Innovative technologies.

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THE LOGISTICS MODELS OF THE LIFE CYCLE OF PHOTOVOLTAIC POWER GENERATION SYSTEMS

Principles of modeling the diffusion and adoption of innovative technologies in renewable energy systems are researched. A generalized dynamic model, in the form of discrete difference equations and of the resulting predictive technologically significant results as separate samples on a discrete axis of the total costs, was offered. The model takes into account economic factors such as price indices, inflation, the total income of potential users of innovative technologies.

Keywords: innovative technologies, mathematical model, renewable energy, diffusion scenario.

The process of technology development in the most General form, can be described by a Fisher-Pry model [1] of technological shift, which was first considered by P. D. Kondratyev in 1934, the process's corresponding curve is called logistics, and is determined by the differential equation (1):

$$\frac{dy}{dt} = \alpha(y(t) - k_1)(k_2 - y(t)); \tag{1}$$

where t is the parameter, reflecting the total costs (time, energy, effort) to the development of this technology, expressed in a cost form; $y(t)$ — technologically significant result, that can be achieved with technology; α is a positive constant, scaling factor; k_1 and k_2 are positive constants bounding the technologically significant result of this technology. Respectively, k_1 is the lower bound $y(t)$, that expresses the initial, extremely low technology capabilities, and k_2 — its technological limit, describing the maximum possibility.

Production potential substitute technology and a temporary reserve of its competitiveness is determined by comparing its technological limit with the limit of technology which is replaced. The difference of technological limits is a quantitative measure of this technological shift. If the boundaries are relatively close, probably, soon will come the new technological shift. Otherwise, we can assume that more advanced technology is at an early stage of development, and it is difficult to assess its technological limit.

You can say [2] that the many manufacturability – an essential feature of the energy systems. The process of development of the many-technological energy system (MTES) also described by a logistic curve, which expresses the most general regularities of the dynamics of translational and cyclic processes. At the beginning of the life cycle of MTES significant costs on its development yields little results – this period corresponds to the first flat part of a logistic curve. Then, with the development of appropriate technology, the low production costs, begin to yield a significant effect, and the curve abruptly rises. Further, as the technologies MTES draw near its technological limits, the development curve again goes through the sloping area, and even the most ambitious investments fail to produce a significant effect.

Detailed studies have shown that over the MTES life cycle experiencing two rises. The first of these occurs at the beginning of the development of MTES and driven by the technology, internal factors. The second rise is due to economic reasons and expresses the readiness of the society to the introduction of relevant innovation and natural growth in public demand for them. The model, which differs from (1) only in that a constant positive scaling factor $\boldsymbol{\alpha}$, is replaced by the function $\boldsymbol{f}(\boldsymbol{t})$, the type of which defines $\boldsymbol{y}(\boldsymbol{t})$, called the hypothesis of Grubler-Fetisov, can serve to describe many similar systems and allows with sufficient accuracy to predict the onset of transition and crisis periods in the development of techno-economic and energy systems and technologies.

When considering the MTES processes development is necessary to consider such properties as a hierarchy [3] and the cumulative. The life cycle of the lower levels of the hierarchy of MTES can be described by a generalized logistic curve. At the same time, a significant result $\boldsymbol{Y}(\boldsymbol{t})$, which is achieved MTES, will be considered as the sum of the significant results of technologies $\boldsymbol{n} = \mathbf{1}, \dots, \boldsymbol{N}$, the components of the system (2): $\boldsymbol{Y}(\boldsymbol{t}) = \sum_{\boldsymbol{n}}^{\boldsymbol{N}} \boldsymbol{y}_{\boldsymbol{n}}(\boldsymbol{t}), \boldsymbol{n} = \mathbf{1}, \dots, \boldsymbol{N}$; (2)

The fundamental model of the innovation diffusion [4] can be expressed by the differential equation: $$\frac{d\boldsymbol{N}(\boldsymbol{t})}{d\boldsymbol{t}} = \boldsymbol{g}(\boldsymbol{t})(\boldsymbol{m} - \boldsymbol{N}(\boldsymbol{t})), \quad (3)$$

where $\boldsymbol{N}(\boldsymbol{t})$ is the cumulative number of users at time $\boldsymbol{t}$**,** that have adopted and use the technology; $\boldsymbol{m}$ – the maximum number of potential users; $\boldsymbol{g}(\boldsymbol{t})$ is the diffusion coefficient, reflecting the likelihood that potential users will adopt the innovation in a small time interval around time $\boldsymbol{t}$. Depending on the formula for $\boldsymbol{g}(\boldsymbol{t})$, the three models of innovation diffusion proposed [5]: the model of external influence, where coefficient $\boldsymbol{g}(\boldsymbol{t})$ is a constant $\boldsymbol{p}$ – can be considered as an external influence emanating from outside the social system; the model of internal influence, presented by Mansfield [6], where coefficient $\boldsymbol{g}(\boldsymbol{t}) = \boldsymbol{qN}(\boldsymbol{t})$; the model of mixed influence, by Bass [7], where coefficient $\boldsymbol{g}(\boldsymbol{t}) = \boldsymbol{p} + \boldsymbol{qN}(\boldsymbol{t})$.

