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GREEN 2020 Editors

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GREEN 2020

Forward

The Fifth International Conference on Green Communications, Computing and Technologies (GREEN 2020), held on November 21-25, 2020, continues the series of events focusing on current solutions, stringent requirements for further development, and evaluations of potential directions. The event targets are bringing together academia, research institutes, and industries working towards green solutions.

Expected economic, environmental and society wellbeing impact of green computing and communications technologies led to important research and solutions achievements in recent years. Environmental sustainability, high-energy efficiency, diversity of energy sources, renewable energy resources contributed to new paradigms and technologies for green computing and communication.

Economic metrics and social acceptability are still under scrutiny, despite the fact that many solutions, technologies and products are available. Deployment at large scale and a long term evaluation of benefits are under way in different areas where dedicated solutions are applied.

We take here the opportunity to warmly thank all the members of the GREEN 2020 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to GREEN 2020. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

We also thank the members of the GREEN 2020 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope that GREEN 2020 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the field of green communications, computing and technologies.

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Economic and Environmental Benefits of Electric, Hybrid and Conventional Vehicle Treatment in Lithuania

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***Abstract*—End-of-Life Vehicles' (ELV) recovery and recycling is encouraged not only due to the targets set in the Directive on ELV, but also due to economic and environmental benefits. Automotive remanufacturing serves as a specific circular marketing system of recovered parts' reuse that can bring economic benefit both for dismantling companies and consumers. Moreover, in terms of greenhouse gas emissions, reuse of the recovered parts or the secondary resources from ELV may save CO_2 emissions in manufacturing new cars or their parts. For this reason, four passenger cars with different engine types were analysed in order to reveal the economic and environmental benefits that ELV dismantling and reuse of the recovered vehicle parts may bring to dismantlers and passenger car owners. The results showed that the greatest economic benefit is that 41% of ELV-hybrid car mass can be sold in parts that would save up to 3,835 Eur as an economic benefit for the dismantlers and 17,153 Eur for the consumers. In addition, 35% of ELV-electric car mass can be sold in parts for reuse and it can bring 8,812 Eur for the dismantling company. Meanwhile, consumers would save up to 6,614 Eur when buying used parts for their car repair. Besides, an ELV-petrol car and an ELV-diesel car can be sold in parts 27% and 25%, respectively, and make economic benefits accordingly. In terms of global warming, treatment of ELV parts can save CO_2 emissions caused by metal extraction. As a result, a secondary resource recovery can save 23–44% CO_2-eq needed for the primary metal extraction.**

Keywords-electric and conventional car; economic benefit; environmental impact; end-of-life vehicles.

I. INTRODUCTION

According to the Circular economy principles, through the reuse, remanufacturing and refurbishing, the global economy is increasing [1]. Automotive recycling is playing a significant role in environmental and economic sectors as more and more End-of-Life Vehicles (ELVs) are generated worldwide. In 2019, there were 1,520,159 registered passenger cars in the Lithuanian market [2]. It means that more than every second Lithuanian resident owns a car. Due to the economic growth and faster living pace, the number of registered passenger cars is increasing every year, as well as that of ELVs. The use of secondary resources, promotion of ELV recycling technologies and the increasing use of recovered and recycled materials provide a promising outlook in order to gain economic and environmental advantages.

There were 210,114 ELVs generated in Lithuania in 2018 [2]. The Directive 2000/53/EC on ELV states: "No later than 1 January 2015, for all ELV, the reuse and recovery shall be increased to a minimum of 95 % by an average weight per vehicle and year. Within the same time limit, the reuse and recycling shall be increased to a minimum of 85 % by an average weight per vehicle and year" [3]. According to the data of Environmental Protection Agency of Lithuania, in 2018 the ELV reuse and recovery rate reached 95.4%, and the reuse and recycling rate – 92.4%.

Automotive dismantling plays a big role in a vehicle's life cycle. While consumers are choosing either to buy a used part or a new one, the prices are making a significant impact on their decision making. In this study, practical research was performed in order to reveal how much it costs to buy all the necessary parts from dismantling companies. Furthermore, the prices of the used parts from dismantlers were compared with the prices of the new parts placed on the market. The difference showed an economical benefit that consumers may have.

The goal of this study is to evaluate and compare the economic and environmental benefits of the treatment and bringing materials back to the market (upcycling) of a Battery Electric Vehicle (BEV), a Hybrid Electric Vehicle (HEV) and Internal Combustion Engine Vehicles (ICEVs). This research is novel firstly because it provides a comprehensive, comparative analysis of the end-of-life passenger cars with four different engine types. Secondly, it applies directly to the Lithuanian conditions; and thirdly, the analysis adds a comparison of Life Cycle Assessment (LCA) results focusing on the end-of-life phase of BEV, HEV and ICEVs powered with diesel and petrol.

This paper is organized as follows: Section I provides the relevance and issues of the study, ELVs recycling and recovery goals, as well as, the situation in Lithuania. Section II introduces the methodology of economic and environmental assessment, inventory analysis, the scope and methods of the research. Section III presents the results of the economic and environmental analysis of selected passengers cars' treatment. Section IV concludes and summarises the paper.

II. METHODOLOGY

In the study, the four passenger cars with different engine types were analysed in accordance with the most popular models registered in the Lithuanian road vehicle fleet. It was also taken into account that the average age of the car is 16 years. Besides, this number is very close to the global average – 15.8 years [4]. The analysed models were 2005–2008 Volkswagen Golf plus with 1.4 petrol engine, 2005–2008 Volkswagen Golf A5 plus with 1.9 diesel engine, 2011–2013 Nissan Leaf with 24 kWh battery and 2003–2009 Toyota Prius 5 door hatchback with hybrid 1,5 petrol engine and 16 kW battery. For the detailed information about each passenger car parts, their weight and composition, International Dismantling Information System was used [5].

Five local dismantling companies were interviewed about each part demand on the market. The prices were checked and compared in e-shops. The economic benefit for dismantlers was evaluated by calculating the prices of the used parts, waste management costs and the value of secondary materials. Labour force and equipment prices were not evaluated and included in the analysis.

For the environmental analysis of selected passenger cars, a methodology of Life Cycle Assessment (LCA) was used. According to Hauschild et al. [6], LCA is an effective tool that can be used in the field of (electric) mobility in order to answer the questions regarding comparisons between different types of vehicles, as well as, to analyse the disposal scenarios, mainly regarding the treatment of the main components, especially batteries, electric motors and car body.

The LCA study of BEV, HEV and ICEVs powered with diesel and petrol was carried out following the procedure and recommendations indicated in the European standards series – ISO 14040 and ISO 14044 [7][8]. The goal of this LCA study is to evaluate the environmental impacts throughout the electric, hybrid and conventional vehicles' production and end-of-life stages. The end-of-life stage involves dismantling, recovery and recycling activities. The ReCiPe method at the midpoint level was used and the indicator of global warming as one of the most significant impact categories was selected, expressed in kg CO_2-eq [9]. For the life cycle impact assessment and interpretation, database Ecoinvent 3.5 and software SimaPro 9.1 were used.

III. RESULTS AND DISCUSSION

The result revealed that most vehicle parts can be reused for the same purpose in HEV – Toyota Prius (42%), while the least number of reusable parts was determined in VW Golf powered with diesel (25%). The economic benefit for dismantlers for each vehicle differs from 2,412 Eur (VW Golf powered with petrol) up to 8,812 Eur, the most valuable parts are in Nissan Leaf, the least valuable parts are in VW Golf with petrol engine. The biggest savings belong to Toyota Prius users (17,154 Eur) and the least difference between the new and used parts belongs to Nissan Leaf users (6,615 Eur). Toyota Prius owners feel much more motivated to look for alternatives instead of buying a new part than Nissan Leaf owners.

According to the surveyed dismantling companies, not many electric cars – Nissan Leaf – are becoming ELVs, because this model is newer than 16 years, still convenient to use, except when an accident occurs. This explains why the price difference between the new and used parts of Nissan Leaf is not considerable. The summarised results of economic benefits for vehicle dismantlers and consumers are presented in Table I.

TABLE I. ECONOMIC BENEFIT FOR VEHICLE DISMANTLERS AND CONSUMERS

Passenger car	The share of passenger cars mass that can be sold as parts for reuse after dismantling, %	Economic benefit for dismantlers, Eur	Price of new parts, Eur	Economic benefit for consumers, Eur
Volkswagen Golf (ICEV-petrol)	27	2,412	12,540	10,128
Volkswagen Golf (ICEV-diesel)	25	2,644	16,560	13,916
Nissan Leaf (BEV)	35	8,812	15,427	6,615
Toyota Prius (HEV)	42	3,835	20,989	17,154

For the environmental impact evaluation, the main vehicle parts, such as the glider, the internal combustion engine/powertrain, Li-ion (from BEV) and Ni-metal (from HEV) batteries were analysed. According to Eurostat statistics, automotive batteries are recycled up to 80% [10]. The glider and engine / powertrain are made mostly from metal, which can be melted and used for the same purpose an infinite amount of times. In this study, it was assumed that the glider and internal combustion engine / powertrain are recycled 100% and batteries – 80%, which means that the recovered amounts of materials can be used in production and save CO_2 emissions.

