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Chapter

Integration of Advanced Technologies for Efficient Operation of Smart Grids

Radu Porumb and George Seriţan

Abstract

The current transition of electrical power systems toward smart grids is encompassing a fundamental change in their structure, as well as operation. This is setting the path to be followed by the hardware and software embedded in electrical power systems, as well as technology adaptation to the "open-source" customers' needs and consumption patterns. This chapter is following the evolution of energy sector, accompanied by constant improvements of technology, which is providing increasingly complex hardware, which embeds power quality improvement devices, for an efficient operation of electrical power assets. This chapter presents a comprehensive survey of continuous advances of renewable energy sources and storage technology which have started the transformation of end users into energy-efficient and clean prosumers, underlining the subsequent energy markets support of peer-to-peer energy trading through novel technologies as blockchain.

Keywords: advanced technology, blockchain, energy efficiency, micro-grid, power quality, smart grid

1. Introduction

At present, the general trend of evolution of society has as a catalyst, the technological revolution. Through the continuous development of information analysis and synthesis capabilities through cloud computing technologies, manufacturing capabilities through 3D printing, as well as local power generation and storage capabilities, the industry is experiencing a huge leap across multiple plans.

Also, at the social level, the need to improve the state of the environment, as a *sine qua non* condition of increasing the quality of life, is felt more and more. This pressure has generated mechanisms to control the sources of pollution, with the energy sector being one of the main actors in this respect. Thus, it can be said that energy efficiency is a vital resource for environmental protection.

Energy efficiency has gained a major significance in the design and implementation of national and transnational projects, due to the importance of concepts and measures resulting from the specific analysis of energy processes. From the perspective of environmental protection, the analogy that each consumed kWh leads to a reduction in carbon footprint by about 1 kg of CO_2 is essential. Also, the concept of "negajouls" is increasingly being met as the measure of increasing energy efficiency defined by measuring unconsumed energy.

These requirements are driving next-generation engineers toward seamless communication with physical systems with the help of artificial intelligence, turning them into dialog enablers between future smart society and its fundamentally supporting technology.

Ensuring the power quality requires an entire investigation chain, from production, transport, distribution to the public network, and distribution to the user. The transfer of energy through this transformation chain cannot provide an ideal quality of the supplied energy. In this respect, the user, on the basis of careful technical and economic analysis, must accept the quality of the electricity provided by the public supply system (within acceptable risk limits) or adopt measures that require investment to achieve an accepted power quality level for the processes which take place at the end of production chain.

2. Energy efficiency

Energy management aims to ensure the judicious and efficient use of energy in order to maximize profit by minimizing energy costs, thus increasing the competitiveness on the market.

Data obtained in the electronic document management system (EDMS) energy management process, although it does not directly lead to energy savings, has a key role to play in identifying savings potential and adopting the most appropriate measures to increase energy efficiency. EDMS is a software program that manages the creation, storage, and control of documents electronically, managing the electronic information within an organization workflow. The implementation of the EDMS allows knowledge of the energy used in each process and provides the premises for achieving an annual energy savings of up to 10% [1–5].

Energy costs are an important element in the cost structure of most products, resulting from production processes. Reducing the energy used ultimately leads to lower production costs and, implicitly, to increased product competitiveness.

Achieving the goals of energy management requires:

- Increasing energy efficiency and reducing energy needs in order to reduce costs without reducing production levels
- Achieving good communication between compartments, specific energy issues, and their accountability regarding energy management
- The development and ongoing use of an energy monitoring system used, the reporting of these values, and the development of specific energy optimization strategies used
- Finding the best ways to increase money savings resulting from investments in energy efficiency of specific production processes by applying the best available technology (BAT) solutions known worldwide
- Developing the interest of all employees in the efficient use of energy and educating them through specific awareness programs to reduce energy losses
- Ensuring the safety of power supply to energy installations

- An overall approach to monitoring and reducing energy needs in any type of organization

- Reducing costs and reducing greenhouse gas emissions

Energy management uses engineering and economic principles to control the energy costs used to provide the necessary services in buildings and industry. Energy cost reductions can come from energy efficiency improvements, and savings can come from changing traditional energy sources with more efficient sources. In this sense, the energy policy implemented within the unit is of particular importance. Five categories of energy policies are met:

- No explicit policy (no delegation of responsibilities on the energy side and no investment to increase energy efficiency)

- Unformulated action directions (occasional tasks and only low-cost measures)

- Incoherent policy (assigning tasks but without responsibilities and only short-term recovery)

- Policy assumed but unmatched by top management (clear allocation of tasks and budget with the same implementation regime as other investments)

- Active involvement of top management (integrating with other forms of management within the unit with the advantage of investing in energy efficiency and reducing carbon footprint)

The main benefits for operators implementing the principles of energy management are:

- Improving the quality of environmental factors

- Improving economic competitiveness by reducing production costs and reducing the intensity of energy used

- Improving energy security

- Reducing the risk of accidents by identifying the weaknesses of the processes

- Improved advertising and image

2.1 Energy management standard

In 2011, International Standardization Organization (ISO) has developed the internationally accepted energy management system (EnMS) standard [1]. Based on this, an organization can develop and implement its own energy policy that sets goals, tasks, and action plans that address legal requirements and existing information relative to significant energy uses.

The standard has a principle "plan-realization-control-action (plan-do-check-act (PDCA))" (**Figure 1**).

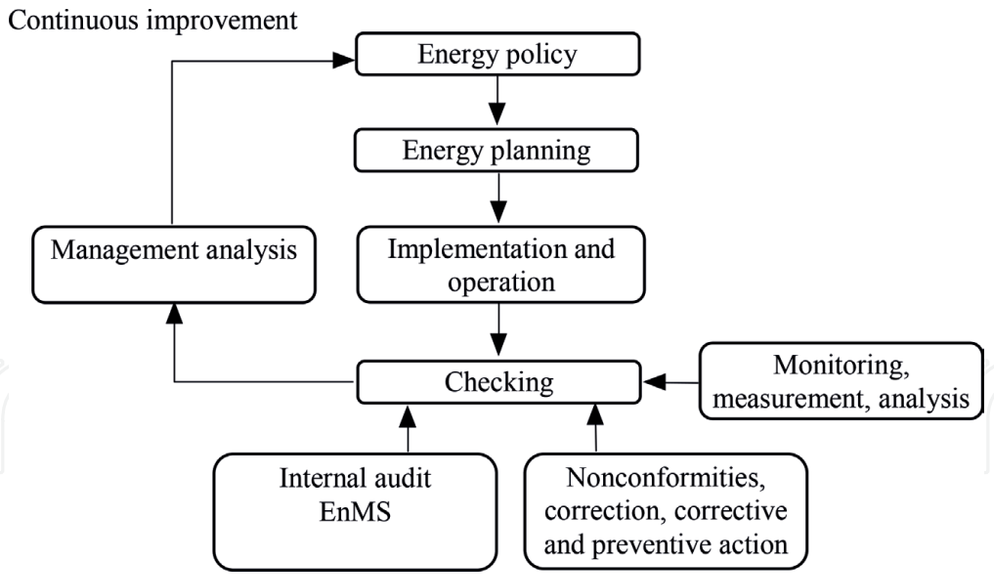


Figure 1.
Energy management system.

Verification includes process monitoring and measurement and the underlying characteristics of operations to determine energy performance against energy policy and its objectives [2, 6–11]. It also includes reporting on the results obtained during the verification.

Action concerns the adoption of measures to continue to perform as planned within the EnMS.

The activity considered is based on an online and offline measurement and processing system. Energy management practically integrates technical issues, legal/regulatory issues and managerial aspects across the entire energy contour and for all energy operators.

The objective is to operate the system under maximum safety and economic efficiency and ensure the security of electricity supply. Technical issues consist of identifying disturbances that cause deviations from normal operating parameters.

The legal/regulatory aspects consist of establishing the framework for the evaluation and monitoring processes, setting the standards and indicators that characterize the functioning of the system being analyzed and setting the reference levels for the parameters to be monitored. Managerial aspects consist of developing strategies/policies to monitor operating parameters that ensure clear and effective determination of responsibility for deviations from standard regulatory levels and thus achieve performance targets.

Strategies/policies are addressed both to energy operators and to electrical/electrical receiver manufacturers.

An important component of the management of implementation and monitoring of the operating parameters of the analyzed system is the strategies/policies of training and education of the employees.

