

## Cyber Physical Energy System

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### **ABSTRACT**

*Cyber Physical Energy System (CPES) are intelligent systems that allow us to add new capabilities to energy systems by integration of communication, computation, information and control. It also includes the unification of both power network technology and the smart communication and management between supply and the demand side through distributed embedded computing. These processes make the operations to be self-configuring, monitoring, controlling. Through this combination, CPES are intended to deliver energy efficiently, reliably and economically (Low cost). This paper presents some benefits, challenges and major faults introduced by incorporating cyber physical systems to energy systems. Integrating computers, communications and control at all points of production, transmission, spreading, consumption and storing of energy, the errors are enlarged and also safety become more complicated. It also presents the architecture of the cyber physical energy systems, areas of application in the energy field, what has been done, and areas not yet explored.*

**Keywords:** *CPES, smart grid, real time*

### **INTRODUCTION**

Despite the work of researchers developing powerful methods and tools for analyzing, modeling and controlling physical processes, there is still a big gap between the cyber world where information is exchanged and transformed and the physical world, in which energy mass are exchanged and transformed. The systems that exchange and remodel energy have a vital interest for human development. With the event of smaller, faster, and a lot of economical computers, as well as, higher and cheaper communication networks, energy systems have modified considerably. Thus, computing and communication capabilities are embedded in all forms of objects and structures within the physical surroundings like the parts of the energy systems. This class of systems involve new challenges in engineering, where cyber and physical co-design will generate energy systems that will exhibit more flexibility, efficiency,

sustainability, reliability, and security. Cyber Physical Energy Systems (CPES) forming and control methods have been shown as another way to address these problems. Recently, the scientific community has begun to fit in the cyber and the physical worlds. In order to achieve this, it has been necessary to construct a methodology that combines both elements. These modern systems are called cyber-physical systems. CPS integrates mechanisms of the cyber world and the physical world to attain a common aim and, through embedded computers systems, monitor and control the physical processes. The major tools of CPS methods are the computing, the communications, and the control. This recent concept incorporates knowledge and engineering ideologies across the computational and engineering disciplines (e.g. biomedical, material science, and other engineering disciplines), in order to

support the current challenges in technology.[1-3]

The variation of likely connections between computational systems and physical environments are the heart of this new modeling standard. It requires a new ground - breaking theory that models cyber and physical resources in a unified framework. Study in CPES shows a remarkable prospect to develop projects in different areas of engineering.[6]

The current upsurge in execution of generation based on renewable energy sources such as wind and solar, along with an improved attention on mitigating emission of greenhouse gasses in amenities such as transport, through electric vehicles, and house hold heating through heat pumps, have led to a problematic design of the coming power system. Integrating these technologies into the power system changes its topology from being centralized with a few large controllable synchronous generators to being decentralized with numerous distributed generating units based on intermittent energy sources.

In order to manage the reorganization of the power system, smarter monitoring and control methods are essential. This issue is addressed by implementing an advanced metering infrastructure through smart meters and phasor measurement units, as well as a further utilization of information and communication technology. ICT helps improve the visibility of current power system operation and enhances the possibilities of advanced control developments. The ICT system build around the power system becomes more unified and the whole system is transitioning into a compound cyber-physical energy system (CPES). The robust interfaces across systems in a CPES involves new trials in sustaining a high security of supply, as fresh factors can

affect the over-all security of the power system. The factors include cyber security, behavior and restraints of near energy systems, and the dynamics of relations between the different systems. In order to accept security problems from ICT and near energy systems, a reexamine of existing power system process methods is necessary. Power system security valuation plays a vital part in retaining a high security of supply.

Nevertheless, it is built on an integrated power system and does not reflect the threats involved by the shift towards a CPES.

This paper presents some benefits, challenges and major faults introduced by incorporating cyber physical systems to energy systems. Integrating computers, communications and control at all stages of production, transmission, circulation, consumption and storing of energy, mistakes are increased and also safety become more complex. It also presents the architecture of the cyber physical energy systems, areas of application in the energy field, what has been done, and areas not yet explored.

