National and Technical University of Athens

School of Naval Architecture and Marine Engineering

Division of Marine Engineering

Diploma Thesis:

"Development of an application in computational environment for the techno-economic feasibility analysis of the shore-to-ship power connection (SSP - Cold Ironing)"

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Abstract

Growing rates of air pollution in port areas lead to search of alternatives covering the electrification of ships while in port. After the toughening of rules and regulations concerning ship emissions, a shore-to-ship power supply perspective is being studied by more and more port authorities, ship-owners and stakeholders through "Cold ironing" process studies. Such initiatives were taken for Greek ports as well. A powerful tool to implement this type of studies went on in this dissertation in a form of a developed application. Application's major configuration was designed following the Patrick Ericsson's and Ismir Fazlagić's proposed configuration for shore-side power supply in their Master of Science Thesis.

CITeST v.1 © application has been developed with the assistance of Microsoft's Visual Studio 2017 programming environment and programming has been made in Visual Basic.NET programming language. While application's major purpose was to implement all the required calculations to achieve a technical and financial feasibility study for a Cold Ironing installation perspective, a function of holding a record with the conclusions of all the – up to now - implemented Greek port researches concerning Cold Ironing perspective in a database form has been developed as well. Database's input data followed the dimensioning of each berthing place power demand comprised in each one of the six Cold Ironing Installation studies made for corresponding amount of ports.

Application's intelligent interface and interactive environment gives the chance even to unexperienced users concerning technical matters to implement a techno-economic feasibility study for a Cold Ironing installation in only a few minutes. A summary of the developed application and an already manually implemented Cold Ironing installation study results comparison occurred as well to demonstrate application's capabilities.

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2. Cold Ironing

2.1 General Information

Cold Ironing (CI) can be also referred as Shore to Ship Power (SSP) or simply shore connection, Alternative Maritime Power (AMP) and Onshore Power Supply (OPS). CI term originate back in time when ships were using coal-fired engines. At that time, when the ships were at berth, they were shutting their engines off. Thereby, the iron engines were cooling down through time and the term was adopted.

Nowadays, CI has its meaning modified. It is used to specify an alternative way to provide electric power to ships from the shore while at berth, allowing them to stop or reduce using their auxiliary diesel engines for electric power coverage. In this way, emissions are eliminated by the ship side and contained on-shore.

Figure 2.1 – Cruise ship while using the auxiliary engines at berth

Figure 2.2 – Shore connection applied at California's port

Interest on CI appliance has a growing rate over the last years on the maritime transports because of the escalating toughening of the rules and regulations indicated after the International Convention for the Prevention of Pollution from Ships in 1973, Annex VI 1997 MARPOL (MARine POLlution) Protocol and later interventions from other international regulations. The most severe legislation is adopted concerning areas which are highly polluted by oxidization known as ECA's (Emission Control Areas).

Figure 2.3 – Existing and possible future ECAs

2.2 Purpose of CI Installation

CI installation can be a motivating force for reducing air pollution near port areas. Thus, a positive effect in numerous aspects of ship emissions' affection into citizens' health (e.g. respiratory problems alleviation) can take place.

After the adjustment of Annex VI of the 1997 MARPOL Protocol which went in effect on May 2005, emission control solutions appliance became inevitable for every ship. Emissions include sulfur oxides (SOx), nitrogen oxides (NOx), ozone depleting substances (ODSs) and volatile organic compounds (VOCs). Inhaling of these compounds can have effects on human health ranging from nose, throat, and airways irritation, coughing, wheezing, shortness of breath, tight feeling around the chest, to serious respiratory diseases like asthma, lung diseases, sensory irritation and cancer. Moreover, exposure of these compounds in the atmosphere can be responsible for the formation of tropospheric ozone and smog or react with other substances and form acid rain.

Taken into consideration all the vulnerable effects of the abovementioned compound production, ship-owners have to consort their fleet with the latest strict limits for sulfur by mass concentration in marine fuel.

Table 2.1 – General sulfur limits for sea areas

Before 1st of January of 2012	4.50 % m/m
Between 1st of January of 2012 and 1st of January of 2020	3.50 % m/m
After 1st of January of 2020	0.50 % m/m

Table 2.2 – Sulfur limits for ECAs

Before 1st of July of 2010	4.50 % m/m
Between 1st of July of 2010 and 1st of July of 2015	3.50 % m/m
After 1st of July of 2015	0.50 % m/m

Apart from the emission reduction, a remarkable factor that ship-owners can take advantage of is the increased time that the vessel spends while moored. In case of cargo ships, the time spent in port is either for loading/unloading or for supplying (fuel, food, fresh water, other provisions supply) and varies from a few hours to a few days. In case of cruise ships and passenger ferries, except from supplying time, a significant amount of time is spent solely for hoteling activities. Hoteling load can reach high values, especially on cruise ships where the hoteling facilities are highly developed (including shops, clubs/bars, pools, casinos, room services, etc. operating 24 hours, 7 days per week), so, auxiliary engines' load would be proportionally high (as well as emission levels). In both cases a large amount of electrical power is devoted for lighting, air-conditioning, heating and a plethora of ship's electrical systems. Shore connection operation can provide sufficient power to a vessel for electrical power demand coverage while at port, rendering zero emission for ship's electrical power production by the sea-side reality.

In addition to the abovementioned, as long as the emission levels are legislated almost with an annual tendency and ECA's number is growing, ship-owners will search for alternative solution to keep their action lawful. Onboard solutions have been adopted, such as scrubber installation and low Sulphur fuel oil or natural gas use. Besides, these solutions can not eliminate the emission rates. Considering scrubber installation has a notable cost and low Sulphur fuel oil cost higher than the regular ones, CI solution can be competitive costly and further examination can be worthy.

By installing an onshore power plant to cover the power demand of berthing vessels, vessel emissions are almost obliterated. Total emission obliteration cannot easily be achieved because of the function of other systems needed at berth, like steam production for cruise ships. Also, auxiliary engines cannot easily be abolished due to the instability and the wide amplitude of the load during ship's maneuvers while approaching the shore. Nevertheless, the mitigation of emission problem of berthing vessels can be significant.

2.3 Implementation constraints

Worldwide fleet functional systems' features distinguish from one another. Ship construction's principals differentiate from region to region, thus, as well as the mechanical; the actual electrical systems are not produced by the same token in each country.

Concerning the on-shore electrical power, each country has a national grid for electrical power distribution with different standards. When a CI solution study takes place, actual national grid's current is the first factor that must be defined.

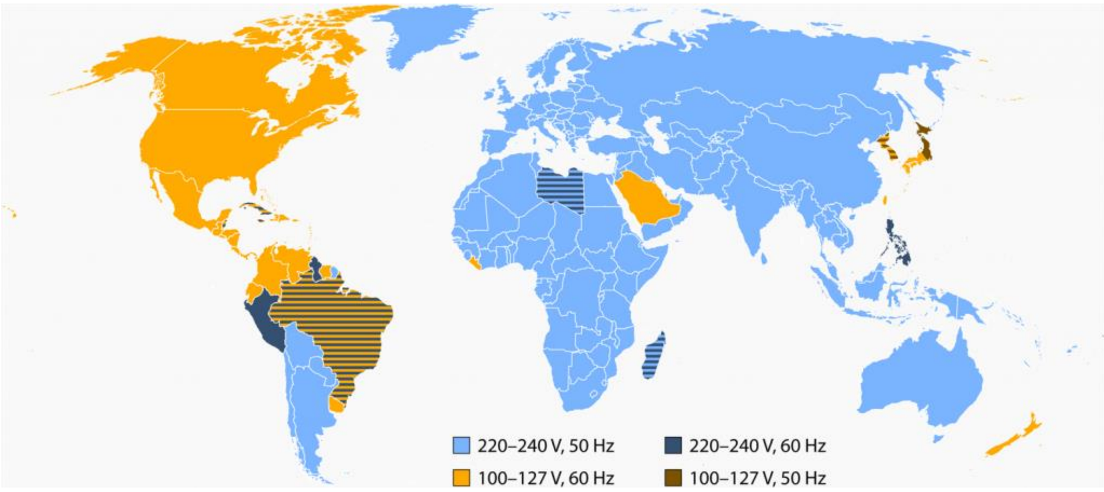


Figure 2.4 – Worldwide current's voltage and frequency standards

Since ships travel all around the world depending on customer needs, most compatibility issues concerning the CI implementation will be faced on possible different voltage and frequency values between the shore procurement and the ship requirement. For example, the diesel generators of a bulk carrier made in Japan in 1990 produce electrical current of 450 Volt and 60Hz. A containership built in Korea in 2008 uses 6600 Volts at a frequency of 60 Hz while a cruise vessel built in Finland in 1985 uses 380 Volts at 50 Hz. On the other hand, shore power frequency is 50Hz in Europe, Asia and Africa but 60 Hz in USA [1].

