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Novel method for calculating installed capacity of stand-alone renewable energy systems

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ABSTRACT

The use of new energy sources to replace traditional energy sources is the worldwide interest based on its irrefutable advantages, especially in regions where supply systems Power supply cannot reach. The devices installed capacity has a significant effect on the economy as well as on system operation. In this paper, formulate and solve the problem of optimizing installed capacity for devices (generators, charge controllers, storage, inverters ...) that are used in independent renewable energy systems. In illustrating this method of calculation, we apply it on a standalone system, i.e., it is not connected to the power supply grid.

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1. INTRODUCTION

The difficulty in choosing the installed capacity is caused by the inability to know precisely the consumption patterns of the load and the received energy. In renewable energy systems, the level of energy emitted at any given moment depends so much on the weather that it is only roughly determined. Together with the load consumption characteristics, the energy traits obtained in real-time are determined with a certain degree of accuracy based on factors such as weather forecasting, characteristics at similar time intervals in the past. This level of deviation is also taken into account when we simulate the system. In the conventional calculation methods [1-10], the authors often choose the installed capacity of the devices based on the estimation of the power consumption and the received power of the generating devices (renewable amount, converter, UPS, …). This is not enough to convince us to calculate the optimal investment cost for the necessary equipment and suggests us to find some more effective method for this issue. To illustrate the proposed method, we assume that energy-consuming objects consume only active power. The characteristics of the load have maximum daytime value and vary between days of the week and between different seasons of the year. The capacity of the load consists of two parts, the fixed component consists of the critical loads, and the component is changeable. That is, it is possible to shift the time of use. To solve this problem, we take the problem to solve the linear programming problem with the number of variables in the thousands. The working model of the system is simulated for a period of a year, with the interval between discrete points equal to 12 minutes [11-20]. The remaining of this paper can be drawn as follows. The second section describes the method. The numerical results and some discussion are provided in the third section. And the last section concludes this research.

2. METHOD

The problem in this paper is related to the research project on the possibility of installing a renewable energy system to replace the generator gas turbine. The characteristic of the load line, in this case, is the uneven energy consumption between different times, and at some point, an exceptionally high demand for electricity occurs. Load routing consists of two parts, fixed and variable, i.e., can change the time of use. Besides, the power converters and the save devices are assumed to be lossless (an accepted hypothesis so as not to complicate the presentation of the main idea of the problem, it can be disassembled. Only by introducing a specific loss factor for each particular type of equipment), the initial and final energy states of the storage device are considered the same at the beginning and end of the period simulation. The obtained energy capacity of wind power generators for 1 kW of installed capacity is as shown in Figure 1. This characteristic is determined based on specific weather rules of each region. In the simulation, to ensure that the system works perfectly for all realities, we include the seasonal weather probability function and the location where the system is installed, i.e., in the simulation. This characteristic is not a static (fixed) characteristic [21-25].

