Addressing the modern need for electrical skills in the maritime sector

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Synopsis

Following the global concern and IMO directives, in particular for greener shipping, ships and ports tend to become more efficient in terms of environmental friendliness, energy consumption as well as services provided. A similar path with some particular common if not identical points is met in offshore power plants. This paper aims at highlighting the needs for cultivation of branches of knowledge required in electrical areas of maritime industry, summarizing the new initiatives to substantially respond to these challenges providing ways to reinforce relevant skills and expertise of crews onboard ships but also of technical staff working in ports or to support offshore plants. Moreover, the discussion is enriched by propositions of measures and courses of actions by extending the deep electrical knowhow already cultivated within Universities but also electrical energy Authorities like the Grid Operators and via the substantial support of relevant International Organizations.

Keywords: marine electrical engineering, shore side electricity, port electrification, offshore platforms for RES, CPD courses.

1. Introduction

Marine electrical engineering issues have been recognized for long as of major importance especially due to the extensive electrification of all system onboard ships according to the All Electric Ship (AES) concept. Nowadays, that green shipping policy has become predominant based upon IMO's and EU resolutions, electrification is the ultimate key towards achieving difficult goals. Besides using electrical means to increase environmental performance of ships, an additional example being a large-scale project at international level is the implementation of shore side electricity so that ships while at berth shut down completely their engines and get electricity from shore which is, in general, produced by more environmentally friendly methods. The latest challenge emerged is related with the offshore plants used to host wind generators or even Photo-Voltaic (PV) panels in the deep sea.

Within this context a new Continuous Professional Development (CPD) course is under development by the University of Strathclyde via the cooperation of the National Technical University of Athens in order to develop and/or upgrade the required skills of the personnel engaged in all the aforementioned initiatives.

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The Institute of Marine Engineering, Science and Technology (IMarEST) has recognized the augmenting demands in the electrical related area since the 1990's and has been relatively activated. Following the great series of dedicated papers, special events and conferences (including the hosting INEC), a Special Interest Group on Marine Electrical issues has been formed and resulted in the MECSS Special Interest Group (SIG) and the homonym series of successful conferences coordinated by Kevin Daffey. Currently, this MECSS Special Interest Group (SIG) has been slightly renamed as Marine Electrical Special Interest Group (MESIG) and using the substantial background of MECSS it to be rejuvenated.

The Institute of Electrical and Electronic Engineers (IEEE) has been addressing the advancements in electrical engineering as a mission and regarding the maritime sector has been promoting the corresponding technological support via the standards, workshops and conferences of its Power and Energy Society (PES) in conjunction with the Industrial Application Society via the Marine System Coordinating Committee (MSCC). A representative result of these efforts consists in the well-known IEEE 45 and IEC/ISO/IEEE 80005 series of standards on ship electric energy systems and shore-to-ship power interfaces (between the port and the ship grids) respectively.

Taking into account that shore and ship grids are coming close to one another, with big amounts of energy transactions quite often at high voltage levels and with penetration of Renewable Energy Sources (RES) in combination with Energy Storage Systems (ESS), it becomes mandatory that a tight cooperation between the maritime industry and the Grid operators must be developed. Within this context, a synergistical scheme with Grid operators in terms of training but also in further developing technical knowledge is also sought.

This paper is to highlight the needs for cultivation of branches of knowledge required in electrically related areas of maritime industry, summarizing the new initiatives to substantially respond to these challenges providing ways to reinforce relevant skills and expertise of crew onboard ships but also of technical staff working in ports or supporting offshore plants.

2. The increased needs for marine electrical knowledge

In this section, the various marine technical areas with increased electrical interest are briefly outlined and discussed.