Multiple solutions were adopted to overcome obstacles of this type. Frequency converters are used for converting the national grid current's frequency into the one needed for the ship to function. Also, voltage transformers can provide current of different voltage when needed. These solutions are expensive and in some cases not all the required equipment are covered from the port facility for shore-to-ship connection. Thus, existing vessels have to retrofit their equipment in some way to acquire the required features for shore-to-ship connection and the new ones have to include the equipment's cost in their financial analysis. In both cases, ship-owners have to consent for the handle of a significant extra cost and the only way to achieve this is by ensuring future profit will be gained.

2.4 Standardization of CI

CI installation is a challenging process in which many parameters have to be managed and constraints to be faced. For these reasons, a European Union recommendation concerning a series of steps and an International standard adoption will be determined forthwith for a further analyzation.

2.4.1 EU Commission Recommendation on the promotion of shore-side electricity for use by ships at berth in Community ports (2006/339/EC)

A description of a typical configuration for shore-to-ship connection suggested by European Union on May 6th of 2006 is given below:

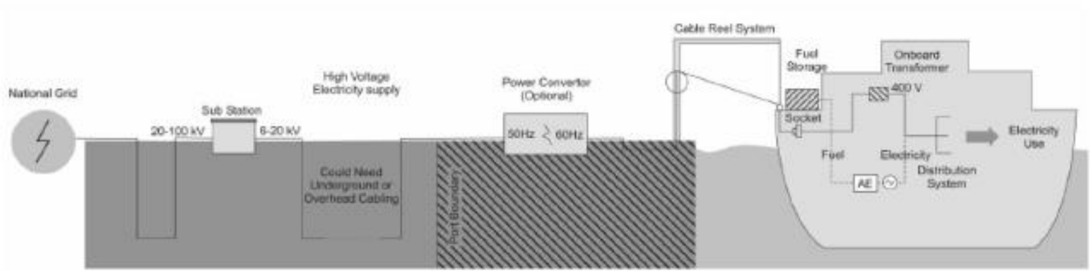


Figure 2.5 - Typical configuration for shore-to-ship connection suggested by European Union

1. A connection to the national grid carrying 20-100 kV electricity from a local substation, where it is transformed to 6-20 kV.
2. Cables to deliver the 6-20 kV power from the sub-station to the port terminal.
3. Power conversion, where necessary. (Electricity supply in the Community generally has a frequency of 50 Hz. A ship designed for 60 Hz electricity might be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating, but not for motor driven equipment such as pumps, winches and cranes. Therefore, a ship using 60 Hz electricity would require 50 Hz electricity to be converted to 60 Hz).
4. Cables to distribute electricity to the terminal. These might be installed underground within existing or new conduits.
5. A cable reel system, to avoid handling of high voltage cables. This might be built on the berth supporting a cable reel, davit and frame. The davit and frame could be used to raise and lower the cables to the vessel. The cable reel and frame could be electro-mechanically powered and controlled.
6. A socket onboard the vessel for the connecting cable.
7. A transformer on board the vessel to transform the high voltage electricity to 400 V.
8. The electricity is distributed around the ship, and the auxiliary engines switched off.

Variations of this configuration were practiced by many ports around the globe.

Prior to this publication, in Juneau, Alaska, shore-connection technology was used to reduce the emissions and succeeded quiet efficiently. In the rest of U.S.A., Los Angeles, Long Beach, San Francisco, San Diego and Seattle ports are already using CI. In Canada ports of Halifax and Vancouver made the first step also. Concerning Europe, Sweden, Germany, Belgium, Netherlands and Finland are some of the present users of CI. Moreover, ports in Norway, Latvia and Italy were introduced for CI application.

2.4.2 International Standard (ISO/IEC/IEEE 80005-1)

The first standard for CI implementation was published on 2012, called ISO/IEC/IEEE 80005-1 Utility Connections in Port - Part 1: High Voltage Shore Connection (HVSC) Systems - General requirements. Nevertheless, on 2019, a second edition came out to cancel and replace the first one.

According to the latest edition (ISO/IEC/IEEE 80005-1:2019), the HVSC systems, onboard the ship and on shore, that supply the ship with electrical power from shore are described.

This standard is applicable to the design, installation and testing of HVSC systems and addresses:

- High Voltage (HV) shore distribution systems,
- shore-to-ship connection and interface equipment,
- transformers/reactors,
- semiconductor/rotating frequency convertors,
- ship distribution systems, and
- control, monitoring, interlocking and power management systems.

It does not apply to the electrical power supply during docking periods, for example dry docking and other out of service maintenance and repair.

Additional and/or alternative requirements can be imposed by national administrations or the authorities within whose jurisdiction the ship is intended to operate and/or by the owners or authorities responsible for a shore supply or distribution system.

It is expected that HVSC systems will have practicable applications for ships requiring 1 MVA or more or ships with HV main supply.

Low-voltage shore connection systems are not covered by this standard.

2.5 Configuration, Equipment and Connection

Installed CI configurations may vary from the abovementioned 2006/339/EC EU Commission Recommendation, but the equipment needed for the installation must consort with ISO/IEC/IEEE 80005-1.

The configuration proposed by the EU Commission has significant advantages. A major benefit is that in case of a quay substation failure (e.g. frequency converter failure), the other berths are still functional and only one berth is affected. Moreover, maintenance, troubleshooting and servicing are characterized by further simplicity.

On the other hand, two major disadvantages were found on this configuration. First one is that due to the location of the frequency converter, each berth will have its frequency converter(s). In this way, dimensioning of the frequency converter has to be done for the power in which the ship with the greater power value will be accommodated. Thus, the recommended configuration cannot exploit the overcapacity of the frequency converter(s) when vessels with less need of power will be berthed. Nevertheless, in case of potential power amplification necessity, parallel connection of more frequency converters will be limited, since the substation is located near the quay and space – especially for cargo ships, e.g. containerships - will be more limited.

The second one refers the lack of galvanic isolation. Galvanic isolation provides a separation of electrical circuits to eliminate stray currents. Difference in ground potential between two communicating circuits is the major reason why galvanic isolation is required. Energy or information exchange is still able between the two circuits by other means, such as capacitance, induction or electromagnetic waves. When the accommodated vessel is using the same voltage with the one provided by the national grid, voltage transformer is bypassed, thus, no galvanic isolation is taking place.

A different approach was made on the CI configuration solution by Patrick Ericsson and Ismir Fazlagić contained in their Master of Science Thesis in Chalmers University of Technology [7]. The proposed configuration has a more centralized scope in which firstly the main port's substation is connected with the national grid. There, one or more parallel connected frequency converters take place. Input and output transformers are connected with each frequency converter to adjust the input and output voltage. A dual frequency option is given by double busbar integration. One busbar is connected with the frequency converters' output current while the second one is connected via a voltage transformer to the national grid. A circuit breaker and a change-over switch are used to transmit power to the berth-side in whichever frequency needed.

In contrast with the decentralized configuration, dimensioning is made according to the actual power demand at the terminal, thus, possible system overcapacity can be exploited by a berth when a vessel with less power demand is accommodated. In this way, only the voltage transformers and the other connection equipment positioned on the quay shall be dimensioned at high power demand, which means cost mitigation.

Alongside with the positive effects, this configuration renders the system more vulnerable to possible system's intermediate equipment failure, for instance, if damage occurs on the 60 Hz busbar, none of the berths can provide 60 Hz current power and only 50 Hz electrical power will be available.

Past financial CI researches estimated that frequency converters' cost occupies almost 1/3 of the total installation cost. Since financial factor got a leading role in such a research, the configuration proposed in Ericsson's – Fazlagić's Master of Science Thesis [7] will be elaborated in this dissertation.

