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Electrical Energy Management System in Double Unpredictability Objects

***Abstract**. This paper presents the concept of electrical energy management system in objects with double unpredictability. The system has been designed based on standard building management modules in LCN technology. A one year simulation conducted using MATLAB software indicates the possibility of a 12%-15% improvement in energy efficiency in objects and a decrease in the cost of purchasing energy from power grid by 14%-15%. The proposed system has been implemented in HMS/BMS laboratory in the Department of Electrical Apparatus at Lodz University of Technology.*

***Streszczenie.** W artykule przedstawiono koncepcję systemu zarządzania energią elektryczną w obiektach o podwójnej nieprzewidywalności. Realizacja proponowanego systemu została wykonana na standardowych modułach systemu zarządzania budynkiem opartego na technologii LCN. Symulacja w pakiecie MATLAB rocznej pracy systemu wskazuje na możliwość poprawy efektywności energetycznej obiektu o 12-15% oraz na zmniejszenie kosztów zakupu energii z sieci w ciągu roku o 14-15%. Zaprezentowany system został wdrożony w laboratorium HMS/BMS w Katedrze Aparatów Elektrycznych Politechniki Łódzkiej. (**System zarządzania energią elektryczną w obiektach o podwójnej nieprzewidywalności**).*

Keywords: energy management system, energy storage, energy efficiency.
Słowa kluczowe: system zarządzania energią, zasobnik energii, efektywność energetyczna.

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Introduction

The paper presents the concept of electrical energy management system in objects with double unpredictability. According to the authors, communal buildings which, in addition, can be equipped with renewable energy source and energy storage can be classified as double unpredictability objects.

Civilization advancement entails economic development. It has been the fastest in the history for the last 100 years. The consequence of this is a drastic increase in energy demand, which is processed in over 80% from non-renewable sources (oil, gas, coal, uranium) [1]. In summary of total energy usage, buildings utilise, depending on a country, from 20 to 40% of energy, placing them most often as third, after industry and transportation [2,3]. It is estimated, that improving buildings' energy efficiency can bring a decrease in energy usage in the European Union in existing buildings by 20%, which yields 60 billion Euro of savings p.a. [4].

The proposed electrical energy management system facilitates a decrease in energy consumption from electrical grid due to the usage of renewable energy sources. What is more, an improvement in an object's energy efficiency is achieved by rational utilisation and consumption control. The system has been realised on the standard building management system modules based on the LCN technology [5,6].

Double Unpredictability Objects

The authors classify individual communal buildings which, in addition, can be equipped with renewable energy source and energy storage can as double unpredictability objects.

Photovoltaic panels or wind turbines have been analysed as renewable energy sources. The work of the two sources is dependent on the weather condition and thus exhibits the stochastic and unpredictable nature [6,7,8,9,10,11].

The profile of power demand of an individual consumer is usually presented as a 60 min average. The obtained profile curve (Fig. 1, black curve) reveals a fairly steady nature and appears to be broadly the same over a few-day cycle. This approach justifies the assumption of a somewhat repetitive characteristics of the consumer demand curve. However, when analyzing the demand on power consumption with a 1 min average, it becomes apparent that the shape of the demand curve looks different. Changes to power demand are easily distinguished by the high volatilities illustrated by the grey curve (Fig. 1).

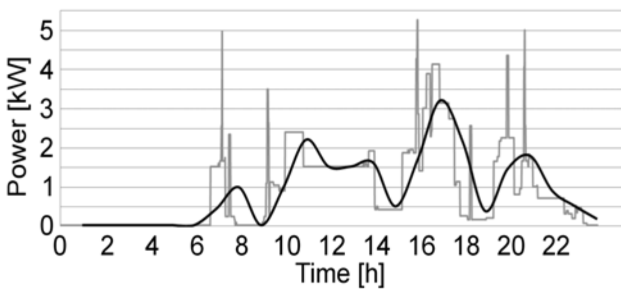

Fig.1. Power demand profile of a communal consumer averaged over 60 min (black curve) and over 1 min (grey curve) [12]

Generally, the shorter averaging times, the more sudden changes to power demand. In light of the above, consumer power demand is highly unpredictable in very short periods of time (a few / several minute sessions) and can significantly vary.

