APPLICATION OF NANOTECHNOLOGY FOR IMPROVING ENERGY SECURITY

*** Engr. Ijeoma Okeke, Dr. Ogechukwu Iloanusi**
Department of Electronic Engineering, Faculty of Engineering,
University of Nigeria,
Nsukka, 410001,
Enugu State,
Nigeria.
Email: ijeoma.okeke@unn.edu.ng, Email: ogechukwu.iloanusi@unn.edu.ng

* Corresponding Author

Abstract

Energy security is critical for the sustenance of the different world economies. In the light of the rising global energy demands, there is need to explore different means of realising this goal. The traditional energy system infrastructure is partitioned into layers which work interdependently with each other in order to supply energy to consumers. Nanotechnology is a growing area of research which is enabling the production of more efficient products which are being employed at these different layers of the energy system architecture for more efficient and optimal energy systems. A more reliable energy system infrastructure will contribute to a more energy secure society. In this paper we show that since the traditional energy system architecture is layered and interdependent, the net-reliability of the system is a function of the product of the reliabilities of the individual components. Thus, the application of nanotechnology to these sub-layers in improving the system's reliability would result in an overall improvement in energy security

Keywords: Energy Systems, Reliability, Security, anotechnology

1. Introduction

Energy is major driver of development in different economies in the world. Therefore, the importance of energy security in the attainment of economic development cannot be over-emphasized. While fossil fuels have been the major energy sources globally, due to increasing energy demands, environmental concerns and climate change, more and more environmentally friendly options are being exploited, resulting in a more diversified energy mix. The overall goal of these efforts is to increase energy production so as to meet the ever rising global demand for energy in a sustainable manner.

Energy security is the uninterrupted availability of energy supply sources at an affordable price [1]. Energy security, while globally important [1] is extremely so for developing countries like Nigeria, whose economic development has for long been forestalled by the perennial unreliability of power supply and distribution [2, 3].

The application of nanotechnology to the development of energy system infrastructure involves the engineering of the functional systems at the molecular level resulting in miniaturised and compact functional systems with better efficiency. These nano-based components have the potential to improve energy security by enhancing energy efficiency along the complete energy supply chain comprising energy production, energy conversion, energy distribution, energy storage, and energy consumption.

Advances in the development of these technologies at the nano-scale make them a veritable tool for the provision of reliable energy systems of the future. Thus, we surmise that in order to improve the energy security issues currently faced by developing economies like Africa, there is need to effectively harness the potentials of nanotechnology in the development and deployment of future energy systems so as to achieve a more energy-secure society.

The rest of this paper is organised as follows: Section II presents a background on the need for reliable energy systems, section III briefly discusses he concept of nanotechnology and systems reliability while section IV covers the application of nanotechnology to the different components of the energy system architecture while the paper is concluded in Section V.

2. The Need for Reliable Energy Systems

The International Energy Agency defines energy security as the *uninterrupted* availability of energy sources at an affordable price [4]. Energy security involves avoiding over-dependence on only one energy source such as fossil fuels and exploiting other sources especially renewables. Significant research efforts are currently focused on energy security due to the globally increasing energy needs.

Some applications of nanotechnology in the energy supply chain include: the use of nano-optimised solar cells resulting in improved efficiency for the photovoltaic systems; the use of nano-optimised membranes and electrodes to produce more efficient fuel cells for mobile electronics applications; the use of nano-sensors in smart grids for the intelligent and flexible management of highly decentralised energy grids; and the use of optimised Li-ion batteries composed of nano-structured electrodes and flexible separator foils to improve energy storage. Similarly, the intelligent management of heating and lighting flux in a building as well as the use of energy efficient bulbs with better energy conversion capabilities will enhance energy security via energy usage. The technological improvements ensure that the energy system sub-components are more reliable and that available energy is produced, distributed and utilised in the most efficient manner with minimal wastages. Therefore, a more reliable energy system infrastructure would therefore provide a framework for an energy-secure society