A study of the advantages and disadvantages of the discussed models on real statistical data lead the authors of [5] to the following conclusions: – the research is ambiguous and does not answer, which of these models best describes the diffusion of innovative technologies; – in the Bass model is considered that the maximum rate of diffusion of an innovation, could not be achieved after the innovation has reached more than 50% of the potential market, that is not always true; – curve of diffusion is considered to be symmetric about the inflection point, however, this assumption is not true, as the actions of existing and potential users are different.

All the above models assume a constant maximum number of potential users $\boldsymbol{m}$. For the cases, when $\boldsymbol{m}$ increases with independent speed, the number of potential users is a function of time $\boldsymbol{m}(\boldsymbol{t})$. Such a model is called dynamic and discussed below. All the real statistics are collections of samples on a discrete axis. Therefore, it seems natural to build models in the form of discrete difference equations and plotting the resulting predictive technologically significant results as separate samples on a discrete axis costs. All further calculations use a discrete version of the model, where the step $\boldsymbol{t}$ is taken equal to unity, and the duration of the simulation denoted by $\boldsymbol{T}$.

The calculations are performed for the following initial data:

$K_{fin}(t)$ – is a financial ratio calculated by the following formula: $K_{fin}(t) = \frac{K^{pp}(t) * K^{COE}(t)}{K^{ACP}(t)}$, where $K^{pp}(t)$ – coefficient of the purchasing power of the region, $K^{COE}(t)$ – the efficiency of photovoltaic generation systems, $K^{ACP}(t)$ is the average end customer price of photovoltaic generation system [8].

It is known [8] $Real\ N(t)$ in the range $t = 1, \dots \tau$ for Germany and the planned value $M(t = 2050)$. Using the method of least squares to estimate the parameters p, q, and $m(t)$ in the range $t = 1, \dots T$ obtained, according to the formula: $m(t+1) = m(t) + K_{fin}(t)\left(p + \frac{q}{M} m(t)\right)\left(M - m(t)\right)$.

Using $m(t)$ as the target value of the installed capacity in the range $t = 1, \dots T$, the projected values of installed capacity are calculated by the formula (4) of dynamic model development and shown in Fig.1:

$$N(t+1) = N(t) + K_{fin}(t)\left(p + \frac{q}{m(t)} N(t)\right)\left(m(t) - N(t)\right). \qquad (4)$$

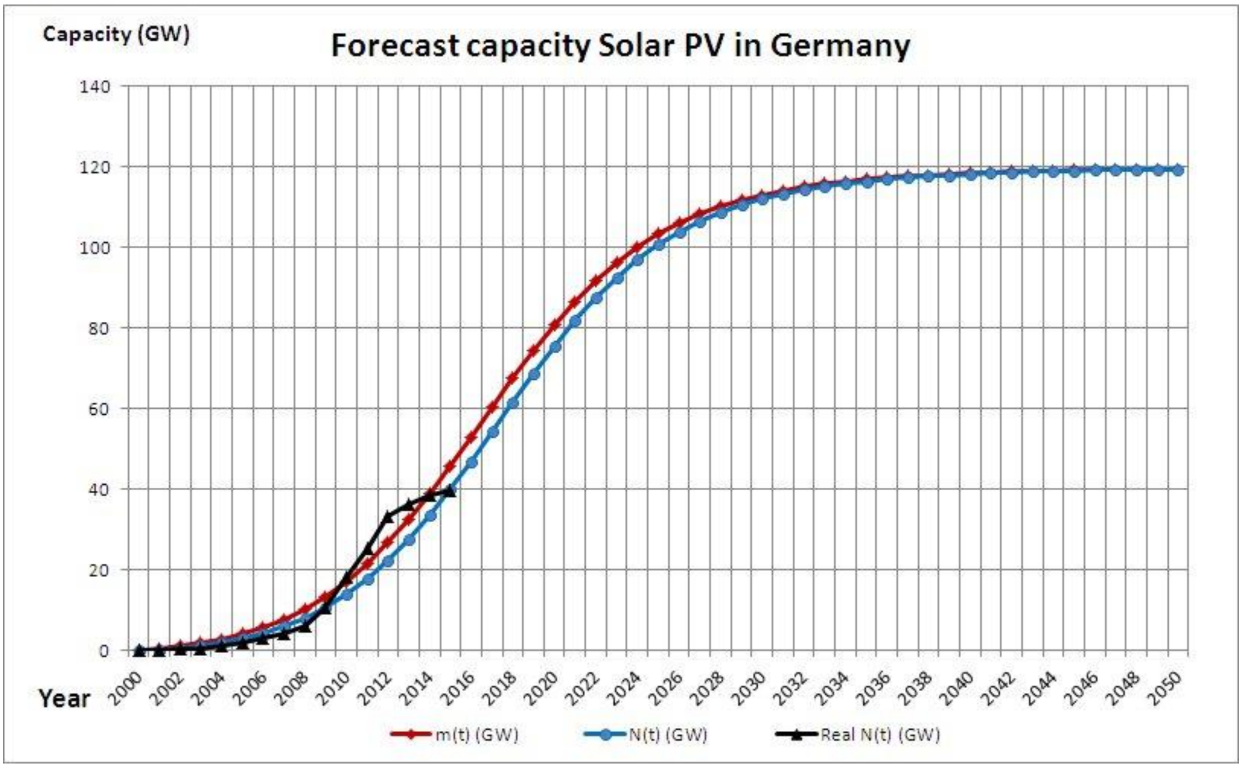

Fig. 1 – The predicted values of the installed capacity calculated by the formula of dynamic model development.

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