The results of LCA (Table II) showed that the end-of-life stage (treatment) of the glider, the internal combustion engine/powertrain, Li-ion (from BEV) and Ni-metal (from HEV) batteries account for only 10% of the environmental impact of the production of all these car parts. For example, treatment of the glider (secondary resource recovery) can save about 37% of CO_2-eq from the glider production needed for primary resource extraction of reinforcing steel, chromium steel and copper. Furthermore, the internal combustion engine treatment can save about 44% of CO_2-eq from the internal combustion engine production needed for primary resource extraction of aluminium, steel, reinforcing steel, platinum, lead and copper. Besides, treatment of powertrain can save about 23% of CO_2-eq from powertrain production needed for primary resource extraction of aluminium, steel, chromium steel and copper. Finally, Ni-metal battery treatment can save about 24% of CO_2-eq from Ni-metal battery production needed for primary resource extraction of nickel, cobalt and zinc.

TABLE II. RESULTS OF GLOBAL WARMING ASSESSMENT DURING VEHICLE PRODUCTION AND TREATMENT STAGES

Vehicle parts	**ICEV-petrol**		**ICEV-diesel**		**HEV**		**BEV**	
	Production, kg CO_2-eq	*Treatment, kg CO_2-eq*	*Production, kg CO_2-eq*	*Treatment, kg CO_2-eq*	*Production, kg CO_2-eq*	*Treatment, kg CO_2-eq*	*Production, kg CO_2-eq*	*Treatment, kg CO_2-eq*
Glider	5,507	519	5,507	519	5,507	519	5,507	519
Internal combustion engine / powertrain	1,018	105	1,697	174	1,358	139	1,610	47
Batteries	n/a	5	n/a	5	719	20	1,851	284
Total	**6,525**	**629**	**7,204**	**698**	**7,584**	**678**	**8,968**	**850**

IV. CONCLUSION

The results showed the economic benefits for dismantling companies and passenger car owners/consumers. Around 42% of ELV-hybrid car mass can be sold in parts that would save up to 3,835 Eur as an economic benefit for the dismantlers and 17,153 Eur for the consumers. Besides, 35% of ELV-electric car mass can be sold in parts for reuse and it can bring 8,812 Eur for the dismantling company, while the consumers would save up to 6,614 Eur when buying used parts for their car repair. Next, an ELV-petrol car and ELV-diesel car can be sold in parts 27% and 25%, respectively. An ELV-petrol car can bring 2,412 Eur economic benefit for the dismantlers and 10,127 Eur for the consumers, while an ELV-diesel car can bring 2,644 Eur economic benefit for the dismantlers and 13,915 Eur for the consumers.

When performing the LCA analysis, there were too few separate car parts in the database to select. Only three options of the automotive parts (glider, internal combustion engine/powertrain and batteries) could be chosen. The LCA results in terms of global warming showed that treatment of ELV parts can save CO_2 emissions caused by metal extraction needed for the production of the analysed vehicle parts. As a result, secondary resource recovery can save 23–44% CO_2-eq needed for the primary metal extraction.

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Health Risks from Exposure to Electromagnetic Waves Radiation from 5G

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***Abstract*— This work shows a compilation of the results of different studies related with the affectations in living organisms produced by electromagnetic waves radiation based on their power and frequency ranges. Currently, the growing of the population throughout the planet makes necessary an analysis of the nature of these electromagnetic waves and their effects on living beings, specially in wireless communications field. The information to be transmitted requires that the next generation of mobile telephony (5G) uses bands with frequencies higher than those used by the current generation and previous generations for its operation; for this reason, it is necessary to establish frequency ranges that could be considered non-harmful for living beings. In the present work, a detailed study was done about electromagnetic waves, including the frequency bands that were previously and currently used in mobile telephony, and some of their effects on living organisms, with the aim of publicizing some of the possible consequences of the evolution of mobile telephony on them.**

Keywords - 5G; electromagnetism; frequency; electromagnetic radiation.

I. INTRODUCTION

The present work deals with the effects of electromagnetic waves radiation on living beings. Electromagnetic waves have the main characteristic of not needing guided medium for propagation; unlike other wave types (such as sound, which needs a material medium to propagate), electromagnetic waves can be radiated in vacuum or in various materials and environments. In [1], electromagnetic wave radiation is defined as a combination of oscillating electric and magnetic fields that propagate through space carrying energy from one place to another. The radiations, ordered according to their wavelength (λ), make up the electromagnetic spectrum, which is discussed in Section II of this work. The wavelength of an electromagnetic wave (λ) is related to its frequency (f) and propagation speed (v) according to:

$$\lambda = v / f. \tag{1}$$

In free space, the propagation speed of electromagnetic waves is equal to the speed of light c; so,

c=light propagation speed= 299 792 458 m/s,
(aproximately $3\text{x}10^8$ m/s).

Therefore, for the radiation of electromagnetic waves:

$$c = \lambda f \tag{2}$$

Since the light speed is constant, as the frequency increases (and the wavelength decreases at the same proportion), the radiated energy increases.

X-rays, radio waves, infrared rays, ultraviolet rays, and visible light are some of the most important types of electromagnetic radiation, and humans have learned to usefully produce and control them.

In this paper, we study the electromagnetic waves from the point of view of their frequency values according to their uses and their Ionizing and Non-ionizing quality. Some of their effects on living organisms are mentioned, and a reference is made to used frequencies in cell phones. The objective and the main contribution of this work is to present some of the results of previous studies about potential risks of the fifth generation of cellular telephony (5G); although there are no solid conclusions or hard data about the effect of this generation, it is already possible to know some of potential risks. In this work, information from previous and current works was collected and presented, indicating the proper references.

The rest of this paper is organized as follows: Section II describes electromagnetic waves in a general way and mentions some of their uses and their effects on living organisms according to their frequencies. It also describes certain characteristics of ionizing radiation and non-ionizing radiation. Section III deals with the generations of mobile

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phones and some of the frequencies used so far. Section IV talks about the situation regarding 5G, showing the results of different studies that have been done in this regard, which is the reason for this work. Finally, conclusions are given in Section V.

II. ELECTROMAGNETIC SPECTRUM, EFFECTS ON THE BODY, FREQUENCIES AND RISKS

Electromagnetic spectrum is the set of frequency values of electromagnetic waves that humans have been able to detect and measure. Within this electromagnetic spectrum are (in order of lowest to highest frequency) radio waves (used for wireless communications, such as radio transmissions, TV, mobile telephony and mobile Internet), microwaves (used for detection radars and domestic microwave ovens), infrared light, visible light, ultraviolet light, X rays and Gamma rays. Figure 1 illustrates the electromagnetic spectrum, showing the frequency range for each classification.

Within the same electromagnetic spectrum, also considering lower and higher frequency, ionizing radiation and non-ionizing radiation are considered. Remember that an ion is an atom that has lost or gained electrons; ionizing radiation is electromagnetic wave radiation which frequency (and energy) is as high that it acquires the ability to extract electrons from atoms of matter through which it passes. Ionizing and non-ionizing radiation mainly depend on where they come from.

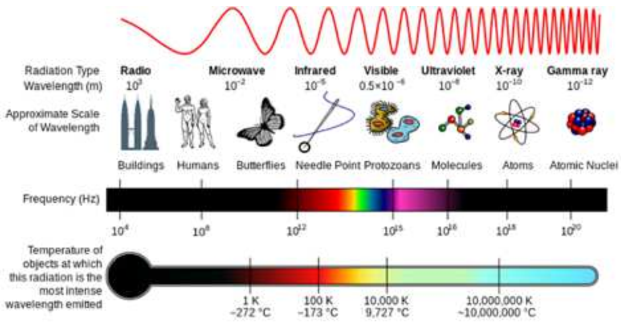

Figure 1: An electromagnetic spectrum illustration [2].

The frequency of non-ionizing radiation is below the ultraviolet light threshold, which means that visible light and wave radiation with lower frequencies fall into this group. Ionizing radiation is found from the ultraviolet frequency light and includes X-rays and Gamma rays.

Ionizing radiation. Ionizing radiation interacts with matter producing excitations and ionizations that induce energy changes at atomic or molecular levels. Directly ionizing particles are electrically charged particles, such as electrons, protons, and alpha particles, that have enough kinetic energy to ionize by collision. Indirectly ionizing particles are uncharged particles, such as neutrons and photons, that can set directly ionizing particles in motion (photons move electrons; neutrons, protons) or initiate nuclear transformation.