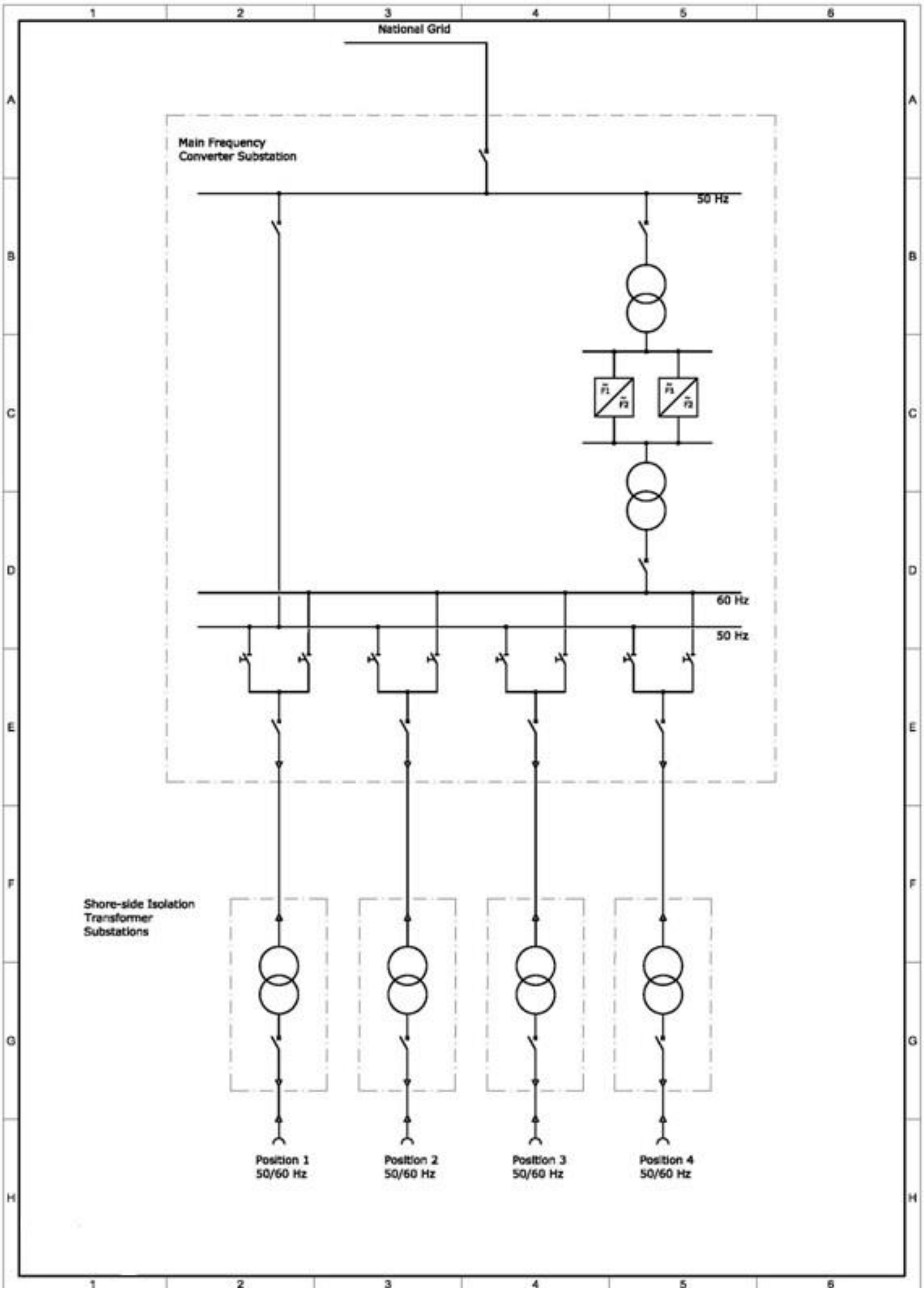


Figure 2.6 – Proposed centralized configuration's electrical drawing

A description of the major equipment will follow to help the reader familiarize with installation's concept.

2.5.1 Frequency converter

As mentioned on Chapter 2.3, some national grid's current functions at different frequency from others, thus, a frequency incompatibility may occur when a ship was constructed in a country where 60 Hz current is utilized and needs to be berthed in a country where 50 Hz current is utilized or vice versa. 60 Hz current is used mainly in North America and a few countries of South America, while almost the rest of the world uses 50 Hz frequency current.

Except from the regular solutions, advanced frequency converters are now provided for port installations. Frequency converters function in low noise levels and have no CO_2 emissions. They can be both air and water cooled. Water cooling is highly suggested in case of port installations, since sea water can be easily drained from sea via water pumps and with a heat exchanger treatment; cooling turns out sufficient. Frequency converter solutions can be found as indoor units or in outdoor containers.

Figure 2.7 – Open rack and containerized ABB PCS frequency converters

More than one frequency converters can be parallel coupled to achieve high power levels. Scalable solutions can be found ranging from 0.1 up to 120 MVA. A cost saving advantage is derived by frequency converter utilization when national grid's energy costs are ranging in lower prices than the operational costs of on-board electricity production. Such a comparison cannot be made in this stage, because engine's maintenance, spare parts and lubricating oil consumption costs are not available.
A suitable instance of a frequency converter designed for port installations is ABB PCS 6000 harbour. This model is a part of ABB's family of PCS 6000 products which are used for a wide range of applications including marine ones. PCS 6000 uses advanced IGCT (Integrated Gate Commutated Thyristor) technology that has been developed by ABB from a proven bipolar semiconductor background (GTO – Gate Turn-off Thyristor). The PCS 6000 converters are based upon IGCT PEBB (Power Electronic Building Block) which has a connection configuration that allows for very good harmonic performance with typically no need for a harmonic filter.

Figure 2.7 – ABB Integrated Gate Commutated Thyristor unit

2.5.2 Voltage Transformers

Multiple voltage transformers are needed on any kind of CI configuration. Concerning the busbar connected with the frequency converters for 60 Hz frequency current transmission, in the first place, voltage transformers are used for transforming the current's voltage from the national grid's value to the required input voltage value for each frequency converter. Afterwards, an output voltage transformer is used to restore the voltage value at the national grid's value. Except the voltage transformer's connection with the frequency converter (both as an input and as an output), a voltage transformer with a 1:1 ratio is used as an intermediate equipment to the connection of the 50 Hz busbar with the national grid following the Ericsson's – Fazlagić's [7] configuration scope.

Figure 2.8 – Substation's Dry-type voltage transformers

Studies concerning operating voltage of the world's fleet visiting Greek ports showed that some vessels are using either 6.6 kV or 11 kV current - mostly Cruise vessels - consequently, a dual voltage transformer must be installed in berth's terminal for this type of vessels. A dual voltage option is derived by a changeover switch which controls the transformer's output current voltage. A remarkable percentage of Containerships do operate either on 6.6 kV or 11 kV as well, thus, the same adjustment should be fitted.

Besides the voltage transformation to a value which ship's electrical system operates, voltage transformer placed on berth's terminal is of great importance because of the abovementioned reason of galvanic isolation requirement. This requirement is provided by preventing the current flow due to different grounding potentials. Voltage transformers are a representative instance of galvanic isolation, for this reason, various installations exist in which voltage transformer ratio is adjusted to 1:1 to serve solely the galvanic isolation requirement. An extra advantage provided by this configuration – locating the voltage transformer on berth's terminal - is that possible cable losses through the transmission of the main substation to the shore-side substation are balanced.

After an overview of our selection options, ABB's RESIBLOC cast-resin voltage transformers operation concluded as a really fitting option for a CI installation perspective. They handle power levels of up to 60 MVA and voltages of up to 72.5 kV. These transformers are a part of 3-phase Dry-type family transformers. Dry-type transformers introduce a plausible solution for a CI installation - as well as for onboard installation - for several reasons:

- Reduced environmental contamination
- Zero leakage of flammable or contaminating substances
- Environmentally friendly production
- Well suited for contaminated areas
- Nonflammable and self-extinguishing
- High capacity to support overloads
- High performance in dealing with seismic phenomenon
- Capable of withstanding the most severe rolling and vibrating conditions

Figure 2.9 – RESIBLOC 3-phase Dry-type voltage transformer

Moreover, a forced air cooling option, as well as an automatic fan utilization option which is being enabled by a temperature sensor can be provided. This option is a low noise option which can improve their power output by up to 40% of its rating.