To conclude, the energy management of individual objects utilising renewable energy sources requires taking into consideration the two aforementioned, unpredictable factors. The first one is the amount of energy from renewable sources and the second is consumer behaviour which translates onto energy consumption. Such systems are called by the authors as double unpredictability objects.

Energy Management Systems

Narasimhan and others [13] presented a draft of an energy management system suitable for any applications requiring management: acquiring energy from different sources, providing energy to different types of users and storing the energy surplus in one or more energy storages. If energy from unpredictable renewable sources is available (photovoltaic panels or wind turbines) it should be used first and conventional sources turned off. Only in case of energy shortage from renewable sources, other energy sources will be activated. Energy management system controls energy usage by all consumers. In case of lower than demanded energy production, the system, based on provided priorities, qualifies which receptions are necessary and must be connected and which ones to disconnect from power. This way the complete power outage is avoided. Additionally in the case of power shortage, consumers should switch to power-saving modes of work. The role of energy management system is to define energy distribution from each source individually to each consumer. Two basic elements of the proposed energy management system are the control unit (CU) and the switching unit (SU). Connecting those two, along with sensors, creates an energy management system platform (Fig. 2).

Priorities with respect to energy sources is often taken into consideration in models of power systems which utilise renewable energy sources [14,15,16].

The model presented by Narasimhan and others [13], as a standard solution, could be implemented in energy management systems of a communal consumer. However, in our opinion it is too complex in certain areas. Managing each and every energy source in not required in case of an individual consumer. A cheaper and simplified solution is achieved by creation of a one bus voltage system integrating all energy sources and storages through switching apparatus and a bidirectional converter dividing energy based on the power balance. Individual consumers do not either require a separate control for each reception. It is thus sufficient to limit the control to a few chosen circuits depending on user preference. The correlation and control of the aforementioned receptions are possible through the usage of building management system.

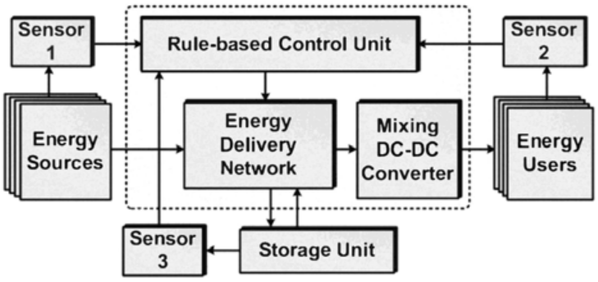

Fig.2. Block diagram of energy management system per [13]

Building Management System

Developed energy-efficient and passive construction is possible only by using modern building management systems (HMS/BMS). Home/building management systems form the commonly called "intelligent installations". Control-measurement and implementation devices network creates building automation system, that reacts in designer-specified manner. Thus, it is apparent intelligence that depends on experience and imagination of designers. Building management systems are developed and evaluated in three most important categories: comfort, safety and energy-efficiency. Building management systems increase the effectiveness of demand-side management. [3,17,18]

The development of renewable energetics along with distributed generation technology causes individual consumer is not only a mere energy consumer, but also a producer. As of today, despite of buying energy in the UE by power companies from renewable sources, this type of activity is unlikely across individual consumers, for whom own sources are of few kW power. The biggest issue in this case is control over such sources, that has to remain under power companies, that in case of power failure would be able to disconnect all potential sources, ensuring service safety during power outage. Therefore, small and renewable energy systems are implemented as selected-load-only. One of the biggest problems in such solution can be the surplus of energy acquired. Ill-fitted sources, too small a energy storage and load off can lead to system damage. Due to stochastic nature of renewable sources work characteristics, system designers are able only to estimate sizes of the energy production, storage and transformation components. One can expect, that HMS/BMS systems will have to develop also towards management of energy produced in their own surroundings. This outlines a new vision of the HMS/BMS systems as support solutions for renewable energetics on the level of communal consumers. [19]

Energy Management Systems in Double Unpredictability Objects (EMS-DUO)

The main assumptions of the proposed EMS-DUO:

1) The primary source of power is electrical grid.
2) Based on the state of charge of the energy storage, EMS-DUO, calculate the power balance of a building (energy generation and consumption).
3) EMS-DUO controls user-selected receivers and allows for their automatic turn on / off. The choice and change of the receivers are made by the user.
4) The process of energy management is conducted by the building management system produced from the standard modules.
5) EMS-DUO operates based on the following criteria:
   - state of charge (*SOC*) of energy storage,
   - price of energy purchased from the power grid,
   - comfort criteria specified by the user.
6) The effectiveness of the EMS-DUO in a building is measured by the amount of saved energy from the grid.