2.1 Improving ship performance via electrical means

Ship performance improvement has been an objective of a plethora of studies after the mandates of International Maritime Organization (IMO) aiming at green shipping, since the first decade of the new millennium. As it is well known the ship performance is measured and monitored via a number of indicators (EEDI, EEXI, CII) all of which are strongly related to the environmental footprint of each vessel (namely the CO2 produced) versus her useful work produced ie the transported cargo at a specific speed. Within this context, a variety of measures with electricity being the driving force have been tested and accredited to ameliorate the ship environmental footprint during sailing or during their berth in ports. Some of them are enumerated and described in brief next, see also Figure 1, (Soghomonian et al 2016, Souflis-Rigas et al 2021, Prousalidis et 2019, Lyridis et al 2019, Sulligoi et al 2015).

>Optimal selection of generator sets: following a good electric load analysis where the electrical needs of the ship in all operating modes is made, a successful selection of the rated power of generators as well as their optimum combination of their simultaneous operation is reflected to their fuel consumption and consequently the emissions produced. It is worth mentioning that due to high electrification of all equipment installed, it has been shown that special attention must be paid to meeting the total needs for reactive power besides those of the active power.

>Shaft Generator systems: These systems also called as Power Take Off (PTO) systems generate electricity exploiting the power of the main engine. Nowadays, that 'slow steaming" and "main engine limiting" techniques are often applied as performance improving measures, PTO's provide an additional degree of freedom towards the same target. More specifically, they can optimize the operating point of the main engine improving the fuel consumption without any increase in the vessel speed but by exploiting the rotating energy of the shaft and produce electricity instead. The electricity produced can be either injected to the ship grid or stored in batteries. Moreover, in certain cases, these systems can act as Power Take In (PTI's) by reversing the power flow and boost the main propulsion mechanism in a hybrid manner. All combinations mentioned can be exploited to improve the total ship performance. Finally, a PTI can act as an emergency propulsion system in case of severe damage of the main engine.

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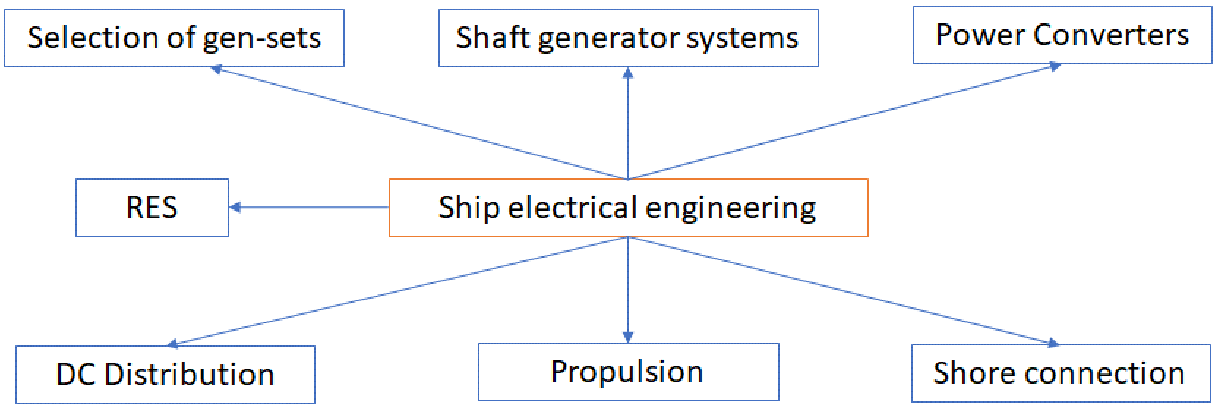

Figure 1. Major components of ship electrical engineering related to sustainable decarbonization.

> Power converters: power electronic converters can be introduced as interfaces between the main ship electric energy system and a motor driven piece of equipment in an attempt to improve the total energy consumption and consequently the ship efficiency. The key aspect the converters contribute is adjusting the no-load losses of the electric motors by regulating the applied voltage. Provided that any harmonic distortion or other power quality problems are resolved, power converters can provide numerous solutions to improve efficiency onboard.

> Renewable energy sources: several environmentally friendly energy sources generate electricity as the latter is flexible to manage, distribute, store and consume. These green energy sources provide an improvement to the efficiency of the ship they are installed adjusting the corresponding indicators. Among the most successful although of limited rated capacity are the PV's deployed in any available surfaces onboard and the waste heat recovery units either based on Organic Rankine Cycle (ORC) technology or on Thermo-Electric Generators (TEG's).

