio of electric energy discharged to expansion work, indicated by η_{tur} .

The expansion efficiency is codetermined by the adiabatic efficiency of the turbine, the mechanical efficiency of the regulator and the efficiency of the electric generator which are all known and fixed parameters. Consequently, the expansion efficiency can also be assumed constant from the engineering perspective. Therefore, if the expansion work that the compressed air has done is obtained, the electric energy discharged to the electric power system can be calculated out.

Due to the throttle's effect, all stages are steady in the expansion process. Supposing the inlet air temperatures of all stages are identical and kept constant which is indicated by T_{int} and the polytropic exponent is indicated by μ , the expansion power can be expressed as follows:

$$P_{N_t}^W = -\frac{N_t q_{tur} R_g T_{int} \gamma}{\mu - 1} (\phi^{\frac{\mu-1}{\mu}} - 1) \quad (10)$$

- 5 where N_t is the stage number of the turbine; ϕ is the ratio of each stage satisfying $\phi = \frac{p_{out,i}^{tur}}{p_{in,i}^{tur}} < 1$ in which $p_{in,i}^{tur}, p_{out,i}^{tur}$ are respectively the inlet air pressure and exhaust air pressure in the i^{th} stage of the turbine, and q_{tur} is the exhaust air rate of the turbine.

The pressure of the CASV over time can be obtained in the same way as described in 2.1.1, which is illustrated as follows:

$$t = \frac{(p_{stor}^1 - p_{stor}) V_{stor}}{q_{tur} R_g T_{stor}} \quad (11)$$

- 10 Hence, the expansion work can be expressed as a function of p_{stor} after multiplication of the formulas (10) and (11):

$$\begin{aligned} W_{tur}(p_{stor}) &= P_{N_t}^W t \\ &= \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor})}{T_{stor} (\mu - 1)} (1 - \phi^{\frac{\mu-1}{\mu}}) \end{aligned} \quad (12)$$

The electric energy discharged by the RCAES system can then be expressed as the multiplication of the expansion work and the expansion efficiency:

$$E_{tur} = W_{tur}(p_{stor}) \eta_{tur} \quad (13)$$

Finally, the efficiency of the RCAES system can be calculated as follows:

$$\eta_{RCAES} = \frac{E_{tur}}{E_{com}} = \frac{W_{tur}(p_{stor}^0)}{W_{com}(p_{stor}^1)} \eta_{com} \eta_{tur} \quad (14)$$

- 15 where $W_{tur}(p_{stor}^0)$ is the expansion work that the compressed air has done when the

pressure of the CAVS decreases from p_{stor}^1 to p_{stor}^0 , and $W_{com}(p_{stor}^1)$ is the compression work that has been done on the compressed air when the pressure of the CAVS increases from p_{stor}^0 to p_{stor}^1 .

Substituting formulas (8) and (12) to formula (14), the expression of the whole RCAES system's efficiency is as follows:

$$\eta_{RCAES} = \frac{c_1 Z_1}{c_2 Z_2 + c_3 Z_3 - c_4 Z_1} \quad (14-1)$$

where

$$c_1 = \frac{N_t T_{int} \mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}} \right), \quad c_2 = \frac{\gamma [T_{in,1}^{com} + (N_{cs}-1) T_{inc}]}{(\gamma-1)};$$

$$c_3 = \frac{T_{inc} \gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}, \quad c_4 = \frac{T_{inc} \gamma}{(\gamma-1)};$$

$$Z_1 = p_{stor}^1 - p_{stor}^0; \quad Z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1 \right) (p_{stor}^1 - p_{stor}^0);$$

$$Z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right].$$

According to the above formula, the efficiency of the RCAES system is a nonlinear function of λ , $p_{val}(=p_{stor}^0)$ and p_{stor}^1 .

According to the above formulas provided by the embodiments of the present invention, the efficiency of the whole RCAES system can be calculated, and the key parameters of various processes of the system such as compression ratio of the compressor, the exhaust air pressure of the throttle and the maximum working pressure of the CAVS are adopted in the calculation of the efficiency. Thus, the efficiency evaluation method of the embodiments of the present invention can consider the impacts of various processes in the system on the efficiency of the whole system.

2.3 Key Parameters' Impacts on the RCAES Systems' Efficiency

2.3.1 The impact of the compression ratio- λ

When the compression ratio increases, more electric energy will be charged into the RCAES system and more thermal energy will be released by the compressor and absorbed by the TES system in the compression process. Consequently, more thermal
 5 energy will be reused by the turbine and more electric energy will be discharged in the expansion process.

The relationship of the compressor's inlet air temperature T_{inc} and exhaust air temperature T_c is as follows:

$$T_c = T_{inc} \lambda^{\frac{\gamma-1}{\gamma}} \quad (15)$$

To establish the relationship of T_c and the turbine's inlet air temperature T_{int} , a
 10 reasonable and applicable technique in engineering is to assume that the gap between them is a constant, indicated by ΔT_{c-t} which represents the efficacy of the TES system. The smaller the value of ΔT_{c-t} is, the better the efficacy of the TES is. Therefore, the relationship of T_c and T_{int} can be expressed as follows:

$$T_{int} = T_{inc} \lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t} \quad (16)$$

Substituting formulas (16) to formula (14), the expression of the RCAES system's
 15 efficiency can be as follows which shows the relationship of the compression ratio and η_{RCAES} :

$$\eta_{RCAES} = \frac{c'_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (14-2)$$

where $c'_1 = \frac{N_t (T_{inc} \lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t}) \mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}} \right)$, and the expressions of $c_2 \sim c_4$ and $z_1 \sim z_3$ are
 as the above.

20 Additionally, to guarantee all stages of the compressor functions, the compression ratio λ should satisfy constraint (17) as follows.

$$\sqrt[N_c]{\frac{p_{stor}^1}{p_{in,1}^{com}}} < \lambda < \sqrt[N_{cs}]{\frac{p_{stor}^1}{p_{in,1}^{com}}} \quad (17)$$

The above constraint guarantees that the pressure of the CASV could reach the maximum working pressure when all the stages work simultaneously.

2.3.2 The Impact of EAPT- p_{val}

- 5 In one aspect, the variety of EAPT $p_{val}(=p_{stor}^0)$ will affect the operation time of both compression and expansion processes. In another aspect, as the exhaust air pressure of the turbine's last stage and total stage number of the turbine both are fixed, the ratio of each stage of the turbine ϕ expressed as the formula (18) will increase and finally change the efficiency of the RCAES system.

$$\phi = \sqrt[N_t]{\frac{p_{val}}{p_{out,N_t}^{tur}}} \quad (18)$$

- 10 That is, ϕ will increase along with increasing of p_{val} . The impacts of the above two aspects both will affect the efficiency of the system. When the exhaust air pressure of the last stage of the turbine is fixed and denoted as p_{out,N_t}^{tur} , formula (18) could be substituted to formula (14) to replace ϕ in c_1 with the formular (18) so as to obtain an expression of the efficiency of the RCAES system over ϕ as follows:

15

$$\eta_{RCAES} = \frac{c_1'' Z_1}{c_2 Z_2 + c_3 Z_3 - c_4 Z_1} \quad (14-3)$$

$$\text{where } c_1'' = \frac{N_t(T_{inc}\lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t})\mu}{(\mu-1)} \left(1 - \left(\sqrt[N_t]{\frac{p_{val}}{p_{out,N_t}^{tur}}} \right)^{\frac{\mu-1}{\mu}} \right), \text{ the expressions of } c_2 \sim c_4 \text{ and}$$

$Z_1 \sim Z_3$ are as the above.

- 20 2.3.3 The impact of the Maximum Working Pressure (MWP) of CASV- p_{stor}^1

Similar to the impact of EAPT, the MWP p_{stor}^1 of CASV will affect the RCAES system's efficiency indirectly through changing its operation time. As the system efficiency η_{RCAES} is a nonlinear function of p_{stor}^1 .