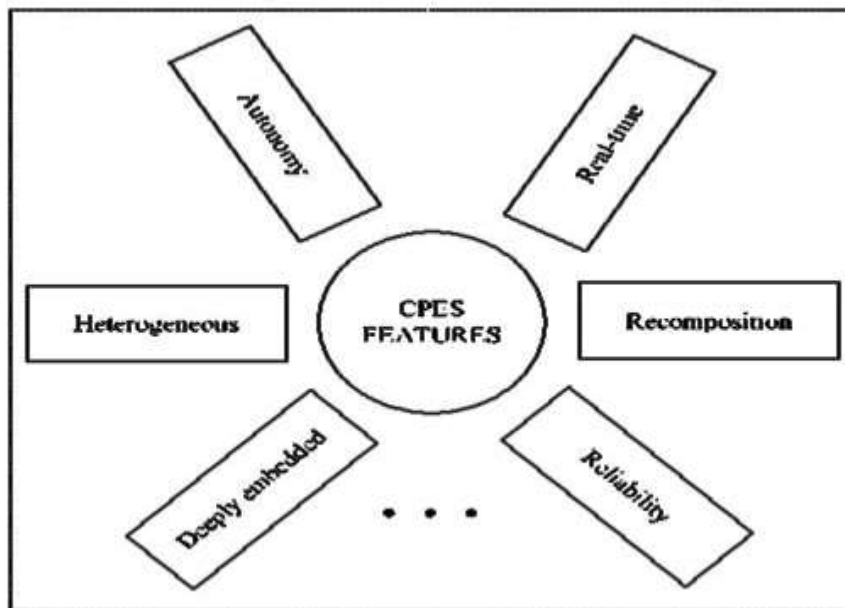
## **LITERATURE REVIEW**

Per the condition of low-carbon economy and energy crisis, many recent IT have been applied to Cyber-Physical Energy Systems (CPES) for saving energy and keeping environment, such as smart grid, electric motors and industrial automation. In these systems, issues about energy effectiveness and system trustworthy control are becoming more significant. The CPES is extended from Cyber-Physical Systems (CPS) applied in the energy area. It demands that system design implants some non-functional properties, such as heterogeneous, autonomy, real-time, etc. CPES consist of energy resources, links, applications, and consumers to satisfy forthcoming energy and environmental

wants. There are a lot of researches on CPS architecture design and analysis, however, research on CPES architecture is few. Gabor Karsai and Janos Sztipanovits[8,9] gave the layers of CPS design and models of real world in CPS. Ying Tan, Steve Goddard and Lance C. Perez[4,10] gave prototype architecture for CPS and the architecture leads to identification of many research challenges. Kim J.E. and Mosse D. gave general framework for design, modeling and simulation of CPS. These papers are short for energy system applications in energy area. Ge et al presented CPES architecture for electric vehicles charging application. They proposed CPES architecture to apply in intelligent charging system for electric vehicles experiment.[7]

Compared to the existing energy system based on real-time embedded systems and network control system, CPES pays more attention to energy resources utilization. It aims to achieve real-time sensing and dynamic monitoring of largescale load system and WAN environment, and provides the network services more flexible, intelligent and efficient. For this purpose, it is needed to figure out the CPES features first for understanding the concept of CPES, then we can do deeply research on CPES. CPES has features of deeply embedded, autonomy, heterogeneous, real-time, reliability, and recomposition, etc. Considering the CPES concept and requirement, the main CPES features are proposed as shown in Figure 1

### CYBER PHYSICAL ENERGY SYSTEM (CPES) FEATURES



*Fig.1: CPES Features.*

### HETEROGENOUS

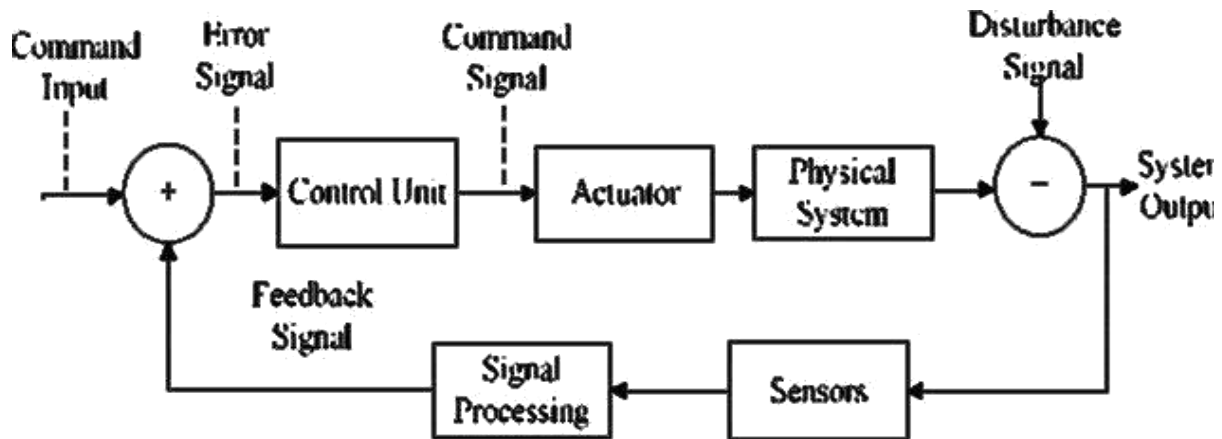
Cyber-physical energy systems (CPES) are assorted, because they compactly couple computation, communication, and control beside with physical dynamics, which are usually considered separately. Devoid of a complete modeling, model based enhancement of CPS includes using an