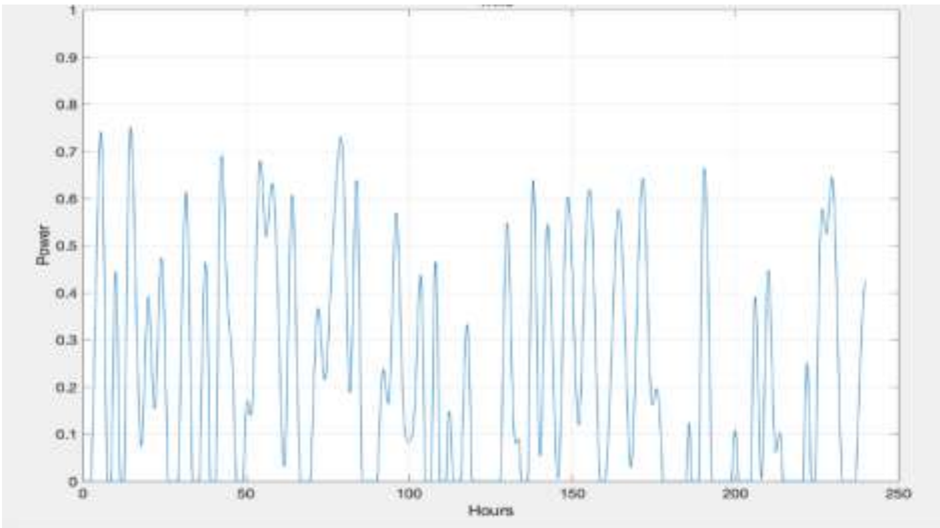

Figure 1. The obtained energy capacity of wind power generators for 1 kW

The basic quantities specifically describe the electricity storage part

$$-P_{\text{sto min}} \le P_{\text{sto}}(t) \le P_{\text{sto max}}, \quad (1)$$

$$W_{\text{sto min}} \le W_{\text{sto}}(t) \le W_{\text{sto max}}, \quad (2)$$

where $P_{\text{sto}}(t)$ – the power of the storage/inverter devices and $W_{\text{sto}}(t)$ – capacity of the storage at moment *t*; $P_{\text{sto min}}$; $P_{\text{sto max}}$; $W_{\text{sto min}}$ and $W_{\text{sto max}}$ – limit discharge, charge, remaining and maximum energy of the UPS to its safety assurance.

$$W_{\text{sto}}(t) = \int_0^t P_{\text{sto}}(t)dt \quad (3)$$

These limits are valid for each type of battery used [4]. Here, $P_{\text{sto}}(t)>0$ if at time t, the UPS discharges electricity, and if $P_{\text{sto}}(t)<0$ at time t, the UPS charges. We have

$$0\le P_{\text{solar}}(t)\le P_{\text{solar max}} \tag{4}$$

$$0\le P_{\text{wind}}(t)\le P_{\text{wind max}} \tag{5}$$

where $P_{\text{solar max}}$ and $P_{\text{wind max}}$ – installed power of wind turbines and solar panels; $P_{\text{solar}}(t)$ and $P_{\text{wind}}(t)$ – actual power of wind turbines and solar panels;

For the load, $P_{\text{load}}(t)$ - the instantaneous capacity of the initial load. As mentioned above, there are two components and can be calculated as

$$P_{\text{load}}(t)=P_{\text{const}}(t)+P_{\text{var}}(t) \tag{6}$$

The load energy consumed W_{load} from $t=0$ to $t=T$, for T simulation time, in this problem, we simulate the system to operate for a year, we have as in [3]

$$W_{\text{load}}=\int_0^T P_{\text{load}}(t)dt=\int_0^T P_{\text{const}}(t)dt+\int_0^T P_{\text{var}}(t)dt=W_{\text{const}}+W_{\text{var}} \tag{7}$$

with

$$W_{\text{var}}=\int_0^T P_{\text{var}}(t)dt \tag{8}$$

Equation of power balance

$$P_{\text{solar}}(t)+P_{\text{wind}}(t)+P_{\text{sto}}(t)=P_{\text{load}}(t)$$

or

$$-P_{\text{var}}(t)+P_{\text{solar}}(t)+P_{\text{wind}}(t)+P_{\text{sto}}(t)=P_{\text{const}}(t) \tag{9}$$

Equation (9) states the fact that the energy obtained from the generators must meet the consumption demand of the load at all times. It is not feasible to solve the equations with a series of conditions, as mentioned above, by the calculus method, so we bring the above problem to a linear form [26-32].

We examine column vectors $\mathbf{P}_{\text{sto}}$, $\mathbf{P}_{\text{solar}}$, $\mathbf{P}_{\text{wind}}$, $\mathbf{P}_{\text{var}}$, whose elements are values corresponding to the quantities $P_{\text{sto}}(t)$, $P_{\text{solar}}(t)$, $P_{\text{wind}}(t)$, $P_{\text{var}}(t)$, at discrete times, with $t_k:\{t_1=0;\, t_k=t_{k-1}+h;\, t_N=T\}$, h - practical steps in the simulation. - 12 minutes. Next, to make writing the quantities simpler, we denote $P_{\text{sto},k}=P_{\text{sto}}(t_k)$, $P_{\text{solar},k}=P_{\text{solar}}(t_k)$, $P_{\text{wind},k}=P_{\text{wind}}(t_k)$, $P_{\text{var},k}=P_{\text{var}}(t_k)$. Then we have