2.5.3 Double busbar system & switchgears

Double busbar system is the major generator of the double frequency procurement to each berths' terminal. According to the Ericsson's – Fazlagić's configuration [7] double busbar is located to the main substation. The same configuration will be chosen in this dissertation as well.

Since repetition is the mother of learning, a reminder that the double busbar system installed to the port's main substation permits the simultaneous usage of 50 Hz and 60 Hz shore power to each berths' terminal is stated here once more. This system must fit with the CI installation requirements, thus, berth terminals' power and voltage demand. In this case, the selection fell on ABB's Unigear ZS1 medium-voltage air-insulated switchgear which is consisted of the following compartments:

- Low voltage compartment
- Apparatus compartment
- Cable compartment
- Busbar compartment

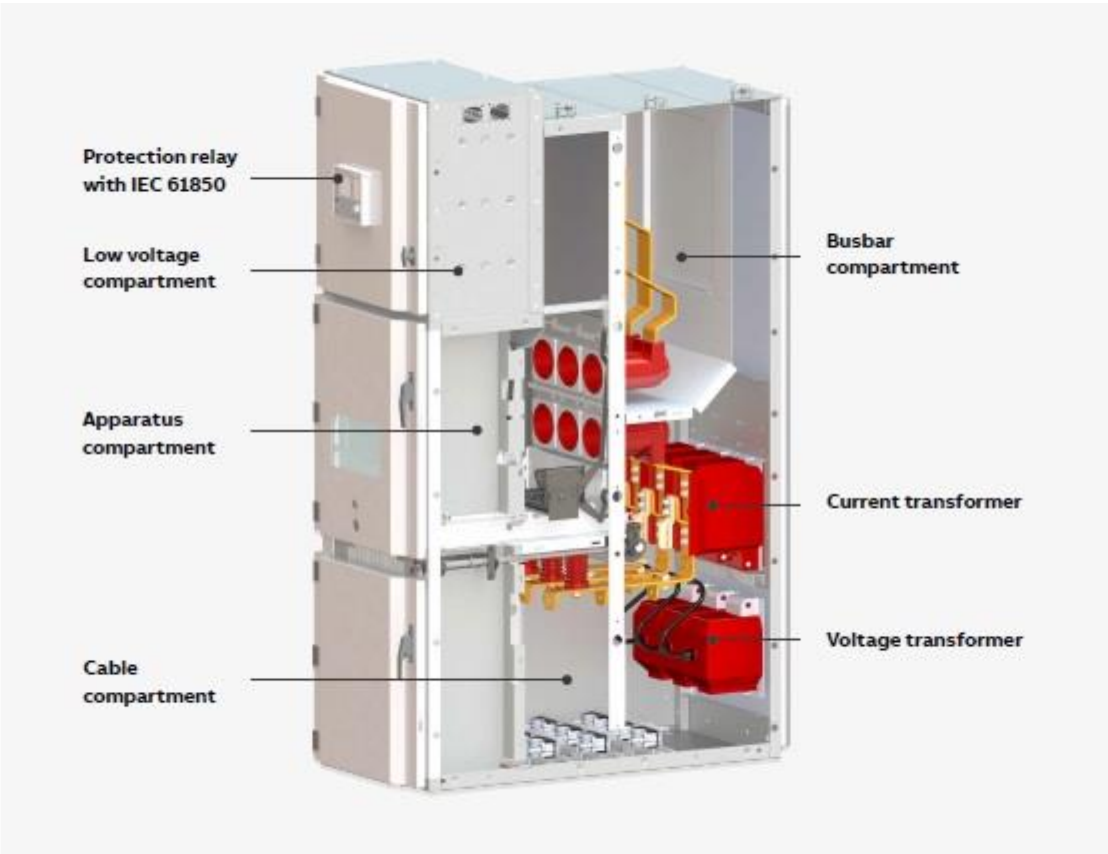


Figure 2.10 – ABB Unigear ZS1 independent compartments

Metallic partitions are used to segregate the compartments. Extra devices used for allowing the user to switch the frequency option from 50 Hz to 60 Hz are depicted in Figure 2.10.

The busbar compartment contains the main busbar system connected to the upper isolating contacts of the circuit-breaker by means of branch connections. The main busbars are made of electrolytic copper. The busbars are covered with insulating material and their form may vary from flat shape to a special D-shape depending on the current rating . There is a single busbar compartment along the whole length of the switchgear up to 31.5 kA. The cable compartment contains the branch system for connection of the power cables to the lower contacts of the circuit-breaker. The feeder connections are made of electrolytic copper and they are flat busbars for the whole range of currents. Appropriate insulation has been taken into consideration through the whole design process.

Earthing switches with short-circuit capacity can be fitted for all the busbar system to guarantee total safety for the system users. To sum up, ABB Unigear ZS1 holds the following features:

Table 2.1 - ABB Unigear ZS1 features

Electrical characteristics					
Rated voltage	[kV]	7.2	12	17.5	24
Rated insulation voltage	[kV]	7.2	12	17.5	24
Rated power frequency withstand voltage	[kV/1 min]	20	28	38	50
Rated lightning impulse withstand voltage	[kV]	60	75	95	125
Rated frequency	[Hz]	50/60	50/60	50/60	50/60
Rated short time withstand current	[kV/3 s]	...50	...50	...50	...31.5
Peak current	[kA]	...125	...125	...125	...80
Internal arc withstand current	[kA/1 s]	...50	...50	...50	...31.5
Main busbar rated current	[A]	...4000	...4000	...4000	...3150

Switch disconnectors are used for the transmission from one frequency busbar to the other. Their role is to keep the main contacts unstressed and consequently the electrical characteristics of the apparatus unchanged. This is achieved by the supply of compressed air through special nozzles instantly when the contacts are open, so the arc discharge is cooled and deionised. This leads to a gradual increase in the arc resistance which causes its extinction.

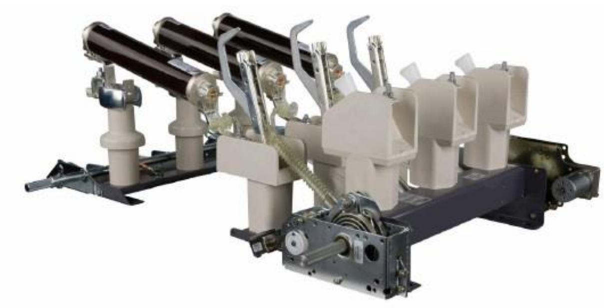


Figure 2.11 – ABB NALF disconnector

2.5.4 Circuit breakers

As the role of disconnectors was previously explained, the fact that their operation is available only when circuit breakers are in the open position must be stated here.

Circuit breakers guarantee the smooth current switching of a system to zero values and prevent the damage of other equipment such as cables, transformers and substations. The concept of smooth current mitigation is gained through an insulation medium which exterminates the electric arc providing enough resistance to achieve the prevention of the propagation of the arc. Insulation medium varies from one installation to another. Vacuum or gas insulated circuit breakers are commonly found in the market. A gas insulated circuit breaker solution will be presented in this dissertation which is ABB's HD4 medium voltage circuit breaker. This circuit breaker uses SF_6 (Sulphur hexafluoride) as an insulation medium and can handle voltages up to 40.5 kV. A Fixed (HD4/S), as well as a withdrawable (HD4/US) solution can be provided by the manufacturer.

Figure 2.12 – ABB HD4 medium voltage SF_6 circuit breakers, Fixed (1) and Withdrawable (2) versions

ABB's HD4 withdrawable version features are shown on Table 2.2.

Table 2.2 - ABB HD4 SF_6 withdrawable circuit breaker features

Electrical characteristics				
Rated voltage / Rated insulation voltage	[kV]	12	17.5	24
Withstand voltage at 50 Hz	[kV]	28	38	50
Impulse withstand voltage	[kV]	75	95	125
Rated frequency	[Hz]		50/60	
Rated normal current (40°C)	[A]	630/4000		630/3600
Rated breaking capacity / Rated short time withstand current (3s)	[kA]	16-50	16...50	16...40
Making capacity	[kA]	40...125		40...100

2.5.5 Cables

Cable arrangement will not only fit with the proposed configuration by Ericsson and Fazlagić [7], but also with the ISO/IEC/IEEE 80005-3 "Draft International Standard - Utility Connections in Port - Part 3: Low Voltage Shore Connection (LVSC) Systems - General Requirements" [13]. Hence, a central cable for the connection of the main substation with the national grid and a cable arrangement of underground cables linking it with the shore-side transformer station will be implemented. The final stage of connection will be generated by a cable reel system and a davit to lift the cables overhead at the appropriate height according to the vessel's need.