In general, the management of any activity/project has multiple approaches:

- Approaches from simple to complex. Start with case studies, disseminate information among specialists, then go through pilot project.

- Bottom-up approaches, starting from the technical aspects and phenomenology and reaching the management of the decision-making activity, with aspects of financing, implementation, monitoring, and corrective measures. There is bottom-up pressure on the management to get the decision to implement the project. Typically, these projects have longer implementation times.

- Top-down approaches, based on the information from the literature and its own experience (case studies, research), the management consults/studies and develops decisions and strategies for implementing the project, hierarchically applied from top to bottom. These projects have shorter implementation times.

- Mixed approaches. This approach is often the most effective way to achieve the project implementation goal.

Improving the energy management of a company, based on the analysis of the current management and the experience of the management team, ensures the continuity of the process and the achievement of some performing actions in the field [12–14].

2.2 Management projects

Management projects must fit into the enterprise's asset, production, and ancillary activity policy and require a clear and concise definition of the benefits of the company (distribution operator, user, equipment manufacturer, energy service provider). From an economic point of view, benefits have to be quantified in money.

It is worth noting the triangle that should be considered permanently during implementation: cost, time, and benefits. Keeping an optimal balance between these three elements contributes to the success of the project. Regardless of the approach, energy management requires the clear definition of goals, objectives, strategies, policies, and implementation plans with deadlines and responsibilities, as part of the plan-do-check-act (PDCA) of the legislation and regulations under consideration.

Management involves the implementation of the PDCA using the possibilities offered by the development of computer systems and control/control systems based on electronic circuits. Also, the electronic control/control circuits have a significant impact on energy efficiency [15].

When implementing energy management projects where control systems based on power electronics are widely used, both benefits and a number of negative effects can occur. The benefits are primarily determined by accurate measurement of energy performance through the improvement of methods and especially of measuring instruments through the development of information technology [16]. In this way, the conditions were created for the monitoring of the electrical process voltages (electrical voltages and currents) over a long period of time and for the accuracy of measurements.

It was possible to track real-time (online) and offline analysis of the analyzed phenomena, and it was possible to obtain the data necessary for carrying out the forecasting activities.

The experience resulting from the analysis of many energy management programs implemented in different sectors of activity has shown that:

- There can be achieved energy and money savings of 5, 12, or 15%, in very short time, with minimal costs or even without costs, only by applying aggressive energy management.

- Energy and money savings of up to 30% can be achieved, with low and average costs, with a short depreciation period; the application of such measures is frequent.

- By realizing high-cost investments in modern technologies and equipment, savings of 50–70% can be achieved, with depreciation periods of up to 5–6 years.

The main barriers to the promotion of energy-efficient products of a technical, economic, financial, and managerial nature are shown in **Figure 2**.

Although some of the barriers shown in **Figure 2** are objective in nature, many are due to insufficient knowledge of the problem, insufficient awareness, and implications for increasing energy efficiency, especially through the reduction of environmental pollution. New technologies or methods for increasing energy efficiency are not immediately adopted, in most cases, by cost-benefit analysis. An in-depth study of energy savings and product quality enhancements can provide arguments for implementing new technologies and gaining economic benefits.

An important barrier lies in personal and institutional inertia, especially in smaller companies. Also, market conditions and unconvincing marketing can be barriers to making products with new features that incorporate less energy.

An important role is the package of regulations that must ensure the promotion of new energy-efficient technologies. The complexity of the integration process associated with interruption during assembly, commissioning, and calibration results in operators being detained, especially in enterprises that require high production reliability, and who are reluctant to assume the risks of using new technologies. Compliance with the new regulations on the conditions of the use of new technologies, especially those relating to environmental compliance and security conditions, leads to delays in adopting them. When deciding on the implementation of new technologies, the investments needed to rehabilitate an installation and adopt new technology with new production capacity must be compared. In some cases, the relatively long recovery of investment in new technologies also limits decision-making on their implementation. Unlike large users, individual users or