2.1. The Traditional Energy System Architecture

The traditional energy system architecture was built hierarchically such that power was generated centrally in generating stations and then transported via cables to end users who are usually located far away from the generating stations. Bulk electrical energy is produced remotely in large scale production facilities and pushed down towards the end users who are located at the lower end of the hierarchy [5]. The hierarchy is roughly divided into the High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) grids as shown in figure 1. The power generated at the power stations which are at a very high voltage (HV) level is stepped down at different points along the transmission path to the medium and low voltage levels which are suitable for transmission and distribution at medium and low voltage grid respectively. The energy flow characteristics in this architecture are top-down and uni-directional. The reliability of the traditional grid was achieved by providing redundant paths along the transmission path. However, the emergence of a variety of distributed generating sources usually at the distribution layer has opened up a new set of possibilities for realising reliability and energy security. The energy system architecture can be divided into 4 major aspects thus: *Production*, *Distribution*, *Storage*, and *Utilisation*.

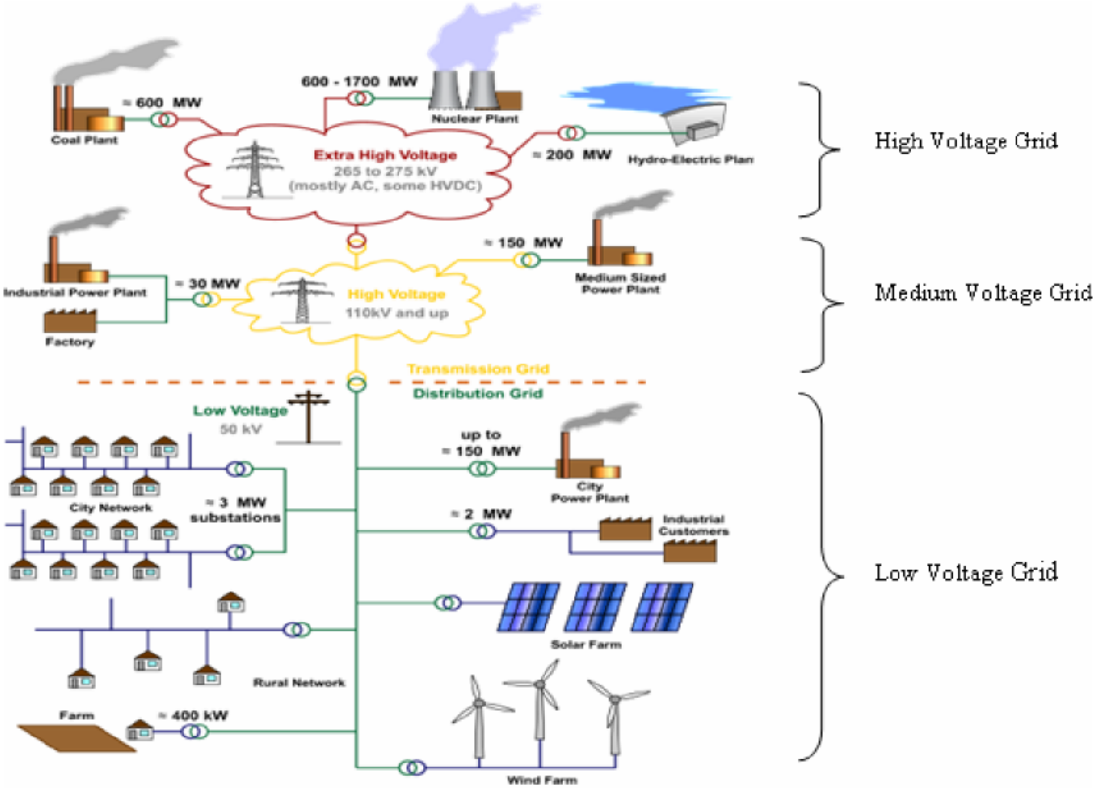

Figure 1: The Traditional Power Grid Architecture adapted from [6]

2.2. Energy System Characteristics – Case of Nigeria

Nigeria's energy system is heavily dependent on oil and gas. Majority of the country's electricity generation comes from thermal plants (77%), with about two-thirds of thermal power derived from natural gas and the rest from oil while Hydroelectricity constitutes the rest (23%) [7]. However, Nigeria has a vast amount of renewable energy resources (such as biomass, solar, hydro, wind and geothermal) which could be exploited for a more diversified energy mix [8].