Additionally, p_{stor}^1 also should satisfy the following constraint (19) to guarantee the efficacy of every stage of the compressor, i.e., the MWP of CASV is reached when all the stages work simultaneously.

$$p_{in,1}^{com} \lambda^{N_{cs}} < p_{stor}^1 < p_{in,1}^{com} \lambda^{N_c} \quad (19)$$

According to the above formulas (14-1), (14-2) and (14-3) provided by the embodiments of the present invention can be adopted to analyze the impacts of the key parameters of various processes on the efficiency of the whole RCAES system, so as to determine the parameter values with which the RCAES system could obtain a better efficiency.

Based on the above solutions, an embodiment of the present invention provides an efficiency evaluation method of an RCAES system which includes parts of compression, thermal energy storage, CASV and expansion, and the method includes the following steps as shown in Fig.2:

Block 201: calculating electric energy charged by an electric power system in a compression process.

Block 202: calculating electric energy discharged to the electric power system in an expansion process.

Block 203: calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system.

Here, gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant.

Specifically, a process of calculating the electric energy charged by the electric power system in the compression process may include the following steps:

calculating compression work of stages except the last stage of a compressor;

calculating compression work of the last stage of the compressor; and

- 5 calculating the electric energy charged in the compression process according to the compression work of all the stages of the compressor.

Here, the stages except the last stage of the compressor are steady stages of the compressor while the last stage of the compressor is an unsteady stage of the compressor. And the compression work of all the stages of the compressor and the electric energy
10 charged in the compression process may be calculated according to the formulas mentioned in Section 2.1, and the specific calculation method will not be described again hereinafter.

Specifically, a process of calculating the electric energy discharged to the electric power system in the expansion process may include the following steps:

- 15 calculating expansion work of the expansion process; and

calculating the electric energy discharged to the electric power system according to the expansion work.

Here, the expansion work of the expansion process and the electric energy discharged to the electric power system may be calculated according to the formulas
20 mentioned in Section 2.2, and the specific calculation method will not be described again hereinafter.

In an embodiment of the present invention, the method may further include the following steps:

- 25 determining an expression of a relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of a compressor;

determining an expression of a relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV;

determining an expression of a relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV; and

analyzing variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle or the maximum working pressure of the CASV according to the expression of the relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV.

Here, the expression of the relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of the compressor has been discussed in Section 2.3, and it may be the following formula:

$$E_{com}(p_{stor}) = \frac{W_{Ncs}(p_{stor}) + W_{Nc}(p_{stor})}{\eta_{com}}$$

$$\text{Herein, } W_{Nc}(p_{stor}) = \alpha_1 \left[\left(\frac{p_{stor}}{p_{in,Nc}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,Nc}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor} - p_{stor}^0),$$

$$\alpha_1 = \frac{T_{inc} V_{stor} \gamma^2 \lambda^{Ncs} p_{in,1}^{com}}{T_{stor} (2\gamma-1) (\gamma-1)}, \quad \alpha_2 = \frac{T_{inc} V_{stor} \gamma}{T_{stor} (\gamma-1)},$$

$$W_{Ncs}(p_{stor}) = \frac{V_{stor} \gamma (p_{stor} - p_{stor}^0) (\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor} (\gamma-1)} [T_{in,1}^{com} + (N_{cs} - 1) T_{inc}] .$$

And the expression of the relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV has been discussed in Section 2.3, and it may be the following formula:

$$E_{tur}(p_{stor}) = W_{tur}(p_{stor}) \eta_{tur}$$

Herein, $W_{tur}(p_{stor}) = \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor})}{T_{stor}(\mu - 1)} (1 - \phi^{\frac{\mu-1}{\mu}})$.

Specifically, the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the compression ratio of each stage of the compressor may be formula (14-2) mentioned above.

5 Optionally, when analyzing the variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the method may further include configuring a range of the value of the compression ratio to make the value of the compression ratio satisfy constraint (17) mentioned above.

Specifically, the expression of the relation between the efficiency of the whole
10 RCAES system η_{RCAES} and the exhaust air pressure of the throttle may be formula (14-3) mentioned above.

Specifically, the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the maximum working pressure of the CASV may be formula (14-1) mentioned above.

15 Optionally, when analyzing the variation of the efficiency of the whole RCAES system under different values of the maximum working pressure of the CASV, the method may further include configuring a range of the value of the maximum working pressure to make the value of the maximum working pressure satisfy constraint (19) mentioned above.

20 Based on the above method, an embodiment of the present invention provides an efficiency evaluation system of an RCAES system which includes parts of compression, thermal energy storage, compressed air storage vessel (CASV) and expansion. As shown in Fig.3, the system includes the following modules:

A first module 301, for calculating electric energy charged by an electric power
25 system in a compression process;

A second module 302, for calculating electric energy discharged to the electric power system in an expansion process; and

A third module 303, for calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system.

5 In the embodiment, gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant.

Specifically, the first module may include sub-modules as follows:

10 A first sub-module, for calculating compression work of stages except the last stage of a compressor;

A second sub-module, for calculating compression work of the last stage of the compressor; and

15 A third sub-module, for calculating the electric energy charged in the compression process according to the compression work of all the stages of the compressor.

Here, the stages except the last stage of the compressor are steady stages of the compressor while the last stage of the compressor is an unsteady stage of the compressor.

Specifically, the second module may include sub-modules: a first sub-module, for calculating expansion work of the expansion process; and a second sub-module, for
20 calculating the electric energy discharged to the electric power system according to the expansion work.

As the specific calculation method of each sub-module has been discussed before, this will not be discussed again hereinafter.

25 In an embodiment of the present invention, the system may further include the following modules:

A fourth module 304, for determining an expression of a relation among the electric energy charged in the compression process, the pressure of the CASV and the

compression ratio of each stage of a compressor;

A fifth module 305, for determining an expression of a relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV;

- 5 A sixth module 306, for determining an expression of a relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV; and

- 10 A seventh module 307, for analyzing variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle or the maximum working pressure of the CASV according to the expression of the relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV.

- 15 As the expressions determined have been discussed before, this will not be discussed again hereinafter.

- 20 Optionally, when analyzing the variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the system may further include an eighth module 308 for configuring a range of the value of the compression ratio to make the value of the compression ratio satisfy constraint (17) mentioned above, and/or configuring a range of the value of the maximum working pressure to make the value of the maximum working pressure satisfy constraint (19) mentioned above.

- 25 A machine-readable storage medium is also provided, which is to store instructions to cause a machine such as the computing device to execute one or more methods as described herein. Specifically, a system or apparatus having a storage medium that stores machine-readable program codes for implementing functions of any of the above examples and that may make the system or the apparatus (or CPU or MPU) read and execute the program codes stored in the storage medium.

The system shown in Fig.3 may further include a memory and a processor, the memory stores instructions executable for the processor. The memory may include the modules 301~308, and through executing the instructions read from the modules 301~308, the processor can accomplish the functions of the modules 301~308 as mentioned above.

- 5 Therefore, an efficiency evaluation system of the RCAES system including a memory and a processor is provided, where the memory stores instruction units executable for the processor, and the instruction units include any or any combination of the modules 301~308.

3. Case Study

- 10 The calculation method of the RCAES system's efficiency proposed in the embodiment of the present invention is applied to an example of the RCAES system, and the impacts of the key parameter of various processes on the efficiency of the whole system are also analyzed through this example.

3.1 System Introduction

- 15 Figure 4 shows a structure of the example of the RCAES system. According to Figure 4, the compressor includes 5 stages and the turbine includes 3 stages. The basic parameters are shown in Table 1 under the comprehensive consideration of the system's operation performance and construction cost.