> Direct Current Distribution: the exploitation of DC offers the merit of eliminated reactive power circulation and, hence, of decreased losses in the cables and the entire distribution network, in general. Moreover, it consists a flexible Grid platform where RES's like PV's which also generate DC electric energy can be directly connected.

> Electric propulsion: the electrification of the main propulsion in combination with green electric power supply provides an almost zero-emission ship solution at least from the so called "tank-to-wake" point of view. When all equipment onboard are electric and monitored and managed by a central Energy Management System, then ship has no adverse environmental footprint while it can be controlled in a fairly optimal way ascertaining minimum losses.

> Ship to shore interconnection (cold ironing): Ships being at berth in ports shut down their main engines but not their auxiliary engines (electric generators) and, hence they still pollute the broader area via their emissions. However, if these emissions can be eliminated if they are supplied by the shore Grid via appropriate interfaces matching voltage, frequency and other operating parameters. Taking into consideration that electricity in inland grids is generated via environmentally friendly methods e.g. RES's, this option has become an imperative measure in many countries all over the world after IMO's resolutions. Based on the ship type and size, the power demands of the ships can be of significant magnitude reaching, if not exceeding, in the case of cruise ships 16 MVA. This measure is the foundation stone of the sustainable transformation of ports outlined in brief next.

2.2 Shore power and Energy transformation of ports

Ports nowadays, being the transportation hubs, are also facing significant challenges in terms of providing innovative services of superior quality as well as high financial, environmental and societal impact. To this end, all ports tend to re-establish their strategic mission according to which they are subject to a transformation into smart energy hubs where electrification, once again, plays a key-role. In particular, the smart hub assets and services of a modern port can include, (Antonopoulos et al 2014, Prousalidis et al 2019, Bosich et al 2023, Kanellos 2017, Kanellos 2018, Lyridis et al 2023, Manos 2023, Manos et al 2023), see also Figure 2.

- *Shore to Ship electric interconnection (Cold Ironing):* as described in the previous section, the foot print of ships can be improved if not completely eliminated if cold ironing facilities are deployed and exploited in ports supplying ships at berth with green electric energy.

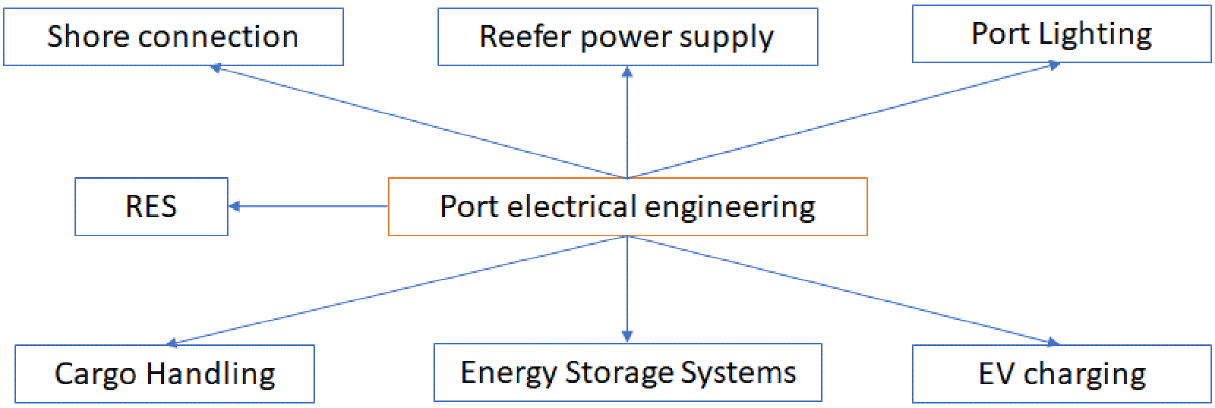

Figure 2. Major components of port electrical engineering related to sustainable decarbonization.