The energy infrastructure is largely government owned. It is planned in the traditional centralised manner whereby energy is generated centrally and then distributed downwards to consumers. Thus, the government is in control of most of the central generating sources [7, 9] with recent changes towards privatisation and Independent Power Producer (I PPs) [7].

The quality of energy supply is best described as epileptic. It is characterised by frequent power outages leading to a high incidence of in-house generation because the national grid does not provide reliable energy required for the smooth running of business enterprises [3]. Therefore, business enterprises would usually purchase costly generators to use as back-up during the frequent outages [3].

Infrastructural management operations are typically performed manually. That is, electricity workers are usually required to manually read meters, and to identify and (or) maintain broken/faulty equipment. However, recent advances in the field of nanotechnology are presenting possibilities for the improvement of some of the shortcomings identified at the different layers of the energy architecture.

3. Nanotechnology and Energy Systems Reliability

Nanotechnology is defined in [10] as the engineering of functional systems at the molecular scale. It is the projected ability to build things from the bottom up inside personal nano-factories (PNs), using currently developed techniques and tools to make complete, highly advanced products [11]. The following section discusses the application of nanotechnology to the development of energy infrastructure in order to improve the overall energy security of a country. More reliable energy system infrastructure would definitely result in improved energy security.

3.1. Energy Systems Reliability

Reliability is the defined in [12] as the probability of a device to perform its purpose adequately for the period of time intended under specified operating conditions. A functional engineering system is usually made up of different sub-components each with its own reliability value. In reliability theory, the overall system reliability is usually computed as a function of the individual reliabilities of the different sub-components making up the system depending on the type of system configuration used. A system can be configured either as series or parallel. A system configuration for which all the sub-components must operate for system success is a series configuration while the parallel system configuration does not require all the sub-components to operate to achieve system success. Parallel configuration however, allows for redundancy in the system such that system success may be achieved even during the failure of one or more of the system components.

Energy systems are similarly composed of different components that work together to produce, transport, store, and deliver power supply to end users. The traditional grid architecture is hierarchical as control flows from the top to the bottom with the output of a higher layer forming the input of the layer just below it. This means that all the sub-components must operate to achieve system success corresponding to a series system configuration.

The reliability of a given system with *n* components in series is given as:

$$R = R_1 . R_2 \ldots R_n = \prod_{i=1}^{n} R_i \quad \text{Eq. 1}$$

Where, R_i represents the reliability values of each of the sub-components

Also, the reliability of a fully redundant system with parallel configuration is given as:

$$R = 1 - \prod_{i=1}^{n} Q_i \quad \text{Eq. 2}$$

Where, Q_i represents the unreliability values of each of the sub-components

Applying the reliability theory to energy systems, we show that the overall reliability of the system can be realised as a function of the individual reliabilities of the four major sub-components of the system vis-à-vis *Production*, *Distribution*, *Storage*, *Utilisation*. Thus the overall system reliability R would be given as:

$$R = R_p . R_d . R_s . R_u \quad \text{Eq. 3}$$

Where: $R_p = reliability\ of\ the\ production\ sources$

$R_d = reliability\ of\ the\ distribution\ infrastructure$

$R_s = reliability\ of\ the\ energy\ storage\ facilities$

$R_u = reliability\ of\ the\ energy\ consumption\ devices$

Thus, it follows that when the reliability and performance of the individual components are improved, the net-reliability of the system would be improved. The application of nanotechnology for the development of these sub-components is part of current research efforts towards improving energy security. The use of nano-based solar cells with improved efficiency for energy production; use of hydrogen and nano carbon filters for hydrogen fuel cells; the use of nano-sensors for intelligent and flexible grid management for highly decentralised power feeds, are a few examples of the application of nanotechnology for improving energy systems. The following section presents the application of nanotechnology at the different sub-layers of the system.