Figure 2.13 – CI cable arrangement option and a closer look at an installation cable

Each cable will have its own insulation, but extra protection can be provided in case of bonded cables which are embedded into conduits. Conduit design and installation have to be examined according to the voltage and current – i.e. power - needs of cable arrangement as well as to the type of installation (underground or overhead). Typical dimensions of cables and conduits are available on the market; concluding in a manageable size for the installation. Final selection of the cables' size will be performed according to the current that passes through them, defined by the following formula:

$$I = \frac{S}{\sqrt{3} \cdot V}$$

Where, I = Rated current

S = Apparent power

V = Current's voltage

According to the abovementioned formula, 350 A current cables are a suitable solution which provides 4 MVA power in case of 6.6 kV current and 6.7 MVA power in case of 11 kV. Consequently, with a parallel connection of more than one cable, coverage of high power needs can be achieved.

Cable reel options vary from application to application. Fixed solutions are available to be applied on each berth, but mobile solutions exist as well. A mobile cable reel system solution not only simplifies the management of long cables, but also provides flexibility on the function of the whole installation, as it can be utilized in more than one berth. An automobile solution is depicted below, as well as an innovative barge cable reel system applied on Sydney port.

(1) (2)

Figure 2.14 – Automobile cable reel system (1) and barge reel system (2)

2.5.6 Connection boxes

The final stage of shore-side equipment selection for a CI installation constitutes from the connection boxes selection. Connection boxes are placed right on the edge of each quay and their amount depends from the type of the vessels that the berthing place is intended to accommodate. Since the position of the berthing Ro/Ro vessels is more or less the same at each port, connection boxes can be fitted in closer distance. On the other side, the rest of the vessels are not of a certain length and their berthing position may vary according to several loading/unloading conditions. Thus, connection boxes for these berthing places must be positioned more concentrated. Connection boxes are placed under a special semi-underground configuration inside receptacle pits. With this configuration, cable length can be mitigated and appropriate insulation amplified. Manufacturers provide a multiple connection socket option which can lead to multiplication of the power transmission ability.

Figure 2.15 – Dual socket connection box inside the receptacle pit under connection process

Connection process premises safety above everything else. For this reason, the next predetermined steps must be followed.

- When cable connection is over, an interlock positioned on the connection box plug is generated and a key secures it to be locked.
- The switchgear connected with the shore-side substation then is generated by using the same key to unlock its function and to allow the current flow. At the same time, key is secured on the switchgear to prevent any undesirable disconnection.
- Finally, the connection is finalized and the vessel can be synchronized to shore-to-ship connection operation and turn off its auxiliary engines.

In addition to the connection accomplished for the shore-to-ship power transmission, a connection made for communication with the shore power function system exists. This connection is executed via a fiber-optic cable according to relevant standardization.

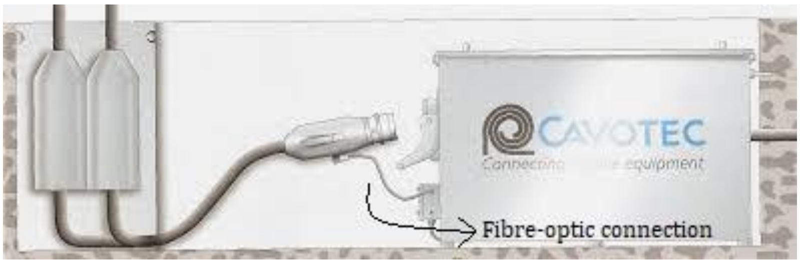


Figure 2.16 – Cavotec connection box including fiber-optic connection cable

2.5.7 Onboard equipment

Equipment needed on the off-shore side contain the entity of the required apparatus the ship must acquire to achieve an efficient and concordant power transmission by the shore-side, as well as a continuous and insusceptible operation off-shore.

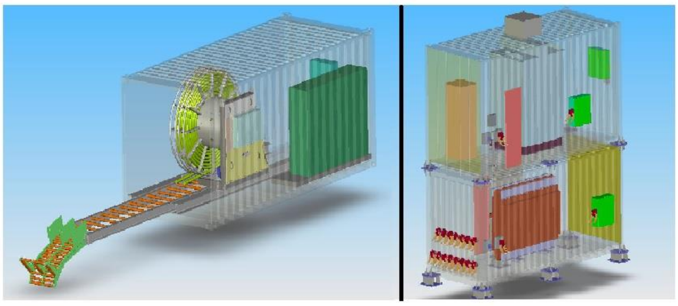
Vessel's operation transition from its independent electrical generation system – induced by the auxiliary engines' operation – to SSP connection is not a simple procedure. This is due to the fact that a step of zero electrical power procurement exists for the while disconnection and connection from one system to the other takes place. A few minutes of shutting down the devices fed by the electrical system may not be so harmful for some cargo ships, but in the case of Ro/Ro vessels – especially Cruise ships - or Containerships that time jeopardizes the reliability of the passengers and the viability of the commodities. For this reason, the most important procurement vessels have to obtain is a synchronizing system, which enables the uninterrupted operation of power transmission. Vessels must be equipped, among others, with circuit breakers and switchgears to facilitate the transition procedure.

Concerning the onboard distribution system, a difference in current's voltage exists between older and newer ships. Older ships use 0.44 kV power distribution systems, while the newer ones use 6.6 kV. Thus, older ships require higher amperage to cover their needs in contrary with the newer ones.

A cable system is another acquisition that must be regulated by the vessel-side. A reel system for the enfolding of the cables, as well as a ramp for an efficient navigation can be fitted.

Such arrangements are provided by some companies as a congregated solution. Cavotec has adopted a bunch of solutions concerning the onboard equipment for AMP. One of them is a fully integrated solution which supplies with a cable management system, a shore connection panel and a voltage transformer the vessel. Two other options are also available by the same manufacturer in a semi-fixed containerized version, as well as in an all-in-one removable container version.

(1)



(2)

(3)

Figure 2.17 – Cavotec AMP onboard equipment solutions. Fully integrated version (1), semi-fixed containerized version (2) and all-in-one removable container version (3).

2.5.8 Installation's preliminary cost prediction

Most of the equipment needed will be installed on the shore-side, thus, the biggest part of the investment has to be covered from the port authorities. A cost approximation can be done in association with other contiguous researches.

In the cold-ironing cost effectiveness study realized by ENVIRON for the Port of Long Beach in 2004, it was calculated that for high voltage applications (6.6kV), the ship retrofit costs ranged between 200,000$ and 574,000$ with an average cost of 400,000$. For low voltage applications, because of the need for a transformer, the ship retrofit cost was calculated between 240,000$ - 1,100,000$ with an average cost of 588,000$. In the same cost effectiveness study, it was calculated that the total power infrastructure costs in order to accommodate 12 vessels where 22,263,000$ so almost 1,855,000 $ per vessel [1].

Undoubtedly, onboard equipment is the main incentive to lead the ship-owners either to move forward supporting the CI installation or to reject it. Nevertheless, this dissertation is focusing on the investment of the shore side, thus, no reference in ship-owner cost will follow.

2.6 Existing CI installations

Maritime transportations are covering a global network o, providing distribution of goods and transportation of passengers which nowadays are impossible to be stopped. Besides, air pollutants and CO_2 excessively high levels in atmosphere are causing more and more problems to human health and to everyday life. Identification of how dangerous impact; emissions from the shipping sector might be, rendered ship-owners, port authorities and stakeholders to alter their stance concerning this matter. Last years, strictness arose in relevant legislations and this subject caused worldwide attention to fell into it.

CI installations are getting additionally widespread due to environmental sensitization which concerns international organizations, as well as national authorities. Older and newer IMO conventions are focusing on air pollutants limitation which led to the ECAs adoption and the requirement for the ship-owners to retrofit their fleet and conform with every legislation renewal. European Commission Recommendation, 2006/339/EC, made a grand step of promoting SSP supply and introducing to many stakeholders its concept.