Parameter	Value	Parameter	Value
$T_{in,1}^{com}$ (the inlet air temperature of the first stage of compressor)	25°C	$p_{stor}^0(p_{val})$ (the initial working pressure of CASV equal to the exhaust air pressure of the throttle)	2.5MPa
$p_{in,1}^{com}$ (the inlet air pressure of the compressor)	0.1MPa	p_{stor}^1 (the maximum working pressure of CASV)	10MPa
η_{com} (the efficiency of the compression process)	75%	λ (the compression ratio of each stage of compressor)	3
η_{tur} (the efficiency of the expansion process)	75%	ϕ (the expansion ratio of each stage of turbine)	1/3
T_{stor} (the temperature of CASV)	20°C	q_{com} (the exhaust air rate of the compressor)	0.46kg/s

ΔT_{c-t} (the gap between the average inlet air temperature and the average exhaust air temperature)	40°C	q_{tur} (the exharust air rate of the turbine)	2.41kg/s
γ (the polytropic exponent of the compressor)	1.4	μ (the polytropic exponent of the turbine)	1.4
T_{inc} (the inlet aire temperature of each stage except the first stage of compressor)	86.35°C	V_{stor} (the volume of the CASV)	100m ³
p_{out,N_t}^{tur} (the exhaust air pressure of the last stage of turbine)	0.11MPa		

Tab.1 Parameters of Practical RCAES System

3.2 Efficiency Evaluation of RCAES system under Basic Parameters

According to formulas (2) and (11), the compression process can be divided into two periods of which the first period takes 3.65h and the second period takes 1.36h, thus, the operation time of the whole compression process is 5.01h, in which the air pressure of the CASV increases from 3MPa to 10MPa. The operation time of the expansion process is 1.14h, in which the air pressure of the CASV decreases from 10 MPa to 3MPa. And it is determined via calculation that the exhaust air pressure of the last stage of expansion process $p_{out,N_t}^{tur} \approx 0.11MPa$. Figure 5 shows the compression power/energy over p_{stor} in the compression process, i.e., Operation Characteristics of Compression in the RCAES System, which is obtained via formulas (3)~(8).

As shown in Figure 5, the working pressure of the CASV p_{stor} increases over the compression power P_{com}^W and the compression work W_{com}^W nonlinearly, and the maximum electric power and electric energy charged into the RCAES system is 277.95KW and 1407.55KWh separately in the compression process according to formulas (3)~(9). According to formulas (10)~(13), it is determined that the electric power discharged by the RCAES system remains 705.10KW and the maximum expansion work discharged is 567.92KWh. The system efficiency then can be calculated as 40.35% according to formula (14).

3.3 The Impact of Compression Ratio

In the formulation of this part, all parameters excluding the compression ratio λ of the RCAES system are given as the basic parameters given in Table 1, and λ may satisfy the following condition according to formula (17).

$$2.5119 \approx \sqrt[N_c]{\frac{p_{stor}^1}{p_{in,1}^{com}}} < \lambda < \sqrt[N_{cs}]{\frac{p_{stor}^1}{p_{in,1}^{com}}} \approx 3.1623$$

Thus, λ is fixed as the following given values successively:

$$2.6, 2.7, 2.8, 2.9, 3.0, 3.1$$

- 5 The electric energy charged in the compression process ($W_{com}^{max} = W_{com}(p_{stor}^1)/\eta_{com}$) and discharged in the expansion process ($W_{tur}^{max} = W_{tur}(p_{stor}^0)\eta_{tur}$) over different λ are given in Figure 6, and they both are monotonely increasing along with increasing of λ . The curves in Figure 6 are obtained according to formulas (3)~(13), (15) and (16). The RCAES system's efficiency η_{RCAES} over different values of λ , i.e., the ratio of E_{tur}^{max}
10 and E_{com}^{max} is given in Figure 7 according formula (14-2).

As shown in Figure 7, the RCAES system's efficiency increases approximately linearly over λ partly because of the narrow feasible region of λ under the given design scheme, although the nonlinearity is indicated by formula (14-2).

- As the compression ratio λ increases more thermal energy is released, resultantly,
15 raising the temperature of High-Temperature TES. Accordingly, the inlet air temperature of the turbine is raised, implying that more electric energy will be discharged in the expansion process. The simulation result shows that there is more electric energy discharged than that charged with a larger λ , so that the efficiency of the RCAES system is increased.

20 3.4 The Impact of EAPT

In the formulation of this part, all parameters excluding the EAPT (p_{val}) are given as the basic parameters in Table 1. Although p_{val} may be given an arbitrary value in the range of 0.1MPa~10Mpa theoretically, p_{val} is fixed as the following given values successively in this formulation:

2.5MPa, 3MPa, 3.5MPa, ..., 6.5MPa, 7MPa

The simulation result is shown in Figure 8, in which E_{com}^{max} decreases approximately linearly over p_{val} while E_{tur}^{max} decreases nonlinearly over p_{val} . As the change rate of E_{tur}^{max} is smaller than E_{com}^{max} , the system's efficiency increases nonlinearly as shown in Figure 9 which is simulated according to formula (14-3), indicating that a larger value of p_{val} causes less energy loss of the system in accordance with the simulation result in Figure 9.

As analyzed in previous parts, the energy charged into the RCAES system are stored in the TES as high-temperature water on one hand and stored in the CASV as high-pressure air on the other hand. For the latter, more energy will be stored with higher pressure given the volume of the CASV. However, the high-pressure air becomes constant temperature and isopiestic after throttling, resulting in the decrement of the capability to work of air per unit mass. Furthermore, more energy loss will be caused by larger difference of the pressure after throttling according to the simulation result. Thus, increasing the value of p_{val} will decrease the energy loss during throttling, thereby raising the efficiency of the whole RCAES system.

3.5 The Impact of the MWP of CASV

In the simulation of this part, all parameters excluding the MWP of CASV are given as the basic parameters in Table 1. According to formula (19), p_{stor}^1 may satisfy the following condition:

$$8.1MPa = p_{in,1}^{com} \lambda^{N_{cs}} < p_{stor}^1 < p_{in,1}^{com} \lambda^{N_c} = 40.5MPa$$

Thus, p_{stor}^1 is fixed as the following given values successively in analysis of the impact of p_{stor}^1 :

10MPa, 15MPa, ..., 35MPa, 40MPa

Figure 10 shows that the electric energy charged in the compression process and discharged in the expansion process both increase approximately linearly over p_{stor}^1 resulting in the system's efficiency decreasing nonlinearly over p_{stor}^1 as shown in Figure

11.

Fixing p_{val} , the capability to work of the high-pressure air will diminish after throttling, leading to efficiency reduction of the RCAES system. The simulation result also shows that the loss is larger with a higher MWP of the CASV.

5 According to all simulation results through 3.1 ~3.5, a higher compression ratio, a higher EAPT and a lower MWP of the CASV in certain range can help improve the efficiency of the RCAES system.

10 However, the system efficiency is only one of the key indicators of the RCAES system, other key indicators, e.g., the maximum electric power, operation hours, the maximum capacity and construction costs may also be considered in practical engineering. The evaluation method proposed in the embodiments of the present invention can still be used as a foundation to accessing the operation performance.

15 The RCAES system is widely concerned in recent years, while research on its efficiency is very limited. Based on the electric-mechanical-thermal energy conversion process of the RCAES system and the basic thermodynamics assumptions, an efficiency evaluation method is proposed in the embodiments of the present invention which is validated by the typical design scheme of the RCAES system. Furthermore, the impacts of key parameters including the compression ratio, the EAPT, the MWP of the CASV may be analyzed in the embodiments of the present invention. The simulation results
20 reveal variation tendency of the system efficiency over a certain range of these parameters.

25 The above description just shows several examples of the present disclosure in order to present the principle and implementation of the present application, and is in no way intended to limit the scope of the present application. Any modifications, equivalents, improvements and the like made within the spirit and principle of the present application should be encompassed in the scope of the present application.

What is claimed is:

1. An efficiency evaluation method of an RCAES (Regenerative Compressed Air Energy Storage) system which comprises parts of compression, thermal energy storage, compressed air storage vessel (CASV) and expansion; the method comprising:
 - calculating electric energy charged by an electric power system in a compression process;
 - calculating electric energy discharged to the electric power system in an expansion process; and
 - calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system;
 wherein gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant.

2. The method of claim 1, wherein a process of calculating the electric energy charged by the electric power system in the compression process comprises:
 - calculating compression work of stages except the last stage of a compressor;
 - calculating compression work of the last stage of the compressor; and
 - calculating the electric energy charged in the compression process according to the compression work of all the stages of the compressor;
 wherein the stages except the last stage of the compressor are steady stages of the compressor while the last stage of the compressor is an unsteady stage of the compressor.