The energy management system in objects with double unpredictability proposed by the authors, EMS-DUO, is based on one bus voltage system integrating all energy sources and storages through switching apparatus and a bidirectional converter dividing energy based on the power balance (Fig 3). The directions of the arrows indicate possible energy flow between the element of the system.

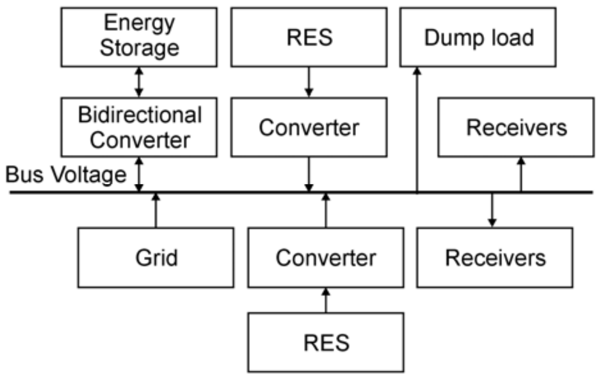

Fig.3. Block diagram of the hybrid system installation of the energy management system in objects with double unpredictability; RES – Renewable Energy Sources.

The level of uncertainty with respect to renewable energy can be decreased by the use of energy storages. In case the amount of energy obtained from renewable sources exceeds the current demand, the surplus can be stored in energy storage. In the opposite situation, the energy is provided from the storage. In the event of a breach of the storage overcharge limit (*SOC* > 90%) or the undercharge limit (*SOC* < 40%), the storage is protected by turning on dump load in case of the overcharge and switching to energy consumption from the power grid in case of the undercharge.

The uncertainty in user behaviour, which translates onto energy demand, is also controlled by the use of energy storage. Due to very dynamic changes in load profile P(t) of communal consumer, in the solution proposed by the authors the system does not track individual energy usage by each receiver. In the case of energy storage-equipped installations, it provides a buffer for energy used and produced in the given timeframe within the facility. Thus, the control unit is the state of charge. The information about the *SOC* is analysed by the analytical unit which subsequently determines the course of action specified by the designer. This way issues resulting from rapid changes in power demand and from unconventional sources' diversified energy production are avoided. The concept of the *SOC* of the energy storage as the control unit has been the subject of the models' analyses [21,22].

New, under development, electrical energy management system will firstly and automatically bypass energy loses connected to typical user "negligence" e.g. lights left on, TV left in stand-by mode (the results of own research [23] indicate, that depending on the number of electronics in home, energy usage by those devices left in stand-by mode accounts for 5 – 10% of total usage) etc. Additionally, the system analyzes actual electric energy costs. As of today, available methods of billing of electric energy are based on tariffs, that in defined timeframes determine constant electric energy rates. There are currently two tariffs in Poland, the day and the night one. The price of electricity during in the day tariff (6:00 – 13:00 and 15:00 – 22:00) is 0.17 €/kWh whilst in the night tariff it is 0.09 €/kWh. The second goal for the system being developed is the analysis of energy costs. Depending on user preference, having a choice of comfortable mode, or economical mode, the system will decide on the use of energy or not.

It should be emphasized, that the authors first draw attention to the comfort and ease of the users. Saving activities result from more precise control of energy resources, or from conscious decisions about energy consumption reduction. This type of activities may be currently realized by building management systems. Therefore, the system's algorithms will be realized by basic programmable controllers dedicated for building automation. It will allow for costs reduction associated with purchase of new apparatus and for efficient implementation of the system and its compatibility with other components of the building's electric wiring.

In order to verify the functional results of EMS-DUO, multi-variant simulations have been conducted for various combinations of the power sources and load profile. It has been assumed that in all cases the building consumes energy from the grid. Firstly, three variants have been proposed: energy consumed solely from the power grid, energy consumed from the grid and energy storage and finally, energy consumed from the grid, renewable sources and energy storage. Then each of the variants has been split in the economical and comfort modes.