Concerning the practical part, countries of North America, Northern and Central Europe took the first initiative by introducing themselves in AMP. When installations seemed to be effective, AMP influence spread to the other regions as well. Nowadays, CI is introduced to countries from Asia and Oceania, like Japan and Australia, and it seems that are many more willing to add it on their agenda.

A summary of existing installations provided by WPCI on 2017 can be found in the next table where year of introduction is indicated.

Table 2.3 - Existing CI installations

Introduced	Port	Country	Capacity [MW]	Frequency [Hz]	Voltage [kV]	Ship type
2000	Gothenburg	Sweden	1.25-2.5	50/60	6.6/11	RoRo, ROPAX
2000	Zeebrugge	Belgium	1.25	50	6.6	RoRo
2001	Juneau	U.S.A.	7-9	60	6.6/11	Cruise
2004	Los Angeles	U.S.A.	7.5-60	60	6.6	Container, Cruise
2005	Seattle	U.S.A.	12.8	60	6.6/11	Cruise
2006	Kemi	Finland		50	6.6	ROPAX
2006	HaminaKotka	Finland		50	6.6	ROPAX
2006	Stockholm	Sweden	2.5	50	0.4/0.69	RoRo

2006	Oulu	Finland		50	6.6	ROPAX
2008	Antwerp	Belgium	0.8	50/60	6.6	Container
2008	Lübeck	Germany	2.2	50	6	ROPAX
2009	Vancouver	Canada	16	60	6.6/11	Cruise
2010	San Diego	U.S.A.	16	60	6.6/11	Cruise
2010	San Francisco	U.S.A.	16	60	6.6/11	Cruise
2010	Verkö, Karlskrona	Sweden	2.5	50		Cruise
2010	Amsterdam	Netherlands	No further information found			
2011	Long Beach	U.S.A.	16	60	6.6/0.48	Cruise
2011	Oslo	Norway	4.5	50	11	Cruise
2012	Prince Rupert	Canada	7.5	60	6.6	
2012	Rotterdam	Netherlands	2.8	60	11	ROPAX
2012	Oakland	U.S.A.				
2013	Ystad	Sweden	6.25-10	50/60	11	Cruise
2012	Helsinki	Finland	No further information found			
2013	Trelleborg	Sweden	0-3.2	50	10.5	ROPAX
2014	Riga	Latvia				
2015	Bergen	Norway		50	0.4/0.69	
2015	Hamburg	Germany	12	50/60	6/10 (50 Hz), 6.6-10 (60 Hz)	Cruise
2015	Civitavecchia	Italy	No further information found			

Through research procedure, an observation of a high interest for potential upgrading of the voltage of power distribution has been made. This potential exists because of the need for SSP service of larger vessels with higher power demands. Achieving a higher voltage current distribution equals to less amperage needed which leads to less power loss through the distribution. Summary shows that; Stockholm and Bergen ports have

been designed for a lower power demand than the others, but a retrofit possibility is of high interest for port authorities.
A program called World Ports Sustainability Program (WPSP) concerning a "greener" contemplation exists and can lead to an introduction to the SSP solution was also made to the following ports [23]:

- Ports of Le Havre, Marseille, Paris, La Rochelle Cedex and Rouen in France
- Ports of Bremen/Bremerhaven, Brunsbüttel, Rostock and Oldenburg in Germany
- Ports of Delfzijl & Eemshaven, Velsen Noord and Terneuzen in Netherlands
- Ports of Southampton and Gravesend in U.K.
- Port of New York in U.S.A.
- Port of Ghent in Belgium
- Port of Setubal in Portugal
- Port of Sohar in Oman
- Ports of Busan and Ulsan in South Korea
- Ports of Kristiansand, Ålesund, Stavanger, Flåm, Fløro (Alden), Gamle Fredrikstad, Haugesund, Drammen and Trondheim in Norway
- Ports of Tokyo, Yokohama in Japan
- Port of Nelson in New Zealand
- Port of Barcelona in Spain
- Port of Panama city in Panama
- Port of Buenos Aires in Argentina
- Port Botany & Port Kembla in Australia
- Port of Tallinn in Estonia

3. CI Researches for Greek Ports

In 2018, the Greek Merchant Navy controlled the world's largest merchant fleet, in terms of tonnage, with a total DWT of 834,649,089 tons and a fleet of 5,626 Greek-owned vessels, according to Lloyd's List ["Lloyd's List Top 100 Most Influential People in the Shipping Industry. Edition 6, page 61". Lloyd's List. Retrieved 22 December 2018.]. Since the CI aspect concerned thoroughly the global maritime society, Greek maritime society, which occupies such a large amount of world's fleet, could be more than interested in following new technologies which leads to compliance with latest rules and regulation concerning environmental matters.

The existing researches have been made for the following ports (ports are referred by date of research implementation):

- Port of Piraeus
- Port of Killini
- Port of Thessaloniki
- Port of Patras
- Port of Heraklion
- Port of Igoumenitsa

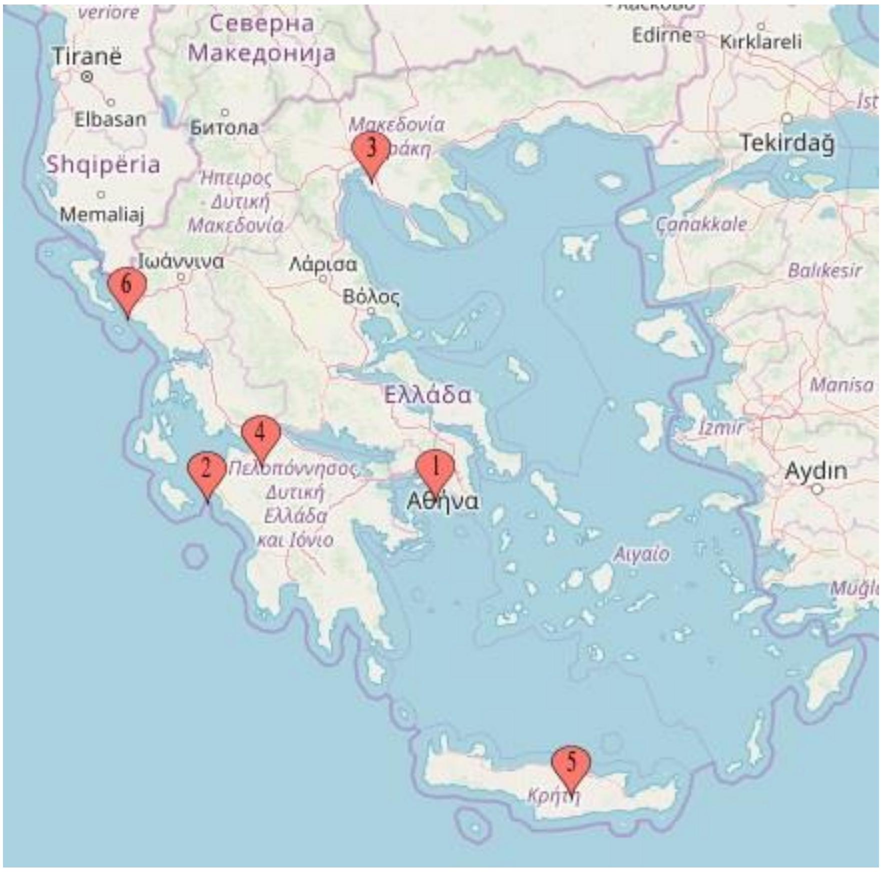


Figure 3.1 – 6 Greek ports for which a CI research was implemented: Piraeus (1), Killini (2), Thessaloniki (3), Patras (4), Heraklion (5), Igoumenitsa (6).

The most significant outcome of these researches was the implementation in practice of such a study in practice for the port of Killini. The inauguration of a pilot CI installation took place in Killini's port on December 20th, 2018. Practically, this installation constitutes the first CI installation in Eastern Mediterranean which is a product of hard work and collaboration of many stakeholders, including the EU co-funded Action "elemed" (electrification in the eastern mediterranean) and the shipping company Levante Ferries.

A brief presentation of the researches made for a potential CI installation in Greek port will be given thereinafter.