3. The method of claim 2, wherein the compression work of the stages except the last stage of the compressor is calculated according to formula (1):

$$W_{N_{cs}} = \frac{V_{stor} \gamma (p_{stor}^1 - p_{stor}^0) (\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor}(\gamma-1)} [T_{in,1}^{com} + (N_{cs} - 1)T_{inc}] \quad (1)$$

- the compression work of the last stage of the compressor is calculated according to formula (2):

$$W_{N_c} = \alpha_1 \left[\left(\frac{p_{stor}^1}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor}^1 - p_{stor}^0) \quad (2)$$

$$\text{herein, } \alpha_1 = \frac{T_{inc} V_{stor} \gamma^2 \lambda^{N_{cs}} p_{in,1}^{com}}{T_{stor} (2\gamma-1)(\gamma-1)}, \quad \alpha_2 = \frac{T_{inc} V_{stor} \gamma}{T_{stor} (\gamma-1)},$$

the electric energy charged in the compression process is calculated according to formula (3):

$$E_{com} = \frac{W_{N_{cs}} + W_{N_c}}{\eta_{com}} \quad (3)$$

5 wherein meanings of parameter symbols in the above formulas are listed in a table as below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
$W_{N_{cs}}$	the compression power of the stages except the last stage of the compressor	γ	the polytropic exponent of the compressor
W_{N_c}	the compression power of the last stage of the compressor	$T_{in,1}^{com}$	the inlet air temperature of the first stage of the compressor
E_{com}	the electric energy charged in the compression process	T_{inc}	the inlet air temperature of each stage other than the first stage of the compressor
η_{com}	the efficiency of the compression process	N_{cs}	the stage number of the penultimate stage
V_{stor}	the volume of the CASV	p_{in,N_c}^{com}	the inlet air pressure of the last stage of the compressor
p_{stor}^1	the maximum working pressure of the CASV	q_{com}	the exhaust air rate of the compressor
p_{stor}^0	the initial working pressure of the CASV	T_{stor}	the temperature of the CASV
λ	the compression ratio of each stage of the compressor		

4. The method of claim 1, wherein a process of calculating the electric energy discharged to the electric power system in the expansion process comprises:

- 10 calculating expansion work of the expansion process; and
calculating the electric energy discharged to the electric power system according to the expansion work.

5. The method of claim 4, wherein the expansion work of the expansion process is
15 calculated according to formula (4):

$$W_{tur} = \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor}^0)}{T_{stor}(\mu - 1)} (1 - \phi^{\frac{\mu-1}{\mu}}) \quad (4)$$

the electric energy discharged is calculated according to formula (5):

$$E_{tur} = W_{tur} \eta_{tur} \quad (5)$$

wherein meanings of parameter symbols in the above formulas are listed in a table as

5 below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
W_{tur}	the expansion work of the expansion process	ϕ	the expansion ratio of each stage of turbine
E_{tur}	the electric energy discharged to the electric power system	T_{int}	the inlet air temperature of each stage of turbine
η_{tur}	the efficiency of the expansion process	N_t	the number of stages of turbine
V_{stor}	the volume of the CASV	μ	the polytropic exponent of the turbine
p_{stor}^1	the maximum working pressure of the CASV	T_{stor}	the temperature of the CASV
p_{stor}^0	the initial working pressure of the CASV		

6. The method of claim 1, further comprising:

determining an expression of a relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of a compressor;

determining an expression of a relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV;

determining an expression of a relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV; and

analyzing variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle or the maximum working pressure of the CASV according to the expression of the relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV.

7. The method of claim 6, wherein the expression of the relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of the compressor is formula (6):

$$E_{com}(p_{stor}) = \frac{W_{N_{cs}}(p_{stor}) + W_{N_c}(p_{stor})}{\eta_{com}} \quad (6)$$

5 herein, $W_{N_c}(p_{stor}) = \alpha_1 \left[\left(\frac{p_{stor}}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor} - p_{stor}^0),$

$$\alpha_1 = \frac{T_{inc} V_{stor} \gamma^2 \lambda^{N_{cs}} p_{in,1}^{com}}{T_{stor} (2\gamma-1)(\gamma-1)}, \quad \alpha_2 = \frac{T_{inc} V_{stor} \gamma}{T_{stor} (\gamma-1)},$$

$$W_{N_{cs}}(p_{stor}) = \frac{V_{stor} \gamma (p_{stor} - p_{stor}^0) (\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor} (\gamma-1)} [T_{in,1}^{com} + (N_{cs} - 1) T_{inc}];$$

the expression of the relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV is formula (7):

$$E_{tur}(p_{stor}) = W_{tur}(p_{stor}) \eta_{tur} \quad (7)$$

10 herein, $W_{tur}(p_{stor}) = \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor})}{T_{stor} (\mu-1)} (1 - \phi^{\frac{\mu-1}{\mu}});$

wherein meanings of parameter symbols in the above formulas are listed in a table as below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
$W_{N_{cs}}$	the compression work of the stages except the last stage of the compressor	γ	the polytropic exponent of the compressor
W_{N_c}	the compression work of the last stage of the compressor	$T_{in,1}^{com}$	the inlet air temperature of the first stage of the compressor
E_{com}	the electric energy charged in the compression process	T_{inc}	the inlet air temperature of each stage except the first stage of the compressor
η_{com}	the efficiency of the compression process	N_{cs}	the stage number of the penultimate stage
V_{stor}	the volume of the CASV	p_{in,N_c}^{com}	the inlet air pressure of the last stage of the compressor
p_{stor}	p_{stor}^1 the pressure of the CASV, the maximum working pressure of the CASV is denoted as p_{stor}^1	q_{com}	the exhaust air rate of the compressor
p_{stor}^0	the initial working pressure of the CASV which is equal to the exhaust air pressure of a throttle p_{val}	T_{stor}	the temperature of the CASV

λ	the compression ratio of each stage of the compressor	ϕ	the expansion ratio of each stage of turbine
W_{tur}	the expansion work of the expansion process	T_{int}	the inlet air temperature of each stage of turbine
E_{tur}	the electric energy discharged in the expansion process	N_t	the number of stages of turbine
η_{tur}	the efficiency of the expansion process	μ	the polytropic exponent of the turbine

8. The method of claim 7, wherein the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the compression ratio of each stage of the compressor is formula (8):

$$\eta_{RCAES}(\lambda) = \frac{c'_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (8)$$

herein, $c'_1 = \frac{N_t(T_{inc}\lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t})\mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}}\right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$,
 $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$, $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1\right)(p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}}\right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}}\right)^{\frac{2\gamma-1}{\gamma}} \right]$, ΔT_{c-t} is the gap between the average inlet air temperature and the average exhaust air temperature, and $p_{in,1}^{com}$ is the inlet air pressure of the compressor.

9. The method of claim 8, wherein when analyzing the variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the method further comprises configuring a range of the value of the compression ratio to make the value of the compression ratio satisfy the following constraint:

$$\sqrt[N_c]{\frac{p_{stor}^1}{p_{in,1}^{com}}} < \lambda < \sqrt[N_{cs}]{\frac{p_{stor}^1}{p_{in,1}^{com}}}$$

10. The method of claim 7, wherein the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the exhaust air pressure of the throttle is formula (9):

$$\eta_{RCAES}(p_{val}) = \frac{c''_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (9)$$

herein, $c_1'' = \frac{N_t(T_{inc}\lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t})\mu}{(\mu-1)} \left(1 - \left(N_t \sqrt{\frac{p_{val}}{p_{out,N_t}^{tur}}} \right)^{\frac{\mu-1}{\mu}} \right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$;
 $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$, $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1 \right) (p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right]$, ΔT_{c-t} is the gap between the average inlet air
 temperature and the average exhaust air temperature, and p_{out,N_t}^{tur} is the exhaust air
 5 pressure of the last stage of turbine, and $p_{in,1}^{com}$ is the inlet air pressure of the compressor.