- *Reefer power supply*: reefers which are temporarily connected to port dedicated power supply facilities have been designed to preserve their contents having high thermal inertia, which allows for non-continuous power supply with only short duty cycles. Thus, they can be seen as a flexible load the power demand of which can be treated as a degree of freedom in the total power demands of the ports
- *Port Lighting*: currently, cutting edge LED technology provides high illumination services with smart lighting capabilities (of hot or cold like colors as well as with smart dimming and/or switching on/off depending on the activities taking place) at fairly low power demands. Moreover, fast internet connections (through Li-fi) can be attained.
- *Renewable energy sources (RES)*: Arrays of photo-voltaic cells (PV's) in possible combination with small scale wind-generators can be installed in appropriate areas (e.g. on top of buildings, in parking areas, etc) within the port jurisdiction producing green energy that can be consumed within the port or stored in batteries or injected to the main Grid at the outermost region of the port. Moreover, as wind or solar potential is usually high in port extended areas port authorities can develop offshore or nearshore wind or PV parks and integrate their operation with port electric system (Kanellos, 2017).
- *Cargo handling equipment:* such equipment mostly referring to cranes and/or pumps with integrated regenerative braking capabilities have a low mean energy demand on an average daily basis as the lifting-down movements offset to a great extent the lifting-ups. Thus, this type of equipment provides some flexibility to the energy demand provided a well designed operating scheme is followed.
- *Energy storage systems*; mainly batteries which can be used either for buffering energy from any renewable energy sources installed in the port pr during off-peak hours or (bunkering and buffering)
- *Electric vehicle charging stations*: charging stations can be deployed in available port areas (e.g. existing parking stations) so that any electric vehicles owned by the port authority (internal transportation) or by travelers can be served.

2.3 *Offshore power plants*

In the previous decades offshore power plants have been developed mainly in order to help the extrusion of oil in the middle of deep seas. Complicated but also advanced infrastructures have been designed and built having a common denominator with ships, i.e. the fact that they have been autonomous energy systems.

Nowadays with the decarbonization policy predominating, offshore or nearshore plants have changed their mission hosting in most cases green energy generation sources like wind-generators and/or photovoltaic cells. The energy produced in these plants is either stored locally in energy storage devices most frequently electric batteries or it is injected to the National Grid via submersed power transmission cables. There are also some initiatives that the electric energy generated is used to produce locally zero-carbon fuels like hydrogen which is also stored locally.

In all cases, the proper operation of such offshore plants necessitates the exploitation of specific multi-purpose support vessels. The design and operation of the latter is a major novel challenge that needs to be addressed accordingly.

A figurative representation of the offshore electrical engineering components is depicted in Figure 3.

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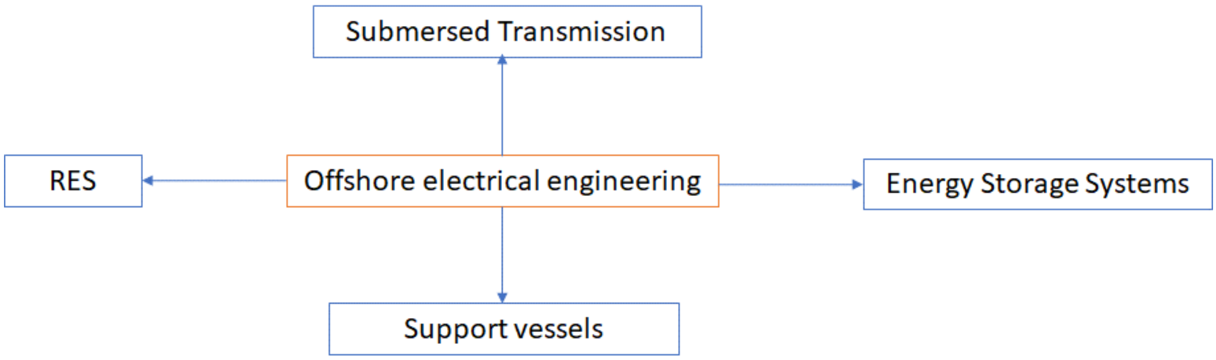

Figure 3. Major components of offshore electrical engineering related to sustainable decarbonization.