In medical applications, the most widely used particles are photons, called X-rays when they are generated electrically in X-ray equipment or linear accelerators, and Gamma rays when they come from radioactive material (such as Plutonium). The discipline that quantifies the amount of energy transferred and absorbed in the irradiated medium is Dosimetry, and the fundamental magnitude is the absorbed dose, which corresponds to the average energy (measured in joules) imparted by radiation at a volume of mass m (measured in kilos). The unit is the Gray (1 Gy = 1J/1kg), used with its multiples and submultiples. In radiation protection, special quantities and units are used, but all of them are based on this fundamental concept [3].

When the irradiated object is living matter, the molecular changes produced by these atomic interactions can interfere with some biological process. Unless a repair mechanism is possible, this interference will determine a permanent biological change, a change that will eventually manifest clinically. The physical processes of energy absorption and ionization occur in femtoseconds (10^{-15} s); the interaction of ions with molecules, in microseconds (10^{-6} s); chemical changes at the cellular level, in seconds; the biological effects, from minutes to years.

Although recent radiobiology studies have found post-radiation cellular responses that appear to lead to genomic changes and / or cellular effects from epigenetic processes, the critical structure at the cellular level remains the Deoxyribonucleic Acid (DNA) molecule. The action of radiation can be direct when the particle hits one of the components of DNA, or indirect when the interaction occurs in water and free radicals such as oxidrile and hydroxyl are formed, which migrate and interact with the DNA. The effects may consist of a single or double chain break, base changes, breakage of hydrogen bonds between the bases, etc.; the consequence is that the cell will undergo a mutation.

One of three things can happen:

a) The mutation is repaired (without errors) and the cell continues its functions as if nothing had happened.

b) The cell “dies” (in radiobiology cell death means permanent loss of clonogenic capacity) due to apoptosis, necrosis, or senescence.

c) The cell survives mutated, that is, there are “repairs” with errors [3]. This is the cause of mutations caused by exposure to ionizing radiation.

The above refers to ionizing radiation, that is, radiation whose frequency exceeds 10^{16} Hz. It is of vital importance (and the main objective of this work) to mention that frequencies lower than those found in visible light and infrared light are, therefore, non-ionizing radiation.

Non-ionizing radiation. Although non-ionizing radiation does not cause the aforementioned adverse effects, there are regulations (for each country internally and internationally) that determine maximum permitted levels of power with the aim of avoiding or minimizing possible damages caused by said radiation. Specific studies have been carried out to determine the possible damage to health caused by radio waves used for telecommunications.

The non-ionizing electromagnetic frequency spectrum is usually subdivided into low frequency from 0 to 3 kHz (US) or 10 kHz (EU), and high frequency or radiofrequency from 3 kHz – 300 GHz (US) or 10 kHz – 300 GHz (EU). In the low frequency range, research results show an increase in probabilistic effects. In the high frequency range upper than microwaves, the number of well documented probabilistic effects is poor.

The levels in the guidelines are conservative and should be reduced with a health factor. For high frequency, many countries have already applied a health factor. However, for low frequency where there is a weak evidence of probabilistic effects, no health factor has yet been implemented in regulations and laws [4].

Exposures to Microwaves (MW, 300 MHz-300 GHz) vary in many parameters: incident Power Density (PD), Specific Absorption Rate (SAR), frequency/wavelength, polarization (linear, ellipsoidal, circular, unpolarized), Continuous Wave (CW) and pulsed fields, modulation (amplitude, frequency, phase), far field/near field, Static Magnetic Field (SMF) and stray Electromagnetic Fields (EMF) of Extremely Low Frequency (ELF, 3-300 Hz) at the location of exposure, overall duration and intermittence of exposure (interrupted, continuous), short-term acute and prolonged chronic exposures. With increased SAR, so-called thermal effects of MW are usually observed that result in significant MW-induced heating. SAR is the determinant main factor of thermal MW effects. The SAR based safety limits intends the protection from the thermal MW effects and damaging absorption, which depends of polarization, frequency, age, sex, and pregnancy status. In addition, the mobile phone SAR values are usually obtained when the phone is positioned about 2 cm from the head, a condition, which is not usually maintained during mobile phone calls. Other aforementioned physical variables of MW exposure have been linked to occurrence of so-called Non-Thermal (NT) biological effects, which are induced by MW at intensities well below measurable heating. The classification of MW effects into thermal and non-thermal is not based on physics of interaction between MW and biological tissues, but rather reflects experimental observation of heating induced by MW exposure, which at SAR levels higher than 2 W/kg may result in thermal injury. Slight temperature increase is also observed in the head tissues during exposure to mobile handset radiation, but this increment is too weak to produce thermal injury and even to be sensed by the exposed subjects while some mobile phone users reported sensation of warmth around the ear.

Some authors have reported pioneering data on the NT effects of Millimeter Waves (MMW, 30-300 GHz, wavelength 1-10 mm in vacuum, to be used in 5G mobile communication) upon exposure of various biological objects. Webb was the first to establish the highly resonant effects of ultra-weak MMW on the induction of λ-phage in lysogenic bacterial E. coli cells. These findings were subsequently corroborated by independent research groups. In these and subsequent studies, the observed spectra of MMW action were found to have the following regularities:

(1) Strong dependence on frequency (frequency windows of resonance type),

(2) Specific PD threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude (so-called sigmoid or S-shaped dependence).

(3) Occurrence of MMW effects depended on the duration of exposure, a certain minimum duration of exposure was necessary for an effect to manifest itself.

These important regularities of NT MMW effects have previously been confirmed by independent laboratories.

Since that time, multiple studies performed by diverse research groups over the world have provided strong evidence for the NT MW effects and have also indicated that there are several consistent regularities in occurrence of these effects:

(i) Dependence on frequency of “resonance-type” associated with relatively narrow frequency windows.

(ii) Dependence on modulation, pulse modulated MW being usually more effective as CW MW.

(iii) Dependence on polarization, right -or left- circular polarization being more defective then opposite circular and linear polarization specifically for each resonance.

(iv) Power windows and sigmoid dependence on PD within specific intensity windows including super-low PD comparable to intensities from base stations.

(v) Thresholds duration of the exposure (coherence time).

(vi) Dependence on post-exposure time, intermittence and duration of exposure resulting in interplay between accumulated effect and adaptation to exposure.

(vii) Dependence on cell density suggesting electromagnetic cell-to-cell interaction during exposure.

(viii) Dependence on several physiological conditions during exposure, such as concentration of divalent ions, oxygen and radical scavengers, stage of cell growth.

(ix) Dependence on genotype.

Cell type, sex, age, individual differences, SMF and stray ELF EMF during exposure can be important for the NT MW effects. The data showing dependence of MW effects on extremely low frequency and static magnetic fields at the location of exposure, suggested as a strategy for reducing health effects from MW of mobile communications [5].

III. MOBILE PHONE GENERATIONS AND USED FREQUENCIES

So, given the growing concern about the damage that new wireless communication technologies could produce in the organism, the question continues: are current wireless communications dangerous or not?

The technological advances in the field of wireless communications are the result of a growing demand not only for the number of devices that are simultaneously available to users, but also for the increasingly diverse services that these devices are capable of providing. The first mobile phones used the frequency bands of the available radio transmissions, so there were no frequencies for their own use, nor the technology to develop networks for exclusive use. Later, other frequency bands were available; the available technologies known as "generations" of mobile telephone networks have been distinguished by the uses and the services that these networks are capable of providing to users.

The aforementioned generations are known as 1G, 2G, 2.5G, 3G and 4G. 4G, currently in use, has its own update, 4.5G, and tends towards 5G.

The migration from each generation to the next has been mainly conditioned to the type of access scheme used and the services that the new generation is capable of providing. These services determine the need to have higher frequencies each time.

As networks evolved, it was necessary to have ever increasing frequencies due to the nature of the content; from voice in real time it evolved to point-to-point text, then to the transfer of image, audio and video files, and currently to the transmission of them in real time (streaming), instant messaging, traffic information for GPS applications, or community video games, to name a few examples. All of this would be impossible if only the 1G frequency bands were used; in addition, frequency modulation was used for those transmissions, which would greatly limit the incorporation of the mentioned content. Then, from the evolution of services and devices, the need arises to use higher frequencies, for which it is essential to assess the risks to health and physical integrity that this implies, not just for people, but in general to alive organisms.

Some signals from Global System for Mobile Communication (GSM) 2G, and Universal Mobile Telecommunications System (UMTS) 3G mobile phones were tested in referred research [5]. Contrary to GSM phones, mobile phones of the 3rd generation irradiate wide-band signal. UMTS MWs may result in higher biological effects due to the presence of selective resonance frequency windows.

Most current discussion regarding MW health effects is focused on the 5G mobile communication, which is promptly enrolled in different countries and uses frequency ranges similar to 2G/3G/4G plus MMW. It follows from available studies that MW, under specific conditions of exposure at ultra-weak intensities below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies, modulations, and polarizations.