$$\mathbf{P}_{\text{sto}}=\left[P_{\text{sto},1},P_{\text{sto},2},\cdots,P_{\text{sto},N}\right]^t;$$

$$\mathbf{P}_{\text{solar}}=\left[P_{\text{solar},1},P_{\text{solar},2},\cdots,P_{\text{solar},N}\right]^t;$$

$$\mathbf{P}_{\text{wind}}=\left[P_{\text{wind},1},P_{\text{wind},2},\cdots,P_{\text{wind},N}\right]^t;$$

$$\mathbf{P}_{\text{var}}=\left[P_{\text{var},1},P_{\text{var},2},\cdots,P_{\text{var},N}\right]^t.$$

The amount of energy consumed can change the time of use and can be calculated as the following

$$W_{\text{var}} = \int_0^T P_{\text{var}}(t)dt = \sum_{n=1}^{N} P_{\text{var},n} h = h \cdot \mathbf{1}^t \cdot \mathbf{P}_{\text{var}} = B_1 = W_{\text{load}} - W_{\text{const}}$$

With 1 - unit vectors of the corresponding size. From the hypothesis that the initial UPS state $W_{\text{sto}}(0) = W_{\text{sto}}(T) = W_{\text{sto},N}$, we get:

$$W_{\text{sto}} = W_{\text{sto}}(0) + h \cdot \mathbf{1}^t \cdot \mathbf{P}_{\text{sto}} = W_{\text{sto},1} + B_2 = W_{\text{sto},N} \text{ or } h \cdot \mathbf{1}^t \cdot \mathbf{P}_{\text{sto}} = B_2 = W_{\text{sto},N} - W_{\text{sto}} \quad (10)$$

Then it can be written (9) in matrix form as the following, where E - the unit matrix. Finally, in matrix form, we have

$$\underbrace{\begin{bmatrix} h \cdot \mathbf{1}^t & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & h \cdot \mathbf{1}^t & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ -\mathbf{E} & \mathbf{E} & \mathbf{E} & \mathbf{E} \end{bmatrix}}_{\mathbf{A}} \cdot \underbrace{\begin{bmatrix} \mathbf{P}_{\text{var}} \\ \mathbf{P}_{\text{sto}} \\ \mathbf{P}_{\text{solar}} \\ \mathbf{P}_{\text{wind}} \end{bmatrix}}_{\mathbf{X}} = \underbrace{\begin{bmatrix} B_1 \\ B_2 \\ \mathbf{0} \\ \mathbf{B}_3 \end{bmatrix}}_{\mathbf{B}} \Rightarrow \mathbf{AX} = \mathbf{B}, \quad (11)$$

with 0 - the vector has no corresponding size.

For (3), it is assumed that the UPS and converter are lossless.

$$0 \le W_{\text{sto,n}} = W_{\text{sto}}(0) + \sum_{i=1}^{n} P_{\text{sto},i} h \le W_{\text{sto max}}; \quad n = \overline{1, N}$$

Or in matrix form

$$-\mathbf{1} \cdot W_{\text{sto}}(0) \le h \underbrace{\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 1 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 1 \end{bmatrix}}_{\mathbf{S}} \begin{bmatrix} P_{\text{sto},1} \\ P_{\text{sto},2} \\ \vdots \\ P_{\text{sto},N} \end{bmatrix} \le \mathbf{1} \cdot \left(W_{\text{sto max}} - W_{\text{sto}}(0) \right).$$

Or $-\mathbf{1} \cdot \dfrac{W_{\text{sto}}(0)}{h} \le \mathbf{S} \cdot \mathbf{P}_{\text{sto}} \le \mathbf{1} \cdot \dfrac{W_{\text{sto max}} - W_{\text{sto}}(0)}{h}$, then

$$\begin{bmatrix} \mathbf{S} \\ -\mathbf{S} \end{bmatrix} \mathbf{P}_{\text{sto}} \le \frac{1}{h} \begin{bmatrix} \mathbf{1} \cdot \left(W_{\text{sto max}} - W_{\text{sto}}(0) \right) \\ \mathbf{1} \cdot W_{\text{sto}}(0) \end{bmatrix}.$$