assembly of models in a variability of formalisms that capture abundant facets of the system design, such as software scheme, networking scheme, physical models, and protocol design. Without a severe uniting structure, system amalgamation and integration of the analysis results for various models remains difficult,

## AUTONOMY

Autonomous cyber physical system combines the physics of motion with advanced algorithms to act on their own

without close human supervision. For Example, Self-driving cars uses the autonomy control block diagram below



*Fig.2: Autonomy Control Block Diagram.*

## REAL TIME

Cyber physical energy system must be able to change its state as a function of time. Car airbag system is a good example of such system. When a cyber-physical safety system in a car detects a crash, the airbag must inflate in tens of milliseconds to avoid injuries of the driver. The success of the airbag system relies upon the crash sensors working accurately and extremely quickly but also upon algorithms processing in real time. Such a time-critical and safety critical functionality requires specific engineering solutions.

## RECOMPOSITION

Recomposability is a concept based on the growing appreciation that the mere selection of a set of plausible subsystems together with a conceivable interconnection pattern does not guarantee the realization of a desired overall system. Recomposability is viewed as a problem of determining which subsystems of an overall system under the conceived interconnection pattern are appropriate in the sense that specific properties of the total system can be recomposed from an information of the matching properties of

the integral subsystem.

## RELIABILITY

The possibility that cyber physical energy systems, comprising all hardware, firmware, and software, will adequately implement the task for which it was designed or projected, for a stated time and in a particular environment.

## DEEPLY EMBEDDED

This feature of the cyber-physical energy systems make sure that the physical and software modules are extremely intertwined, each operating on diverse spatial and temporal scales, exhibiting numerous and diverse behavioral models, and relating with each other in various ways that alter the framework.