While MMW are almost completely absorbed within 1-2 mm in biologically equivalent tissues, it may penetrate much deeper in live human body. Biological objects including human being are not in thermodynamical equilibrium. Thus, except for considering penetration of 5G/MMW into biologically equivalent tissues being in thermodynamical equilibrium, the response of live human body should also be considered. Alive body represents a complicated system with fundamental frequencies; many of them lie in the MMW range. In particular, the acupuncture system (meridians of organs) has been considered as a waveguide system for these MMW fundamental modes in the Soviet/Russian literature.

From this point of view, MW penetrates human body far deeply as compared to "dead" models. Electromagnetic origin of Chinese meridians has been studied in several Soviet research teams. For example, Sit'ko et al. described the frequency of 56.46 GHz, which was found during an ordinary search for therapeutic frequencies based on sensorial reactions of a patient with duodenal ulcer. Negative sensation (defined as spastic contraction of musculus quadriceps femoris) was repeatedly observed under applying MMW at this frequency. This sensory reaction allowed tracking the Chinese stomach meridian by using a static magnet at 4 mT. Exposure at the frequency of 56.46 GHz has worsened health condition of the patient. Thus, this exposure was aborted, and the patient received treatment at the resonance therapeutic frequency found by typical positive sensations. After successful healing the duodenal ulcer at the MMW resonance therapeutic frequency, the negative response of the patient to the frequency of 56.46 GHz disappeared.

When a very fast RF pulse enters in a human body, it generates a burst of energy (a Brillouin precursor) that can travel much deeper than predicted by the conventional models. Brillouin precursors can be formed by high-speed data signals as used in 5G.

To what extent the 5G technology and the Internet of Things will affect the human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis and almost complete absence of MMW in atmosphere due to effective absorption (which suggests the lack of adaptation to this type of radiation), the health effects of chronic MMW exposures may be more significant than for any other frequency range. From the health perspectives, implementation of the 5G technology is premature. Extended research with chronic exposure of human cells, animals and man is needed to exclude the potentially harmful of 5G signals [5].

IV. 5G TECHNOLOGY

So, about 5G and its technological requirements, a large amount of new and harmonized spectrum is needed for mobile services, which is essential to ensure that 5G services can meet expectations and develop its full potential. 5G technology needs spectrum in three key frequency bands to provide greater coverage and include all use cases. The three bands are below 1 GHz, from 1 to 6 GHz, and above 6 GHz.

a) Below 1 GHz: This spectrum will be used to provide broad coverage in urban, suburban, rural areas and contribute to the support of Internet of Things services.

b) 1 to 6 GHz: This spectrum offers a good combination of coverage and capacity benefit, and includes the range between 3.3 and 3.8 GHz, which is expected to be used to develop the first 5G services.

c) Above 6 GHz: This spectrum is required for ultra-fast broadband speeds contemplated for 5G. The focus will be on the bands above 24 GHz, including the 24 GHz and / or 28 GHz bands, which have sparked growing interest and can be easily implemented on the same device, due to their proximity. Furthermore, there is some interest in exploring the bands found in the frequencies from 6 to 24 GHz [6].

According to [7], exposure of humans to MMW can occur through 5G devices with frequencies above 6 GHz, and may be primarily on the skin and, to a lesser extent, on the eyes. This is due to the very low penetration depth of this

MMW. Therefore, it is important to investigate whether there are any health-related effects on the skin and/or effects associated with the skin. These include acute skin damage from tissue heating (burns), but possibly also less acute effects (such as inflammation, tumor development, etc.). Such effects could appear after prolonged and repeated heating of superficial structures (the skin). This would mean that there are thermal effects that are not due to acute but chronic damage. It may also be that local exposure causes energy deposition in the dermis of the skin, which may be so great as to affect nerve endings and peripheral blood vessels through warming mechanisms. That study typically used exposures around 60 GHz at a power density of 10 mW/cm^2 on the skin in the sternum area to produce systemic effects. The aim was to treat certain diseases and complaints. The idea was that the treatment induces the release of the body's own opioids and additionally stimulates the peripheral nerves. The stimulation would depend on a local thermal effect, which, due to the frequencies, induces locally high SAR values, even at low power densities, thus warming the tissue.

Due to the contradictory information from various lines of evidence that cannot be scientifically explained and given the large gaps in knowledge regarding the health impact of MMW in the 6–100 GHz frequency range at relevant power densities for 5G, research is needed at many levels. It is important to define exact frequency ranges and power densities for possible research projects. There is an urgent need for research in the areas of dosimetry, in vivo dose-response studies, and the question of non-thermal effects. It is therefore recommended that the following knowledge gaps should be closed by appropriate research:

- Exact dosimetry with consideration of the skin for relevant frequency ranges, including the consideration of short intense pulses (bursts).
- Studies on inflammatory reactions starting from the skin and the associated tissues.
- In vivo studies on the influence of a possible tissue temperature increase (e.g., nude mouse or hairless mouse model).
- In vivo dose-response studies of heat development.
- Use of in vitro models (3D models) of the skin for molecular and cellular endpoints.
- Clarification of the question about non-thermal effects (in vitro).

An unrealistic scenario, however, is that MMW exposures at realistic power densities could cause systemic body warming in humans. Any local heat exposure would be dissipated by the body's normal heat regulation system. This is mainly due to convection caused by blood flow adjacent to the superficial skin areas where the actual exposure takes place. In summary, it should be noted that there are knowledge gaps with respect to local heat developments on small living surfaces, e.g., on the skin or on the eye, which can lead to specific health effects. In addition, the question of any possibility of non-thermal effects needs to be answered.

Since the ranges up to 30 GHz and over 90 GHz are sparingly represented, the authors in [7] mainly cover studies done in the frequency range from 30.1 to 65 GHz. Also, the majority of studies with MMW exposures show biological responses. From this observation, however, no in-depth conclusions can be drawn regarding the biological and health effects of MMW exposures in the 6–100 GHz frequency range. The studies are very different and the total number of studies is surprisingly low. The reactions occur both in vivo and in vitro and affect all biological endpoints studied.

There does not seem to be a consistent relationship between intensity (power density), exposure time, or frequency, and the effects of exposure. On the contrary, and strikingly, higher power densities do not cause more frequent responses, since the percentage of responses in most frequency groups is already at 70%. Some authors refer to their study results as having "non-thermal" causes, but few have applied appropriate temperature controls. The question therefore remains whether warming is the main cause of any observed MMW effects?

In order to evaluate and summarize the 6–100 GHz data in this review, in [7] the following conclusions was reached:

a) Regarding the health effects of MMW in the 6–100 GHz frequency range at power densities not exceeding the exposure guidelines the studies provide no clear evidence, due to contradictory information from the in vivo and in vitro investigations.

b) Regarding the possibility of "non-thermal" effects, the available studies provide no clear explanation of any mode of action of observed effects.

c) Regarding the quality of the presented studies, too few studies fulfill the minimal quality criteria to allow any further conclusions [7].

In [8], authors have investigated the effects of 5G radiations for different frequency candidates on human brain. This has been achieved by using Computer Simulation Technology (CST) software by conducting simulations on a Specific Anthropomorphic Mannequin (SAM), shown in Figure 2. A SAM is a model designed according to different international standards representing the average material properties of the head by calculating the SAR, in order to check whether the resulting exposure is safe or not by comparing it to the safety limit of exposure to high frequency radiations set by different international standards.

The most affected areas are the ones proximate to the antenna. It can be concluded that the SAR for first and second candidate are above the safety exposure limit set by the Federal Communications Commission (FCC) of 1.6 W/kg for 1g averaging mass since the results obtained had SAR values of 2.501 and 2.702 W/kg at 29 and 33 GHz respectively. However, the results of SAR obtained for 10g averaging mass are considered below the safety exposure limit according to ANSI/IEEE standards since the safety exposure limit of such standards is 2.0 W/kg for 10g averaging mass while the results obtained were 0.6291 and 0.45045 at 29 and 33 GHz respectively. 87/5000. Moreover, the impact was negligible in areas not surrounding the mobile device.

Figure 2. Specific Anthropomorphic Mannequin, SAM [8].

More studies should be done in order to determine the SAR values for the other candidates and to study the impact of such waves on the human's head while taking into consideration more parameters in order to obtain accurate and reliable results [8].

In [9], energy absorption mechanisms and near-field body-antenna interactions were studied at frequencies of relevance for 5G. While at the lower frequencies (e.g. 2 GHz) and for short separation distances, the energy deposition is dominated by the coupling of the reactive near-field, at 24 GHz and above this factor is small and it becomes negligible for device to body separation distances larger than 1 cm.

For the investigated frequency range, the largest increased power absorption, compared with the zero-order interaction, was found for an exposure scenario with significant multiple reflections between the antenna and the body surface: part of the reflected energy at the skin interface interacts with the antenna and is scattered back towards the body. The presence and relevance of this phenomenon is dependent by the antenna design, the separation distance and operating frequency. This effect is expected to be visible only for electrically large antennas and it decreases with increased separation distance and frequency. Despite the multiple reflections, the spatial energy distribution (the topography) was found to be well characterized by the free-space incident field.