It is worth noting that the three different domains of increased electrical engineering interest are interrelated as ports are expected to act both as transportation hubs for all ships (including their cargo/passengers) but also as energy hubs. The necessary infrastructure required for all sophisticated and often bidirectional energy transactions must be carefully designed and installed, while it must also be operated by skilled and well trained personnel, which is further discussed next.

3. Developing, Cultivating and Disseminating knowledge

3.1 The modules to be covered

Based on the above discussion about the areas of expertise that must be developed to address the challenges of sustainable decarbonisation the following branches of knowledge have been recognised:

> Fundamentals: electric quantities, electric circuitry analysis principles,
> Rotating electric machinery: synchronous generators, asynchronous motors, synchronized operation of generators, active and reactive load sharing
> Power distribution: transformers, cables, switchboards, circuit breakers and switching devices
> Protection systems: short circuit calculations, selectivity, protection coordination
> Earthing/Grounding: protective earthing, system earthing, common mode earthing
> Power electronic converters: power electronic switches, bridges, rectifiers, inverters, converters, power/torque/frequency control techniques
> Renewable energy sources: PV's, wind-generators, waste heat recovery units
> Energy storage systems: batteries, other units of energy buffering
> Electric energy systems: design and operation principles, High Voltage
> Shore power interconnection interfaces
> Smart grids: integrated optimum operation of multiple power sources via a supervisory monitoring Energy Management System. Applications in ships, ports and offshore plants
> Power Quality: harmonic distortion, transients, dips and spikes

Taking into consideration that all these courses are strongly related to the maritime sector, their contents can be based on the STCW/ETO modules namely the training material dedicated to provide technical and electrical knowledge to the seafarers in order to comply with IMO conventions.

Depending on the background of the people to assimilate the aforementioned knowledge, the components above can be integrated in either a Continuing Professional Development (CPD) short seminar course or a Master of Engineering (MEng) curriculum of fairly longer duration. The former will be addressed to technicians who must get acquainted in a short time interval (about 15 days) with the core knowledge, while the latter will be most appropriate to graduate engineers who wish to acquire deeper knowledge and develop expertise in a more thorough manner.

The three different disciplines of marine electrical engineering as discussed will face a diversification of the modules as indicatively shown in Figure 4.

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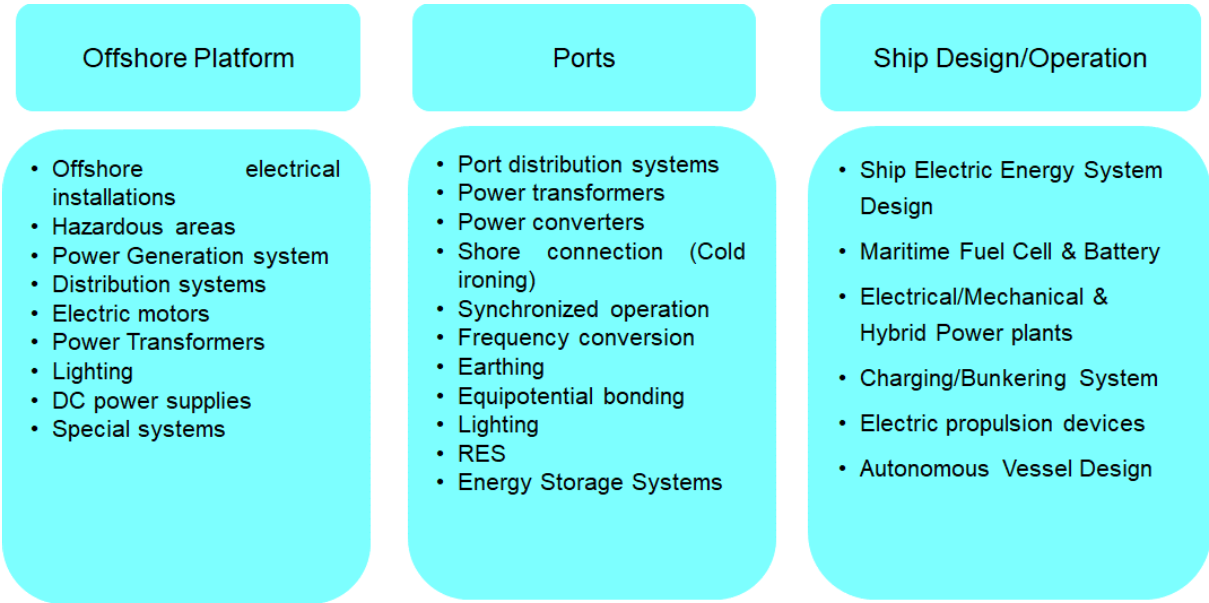