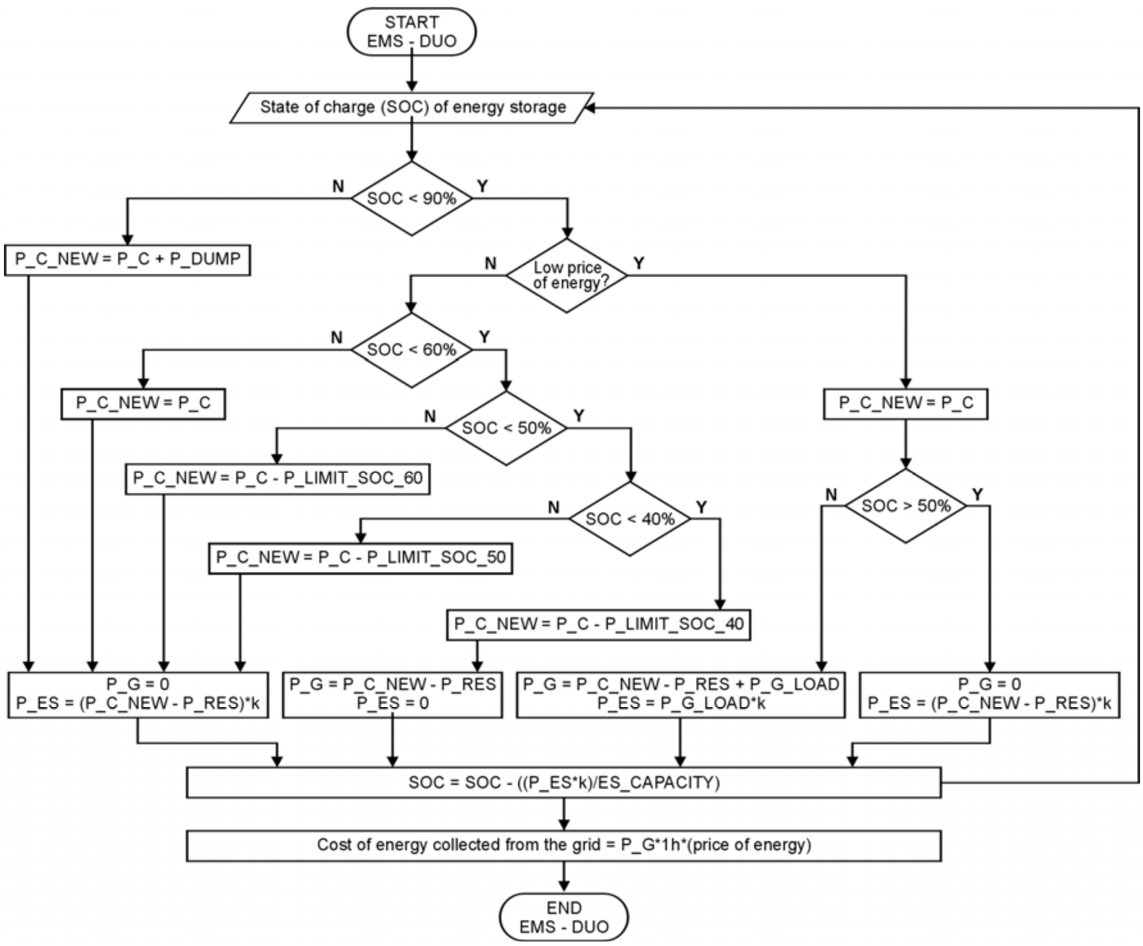

Fig.4. The algorithm of the energy management system in objects with double unpredictability in economical mode

Table 1. Power source variants of a communal building

Power System Elements	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5	Variant 6 EMS-DUO
Grid	✓	✓	✓	✓	✓	✓
Energy Storage			✓	✓	✓	✓
Renewable Energy Sources					✓	✓
Economical Mode		✓		✓		✓

As a result, six variants have been analysed in a communal building with respect to the power sources. In contrast to the comfort mode, the economical mode has the function to switch off the receivers which have been specified by the user as low priority ones.