4. Major Aspects of Improving Energy System Reliability:

Nanotechnology has been separately employed to enhance the performance of the different energy sub-system components. Thus, technological innovation at the nano-scale is a major driver for the uptake of renewables for sustainable energy systems of the future. As the technology matures, further research efforts are targeted towards developing more efficient and reliable components for the energy sub-system components. The role of nanotechnology in improving energy system reliability would be presented along the lines of the major aspects of the energy infrastructure: Energy Production, Energy Distribution, Energy Storage and Energy Utilisation. Our goal is to show that more reliable energy systems would result in improved energy security in the society.

4.1. Energy Production

One of the key research efforts towards improving energy security is in the area of developing technologies which enables the efficient exploitation of a more diversified array of renewable energy resources. The world's growing energy needs as well as the increased awareness for sustainability has resulted in an increased adoption of renewable sources enabled by nanotechnology such as: improved fuel cells and optimised/flexible solar cells for energy production. Nanotechnology has thus, been employed in the exploitation of solar energy resources as well as biofuels. More efficient fuel cells have been developed using carbon nano-tubes and nano-fibres. Some of the initial commercial portable fuel cells improve conventional methanol polymer electrolyte membrane (PEM) fuel-cell technology with nano-structured catalytic layers and MEMS-based micro reformers. Nanotechnology has also enabled the production of optimised/flexible solar cells using thin film nanostructures. These developments enable the efficient exploitation of natural resources for increased energy production in a sustainable manner.

4.2. Energy Distribution

Advances in nanotechnology have enabled the production of smaller, faster, more sensitive and more efficient sensors that can be used on the energy distribution grids. Additionally, the development of HV Transmission Super Conductors as well as Carbon nano-tubes power lines has enabled more efficient energy transmission from the central generating centres to the distribution grid. These improved technologies enable more efficient and lower energy losses along the path of energy transmission/distribution.

4.3. Intelligent Grid Management

Intelligent grid management refers to the employment of computer-based remote control and automation technologies for efficient energy delivery. This is usually achieved in the context of smart grid. A smart grid is defined as a modernized electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity [13]. The architecture of a typical intelligent distribution grid which is enabled by nano-sensors is shown in figure 2. Nano-sensors are deployed at the different layers of the architecture which provide real-time information on the state of the grid and can be used to automate the management process such as fault detection, meter readings, etc.