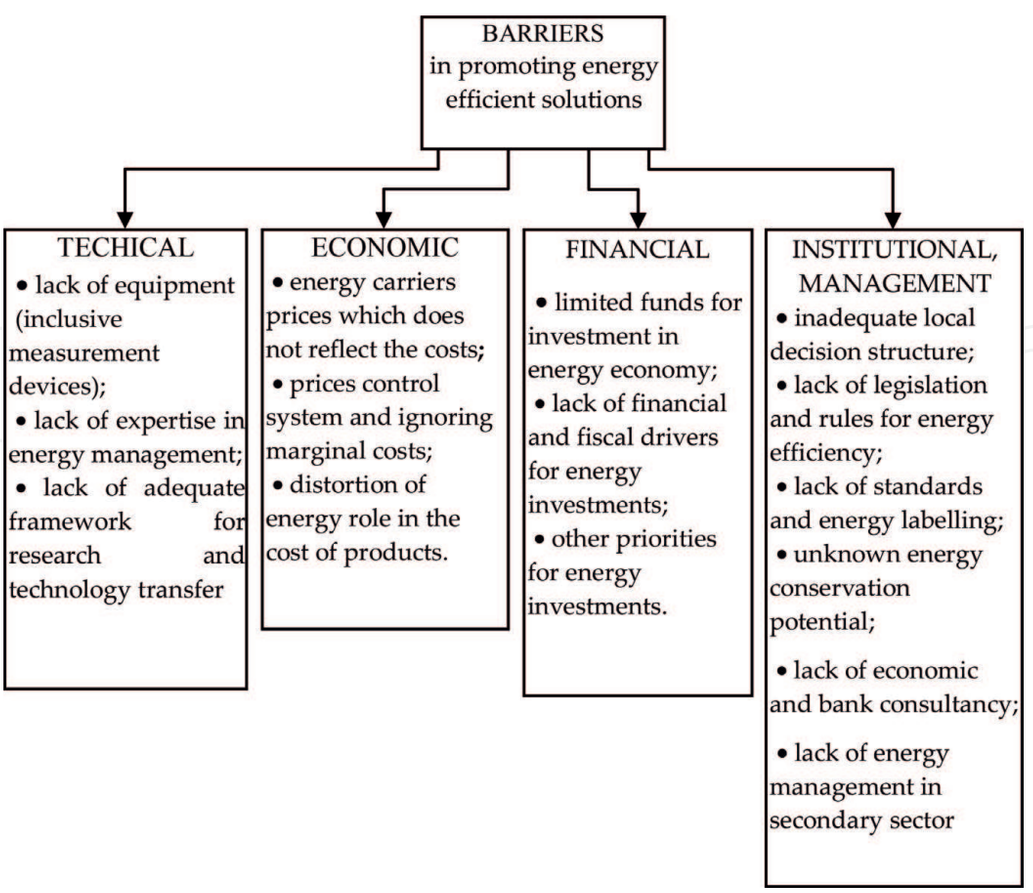


Figure 2.
Barriers in energy-efficient solutions promoting.

small and medium businesses do not have information, technical and managerial capabilities, and data on efficient funding schemes to conduct a detailed analysis, which limits their access to new technologies. Also, there may be difficulties in putting them into operation and using these technologies.

3. Power quality management in smart grids

Monitoring the quality of electrical energy in a node of the electrical network is intended to determine the characteristics of the voltage and current curves as well as the variations in the frequency of the voltage in the network in relation to a set of standardized technical indicators. The monitoring of the quality indicators of the electricity and the adoption of the measures necessary to maintain them at the level stipulated by the quality standards fall within the obligation of the network operators.

Wide implementation of renewable energy sources can have a negative impact on the quality of electricity (voltage variations, harmonic disturbances, voltage fluctuations, and increase in voltage gaps).

The development of smart grids and micro-grids leads to increased electricity production in low-voltage (low-power generation) networks and changing user type (intelligent user systems, electric vehicle charging stations, etc.) which can lead to the emergence of important electromagnetic disturbances that could lead to lowering the level of electricity quality in the nodes of this network.

The implementation of smart grids requires measures adopted at the level of each operator in the power system to ensure the required objectives [11, 17–22].