Fig. 4 shows the algorithm of proposed system. EMS-DUO analyses the *SOC* of the storage. If the energy storage is charged (*SOC* > 90%) dump load is turned on for protection against overloading. Aggregated load equals then (1).

(1) $$P\_C\_NEW = P\_C + P\_DUMP$$

If *SOC* < 90 %, then the load remains unchanged (2).

(2) $$P\_C\_NEW = P\_C$$

During day tariff, if the storage is charged (*SOC* > 40%), the consumer demand for power is satisfied from the storage including the power provided by the RES. If the storage is discharged, energy from the grid is consumed. During night tariff, if the storage is discharged (*SOC* < 40%) energy is consumed from the grid to meet consumers' demand and charge the storage, *P_G_LOAD* less the amount of energy obtained from the RES.

If the storage is charged, it provides the energy taking in consideration the amount of power provided by the RES. The amount of power required to charge the storage *P_G_LOAD* (3) depends on the current power demand from consumer as well as the amount of power delivered by the RES.

(3) $$P\_G\_LOAD = \begin{cases} P\_G\_LOAD` \\ for\ \ P\_C\_NEW > P\_RES \\ \\ P\_G\_LOAD` + (P\_RES - P\_C\_NEW) \\ for\ \ P\_C\_NEW < P\_RES \end{cases}$$

In economical mode load limit may happen (4), which is a function of current *SOC* value and standing electrical energy price (5).

(4) $$P\_C\_NEW = P\_C - P\_LIMIT$$

(5) $$P\_LIMIT = f(SOC,\ PRICE)$$

Based on the balance of power the system analyzes consumer's power demands, renewable energy availability and storage's energy availability.

While the energy storage is fully charged, the system does not limit the usage even in economical mode. The system analyzes currently standing electrical energy price. This means, that thanks to proper energy policy, such energy circulation is possible (favorable purchase), that financial savings are available with no simultaneous resignation from used loads. It may also be the case, that an economically better solution will be the purchase of "cheap" grid energy than storage's energy consumption along with the loses which occur in the energy storage itself and in inverters. Example of discontinuity in function *P_LIMIT* is expressed by (6).

It needs to be emphasized, that value of limited power *P_LIMIT* depends on user's preferences. First, decorative lighting may be turned off, internal and external. Another way to limit power is to reduce lighting power by 10%, for what modern building management systems allow. In the literature [24] one may encounter a way to limit power by increasing temperature in range 0,5–1,5^{o}C in the air-conditioning systems. In the presented conception the authors presume, that *P_LIMIT* value will not be higher than 15% of temporary consumer's power demands *P_C*.

(6) $$P\_LIMIT = \begin{cases} 0\ \ for\ \ (Low\ PRICE\ \ or\ \ SOC > SOC_{\min 1}) \\ \\ P\_LIMIT\_SOC\_60 \\ for\ \ (High\ PRICE\ \ and\ \ 50\% < SOC < 60\%) \\ \\ P\_LIMIT\_SOC\_50 \\ for\ \ (High\ PRICE\ \ and\ \ 40\% < SOC < 50\%) \\ \\ P\_LIMIT\_SOC\_40 \\ for\ \ (High\ PRICE\ \ and\ \ SOC < 40\%) \end{cases}$$

Using the energy storage allows for storing both the renewable energy and the grid-purchased energy in periods when it is cheap. Proposed electrical energy management system with energy storage analyzes consumer's energy demands, the amount of energy provided by renewable sources, state of charge of the energy storage and the energy price. The value of collected or expended power from/to the energy storage is a function of the below parameters (7).

(7) $$P\_ES = f(SOC,\ PRICE)$$

The same parameters influence the power collected from the electric grid. Additionally, power collected by the energy storage is included, which may be charged by "cheap" energy (8).

(8) $$P\_G = f(SOC,\ PRICE,\ P\_ES)$$

It must be considered, that using the energy storage alone does not reduce energy usage by the individual consumer. Quite the contrary, for the systems without renewable sources, more grid energy is collected in connection with storage's and inverter's efficiency. However the time, in which the energy is collected, is changed and that has direct transition on the price. In such a configuration, the systems works in the peak shaving mode. Actual reduction in energy usage may happen as a result of working building management system. The presented system connects the two benefits into one electrical energy management system in objects with double unpredictability.