The effect of multiple reflections, when present, contributes to a change in the input impedance of the antenna. For an antenna designed for free space conditions, the induced mismatch contributes to a lowering of the output power compared with the free-space condition which, in part, mitigate the effect of enhanced power absorption.

At or around the millimeter wave range, the electromagnetic fields from the antenna in free space can be used to characterize the energy absorption in the skin also for devices intended to be used in close proximity of the body. In addition, since the contribution from coupling of the reactive near-field is small, free-space power density seems a reasonable quantity to characterize exposure in the 'higher' frequency range of interest for mobile communications (24 GHz to 100 GHz). Overall, in relation to the wide safety margins typically included in the exposure limits, the effects of near-field body interactions are negligible when evaluating compliance at the mmW [9].

Now, according to [10], to provide context for understanding how the strength of wireless signals from a 5G small cell transmitter diminishes with distance, they calculated typical exposures from 60-watt ERP 5G source at 39 GHz mounted on a pole 25 feet above ground. The example described here is one application of a 5G wireless technology; other applications may differ in the details. The exposures in Figure 3 are expressed as a percent of the FCC's maximum permissible exposure limit on power density of exposures of the general public (1 mW/cm^2), applied to the range of frequencies between 1.5 and 100 GHz. This is a convenient way to compare exposures from RF sources operating at different frequencies and exposure limits.

Figure 3 illustrates the signal strength from an example 5G small cell antenna mounted on a telephone pole (transmitting at 39 GHz). In addition, the signal strengths shows that exposures to RF from the small cell antenna are very low and diminish quickly with distance. RF signals from the small cell antenna measured inside buildings would be even lower. The calculated exposure in Fig. 3 at 50 feet is 0.7% of the FCC's standard directly in the main beam of the antenna, assuming all transmitted power is focused in a single direction; exposures outside the main beam of the antenna are lower. Small cell antennas are mounted far above the ground; therefore, exposure is in what is termed the far field. At farther distances, the exposure is progressively lower, becoming less than 0.1% at 150 feet and vanishingly small at 500 feet.

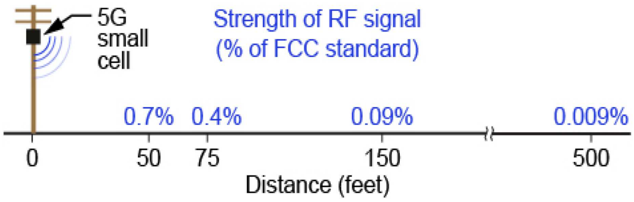

Figure 3. 5G signals from a pole-mounted small cell antenna as a function of distance [10].

Another way to compare the RF exposure of common devices or sources is to rank them by relative intensity. Figure 4 shows the contribution of eight common sources of RF exposure expressed as a percent of the FCC limit. Figure 4 illustrates that the RF signal at a middle distance from 5G small cell antenna is roughly 5 times lower than a cordless phone and 20 times lower than a cell phone, both of which are typically used close to the body, but is higher than some other common sources of RF. These values represent typical exposure levels. If a person was to use a cell phone near a 5G small cell antenna, then the cell phone may only need to transmit at a low power level to communicate over the shorter distance, and RF exposure from the cellphone could be lower. It may be surprising to some that the human body and the earth itself are sources of exposure throughout the RF frequency range, including at 5G frequencies.

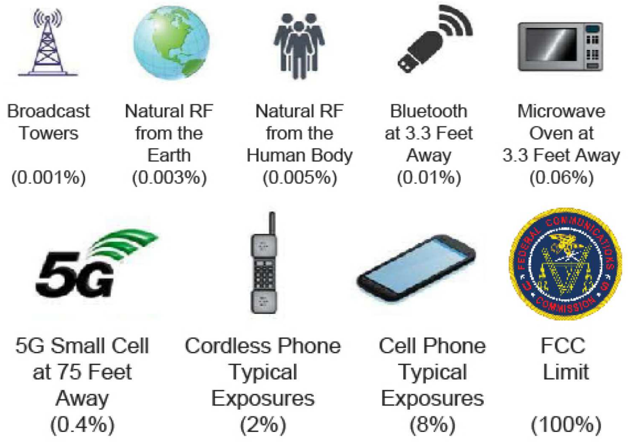

Figure 4. Ranking of common examples of RF sources by percent of FCC limit from lowest (left) to highest (right) [10].

To date, the only confirmed biological difference between exposures to RF frequencies less than 6 GHz and RF frequencies above 6 GHz is that at the higher frequencies the body’s electrical properties better limit energy deposition to a shallow depth, largely confined to the skin. Thus, at frequencies above 6 GHz the hazard to be avoided is painful heating of the skin.

Fixed small cell wireless communication installations—such as small cell antennas—that operate in compliance with the regulations of the FCC will produce RF exposures well within the recommended exposure limits of the FCC, ICNIRP, and IEEE. Research to date does not provide a reliable scientific basis to conclude that the operation of these facilities will cause or contribute to adverse health effects in the population. Research on RF will continue, as often occurs with new technologies, but not because public health authorities have established that the use of RF communication technologies today causes adverse health effects [10].

On the other hand, based on the discussions carried out in [11], there are clearly some open questions regarding exposure levels and assessment in 5G and future wireless devices:

- Multiple antennas technology is one of the key enablers of 5G for achieving high data rates, but it will increase the exposure in near field. For instance, what would be the number of antennas that can be placed on a user device while maintaining a safe exposure level? In addition, the way in which the position of the hand(s) on a multi-antennas wireless device affects the SAR, needs to be evaluated.
- In the first stage of 5G implementation, 5G networks will operate in parallel with current mobile systems, with an unavoidable global increase in the exposure level that needs to be measured.
- The number of smart IoT devices, in the close proximity of people, is likely to increase exponentially in the future and the impact of these devices on exposure needs to be assessed.
- The deployment of small cells helps to reduce the levels of transmit power, but what about dense or very dense deployment of small cells? Will it increase the overall aggregated power as compared to a macro cell and create more EMF exposure? This should be properly explored.
- The current safety rules regarding RF exposure do not specify limits above 100 GHz whereas spectrum use will inevitably move to these bands over time. Hence, there is a need for further investigating the effects of exposure at these frequencies and, then, defining new safety limits.

A comprehensive survey on the assessment, evaluation, limitation, and mitigation of exposure risk for current and future wireless devices and equipment is provided in [11]. From a human health point of view, it appears that the possibility of a brain tumor has been the main cause for concern related to the extensive use of wireless devices, although the effects of EMF exposure in new parts of the body are now being investigated (for example, eyes). Meanwhile, with the advent of 5G, more efforts have been made to understand the thermal and non-thermal effects of mmWave exposure on the human body. Regarding EMF exposure assessment, the most common metrics and assessment frameworks used in wireless communications to measure exposure were presented. It was also explained how new and more generic metrics have been defined by combining existing metrics to better reflect the exposure of large geographic areas and it was argued that a generic metric to measure individual exposure would also be of interest. Existing exposure guidelines were also reviewed and explained how they can be updated to better reflect the true nature of EMF exposure, i.e. better considering the duration of exposure. Finally, some insights were provided on how key 5G enabling technologies such as densification, massive MIMO, and mmWave, will affect EMF exposure in the near future; for example, the dense deployment of small cells and IoT devices is very likely to increase overall environmental exposure. There could be some technical opportunities in 5G to raise awareness of wireless users' exposure and allow them to decide if they want to reduce it at the cost of, for example, lower Quality of Service (QoS) [11].

V. CONCLUSIONS AND FUTURE WORKS

The laws to establish regulations about the maximum limits allowed for 5G technology depend on the local regulations of each country; however (and although the effects of non-ionizing electromagnetic waves on living organisms are known), the large number of variables and factors that intervene in the process makes it very difficult and premature to know what will happen when 5G technology is implemented. The truth is that, due to the working frequencies that are considered for the entire network, it is possible to estimate that the risk is relatively low. Currently, 2.4 GHz frequency is used for most digital communications, so the frequency ranges are far from the frequency values considered highly dangerous. Although the transceiver antennas are not entirely innocuous, their distance from the users makes them safe, while security measures must be strictly monitored for mobile devices, since they are used personally.

The present work is a compilation of some research reports carried out by different authors and institutions; although different procedures were carried out for their respective contributions, and these contributions provide valuable information on the subject, all authors agree on at least two conclusions:

- Health risks from exposure to radiation from electromagnetic waves of 5G technology are directly related to the distance to the transmitting stations, since the intensity of the signals emitted is inversely proportional to said distance, in addition to depending on the environment and transmission conditions, so each case is particular.
- It is necessary to carry out more exhaustive investigations, which will be achieved over time; to date, 5G technology has not yet been implemented in commercial services, and the real risks can be measured effectively to the extent that there is more infrastructure for this new generation.

Future work will consist of monitoring and making a permanent observation and measurement in specific situations; however, the experience that we have concerning electromagnetic waves and previously existing networks means a base from which it has been possible to start.