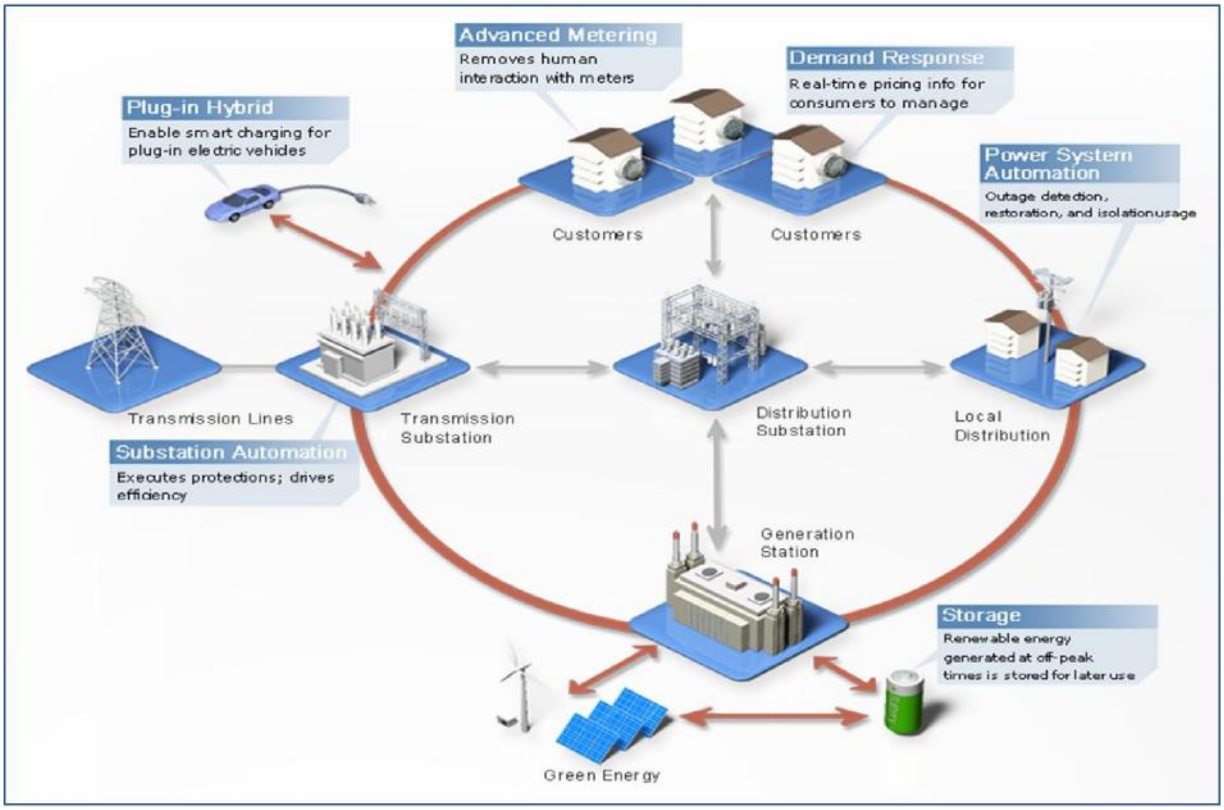

Figure 2: An Intelligent Energy Distribution Grid [14]

4.4. Energy Storage

Energy storage technologies play a vital role in improving energy security. Energy storage is becoming extremely important due to increasing uptake of renewable energy sources such as solar and wind which do not have constant availability. There is need to harness these energy resources when they are most abundant and to store the energy produced for use at a future time when it would be required. Nanotechnology has enabled the production of optimised batteries using nano-structured electrodes. It has also enabled the development of super capacitors using nano-carbon fibres which can be used in place of batteries in some application areas such as cars. Thus, energy storage technologies have benefited from recent advances in the field of nanotechnology resulting in the production of optimised and more efficient varieties thereby improving energy security.

4.5. Energy Utilisation

Efficient energy utilisation improves energy security because it ensures that the limited energy production capacity of the generation sources are efficiently utilised while minimising wastages. Nanotechnology has been applied to the improvement of three major aspects of energy utilisation namely: lighting, thermal insulation and air conditioning. The use of nano-based energy efficient light bulbs reduces the amount of energy consumed for lighting applications. Additionally, nano-structured coatings and nano-bases air quality sensors can be used for energy-efficient buildings to reduce the amount of energy utilised for heating applications. Similarly, nano-improved coolants/refrigerants with greater efficiency can be used in modern air conditioning systems to improve the efficiency of energy conversion in these systems thereby reducing the amount of energy used for air conditioning applications. **5. Conclusion**

Advances in nanotechnology have resulted in the development of more efficient and reliable sub-components of the energy system. Since net system reliability is a function of the reliabilities of the different sub-systems, in this paper, we have shown that the application of nanotechnology to the different components of the layered and interdependent energy system architecture results in efficiency optimisation and performance improvement thereby improving the overall energy security of the society. Thus, we surmise that the continuous application of research and development efforts towards the deployment of more reliable and efficient nanotechnology solutions at the various sub-systems would enable the realisation of a more energy–secure future for our society

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