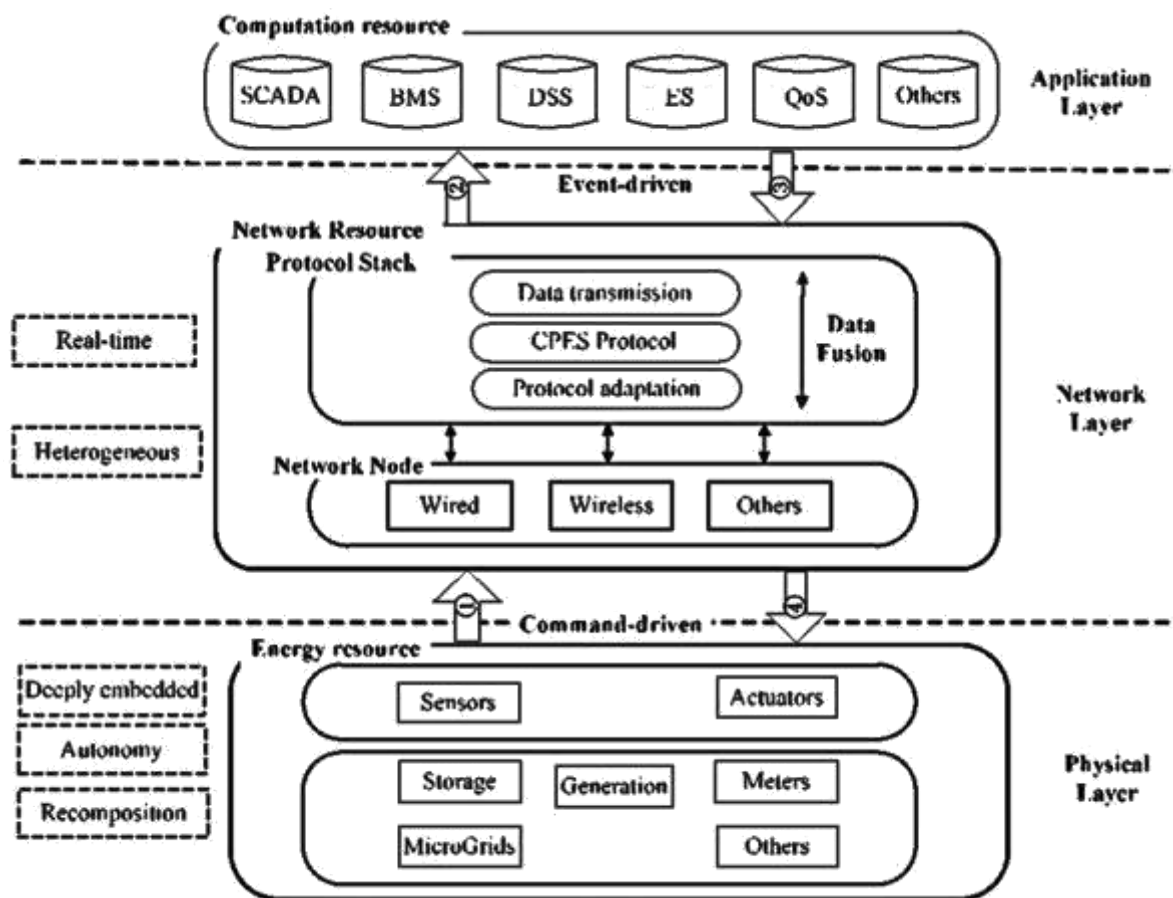
## STRUCTURAL DESIGN OF CYBER PHYSICAL ENERGY SYSTEMS

The CPES denotes a new class of extensively distributed and globally interrelated energy systems that incorporate computation, communication and control processes. The structural design and proof in a CPES development is the key works. In this paper, a new

CPES application structural design is suggested based on the attribute of energy systems, such as heterogeneous, reliability, autonomy, etc.

Cyber-Physical System(CPS) is a future intelligent system based on the plan of network and rooted system. Architecture frame is the key technology of CPS. We analyzed the concept and features of CPS,

proposed a three-layers architecture frame. They are physical layer, network layer and application layer. We discussed each layer, introduced the description of layers. The three-layers architecture frame was proved to be congruent to concept and features of CPS by the experiment in intelligent traffic system. The three-layers architecture frame can be the direction of research in CPS in the future.



*Fig.3: CPES Architecture.*

Only to establish a scientific and rational CPES architecture, it is able to satisfy the demands of energy systems. The CPES layered architecture is distribution architecture combined with the embedded system. The layered architecture should include an information-centric protocol stack to support data fusion for making the data into the network and converting to high-level information for applications.

In this article, a layered architecture is given for CPES shown in Figure 3. The architecture is divided into three layers:- physical layer, network layer and application layer. Data is perceived by physical layer, and transmitted by network layer, and then formed control information through application layer, finally, the control information gives feedback to the physical layer forming a closed -loop of information processing.



The CPES architecture embodies the requirements and features of CPES. The computation nodes (such as sensors, actuators) are deeply embedded into the physical environment, and perceive the environment change in real-time. The respond to the specific circumstances reflects the computation processed deeply embedded into physical processes; a large number of different energy resources and network resources reflect the heterogeneity;[5] the closed-loop reflects the CPES autonomy; the combination of networks and computing reflect the real-time; the entire system design rationality and security reflects the reliability; when certain energy resources or network resources run failure, the CPES can recompose by itself.

### **BENEFITS OF CYBER PHYSICAL ENERGY SYSTEM**

Key benefits of cyber physical energy systems include

1. Enhanced energy efficiency
2. Cost-effectiveness of resource management
3. Operational agility and flexibility in dynamic environments
4. Safety and resilience of interdependent critical infrastructures
5. Human-centric services such as comfort, privacy, health, and well-being driven by the fundamental push for a sustainable economy

### **CHALLENGES OF CYBER PHYSICAL ENERGY SYSTEM**

For the future development of the CPES there exists many questions that need to be solved. Each of them represents a new opportunity to make interesting contributions to the development of future energy systems. Some of the main challenges in this area are:

#### **Networks Limitations**

The first problem depends on learning how to live with networks restrictions in the

energy systems that run on a cyber physical framework. While small-scale systems can use specialized real-time networks, national-scale systems (like a national power grid) will inevitably rely on the internet or other network communication of large-scale for part of their operation. It is necessary to understand what parts of a real time, closed-loop system can be put in communications protocol networks and which parts cannot. Also, we need to analyze the limitations for the diverse physical energy systems with time delays and network throughput such that it can ensure stability and performance.