11. The method of claim 7, wherein the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the maximum working pressure of the CAVS is formula (10):

$$10 \quad \eta_{RCAES}(p_{stor}^1) = \frac{c_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (10)$$

herein, $c_1 = \frac{N_t T_{int} \mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}} \right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$, $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$,
 $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1 \right) (p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right]$, $p_{in,1}^{com}$ is the inlet air pressure of the
 compressor.

12. The method of claim 11, wherein when analyzing the variation of the efficiency of the whole RCAES system under different values of the maximum working pressure of the CASV, the method further comprises configuring a range of the value of the maximum working pressure to make the value of the maximum working pressure satisfy
 20 the following constraint:

$$p_{in,1}^{com} \lambda^{N_{cs}} < p_{stor}^1 < p_{in,1}^{com} \lambda^{N_c}$$

13. An efficiency evaluation system of an RCAES (Regenerative Compressed Air Energy Storage) system which comprises parts of compression, thermal energy storage, compressed air storage vessel (CASV) and expansion; the system comprising:

25 a first module, for calculating electric energy charged by an electric power system in

a compression process;

a second module, for calculating electric energy discharged to the electric power system in an expansion process; and

a third module, for calculating a ratio of the electric energy discharged in the expansion process to that charged in the compression process, and taking the ratio as an efficiency of the whole RCAES system;

wherein gas in operation is ideal gas, air mass flow rates in the compression and expansion processes are known and constant in operation, an isothermal model is adopted for the CASV of which the temperature is the same with ambient circumstances, and the temperature and pressure of compressed air after throttling become constant.

14. The system of claim 13, wherein the first module comprises:

a first sub-module, for calculating compression work of stages except the last stage of a compressor;

a second sub-module, for calculating compression work of the last stage of the compressor; and

a third sub-module, for calculating the electric energy charged in the compression process according to the compression work of all the stages of the compressor;

wherein the stages except the last stage of the compressor are steady stages of the compressor while the last stage of the compressor is an unsteady stage of the compressor.

15. The system of claim 14, wherein the first sub-module calculates the compression work of the stages except the last stage of the compressor according to formula (1):

$$W_{N_{cs}} = \frac{V_{stor}\gamma(p_{stor}^1 - p_{stor}^0)(\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor}(\gamma-1)} [T_{in,1}^{com} + (N_{cs} - 1)T_{inc}] \quad (1)$$

the second sub-module calculates the compression work of the last stage of the compressor according to formula (2):

$$W_{N_c} = \alpha_1 \left[\left(\frac{p_{stor}^1}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor}^1 - p_{stor}^0) \quad (2)$$

$$\text{herein, } \alpha_1 = \frac{T_{inc}V_{stor}\gamma^2\lambda^{N_{cs}}p_{in,1}^{com}}{T_{stor}(2\gamma-1)(\gamma-1)}, \quad \alpha_2 = \frac{T_{inc}V_{stor}\gamma}{T_{stor}(\gamma-1)},$$

the third sub-module calculates the electric energy charged in the compression process according to formula (3):

$$E_{com} = \frac{W_{Ncs} + W_{Nc}}{\eta_{com}} \quad (3)$$

wherein meanings of parameter symbols in the above formulas are listed in a table as below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
$W_{N_{cs}}$	the compression power of the stages except the last stage of the compressor	γ	the polytropic exponent of the compressor
W_{N_c}	the compression power of the last stage of the compressor	$T_{in,1}^{com}$	the inlet air temperature of the first stage of the compressor
E_{com}	the electric energy charged in the compression process	T_{inc}	the inlet air temperature of each stage other than the first stage of the compressor
η_{com}	the efficiency of the compression process	N_{cs}	the stage number of the penultimate stage
V_{stor}	the volume of the CASV	p_{in,N_c}^{com}	the inlet air pressure of the last stage of the compressor
p_{stor}^1	the maximum working pressure of the CASV	q_{com}	the exhaust air rate of the compressor
p_{stor}^0	the initial working pressure of the CASV	T_{stor}	the temperature of the CASV
λ	the compression ratio of each stage of the compressor		

16. The system of claim 13, wherein the second module comprises:
a first sub-module, for calculating expansion work of the expansion process; and
a second sub-module, for calculating the electric energy discharged to the electric power system according to the expansion work.

10 17. The system of claim 16, wherein the first sub-module calculates the expansion
work of the expansion process according to formula (4):

$$W_{tur} = \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor}^0)}{T_{stor}(\mu - 1)} (1 - \phi^{\frac{\mu-1}{\mu}}) \quad (4)$$

the second sub-module calculates the electric energy discharged according to formula (5):

$$E_{tur} = W_{tur} \eta_{tur} \quad (5)$$

wherein meanings of parameter symbols in the above formulas are listed in a table as below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
W_{tur}	the expansion work of the expansion process	ϕ	the expansion ratio of each stage of turbine
E_{tur}	the electric energy discharged to the electric power system	T_{int}	the inlet air temperature of each stage of turbine
η_{tur}	the efficiency of the expansion process	N_t	the number of stages of turbine
V_{stor}	the volume of the CASV	μ	the polytropic exponent of the turbine
p_{stor}^1	the maximum working pressure of the CASV	T_{stor}	the temperature of the CASV
p_{stor}^0	the initial working pressure of the CASV		

18. The system of claim 13, further comprising:

a fourth module, for determining an expression of a relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of a compressor;

a fifth module, for determining an expression of a relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV;

a sixth module, for determining an expression of a relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV; and

a seventh module, for analyzing variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle or the maximum working pressure of the CASV according to the expression of the relation between the efficiency of the whole RCAES system and any of the compression ratio of each stage of the compressor, the exhaust air pressure of a throttle and the maximum working pressure of the CASV.

19. The system of claim 18, wherein the fourth module determines that the expression of the relation among the electric energy charged in the compression process, the pressure of the CASV and the compression ratio of each stage of the compressor is

formula (6):

$$E_{com}(p_{stor}) = \frac{W_{N_{cs}}(p_{stor}) + W_{N_c}(p_{stor})}{\eta_{com}} \quad (6)$$

$$\text{herein, } W_{N_c}(p_{stor}) = \alpha_1 \left[\left(\frac{p_{stor}}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{p_{in,N_c}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right] - \alpha_2 (p_{stor} - p_{stor}^0),$$

$$\alpha_1 = \frac{T_{inc} V_{stor} \gamma^2 \lambda^{N_{cs}} p_{in,1}^{com}}{T_{stor} (2\gamma-1)(\gamma-1)}, \quad \alpha_2 = \frac{T_{inc} V_{stor} \gamma}{T_{stor} (\gamma-1)},$$

$$5 \quad W_{N_{cs}}(p_{stor}) = \frac{V_{stor} \gamma (p_{stor} - p_{stor}^0) (\lambda^{\frac{\gamma-1}{\gamma}} - 1)}{T_{stor} (\gamma-1)} [T_{in,1}^{com} + (N_{cs} - 1) T_{inc}];$$

the fifth module determines that the expression of the relation among the electric energy discharged in the expansion process, the pressure of the CASV and the maximum working pressure of the CASV is formula (7):

$$E_{tur}(p_{stor}) = W_{tur}(p_{stor}) \eta_{tur} \quad (7)$$

$$10 \quad \text{herein, } W_{tur}(p_{stor}) = \frac{N_t T_{int} \mu V_{stor} (p_{stor}^1 - p_{stor})}{T_{stor} (\mu-1)} (1 - \phi^{\frac{\mu-1}{\mu}});$$

wherein meanings of parameter symbols in the above formulas are listed in a table as below:

Parameter Symbol	Meaning	Parameter Symbol	Meaning
$W_{N_{cs}}$	the compression work of the stages except the last stage of the compressor	γ	the polytropic exponent of the compressor
W_{N_c}	the compression work of the last stage of the compressor	$T_{in,1}^{com}$	the inlet air temperature of the first stage of the compressor
E_{com}	the electric energy charged in the compression process	T_{inc}	the inlet air temperature of each stage except the first stage of the compressor
η_{com}	the efficiency of the compression process	N_{cs}	the stage number of the penultimate stage
V_{stor}	the volume of the CASV	p_{in,N_c}^{com}	the inlet air pressure of the last stage of the compressor
p_{stor}	p_{stor}^1 the pressure of the CASV, the maximum working pressure of the CASV is denoted as p_{stor}^1	q_{com}	the exhaust air rate of the compressor
p_{stor}^0	the initial working pressure of the CASV which is equal to the exhaust air pressure of a throttle p_{val}	T_{stor}	the temperature of the CASV
λ	the compression ratio of each stage of the compressor	ϕ	the expansion ratio of each stage of turbine

W_{tur}	the expansion work of the expansion process	T_{int}	the inlet air temperature of each stage of turbine
E_{tur}	the electric energy discharged in the expansion process	N_t	the number of stages of turbine
η_{tur}	the efficiency of the expansion process	μ	the polytropic exponent of the turbine

20. The system of claim 19, wherein the sixth module determines that the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the compression ratio of each stage of the compressor is formula (8):

$$\eta_{RCAES}(\lambda) = \frac{c'_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (8)$$

herein, $c'_1 = \frac{N_t(T_{inc}\lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t})\mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}}\right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$,
 $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$, $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1\right)(p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}}\right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}}\right)^{\frac{2\gamma-1}{\gamma}} \right]$, ΔT_{c-t} is the gap between the average inlet air temperature and the average exhaust air temperature, and $p_{in,1}^{com}$ is the inlet air pressure of the compressor.

21. The system of claim 20, wherein when analyzing the variation of the efficiency of the whole RCAES system under different values of the compression ratio of each stage of the compressor, the system further comprises an eighth module for configuring a range of the value of the compression ratio to make the value of the compression ratio satisfy the following constraint:

$$\sqrt[N_c]{\frac{p_{stor}^1}{p_{in,1}^{com}}} < \lambda < \sqrt[N_{cs}]{\frac{p_{stor}^1}{p_{in,1}^{com}}}$$

22. The system of claim 19, wherein the sixth module determines the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the exhaust air pressure of the throttle is formula (9):

$$\eta_{RCAES}(p_{val}) = \frac{c''_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (9)$$

herein, $c_1'' = \frac{N_t(T_{inc}\lambda^{\frac{\gamma-1}{\gamma}} + \Delta T_{c-t})\mu}{(\mu-1)} \left(1 - \left(N_t \sqrt{\frac{p_{val}}{p_{out,t}^{tur}}} \right)^{\frac{\mu-1}{\mu}} \right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$;
 $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$, $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1 \right) (p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right]$, ΔT_{c-t} is the gap between the average inlet air
 temperature and the average exhaust air temperature, and $p_{out,t}^{tur}$ is the exhaust air
 5 pressure of the last stage of turbine, and $p_{in,1}^{com}$ is the inlet air pressure of the compressor.

23. The system of claim 19, wherein the sixth module determines that the expression of the relation between the efficiency of the whole RCAES system η_{RCAES} and the maximum working pressure of the CAVS is formula (10):

$$10 \quad \eta_{RCAES}(p_{stor}^1) = \frac{c_1 z_1}{c_2 z_2 + c_3 z_3 - c_4 z_1} \quad (10)$$

herein, $c_1 = \frac{N_t T_{int} \mu}{(\mu-1)} \left(1 - \phi^{\frac{\mu-1}{\mu}} \right)$, $c_2 = \frac{\gamma[T_{in,1}^{com} + (N_{cs}-1)T_{inc}]}{(\gamma-1)}$, $c_3 = \frac{T_{inc}\gamma^2 p_{in,1}^{com}}{(2\gamma-1)(\gamma-1)}$,
 $c_4 = \frac{T_{inc}\gamma}{(\gamma-1)}$, $z_1 = p_{stor}^1 - p_{stor}^0$, $z_2 = \left(\lambda^{\frac{\gamma-1}{\gamma}} - 1 \right) (p_{stor}^1 - p_{stor}^0)$,
 $z_3 = \lambda^{N_{cs}} \left[\left(\frac{p_{stor}^1}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{p_{stor}^0}{\lambda^{N_{cs}} p_{in,1}^{com}} \right)^{\frac{2\gamma-1}{\gamma}} \right]$, $p_{in,1}^{com}$ is the inlet air pressure of the
 compressor.

24. The system of claim 23, wherein when analyzing the variation of the efficiency of the whole RCAES system under different values of the maximum working pressure of the CASV, the system further comprises an eighth module for configuring a range of the value of the maximum working pressure to make the value of the maximum working
 20 pressure satisfy the following constraint:

$$p_{in,1}^{com} \lambda^{N_{cs}} < p_{stor}^1 < p_{in,1}^{com} \lambda^{N_c}$$

25. A non-transitory machine-readable storage medium, storing instructions to cause a machine to execute the method of any of claims 1-12.