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Power Electronic Converters Review for Wind Turbine Applications: State of Art, Reliability and Trends

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***Abstract*--Wind energy has recently became the most promising renewable energy. The global cumulative installed wind power capacity increased dramatically to reach 627GW in 2019. In order to handle the growing size and more stringent grid codes, researchers have developed and improved many converters topologies. Some of these converters are commercialized while others are still in development. This paper presents the state-of-the-art of the power converters usable in wind turbine applications, an overview of the most interesting converters topologies and their efficiency in Wind Turbine Systems (WTS). As reliability became essential in WTS, especially in offshore turbines, a detailed study on the reliability of the static converters used in WTS with a comparison analyse of the most reliable configurations and their fault tolerant ability. The study shows the importance of the choice of the power converter topology in the overall reliability of WTS.**

Keywords- Power Electronic Converters; Wind turbine; reliability; trends.

I. INTRODUCTION

Unlike the fossil fuel energy, with renewable energies, it is possible to produce electricity without harming the environment. In the last decade, with global awareness of climate warming, electricity production from the energy renewable has come under increasing attention. In 2019, the power production from renewables energies has reached 2530GW, it is about a third of total installed electricity capacity. Wind power is the second most renewable energies installed in the word with 627GW which represents 21% of global energy renewable electricity production [1].

The used technology in wind turbine applications has changed since the power capacity penetration has grown dramatically to reach, for example, 14% of all electric energy consumption in Europe and 41% of all electric energy consumption in Denmark [2]. The first configuration used in wind turbine applications was a fixed-speed Squirrel-Cage induction Generator (SCIGs) directly connected to the grid.

Recently, as the power capacity of the wind turbines increases, regulating the frequency and the voltage in the grid becomes a very important issue, the technology has developed toward variable speed. Permanent Magnet Synchronous Generator (PMSG) connected to the grid through a power converter shows nice properties like high efficiency, small size, and low maintenance; hence, it is a nice choice for wind turbine applications.

The purpose of this paper is to give an overview of recent converters technologies used in WTS. On other hand, as reliability is a major challenge in WTS, a comparative study about reliability of those converters is presented.

In section II, an overview of existing technology market developments of wind power generation. In section III, the most used wind turbine configurations and currents promising power converters topologies for WTS are presented. In section IV, the reliability of WTS components is analyzed. In section V, as they constitute one of major source of failure, a study about reliability of power converters used in WTS is presented. Finally, the conclusions are presented in section VI.

II. WIND TURBINE SYSTEMS

The wind power installed capacity is growing significantly since 1999 to reach 58 GW installed only in 2019. Therefore, the cumulative installed wind power capacity increased exponentially from 6100 MW in 1996 to 627 GW in 2019. Estimation predicts that this number would reach 2015 GW in 2030. Approximately 10 countries have more than 83% of all cumulative installed wind power capacity in the world, including 5 countries in Europe (Germany, Spain, UK, France, Italy), 2 in the Asia-Pacific (China, India), 2 in North America (US, Canada) and 1 in Latin America (Brazil), [1]. This dominance is shown in Figure 1 and it's obvious that countries with high technology advancements have a higher growth rate and higher penetration of wind power electricity. The large turbine presents a lot of advantages. They allow capturing a high power with low installation and maintenance costs compared to the small turbines. Hence, the size of the commercial wind turbine has greatly increased in the last decade as presented in Figure 2. The largest wind turbine reported in 2020 is 12MW with a diameter of 220 m (General Electric Haliade-X 12MW), and it is will be commissioned in 2021.

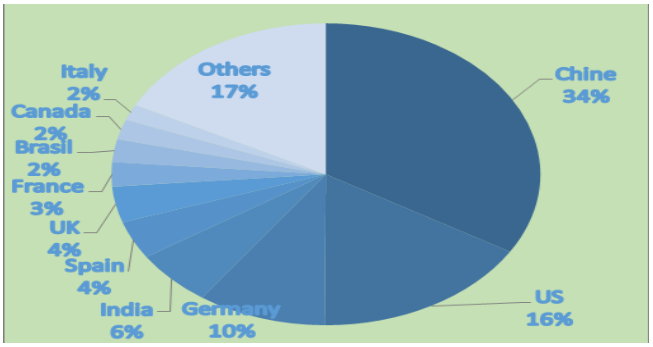

Figure 1. Renewable wind energy capacity in the word [1].

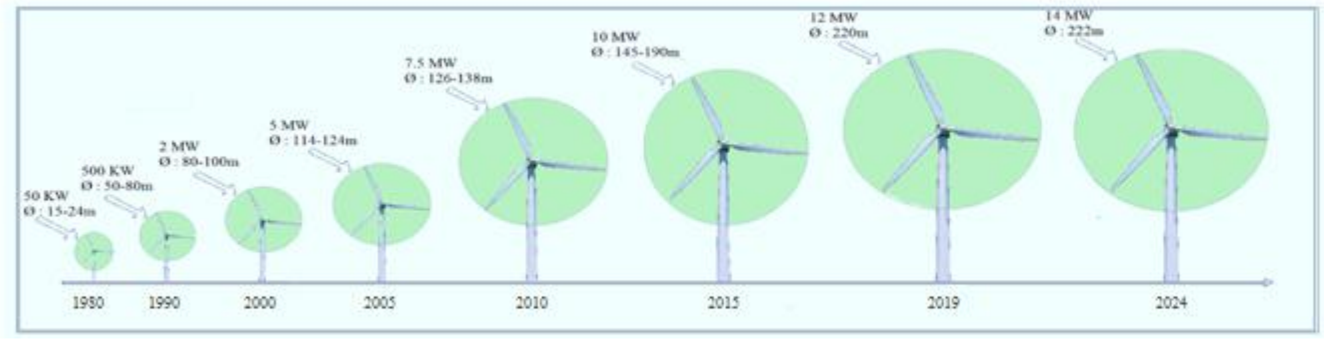

Figure 2. Evoluion of wind turbine size since 1980 .

Siemens Gamesa has announced that they are developing 14 MW wind turbine with a rotor diameter of 222 m. It announced that the turbine will be available in 2024 [3]. Denmark based wind turbine company Vestas remained the world’s largest wind turbine manufacturer and supplier in 2018 [4], due to its wide geographic diversification strategy and strong performance in the U.S. market.

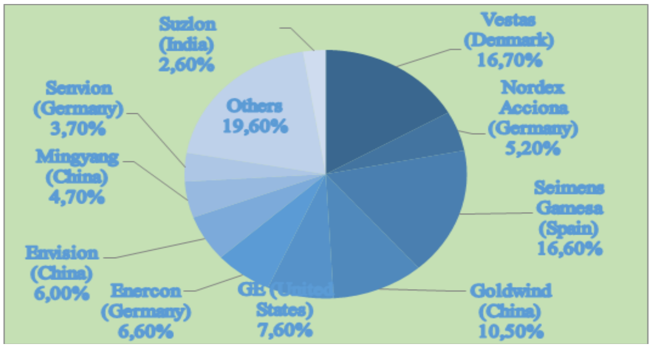

Figure 3. Top 10 Wind turbine suppliers market share in 2018 [4].

The top 10 wind turbine manufacturers in the world are shown in Figure 3. The world’s largest wind turbine companies account for over 75% of the global installed capacity every year, and their industrial dominance is expected to continue over the future.

III. WIND TURBINE CONCEPTS AND CONVERTERS TOPOLOGIES

Depending on the types of generator, power converters and speed control, most wind turbine can be classified into following four types:

- Type 1: Fixed-speed wind turbine systems;
- Type 2: Semi-variable speed wind turbine with variable rotor resistance;
- Type 3: Variable speed wind turbine with partial-scale converter;
- Type 4: Variable speed wind turbine with a full-scale converter.

All those wind turbine technologies have been used and commercialized in the last 30 years. Due to their efficiency the two last configurations are the most dominant technologies in the market. The power converters is one of the most important components of Wind Turbine System (WTS). The main objective of the power converters is to ensure the generator speed variation control in the turbine system. To accomplish this purpose, different topologies of converter have been proposed in the literature in the last decades. Recently, with the growing wind turbine penetration, these converters have to fulfil several technical requirements. The converter cost is an important factor, since it represents approximately 7%~8% of the global cost of the wind turbine system [8][9]. The cost of maintenance must also be as low as possible to reach less expensive and competitive energy compared with the others sources of energy, reliability is also an important element in the choice of the converters. The efficiency of the converters is also very important, especially in high power wind turbines where even, 1% efficiency improvement can save thousands of dollars over a period of a few years [19]. The output power quality of the converters is a primordial in the comparison between the different topologies. The output voltage should be as close as possible to the sinusoidal shape with low total harmonic distortion (THD) and small filter for a better converter [12][17]. The power converters can be classified as direct and indirect according to the different stages of the conversion. Overall, the indirect Back-to-Back (BTB) converters technology is the most used in the wind turbine applications [10].