3.1 Port of Piraeus case study

Piraeus port is the largest port in Greece and one of the largest ports in Europe. It contains three terminals for containers, one cargo terminal, one automobile terminal and one passenger terminal. Container terminals have total capacity of 6.7 million TEUs (Twenty feet Equivalent Units) while passenger terminal is the largest in Europe and one of the largest in the world (Piraeus was the busiest port for 2014 when it received about 18.6 million passengers). Piraeus port serves the need of transportation between the majority of the Greek islands, including the Saronic Gulf islands, the Cyclades islands, Crete, islands on the Northern Aegean Sea and Rhodes among others.

Figure 3.2 – Piraeus port passenger terminal

The following description of Piraeus port case study is exclusively a result of Kampylis Panagiotis study [1] which will be briefly presented in this chapter.

The characteristics of the equipment acquired for a CI installation- described in Chapter 2 – require a port's power demand analysis. By extension, a particular power demand analysis must be done before designing such an installation. The power demand analysis will be divided by the type of the berthing vessels. Thus, a power demand analysis will be done separately for cruise ships, for ferries and for containerships.

3.1.2 Power demand analysis for Piraeus' RoRo ferries

The power demand analysis made for RoRo ferries was according to the RoRo fleet using Piraeus' passenger terminal in weekly basis. Decisive factors where the round trip time, as well as, the type, the capacity, the number and the load factor of ships' diesel generators. Ferries with low passenger capacity which have low power load (e.g. hydrofoils) and older vessels were not part of this study. Concentrated information about the abovementioned specifications are indicated on the following table:

Table 3.1 – Piraeus Ferries' information [1]

	MAIN DIMENSIONS					GENERATORS	
	L (m)	B(m)	Passengers	Cars	G.R.T.	Number	Output (kW/gen)
FESTOS PALACE	214	26.4	2200	600	24352	3	2300
KNOSSOS PALACE	214	26.4	2200	600	24352	3	2300
BLUE STAR DELOS	145.9	23.2	2400	430	18498	3	1320
BLUE STAR PATMOS	145.9	23.2	2400	430	18498	3	1320
BLUE STAR PAROS	124.2	18.9	1474	230	10438	3	990
BLUE STAR NAXOS	124.2	18.9	1474	230	10438	3	990
BLUE GALAXY	192	27	1740	780	29992	3	1000
BLUE HORIZON	187.1	27	1497	780	27230	4	1325
BLUE STAR 1	176.1	25.7	1890	641	29858	3	1260
BLUE STAR 2	176.1	25.7	1890	641	29560	3	1260
NISSOS MYKONOS	141	21	1915	418	8129	3	1080
ARIADNE	196	27	1845	650	30882	3	1100
						1	1100
NISSOS RODOS	192.5	27.3	850	748	29733	3	1000
SPEEDRUNNER III	100.3	17.1	688	120	4697	3	455
PHIVOS	99.5	17	1200	125	3437	3	500
HELLENIC SPIRIT	204	25.8	1850	1100	32694	3	1485
OLYMPIC CHAMPION	204	25.8	1850	1100	32694	3	1485
KYDON	192	27	1750	703	29991	3	1000
SUPERFAST XII	199.9	25	1637	649	30902	3	2000
DIAGORAS	141.5	23	1462	274	12499	1	1180
						2	1220
HIGHSPEED IV	92.04	24	1045	188	6274	4	350
FLYING DOLPHIN	32.24	5.8	155	0	161	2	28

WINTER TIMETABLE				
	ARRIVAL AT PIRAEUS	DEPARTURE FROM PIRAEUS	TURNAROUND TIME (min)	WEEKLY TURNAROUND TIME (min)
BLUE HORIZON/KYDON	6:00	21:00	900	2250
KNOSSOS PALACE/FESTOS PALACE	6:00	21:00	900	2250
ELYROS/BLUE GALAXY	6:00	21:00	900	2250
BLUE STAR PAROS	20:00	7:30	690	4830
BLUE STAR NAXOS	15:00	17:30	150	1050
DIAGORAS	9:40	15:00	320	960
BLUE STAR PATMOS/BLUE STAR DELOS	23:25	7:25	480	3360
BLUE STAR 2	7:45	18:00	615	1845
SUPERFAST XII	6:10	19:00	770	2310
BLUE STAR 1	7:55	20:00	725	2175
ARIADNE	7:25	21:00	815	2445
NISSOS MYKONOS	0:00	16:00	960	2880
NISSOS RODOS	7:25	21:00	815	2445
VINTSENTZOS KORNAROS	6:30	17:00	630	1260
ADAMANTIOS KORAIS	20:30	14:30	1050	2625
POSEIDON HELLAS	9:30	10:00	30	6405
	12:45	13:15	30	
	13:00	13:30	30	
PHIVOS/APOLLON HELLAS	17:30	7:15	825	7280
	19:35	10:00	865	
	13:05	16:00	175	

A load factor must be defined for the final calculations about ferry power demand. A specified study of a four vessel sample with high power demand is chosen to define this factor. Information of these vessels is the following:

Table 3.2 – Piraeus' four Ferry sample with high power demand information [1]

Ship	Hotelling Load (kW)	Load Factor
Ferry 1	2800	0.406
Ferry 2	1362	0.344
Ferry 3	1280	0.395
Ferry 4	1220	0.337
Average		0.370

Load factor was calculated by the division actual power demand to the auxiliary engines' power capacity. An average value of 0.37 load factor will be used for further calculations. After the required calculations, the final results about the power demand for each of the aforementioned ship are the following:

Table 3.3 – Final hoteling load power demand for Piraeus RoRo ferries [1]

Vessel Name	Number of D/G	D/G Output (kW)	Hoteling Load (kW)
FESTOS PALACE	3	2300	2553
KNOSSOS PALACE	3	2300	2553
BLUE STAR DELOS	3	1320	1465
BLUE STAR PATMOS	3	1320	1465
BLUE STAR PAROS	3	990	1099
BLUE STAR NAXOS	3	990	1099
BLUE GALAXY	3	1000	1110
BLUE HORIZON	4	1325	1961
BLUE STAR 1	3	1260	1399
BLUE STAR 2	3	1260	1399
NISSOS MYKONOS	3	1080	1199
ARIADNE	3	1100	1628
	1	1100	
NISSOS RODOS	3	1000	1110
KYDON	3	1000	1110
SUPERFAST XII	3	2000	2220
DIAGORAS	1	1180	1339
	2	1220	

A fair way to design the Piraeus RoRo ferry berths will be according to the highest power demand of the vessels indicated in Table 3.3, thus, around 2600 kW power demand per berth. Nevertheless, vessels of this peak power demand are sister ships and they never berth the same time. As a consequence, solely one berth can be dedicated for the berthing needs of these vessels, since not all the vessels reach the highest power demand and the rest for a lesser power demand. Specific information about the RoRo ferries' operating frequency and voltage is not available for the abovementioned ships. However, the available information is that; operating frequency depends from the construction country of the vessel; and since these vessels are mostly constructed in Japan or Europe, operating frequency may be either 50 Hz or 60 Hz. Moreover, an operating voltage range value is available and this diversifies from 380 V to 460 V.

By observing the traffic of RoRo ferries in Piraeus port, an amount of five ferry berthing places operating in 6.6 kV voltage is sufficient. To sum up, assuming a power factor value of 0.8 the following characteristics will be applied for the ferry berthing places:

Table 3.4 - Ferry berthing places maximum power demand for Piraeus port [1] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2800	3.5
2	2300	2.875
3	2000	2.5
4	1600	2
5	1600	2
Total	11900	12.875

3.1.2 Power demand analysis for Piraeus' Cruise vessels

Cruise vessels power demand is significantly higher than other ships; because of the increased time spend at berth and the high hoteling load demand. A convenient and fast approach of the cruise ships' power demand can be made by defining a new factor called Power per passenger ratio (PL) which represents the division of ship's Power demand per passenger, i.e. kW/passenger. In this way, the following results were extracted for a few cruise ships berthing on Piraeus port.