At the user's level (prosumer):

- Efficient energy use systems
- Energy production from local sources
- Intelligent buildings
- Automation of user equipment

At generation level:

- Adaptive production with a focus on renewable energy sources
- Environmental pollution control for conventional sources

At network level:

- Station automation (SA—substation automation)
- Power quality (PQ) and network monitoring (PM—power monitoring)
- Power management in the system (EMS—energy management system)
- Wide use of power electronics
- Asset management in the system and their monitoring

- Automation of distribution
- Management of distribution systems
- Advanced metering infrastructure (AMI)

At the level of communication systems:

- Ensuring the security of the communication circuits
- The development of communication platforms

The main issues to be monitored in smart grids to ensure the required quality of electricity provided to end users are:

- The direction of power flow in the transmission and distribution networks
- Voltage level in all nodes of the power grid (in classical systems it is sufficient to monitor the voltages in the representative nodes)
- The value of the power factor in all the nodes of the electric network
- System unbalance (especially in low-voltage networks) and neutral conductor loading
- The voltage curve distortion level in all nodes of the electrical network (in classical systems, monitoring at the common point of coupling of the users is sufficient)
- Micro-grid insularity

The data obtained from the monitoring shall transmit information for the adoption of measures to frame the voltages of the nodes of the electrical network within the accepted limits of the quality of the electric power [15]:

- Self-configuring the network to ensure continuity in the feed;
- Ensuring robustness against physical and computer attacks;
- Correlation of the sources of generation with the possibilities of storage of electricity;
- Reactive power control systems;
- Control of voltage curve distortion;
- Control of unbalanced load-limiting systems

4. Micro-grid

Intelligent "power" grids are characterized by the widespread use of modern technologies, IT procedures for system management, and extended automation and the use of current energy management systems, a high-quality power supply service

by the possibility of self-correcting the effects of defects. Within "smart" electricity networks, a particular attention is paid to communication systems that need to provide data and order transmission for optimal network operation with high energy efficiency and minimum energy prices for users.

Although under the electricity market, the minimization of energy losses in electrical networks is not a preoccupation with the need to ensure the requirements of users and producers; the existence of detailed information on the state of the system can provide the conditions for choosing an energy transmission structure so as to ensure the minimization of energy losses in the conditions of the restrictions determined by the specific requirements of the electricity market.

The operation of renewable energy sources with uncontrollable generated power and the wider availability of micro-networks using local energy sources determine that two-way power circuits can be drawn on the lines of the power system to be taken into account in the determination programs of losses.

Micro-grid development plays an important role in reducing energy losses by limiting the power flow on power lines, while the micro-network is powered by its own sources (wind and solar). The operation of a micro-network with the optimal use of local power sources requires a reliable communication network to acquire all the information required for micro-network management [22–28].

As an example of communication circuits, **Figure 3** shows a micro-circuit diagram with circuits that include information on operating parameters, purchased energy prices, and power source supervisory control to provide users with high quality energy, and reduced losses.

In principle, micro-processing management, based on information on the state of internal sources and the price of electricity on the energy market, must provide the users of the micro-network with the lowest electricity offered. In this respect, it