A. Two-levels Voltage Source Converter (*2L-VSC*)

The two-levels voltage source converters are the most widely used converters on the market. For its simple, configuration this technology is mastered and well established in the field of wind energy conversion. It is considered a dominant topology used in around 90% of the wind turbines with power less than 0.75 MW. As illustrated in Figure 4, the Voltage Source Rectifier (VSR) and the Voltage Source Inverter (VSI) are back-to-back and are connected to a dc-link capacitor. This dc-link ensures the decoupling between the generator and the grid, therefore transient in the generator do not appear on the grid side. The VSR controls the torque and speed of the generator, while the VSI controls the voltage of the dc-link and the reactive power of the grid.

The VSR and the VSI are generally made with low-voltage transistors (LV-IGBT) arranged in a matrix. The switching frequency of VSR and VSI are fixed between 1 and 3 kHz to achieve low witching loss and high power density [5].

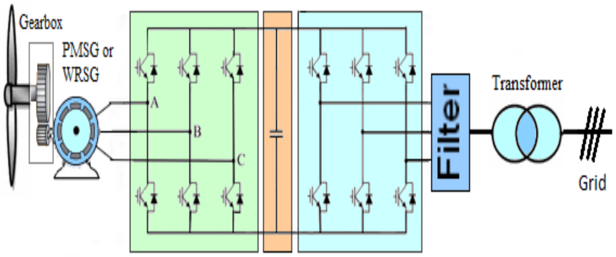

Figure 4. BTB based on the two-levels voltage source converter.

B. *Parallel two-levels Voltage Source Converter (2L-VSC)*

To achieve high current capacity, two or more VSC converters can be connected in parallel depending on the power required. As illustrated in Figure 5, two VSC modules are connected in parallel to reach a power of 1.5 MW corresponding to type 4 of the wind turbines. For type 3 of the wind turbines, connecting two modules in parallel can achieve a power of 5 MW. This configuration allows a wide margin for redundancy operation. To improve the system efficiency in the case of under production one or more converter modules can be put out of service. The redundancy of the converters allows to the wind turbine to continue operating at reduced capacity in the case of a fault in the converters, after the faulty module is isolated. In the Gamesa G128, more than 6 power converters are connected in parallel to reach a nominal power of 4.5 MW [11]. However, the major disadvantage is that a large number of modules lead to the complexity control and congestion of the system.

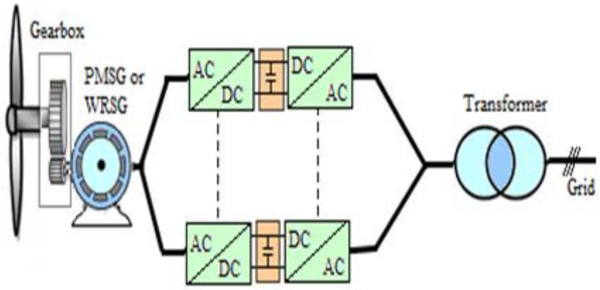

Figure 5. WTS with parallel connected BTB Two-levels VSCs

C. *Three-levels Neutral-Point Clamped Converter (3L-NPC)*

Another solution that has been widely studied in the literature for type 4 of the wind turbines is the three-levels Neutral Point Clamped converter (NPC). In this configuration, an arrangement of four power switches per leg, clamped with diodes to a midpoint of the dc-link. With this configuration, each power device has to block only half of the total converter voltage then the power of the converter can be doubled [13]. The output phase voltage of the converter contains three-levels leading to a reduced voltage variations dv/dt and electromagnetic interference compared to the 2L-VSC converters [12][13][16][20]. The main drawback of 3L-NPC is that the power switches do not have symmetric losses, forcing a derating of the devices. As shown in Figure 6, NPC converters enable medium voltage operation, and commercial wind turbines reached 6 MW rated power without connecting serial or parallel switching devices. These converters are installed and marketed with the "Multibrid M5000" wind turbine [6][22].

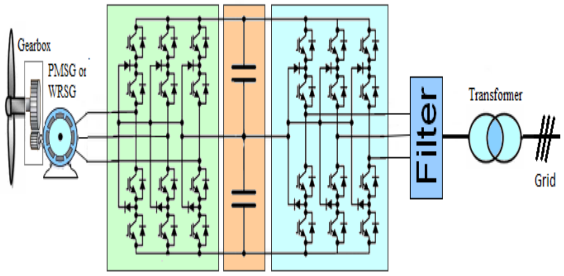

Figure 6. Three-levels Neutral-Point Clamped Converter (3L-NPC) .

D. *Three-levels Active Neutral-Point Clamped Converter (3L-ANPC)*

The Active Neutral Point Clamp (ANPC) converters, illustrated in figure 7, have a structure almost identical to the NPC converters, the diodes are replaced by Insulated Gate Bipolar Transistor (IGBT) switches. Although more active switches are used, that allowing more redundancy to maintain the frequency and the same switching losses in all the IGBT switches, [6][12][23][24]. In similar operations, BTB 3L-ANPC converters are capable of handling 32% higher power (up to 7.12 MW) and 57% higher switching frequency (1650 Hz) compared to 3L-NPC BTB converters. This configuration has been applied more recently in the field of MV drives and can also be used in the wind turbine system sector [18]. Vestas, one of the leading manufacturers, is currently studying this power converter topology, [19].

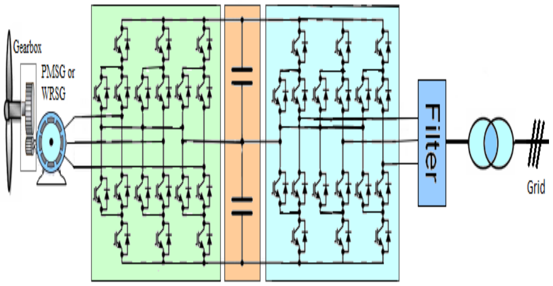

Figure 7. Three-levels Active Neutral-Point Clamped Converter (3L-ANPC).

E. *Three-levels Flying Capacitor Converter (3L-FC)*

The configuration of the Flying Capacitor converter (FC) is similar to the NPC converter, where the clamping diodes are replaced by the floating capacitors. The concept of FC was introduced in the early 1970, and was introduced into machines drives applications in the 1990. The converter generates additional voltage levels while reducing voltage stress on the drive [14]. The power switches, setting an FC between two devices, is illustrated in Figure 8. Each pair of switches with an FC constitutes a power cell.

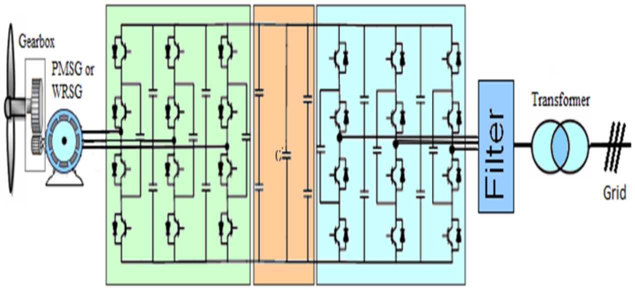

Figure 8. Three-levels Flying Capacitor Converter (3L-FC)

The most important difference with the NPC topology is that the FC has a modular structure and additional cells can be connected, increasing the number of voltage levels of the converter and the power rate.

The advantages of the flying capacitor multilevel converter are flexible switch mode, high protection ability to power devices, to control active power and reactive power conveniently [25][26]. The 3-levels configuration has found a practical application, but has not yet found a commercial success in wind turbines.

IV. WIND TURBINE SYSTEM RELIABILITY

Recently, with the orientation of wind energy manufacturers towards offshore wind turbines, the issue of the reliability of wind systems has become a major preoccupation for what it generates maintenance costs caused by accessibility limited of wind farms. This problem has been extensively studied in literature to identify a major failure in wind systems. Researchers have conducted surveys of the reliability of wind systems at various wind sites around the world to identify the most common faults in these systems [27-31]. According to a study published by the University of Kassel, Germany in 2006 [27], based on the recovery of maintenance data from a 13 years (1993-2006) on a wind power site Germany, the power converters is a leading cause of failure in wind system as shown in Figure 9. Another study [28], shows that the use of maintenance data recorded for 11 years in a field of 650 wind turbines in Germany allowed researchers to identify the main causes of failures on this site. The conclusions given in [28] show that the defects in the converters represent a large part of these defects. They are ranked in 3rd position just behind the faults in the electrical system control and the mechanical defects in the rotor.

More recently, in 2016, a study of the City University of Hong Kong on two wind farms in China [29], the researchers found different results: -The first project, which contains 61 wind turbines of 1.5 MW, with data recovered over a period of 4 years between 2009 and 2013, the result shows that electrical systems (converters) account for 14% of the failures. The control of the wind system accounts for the largest share of these defects with 35% of total defects recorded over this period. The second project contains a small number of wind turbines, 46 wind turbines, but with a power greater than that of the first project, 2 MW by a wind turbine. The analysis of maintenance data over a period of two years show that electrical systems (converters) account for 26% of failures, equal to failures rate found in the control system.