1/6

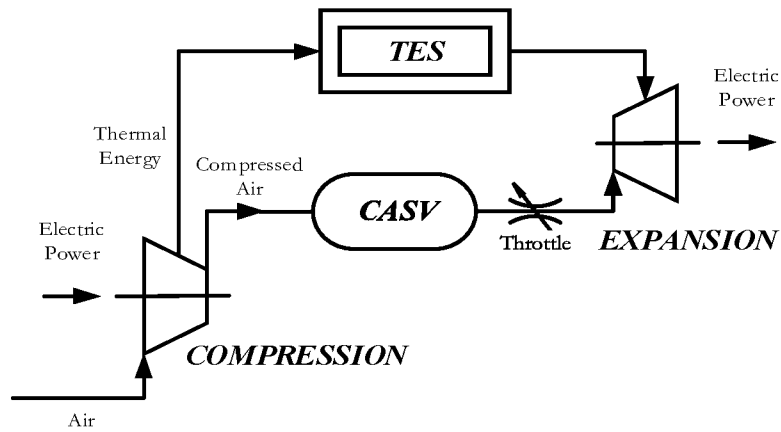


Figure 1

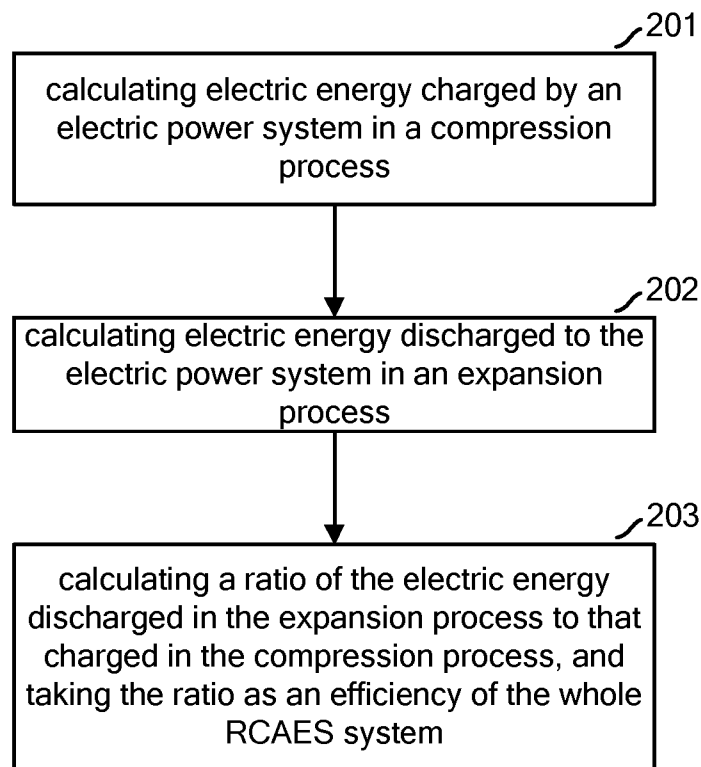


Figure 2

2/6

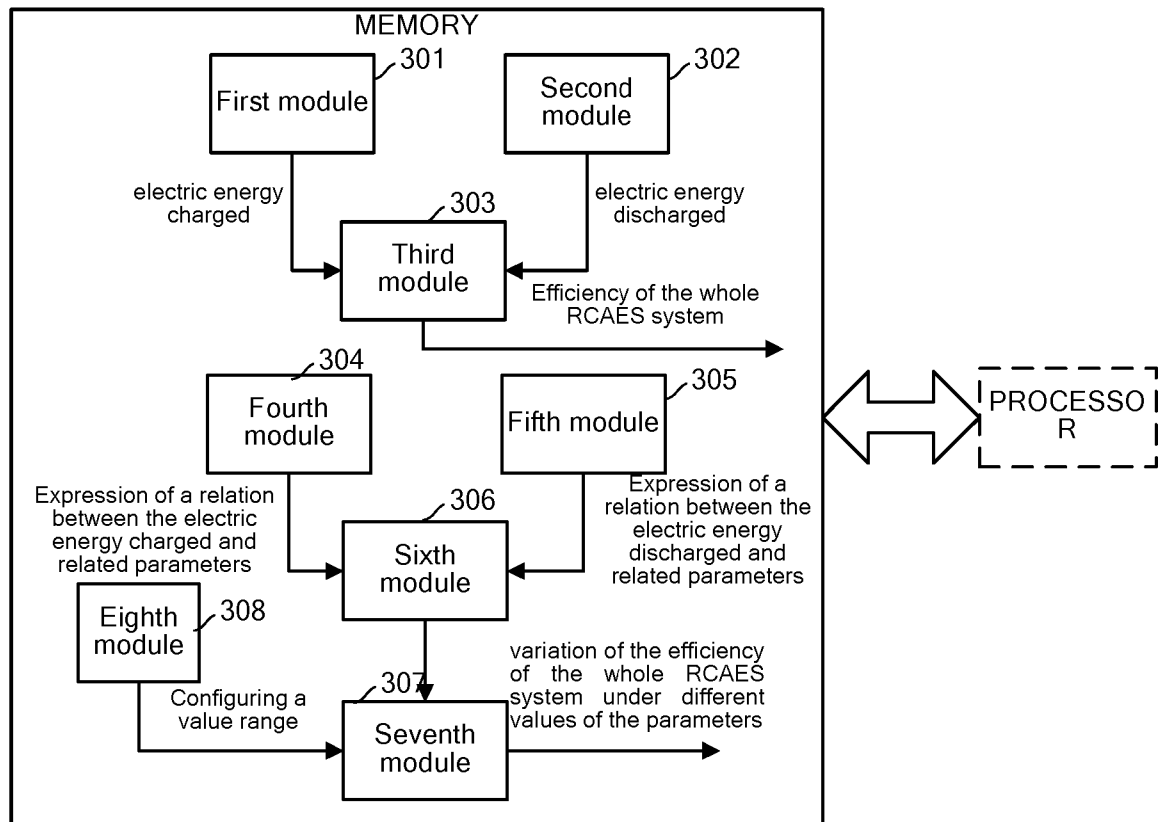


Figure 3

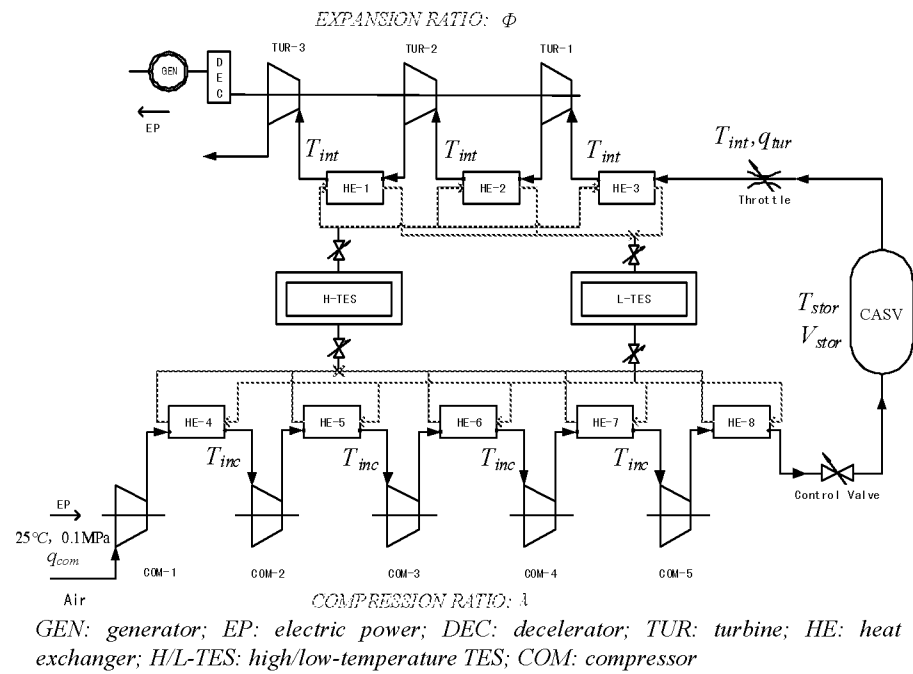


Figure 4

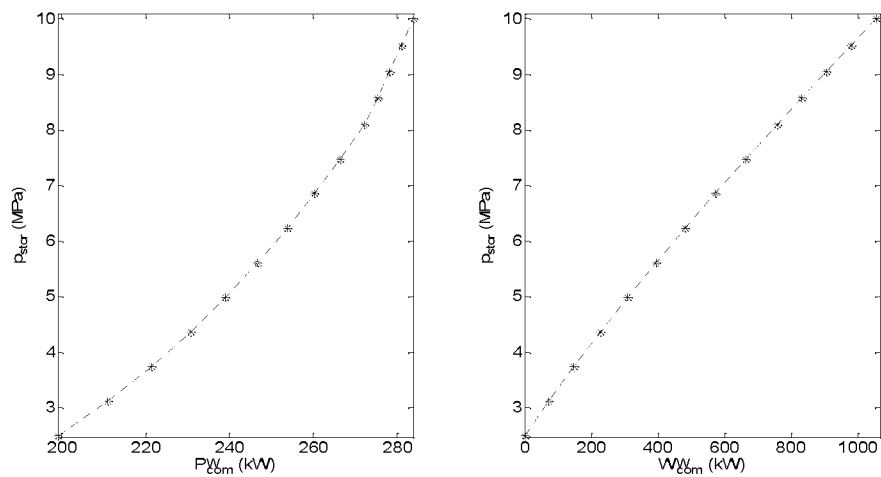


Figure 5

4/6

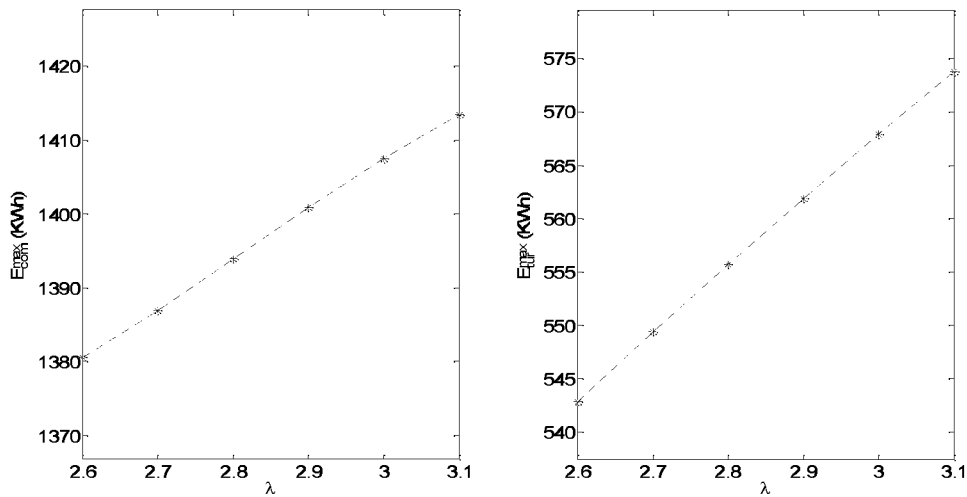


Figure 6

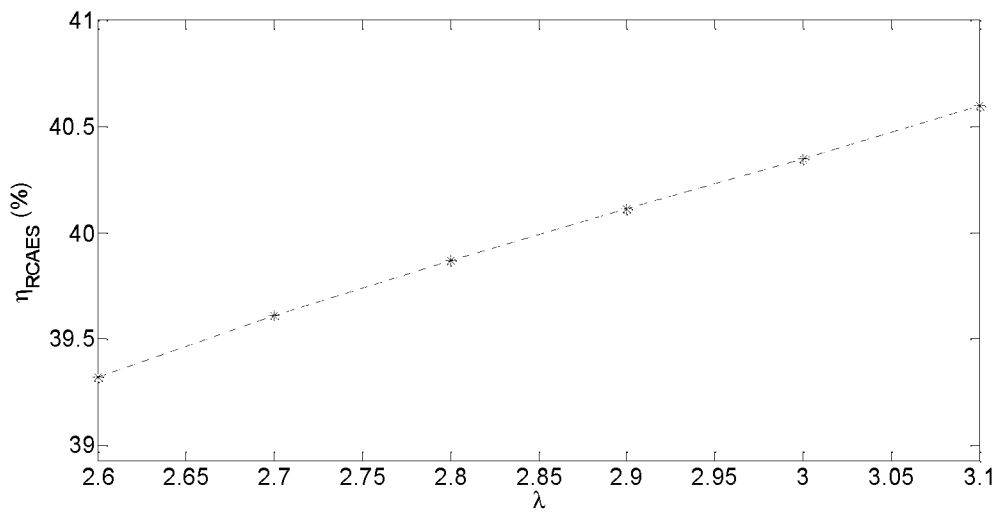


Figure 7

5/6

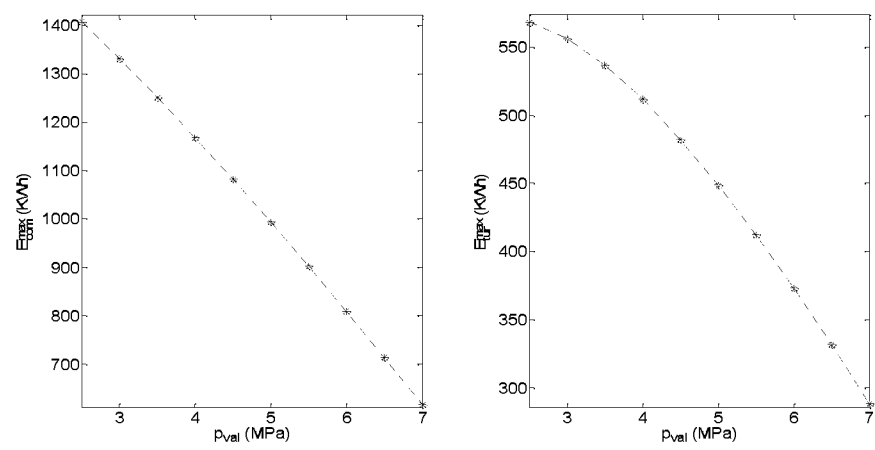


Figure 8

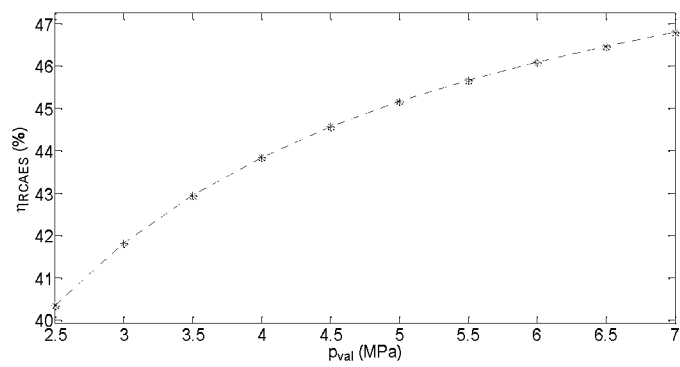


Figure 9

6/6

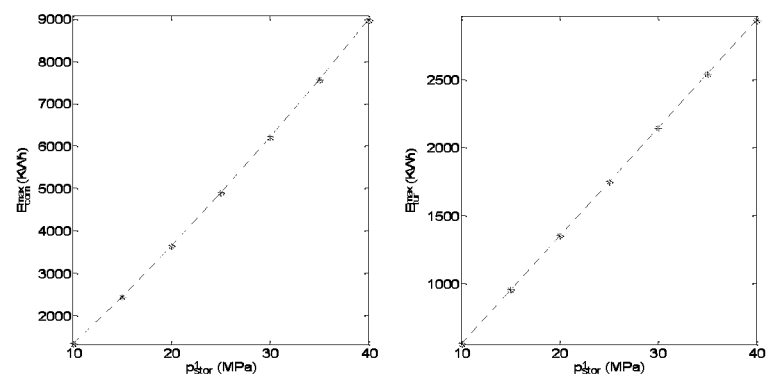


Figure 10

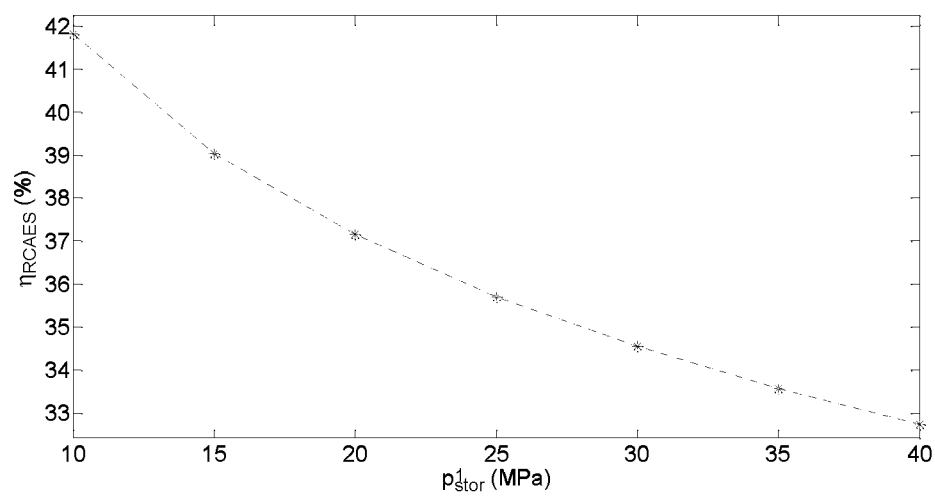


Figure 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2014/081173

A. CLASSIFICATION OF SUBJECT MATTER

F04B 41/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04B 41/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT, CNKI, EPODOC, WPI: compressed w air, thermal, efficiency, evaluation, charg+, discharg+, ratio, electric w energy, expansion

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 103225598 A (TSINGHUA UNIVERSITY) 31 July 2013 (2013-07-31) description, paragraphs [0022] to [0029] and figures 1 and 2	1-25
A	CN 102661175 A (XI'AN JIAOTONG UNIVERSITY) 12 September 2012 (2012-09-12) the whole document	1-25
A	CN 1482349 A (XI'AN JIAOTONG UNIVERSITY) 17 March 2004 (2004-03-17) the whole document	1-25
A	CN 102052256 A (INSTITUTE OF ENGINEERING THERMOPHYSICS, CHINESE ACADEMY OF SCIENCES) 11 May 2011 (2011-05-11) the whole document	1-25
A	CN 102518480 A (NORTH CHINA ELECTRIC POWER UNIVERSITY) 27 June 2012 (2012-06-27) the whole document	1-25
A	US 2009/0217898 A1 (GENERAL ELECTRIC COMPANY) 03 September 2009 (2009-09-03) the whole document	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

16 March 2015

Date of mailing of the international search report

30 March 2015

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2014/081173

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
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CN	102661175	A	12 September 2012	Non e			
CN	1482349	A	17 March 2004	CN	1225597	C	02 November 2005
CN	102052256	A	11 May 2011	CN	102052256	B	18 December 2013
				JP	2013510257	A	21 March 2013
				US	2012216520	A1	30 August 2012
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CN	102518480	A	27 June 2012	Non e			
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