Figure 4. Indicative Grouping of training modules per specialty of marine electrical engineering.

3.2 The role of Institutions

The curricula discussed are to be initiated and developed by universities (like the University of Strathclyde and the National Technical University of Athens) but they need the support of several other stakeholders, the role of which is analyzed in brief next.

IMarEST

As already mentioned, the Institute of Marine Engineering, Science and Technology (IMarEST) has already been active in marine electrical issues for quite a long. Taking into account its long experience its role can comprise:

- Accreditation of the CPD courses
- Promotion of the curricula via its branches worldwide and via the series of events related to marine engineering (workshops, conferences, webinars etc)
- Support the training via high quality instructional material based on its publications but also via instructors-members of IMarEST
- Develop novel training material within the framework of SIG's like MESIG. The latter could have a substantial role in all the activities of the curricula which will encourage the whole effort to restart its productivity

IEEE

The Institute of Electrical and Electronic Engineers in the maritime related issues has been particularly active in developing standards and recommendations which provide priceless instructions to system designers. More specifically, IEEE/PES/Marine system Coordinating Committee has as predominant task to develop/amend a big series of standards; in coordination with the IEEE Industrial Application Society (IAS) a number of standards have been developed and published:

o IEEE 45.1-8, Recommended Practice for Electrical Installations on Shipboard
o IEEE 1580, Recommended Practice for Marine Cable for Use on Shipboard and Fixed or Floating Platforms
o IEEE 1662, RP for the Design and Application of Power Electronics in Electrical Power Systems
o IEEE 1709, Recommended Practice for 1 to 35 kV Medium Voltage DC Power Systems on Ships

It is worth noting that 45.1, 45.2, 45.3 and 45.7 are in amendment process (each one at different stage). Anyhow, it is underlined that standards have among others an instructional role, providing the accumulated experience of the Past to design engineers. In the case of marine electric energy systems where safety and reliability are of uttermost importance, these standards or recommended practices are priceless and, hence, extracts of them can consist the core material of the CPD or MSC modules under discussion.

Grid Operators (DSO's and/or TSO's).

Grid Operators namely Distribution System Operators-DSO's and Transmission System Operators-TSO's) have cultivated for long the massive electrification of many sectors of human activities. Within this context, their role, in particular that of DSO's, encompasses the provision of the electrical supply to ports for the electric interconnection of ships. Moreover, they are responsible for the deployment of offshore plants in the sea and their interconnection with the mainland Grid. In the particular case of Greece, HEDNO is the sole Distribution System Operator in Greece and has been engaged in the implementation of decarbonized energy transformation of ports in parallel to the sustainable transformation of its own distribution networks.

Thus, HEDNO, on the one hand has to retrofit its network by installing modern, environmentally friendly and high efficiency components (e.g. underground cables, low loss transformers) upgrade its network so that RES are easily plugged-in, but also extend its network so that ports with their advanced role as energy hubs be served, too.

Therefore, HEDNO can be recognized as the Institution that has the expertise to pave some of the major next steps, and hence should contribute to the development of the relevant know-how not only for itself but for the entire society, too. Within this frame, HEDNO has established a multi-purpose CPD program for its own personnel, but in view of the upcoming challenges in the maritime related electrical applications wishes to get engaged in the CPD discussed in this paper, too. Some indicative cases include the quasi-real field and/or laboratory environment in its own Schools, where trainees can get accustomed with the components of the new highly advanced electrical technology described above.