We have

$$\begin{bmatrix} \mathbf{0} \\ \mathbf{S} \\ -\mathbf{S} \\ \mathbf{0} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{P}_{\text{var}} \\ \mathbf{P}_{\text{sto}} \\ \mathbf{P}_{\text{solar}} \\ \mathbf{P}_{\text{wind}} \end{bmatrix} \le \frac{1}{h} \begin{bmatrix} \mathbf{0} \\ \mathbf{1} \cdot \left(W_{\text{sto max}} - W_{\text{sto}}(0) \right) \\ \mathbf{1} \cdot W_{\text{sto}}(0) \\ \mathbf{0} \end{bmatrix} \Rightarrow \mathbf{CX} \le \mathbf{D} \quad (12)$$

For clarity, we re-enumerate the conditions in the form of inequality as follows, Correspondingly, in matrix form

$$\begin{bmatrix} \mathbf{0} \\ -\mathbf{1} \cdot P_{\text{sto min}} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} \le \begin{bmatrix} \mathbf{P}_{\text{var}} \\ \mathbf{P}_{\text{sto}} \\ \mathbf{P}_{\text{solar}} \\ \mathbf{P}_{\text{wind}} \end{bmatrix} \le \begin{bmatrix} \mathbf{1} \cdot P_{\text{load}} \\ \mathbf{1} \cdot P_{\text{sto max}} \\ \mathbf{1} \cdot P_{\text{solar max}} \\ \mathbf{1} \cdot P_{\text{wind max}} \end{bmatrix} \quad (13)$$

Energy users will feel comfortable with less adjustment to their energy consumption. Therefore, in this case, we use the target function, which is the load capacity that it can change when using the minimum, i.e. $\sum P_{\text{var},\, i} \to \min$ and is written in matrix form like this

$$F = \begin{bmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{P}_{\text{var}} \\ \mathbf{P}_{\text{sto}} \\ \mathbf{P}_{\text{solar}} \\ \mathbf{P}_{\text{wind}} \end{bmatrix} \to \min \tag{14}$$

Total number of variables when simulating the system in a year with an observation step of 12 minutes was 43 8000 variables [28-32].

3. NUMERICAL RESULTS AND DISCUSSION

The simulations were carried out over 1 year, suitable for different characteristics of wind and solar energy (different weather conditions). In which the functions and are dynamic functions, i.e., includes the probability function of weather (sunshine, wind) at the survey point. Figure 2, Figure 3, Figure 4 show the probability that the system can operate correctly can meet the requirements of the consumption load corresponding to the installed power of the generator. In Figure 2, when the installed capacity of the sources $P_{\text{solar}}(t)$ =3 kW, $P_{\text{wind}}(t)$ =3 kW, at the power level of the UPS is equal to 3.5 kW and its capacity is 5 kW, only 80% of the capacity of the system, that is, the sources supply enough to meet the demand. This probability remains constant as the capacity increases, and (or) the capacity of the set is increased (Figure 2). This is explained by the fact that the sources of wind and solar energy strongly depend on the weather factors, and therefore when the sun and (or) the wind is weak, the actual amount of power obtained does not meet the consumption demand. In Figure 3 and Figure 4, it can be seen that when increasing the installed capacity of wind turbines or solar panels by 1 kW, the power of the UPS is equal to 3.5 kW and its capacity. By 4 kW, the probability for the system to operate correctly is approximately 100%, i.e., the source always meets the load.