#### **CPES Modeling**

The demand to find an integrated structure for modeling CPES, it is necessary to outline methods for modeling cyber and physical resources. The energy systems should have CPES methods specialized that consider the key features of the cyber and the physical world. Additionally, these new modeling methodologies should reduce the models in order to search an appropriate balance between complexity and usefulness.

#### **Computational Prediction of System's Uncertainty**

Finally, one major problem in designing CPES and smart grids (SG) based on Microgrids (MG) is given by the characteristics of the environment.[11-13] CPES have to operate in very harsh physical environments, with big contents of uncertainty. These uncertainties must be modeled with appropriate physical and cybernetic models, based on on-line prediction or other useful tools. An example of this issue is the load prediction for a distribution grid with high penetration of distributed generators (DG) based on intermittent technologies such as photovoltaic (PVs) and wind turbines.

#### **WHAT HAS BEEN DONE SO FAR IN**

**CYBER PHYSICAL ENERGY  
SYSTEM**

Various researches has been done on cyber physical system application in energy industry, from the works are microgrid, smart grid, smart homes, smart appliances and smart renewable energy.

**Smart Grid and Renewable Energy[14-16]**

Smart grid and renewable energy research and development have been in the front position of people awareness and thus a high urgency for policy makers. The aim is to increase energy efficiency by investing in upgrading of the energy framework.

**Microgrid**

A microgrid is a distinct energy system containing of dispersed energy sources (together with demand administration, storage, and generation) and loads proficient of operating in parallel with, or freely from, the chief power grid to the whole electrical network.[17-19] The key reason of using microgrid is to permit local, trustworthy, and reasonable energy safety for urban and rural cultures, while also provided that answers for marketable, industrial, and federal government customers. Profits that cover to utilities and the community at large include reducing greenhouse gas emissions and reducing stress on the transmission and distribution line. Microgrids are reduced forms of the local power grid. Microgrid varies from local electrical grids by provided that a nearby proximity between generation and power usage, resultant in efficacy upsurges and transmission reductions. Microgrids also incorporate with renewable energy sources such as solar, wind power, small hydro, geothermal, waste-to-energy, and combined heat and power (CHP) systems.[20, 21]

**Benefits of CPES**

It provides power reliability, quality, and security for end users and operators of the

grid

- Enhances the integration of distributed and renewable energy sources
- Cost competitive and efficient
- Enables smart grid technology integration.
- Locally controlled power quality.
- Increased customer (end-use) participation.
- It reduces carbon discharge and greenhouse gas emissions by maximizing clean local energy generation

**EXTENDED FUTURE PLAN AREAS  
OPEN TO BE EXPOSED**

An energy system is a system primarily designed or developed to provide energy to end users. It defines all components related to the production, conversion, delivery and use of energy, this Energy can be in form of heat, fuels, and electricity. Cyber physical systems over the year have found so many applications in the energy sector and common example is the smart grid, which refers to an electric grid, a network of transmission lines, substations, transformers and digital technology that allow for two-way communication between the utility and also the sensing along the transmission line so as to ensure efficient delivery the power from power plant to end user.

Despite the advancement in cyber-physical energy system, there are still areas where cyber physical system has not been effectively explored in the energy sector. Some of these areas are;

1. The petroleum industries, including oil companies, petroleum refiners, fuel transport and end-user sales at gas station
2. The gas company, with natural gas extraction, and coal gas mining as well as logistics and sales.
3. The coal industry
4. The nuclear power industry

5. The renewable energy industry, including substitute energy and maintainable energy companies, together with those involved in hydroelectric power, wind power and solar power generation.
6. Outdated energy industry based on the gathering and distribution of firewood, the use of which, for cooking and heating, is particularly common in underdeveloped countries.