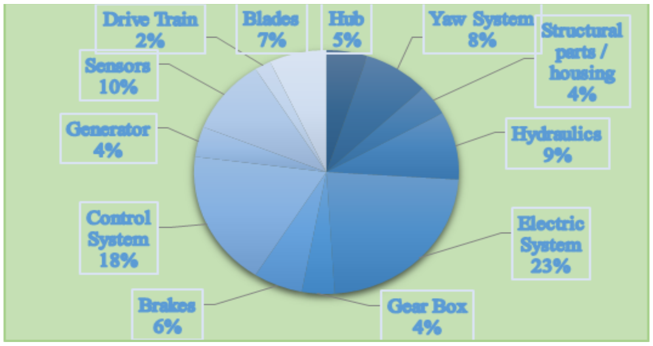

Figure 9. Share of main components of total number of failures [27].

The wind turbines designed in 2000 are generally based on fixed or semi-variable speed technology, different from the technology generally used this last decade based on the synchronous machine with variable speed. It can be noted that the zone of the installation of these fields also plays an important role in the rates of defects of the components. Another point that can be made is that the reliability of wind turbines systems depends on the reliability of the used components and experience of the manufacturers. However, despite the difference in the failure rates between the different components of the wind system, which can be found in the different studies, the defects in the converters are considered as a major element in the shut-down of the service in the almost all of these studies.

V. CONVERTERS RELIABILITY IN WIND TURBINES APPLICATIONS

In the following, a deep analysis of the different reliability studies carried out on wind turbines around the world is proposed. The purpose of this analysis is to find a link between the different systems used in wind turbines and the failure rate in power converters. This study will allow us to identify the causes of failures in power converters and to propose the solutions and topologies to be used to improve the reliability of wind turbine systems. In [28] and [30], the results of the data recovered on the wind farms, affirm that, contrary to that is widespread in the literature, the failures in the systems with direct drive permanent magnet synchronous generator (PMSG) are more significant to those with indirect drive doubly-fed induction generator (DFIG). In their conclusions, the authors ask questions about the usefulness of the systems based on PMSG generators with the number of failures recorded, while it is supposed to improve the reliability of wind turbines systems. In the same study of the

TABLE I. COMPARISON OF BTB CONVERTERS TOPOLOGIES FOR HIGH POWER WIND TURBINES [6].

	2L-VSC	**Parallel 2L-VSC**	**3L- NPC**	**3L-ANPC**	**3L-FC**
Typical Power	0.75 MW	5.0 MW	3.0-12.0 MW	3.0-12.0 MW	3.0-12.0 MW
Number of Converters	1	6	1	1	1
Number of Switches	12	72	24	36	24
Switching devices	LV-IGBT	LV-IGBT	MV-IGBT/ICGT	MV-IGBT/ICGT	MV-IGBT/ICGT
Diodes	0	0	12	0	0
Capacitors	0	0	0	0	6
Device voltage Stress	V_{dc}	V_{dc}	$V_{dc}/2$	$V_{dc}/2$	$V_{dc}/2$
Reliability of System	++	+++	+++	+++	++
Redundancy	No	Yes. Module redundancy	No	No	No
Advantages	Simple and matured technology	Redundancy	Low harmonic Matured technology	Low harmonic Equal loss distribution	Low harmonic
Disadvantages	Limited Power	Complex control	Unequal loss distribution	A large number of switches	Complex control
Technology status	Highly Mature	Highly Mature	Well established	Research Only	Research Only
Power Density	Moderate	Low	High	High	High

University of Columbia [30], the failure rates in the electrical converters used in the case of the two systems (Geared/ Direct drive) are studied and compared. The failures at the converters are greater in the case where the system is based on direct drive technology. In another study [31], maintenance data from 2220 turbines were studied to determine the failure rate in the various components of these systems. The wind turbines studied are modern types, with power ranging between 1.5 MW to 2 MW. They are divided into two groups, depending on the training configuration. The first group is made up of 1800 turbines based on the DFIG generators. The second group consists of 400 turbines equipped with the PMSG generators. It should be noted that the converters used in the two configurations belong to the same manufacturer, which will allow us to analyse and compare the failures of these converters for each configuration. The comparison between the failure rates of the power converters of the two systems illustrated in Figure10 shows that the converter in the direct drive system with PMSG generators presents annual failure rate of 0.593 which is approximately four times more than the failure rates recorded in the system based on the DFIG generators.

To answer the questions on the number of significant failures recorded in PMSG generators systems compared to systems based on the DFIG generators, asked by the authors in, [28][30].

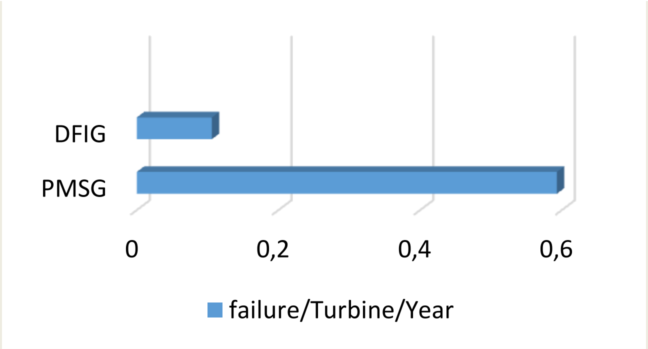

Figure 10. Annual failure rate [31].

This difference is mainly due to the increase in failures in power converters. Knowing that for the same power value of a turbine, the used converter in the PMSG systems must have a power three times higher than that of the converter used in DFIG systems, since in the latter case, the power supplied via the converter represents only part of the overall power supplied by the turbine. Since the maximum power of a two-levels converter does not exceed 750 kW, to increase the powers in PMSG systems, manufacturers tend to put in parallel several two-levels converters as presented in Figure 5, which generates the increase of the number of switches and proportionally the number of failures in the system. Figure 11 illustrates a comparison between the failures of converters recorded in two studies [30][31] with turbines of different powers. It is noted that the increase in the power of the turbine generates the increase in the difference between failure rates between the DFIG systems and the PMSG systems, due to the paralleling of two-levels converters to achieve the desired power.

In the literature, the reliability of the power converters is linked only to the redundancy of the system, something which could be sufficient in the case of onshore wind turbines. Furthermore, in offshore wind turbines where for economic and production reasons, the reliability requirement is more important any source of failure must be considered.

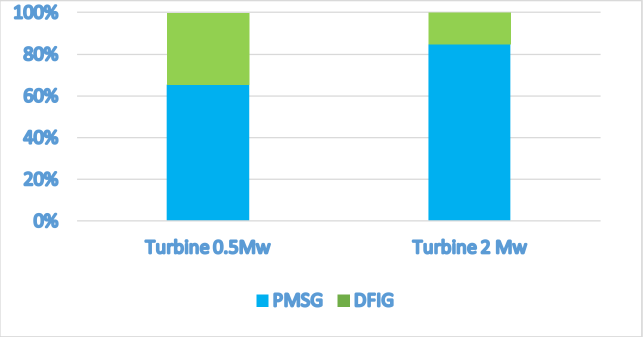

Figure 11. Converters failures rates based on the power of the turbine.

Therefore, in this study the analysis of several maintenance data from different wind farms around the world, allowed us to identify the importance and the need to take into account the number of switches used in the converters as a criterion for the reliability of energy conversation systems. Moreover, the choice of the most reliable converter topology is depending on the power of the application. In Table I, an example of reliability of converters for a 5 MW wind turbine, in this case the paralleling of 2-level converters do not offer higher reliability since the number of switches which are fragile components becomes very important and decrease the reliability of the whole system. Multilevel converters, especially modified 3-level NPC converter with redundant arm [32][33][34] can be the most suitable for this application, as they present redundancy and low number of switches.

VI. CONCLUSION

The global production capacity of wind turbines has been steadily increasing over the past ten years, and as a result the penetration rate has risen dramatically, which imposes more requirements and constraints on the design of the wind turbines systems. This paper gives a summary of the latest technologies and industrial solutions used in the field of wind turbines. The paper shows the importance of power converters in the performance and efficiency of the wind turbines systems. Several topologies of converters are studied in the literature. However, only a few topologies are used today in the real industry applications. The choice of the converters is important in the global wind turbines systems. The two-levels converters are most used but with the current trend towards systems with high power levels and high voltage levels, multilevel converters, especially three-levels NPC converters represent the most suitable system. For reliability of the power converters issues, the failures at the level of converters are proportional to the number of switches used in the energy conversion system. The majority of recent studies claim that, contrary to popular belief, failures in systems based on PMSG generators are greater than those in systems based on the DFIG generators. In our study, we explain the reasons which are mainly due to the significant increase in failures in the power converters system. However, systems based on the PMSG generators remain the most reliable for onshore wind turbines since the downtime caused by a failure at the converters is significantly lower than that caused by a failure of the gearbox.

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