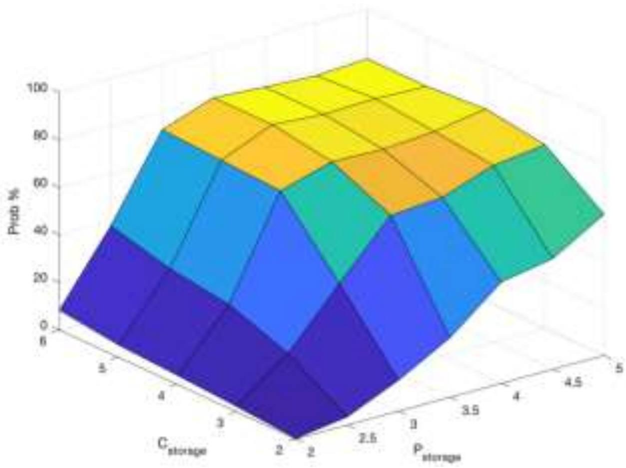

Figure 2. $P_{\text{solar}}(t)$ =3 kW, $P_{\text{wind}}(t)$ =3 kW

From these results, the larger the installed capacity of the wind and solar power systems, the lower the capacity/capacity of the units. This is evident because the more extensive the installed capacity, the larger the actual capacity of the generated transmitters, and therefore, of course, the required capacity/capacity of the units decreases. From the above calculation, it is clear that we can ultimately determine the optimal investment cost for each energy consumption based on the calculation and selection of the parameters of the equipment necessary.

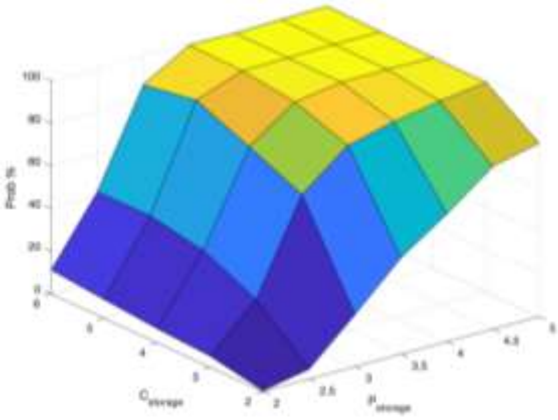

Figure 3. $P_{\text{solar}}(t)$ =3 kW, $P_{\text{wind}}(t)$ =4 kW

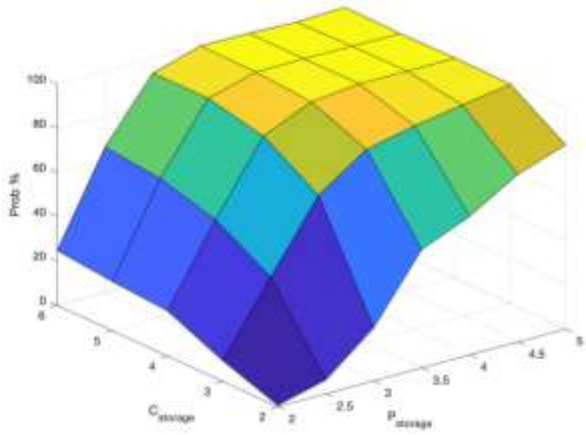

Figure 4. $P_{\text{solar}}(t)$ =4 kW, $P_{\text{wind}}(t)$ =3 kW

The results of the simulation are quite reasonable; when the installed capacities are large, the probability of the system working perfectly is greatest. This corresponds to the fact that the energy obtained and from the UPSs always meets the consumption of the load. Conversely, when the installed capacities are smaller, the probability of the system working perfectly is also reduced, corresponding to the fact that energy does not meet the consumption of the load. From the results obtained, the choice of design capacity becomes much simpler and more efficient. Clearly, the method described in the paper has shown outstanding advantages in calculating the installed capacity of independent renewable energy systems. This problem is perfectly applicable to the calculation of non-independent (grid-connected) renewable energy systems.

4. CONCLUSION

In this paper, formulate and solve the problem of optimizing installed capacity for devices that are used in independent renewable energy systems. In illustrating this method of calculation, we apply it on a standalone system, i.e., it is not connected to the power supply grid. From the results, we can see that the results of the simulation are quite reasonable; when the installed capacities are large, the probability of the system working perfectly is greatest. This corresponds to the fact that the energy obtained and from the UPS always meets the consumption of the load. Conversely, when the installed capacities are smaller, the probability of the system working perfectly is also reduced, corresponding to the fact that energy does not meet the consumption of the load. From the results obtained, the choice of design capacity becomes much simpler and more efficient.

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