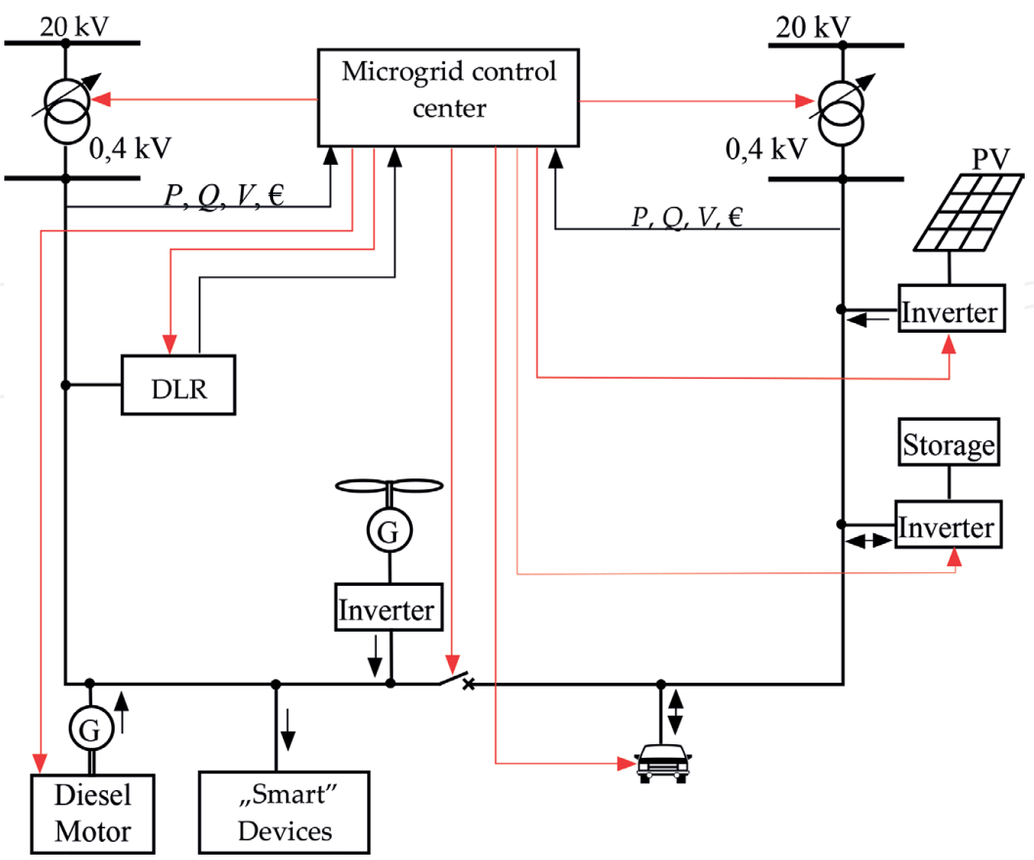


Figure 3.
Energy and information transfer into a micro-grid.

can use the additional possibilities offered by the "smart" receivers whose load can be changed without affecting the user's "comfort," the energy stored in the battery of the electric cars in the area, as well as the local electrical storage facilities.

5. Smart grids and blockchain

The blockchain-based shift in paradigm is brought by a 2008 article of Satoshi Nakamoto [29], which sparked a true revolution for the future use of Internet. The base layer of these changes signifies that it brings fundamental change in the fabric of the Internet, changing it form an *Internet of information* to an *Internet of value* [30]. The core function of the latter is that it enables peers to exchange values over the net, without fear of getting ripped off. The distributed nature of micro-grids is naturally adoptable by the inherent distributed profile of blockchain. Blockchain is operated using a distributed ledger, which is available to all participants to a common blockchain-based market scheme. The ledger is the receptacle of truths; each and every transaction is being verified, timestamped, ran through an advanced crypto machine, and added to the ledger. Another intrinsic secure feature of the ledger-based transactions is the fact that each transaction is traceable and is validated only by the transaction which preceded it. This architecture is basically sound for any security beach, since a hacker who gains access to the platform and wants to change a section of a ledger must change all the sections contained in the distributed ledger, to all peers. The success of this endeavor is virtually impossible.

The smart grids are basically arrays of technologically backed generation units, intelligently linked to the consumption units, which are the beneficiaries of wisely developed utilization strategies. These strategies sprung from the need of optimization of the usage of energy assets, in order either to maximize the revenues or minimize the losses, either energy or monetary wise.

The two apparently disparate paradigms show peculiar similarities with respect to the common management policies. By concealing the operation of the system (either physical or software) to a mathematical algorithm, designed to act as a business enabler for the lucrative peers, as well as a solid-rock guardian for possible intruders, the marriage between physical micro-grid (or smart grid) and the automated and collaborative system peer-to-peer blockchain network could be the best follow-up yet.

However, every technological breakthrough has both a bright side and a not-so-bright side. The latter one resides in the inherent energy-intensive nature of blockchain-based technology, which is an energy-intensive technology, which pays tribute to the constant care for locking down the information and continuous search for certitude in keeping the peers out of reach of hackers, activity which implies constant checking (every 10 seconds) of proof of work in every ledger at every peer, irresponsive to the continuous energy trading process. This feature of blockchain will need further improvement, since the energy quantities transitioned over micro-grid energy markets are small, and the overall gain of the community risks to become negative.

6. Conclusions

This chapter has discussed the framework of current electrical power system development into more elaborate and complex forms, which entails the *sine qua non* presence of the Internet. Energy efficiency domain is converging with the need for

power quality improvement in the advent of smart grid solid-state technologies. This trend is supported by the seamless integration of IoT at both generation and consumption extremities, as well as their evolution toward micro-grids and smart grid, economically enabled by the blockchain-based micro-market schemes.

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