As a summary the schematic of the CPD/MSc prost-graduate curriculum with the roles of the associated partners i.e. Institutes, Universities and Grid Utilities is illustrated in Figure 5.

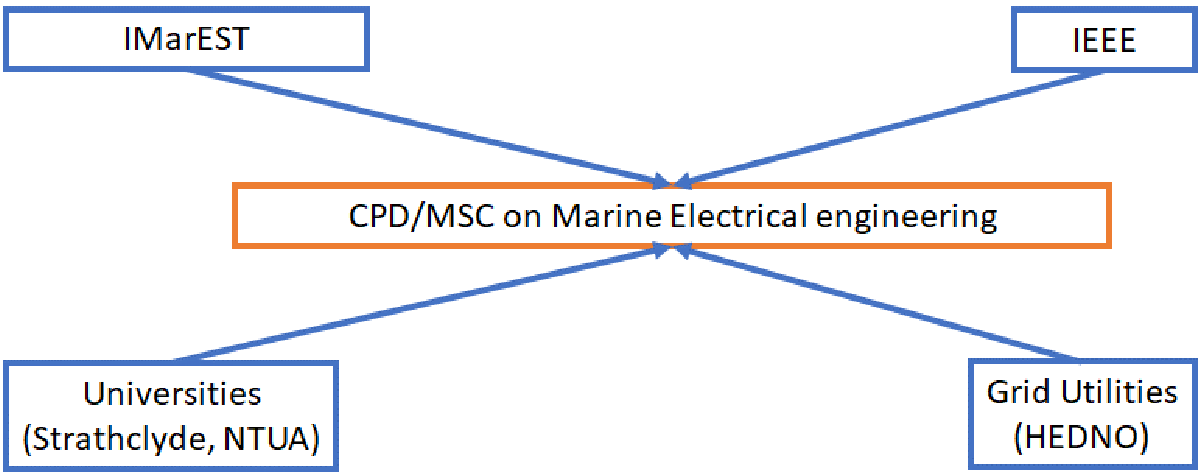

Figure 5. Figurative Schematic of the proposed curriculum on marine electrical engineering.

4. Conclusions

This paper makes the effort to highlight the needs for cultivating the branches of knowledge required in electrical areas of maritime industry, summarizing the new initiatives and substantially respond to the new challenges. The concept of a new curriculum either in a CPD or in MEng format is developed aiming at reinforcing

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relevant skills and expertise of crew onboard ships but also of technical staff working in ports or in supporting services of offshore plants. *The host of this effort is the University of Strathclyde (Glasgow) but will be substantially supported by NTUA, too. Moreover, IMarEST can promote and accredit the course, while IEEE could support the course, too via its electronic database of standards. Moreover, a Grid Utility like HEDNO, can enrich the syllabus by providing quasi-real field testing environment.*

Nomenclature

AES	:	All Electric Ship
CII	:	Carbon Intensity Indicator
CPD	:	Continuous Professional Development
DSO	:	Distribution System Operator
EEDI	:	Energy Efficiency Design Index
EEXI	:	Energy Efficiency Existing Index
ESS	:	Energy Storage Systems
EU	:	European Union
HEDNO	:	Hellenic Electricity Distribution Network Operator
IEC	:	International Electrotechnical Com mittee
IEEE	:	Institute of Electrical and Electronic Engineers
IMarEST	:	Institute of Marine Engineering, Science and Technology
IMO	:	International Maritime Organization
LED	:	Light Emitting Diode
MECSS	:	Marine Electrical and Control Systems Safety Conference
MSCC	:	Marine System Coordinating Committee
NTUA	:	National Technical University of Athens
ORC	:	Organic Rankine Cycle
PTO	:	Power Take Off
PTI	:	Power Take In
PV	:	Photo-Voltaic
RES	:	Renewable Energy Sources
TEG	:	Thermo-Electric Generator
TSO	:	Transmission System Operator

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