### **FACTORS RESPONSIBLE FOR POOR EXPLORATION OF CYBER PHYSICAL SYSTEM IN AREAS NOT YET EXPLORED.**

There are some challenges that arise due to the fact of energy generation infrastructure such as thermal plants, nuclear power plants, hydro-electric power plant etc. which were established before the advent of cyber-physical systems and their application in energy system. Some useful application of cyber physical systems in this areas are briefly discussed below.

#### **Self-Sustainable Intelligent Sensor Nets**

In energy systems, sensors technique plays an important role for the operation of IoT and cyber physical systems. A sensor is a device sensitive to light, temperature, radiation level and other physical quantities, that transmits a signal to measuring or control instrument. It is a useful device that converts information from physical world into data in cyber systems. However, concerning the application of sensor, general problems arise on how to interlink this information efficiently.

Basic foundation for the establishment of sensor nets is to gather and transfer the real time information from the energy generating system to computer and with the network algorithm in cyber networks, the enhanced algorithm will be shifted back to the physical system, so as to realize better controlling of the process.

Based on the monitoring of the real condition, optimal maintenance periods would also be obtained and forwarded to the physical system via sensor nets. Another innovation of this system is self-sustaining,

#### **Synchronous Production Through Semi-Autonomous Planning and Human Centered Decision Support**

Part of the biggest problem for the application of cyber-physical systems, is the “real-time” link of physical invention and digital factory. Besides, with a view to different information technology systems existing in companies, how to merge all these relevant data from different systems to the implementation of cyber physical system arises as another problem. With these in mind, a synchronous production model has been developed based on “synchronous production through semi-autonomous planning and human-centered decision support (SOPHIE)”. Three level of object have been constructed for the implementation of synchronous production. They are physical level, cyber level and automation level. By description and modeling objects within the production system, digital factory would be mapped to the cyber level. Here within the automation level, all the involved systems would be gathered and sorted in a pyramid manner. Therefore, with the help of these structured information systems, dynamics of the physical objects can be reflected real time to automation system. In the digital system, the status of planned and actual process can be provided based on the valid and continuously update simulation model. Taken together, with the development of the synchronous production model, the real-time link between physical production and the digital factory becomes possible; the general logic of this model can also be transferred to different industries.



### **Resource Control for Socio-Cyber Physical Systems**

Considering the scopes of general value-added chain, the application of cyber physical system can also be extent to the maintenance issues, as the scheduling of maintenance activities plays an important part for the readiness and reliability of production amenities. They are not only concerned to the real-time monitoring conditions of machines, but also to the scheduling of staffs, availability of other resources and so on. With existing but developed Iot technologies, facilities are equipped to be smart. However, considering the dynamics of the on-time integration of all relative information. It is not just “marginal” involving of decentralized data and digital system, but unifying and structuring of these real-time information for the general arrangement. With this in mind, combination of “socio” perspective, interaction and collaboration between human and smart object would be focused. As a outcome, mobile support for internal and external upkeep personnel would be understood, so as to progress efficacy and elasticity for the on-site and off-site upkeep.

Based on the systematic modeling and optimization of maintenance processes, all kinds of information related to the product and production resources would be merged as in resources control.

As the output, the control will create lists of tasks, where different roles of users will be adapted. Contents of the lists include not only detail tasks, but also necessary resources required, resources availability, competence required, machine states and relative schedules. Thus with the usage of resources control, efficiency and efficacy would enhance considering the management of maintenance activities.

### **CONCLUSION**

In this work, the CPES concept is introduced and its main features are identified in order to address the current challenges in energy systems issues. The key CPES study areas are identified as: modeling energy systems, energy efficiency, energy resource management, and energy control. In each of them, the research challenges are identified. The CPES approach offers some important aspects to address current challenges in energy systems such as network limitations, computing efficiency, uncertainty prediction, and unified framework of modeling for CPS components of the energy systems. CPS are meant to play an essential role in the plan and expansion of forthcoming engineering systems with new know-hows that far exceed today's levels of autonomy, functionality, usability, reliability, and cyber security. In this paper, some benefits, challenges and major faults introduced by incorporating cyber physical systems to energy systems. Integrating computers, communications and regulate at all levels of production, transmission, spreading, consumption and storage of energy, the mistakes are enlarged and also safety become more composite. It also presents the architecture of the cyber physical energy systems, areas of application in the energy field, what has been done, and areas not yet explored.

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