The presented algorithm of the energy management systems in objects with double unpredictability has been implemented in MATLAB. The simulations have been conducted for all the six variants presented in Table 1 for a communal building. Real life data from communal objects has been used. The results of the calculations are presented in Table 2. Variants 5 and 6 are related to the work of the energy management system in objects with double unpredictability in comfort and economical modes.

The 50% decrease in usage of energy from the grid is a result of the utilisation of the renewable energy sources which translates onto a direct reduction of the cost of energy purchase. The cost analysis of the renewable energy purchase as well as the exploitation is not the subject of this research. The primary aim of the authors was to evaluate a potential improvement in the energetic and economical effectiveness of an object benefiting from renewable energy sources as well as energy storage by the use of the authors-developed algorithms of energy management systems in objects with double unpredictability.

Table 2. Results of one-year energy management system simulation in MATLAB

Power source variants	1	2	3	4	5	6 EMS-DUO
Usage of power from grid in relation to variant 1	100%	94%	102%	95%	42%	37%
Cost of energy in relation to variant 1	100%	93%	94%	85%	42%	36%

Depending on the consumer power demand, the activation of EMS-DUO system improves energy efficiency of a building by approximately 12% (9) and lowers the costs of energy purchase from the grid by around 14% (10) in a one – year period.

$$EE_{w5-w6} = \frac{E_{w5} - E_{w6}}{E_{w5}} = \frac{42\% - 37\%}{42\%} = 12\% \quad (9)$$

where: EE_{w5-w6} – parameter of improvement in object energy efficiency due to the activation of EMS-DUO; E_{w5}, E_{w6} – parameter of energy usage in object powered as per variant 5 or 6.

$$S_{w5-w6} = \frac{C_{w5} - C_{w6}}{C_{w5}} = \frac{42\% - 36\%}{42\%} = 14\% \quad (10)$$

where: S_{w5-w6} – relative savings in cost of energy purchase from the grid due to the activation of EMS-DUO; C_{w5}, C_{w6} – cost of energy purchase in object powered as per variant 5 or 6.

The results of the simulation of a building consuming energy from the grid as well as energy storage (variant 3) meet the assumptions about the potential increase in energy consumption (102%) with a simultaneous decrease in the cost of energy purchase (94%).

Consumer benefiting from energy management systems and dispersed generation bear minimal implementation costs of the proposed electrical energy management system, EMS-DUO utilising building management system modules and the apparatus used in dispersed generation microsystems which is important for popularisation and commercialisation of the proposed solution.

The proposed EMS-DUO system has been implemented in the laboratory in the Department of Electrical Apparatus at Lodz University of Technology. The implementation of the proposed algorithms ensured the system operates properly with no additional investment in apparatus.

Conclusion

The concept of the electrical energy management system in objects with double unpredictability relies on the analysis of two fundamental parameters. The first one is the level of charge of the energy storage, the second – energy price purchased from the grid. Thanks to such simplification, it is possible to implement the system with the use of basic programmable controllers used in building automation systems without added investment costs. The implementation of energy storage allows avoiding issues derived from rapid changes in power demands and from diversified energy production by unconventional sources. Depending on user preferences, the presented system may bring, energy efficiencies of a building of approximately 12% and lower the costs of energy purchase from the grid by around 14% in a one – year period.

From the power companies' point of view, consumers using energy storage, also the ones working in the peak shaving mode, of the storage capacity similar to daily energy demands, become the consumers with almost constant power demands from the electricity grid. It would be a comfortable situation for the power company, reducing the problem of uneven power load during the day.

Nomenclature

P_C	Consumer's power demands.
P_C_NEW	Consumer's power demands as a result of electrical energy management system.
P_G	Input power from the electricity grid.
P_LIMIT	Power value disconnected for reduced usage based on user specified criteria.
P_ES	Power absorbed or expended to/from the energy storage. *P_ES* > 0 – storage discharge; *P_ES* < 0 – storage charge.
P_DUMP	Additional demands available in the case of produced energy surplus during storage's full storage capacity.
P_G_LOAD	Power absorbed from the grid to charge energy storage during night tariff.
ES_CAPACITY	Energetic capacity of energy storage.
k	Coefficient indicating the efficiency in charge / discharge of storage.

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