Table 3.5 - Cruise vessels' PL factor calculation [1]

Name	L	B	Passengers	Crew	Hotel Load (kW)	kW/passenger
Mein Schiff 2	264	32	2130	850	4100	1.925
Norwegian Sun	260	32	2002	968	5600	2.797
Norwegian Pearl	294	32.3	2399	1100	7200	3.001
Norwegian Star	294	32.3	2240	1100	9000	4.018
Star Princess	290	32.6	2600	1200	10500	4.038
Diamond Princess	288.33	37.5	3078	1060	11500	3.736
Golden Princess	252	32.6	2598	1060	10500	4.042
Island	293	32.2	1970	905	7200	3.655
Saphire Princess	288.3	37.5	3078	1060	9600	3.119
Rhapsody of the Seas	278	32	2435	765	5300	2.177
Serenade of the Seas	285	32	2400	900	5500	2.292
Radiance of the Seas	293.2	32.2	2501	859	5300	2.119
Dawn Princess	261	56	1998	924	6800	3.403
Pacific Dawn	245	56	2020	660	6700	3.317

The used data for the present analysis was found in “Air pollution emission inventory”, a report prepared by US Forest service and Alaska department of environmental conservation for Skagway, Alaska in 2008. In this report, data concerning hotel load, fuel consumption, emissions and engine type are gathered from 24 different cruise vessels berthing at Skagway. Since many of these ships visit Piraeus port as well their data could be used for the calculation of cruise berth power demand. The average value of PL factor is 3.117 kW/passenger.

The electrical power required for the cruise vessels in terms of time will be derived from the following expression:

$$Energy\ (kWh) = PL\ \left(\frac{kW}{passenger}\right) \cdot passengers \cdot berthing\ time\ (h)$$

Cruise ships’ electrical system specifications (operating voltage and frequency) vary according to the construction country of the vessel. The following results regarding voltage and frequency were derived by a sample of 30 cruise vessels with a passenger capacity from 2000 to 3500 passengers:

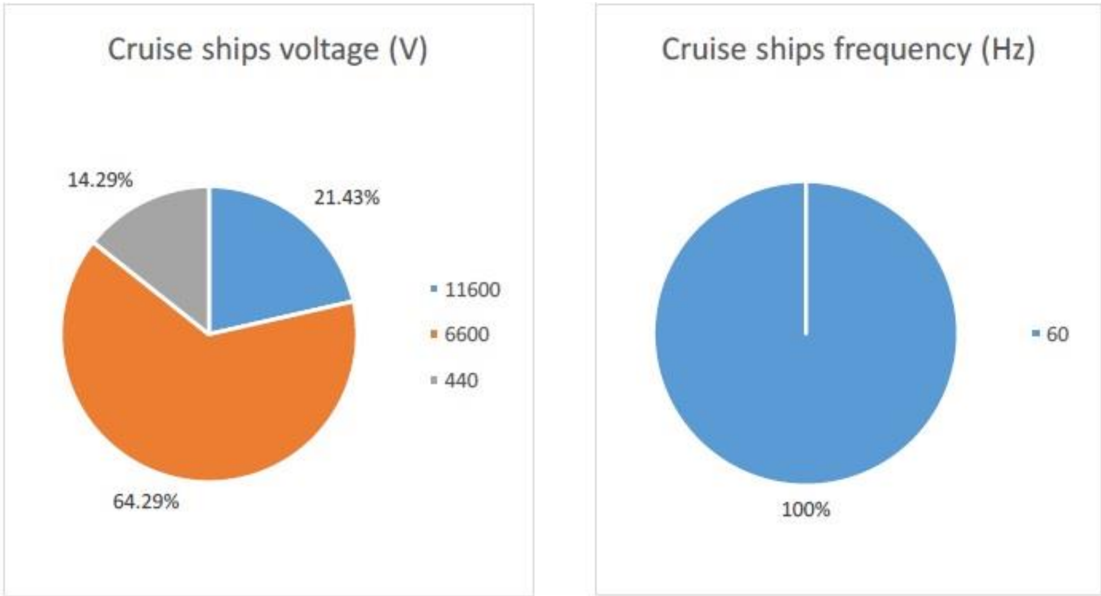


Figure 3.3 – Voltage and frequency characteristics for a 30 cruise vessel sample [1]

Finally, Piraeus' cruise berths will be designed according to the highest power demand of the vessels indicated in Table 3.5, thus, 11500 kW power demand per berth. Nevertheless, one berth can be dedicated for the berthing needs of a smaller cruise ship, since not all the vessels reach the highest power demand. By observing the traffic of cruise ships in Piraeus port, an amount of three cruise berthing places is sufficient. Their operating voltage will be either 6.6 kV or 11 kV. To sum up, assuming a power factor value of 0.8 the following characteristics will be applied for the cruise ship berthing places:

Table 3.6 - Cruise berthing places maximum power demand for Piraeus port [1] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	11500	14.375
2	11500	14.375
3	4800	6
Total	27800	34.75

3.1.3 Power demand analysis for Piraeus' Containerships

Containership Piraeus terminal traffic is showing a growing tendency the last years which lead to the construction of a 3rd pier to add a capacity of 2.7 million TEUs and to an increase of total capacity to 6.7 million TEUs. Ports calls were predicted using the arrivals schedule of 3 summer months on 2016 which was available in Piraeus Containership Terminal (PCT) website. Calculations of the PCT data showed that the average port calls at the containership terminal are around 190 per month. Assuming the same value in an annual rate, this means around 2300 containership calls per year. Their berthing time has an average of 19 hours at berth.

Containerships are categorized according to their length in feeders, with length less than 140 m and deep sea container vessels with length more than 140 m. Power demand analysis was not available due to lack of readily detailed information about the vessels approaching Piraeus port containership terminal, thus, power demands while at berth will be calculated using two other sources, a 2006 report conducted by Port of Rotterdam authority [11] and a dataset of 12 container vessels port calls in summer of 2016 which was obtained after a contact made with a major shipping company.

- <u>Port of Rotterdam research calculations</u>

Results of this research are depicted on the following charts:

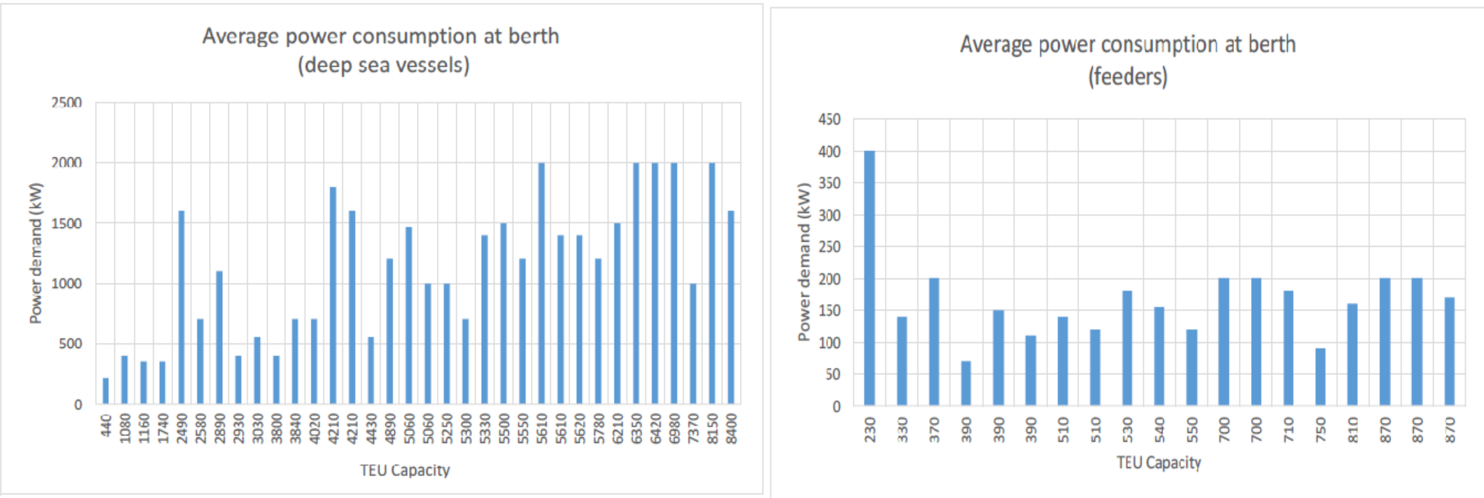


Figure 3.4 – Average power consumption for feeders and deep sea container vessels while at berth of Rotterdam port [1]

Feeder and deep sea container vessels' electrical system specifications (operating voltage and frequency) vary according to the construction country of the vessel. The following results regarding voltage and frequency were derived by the sources of researches:

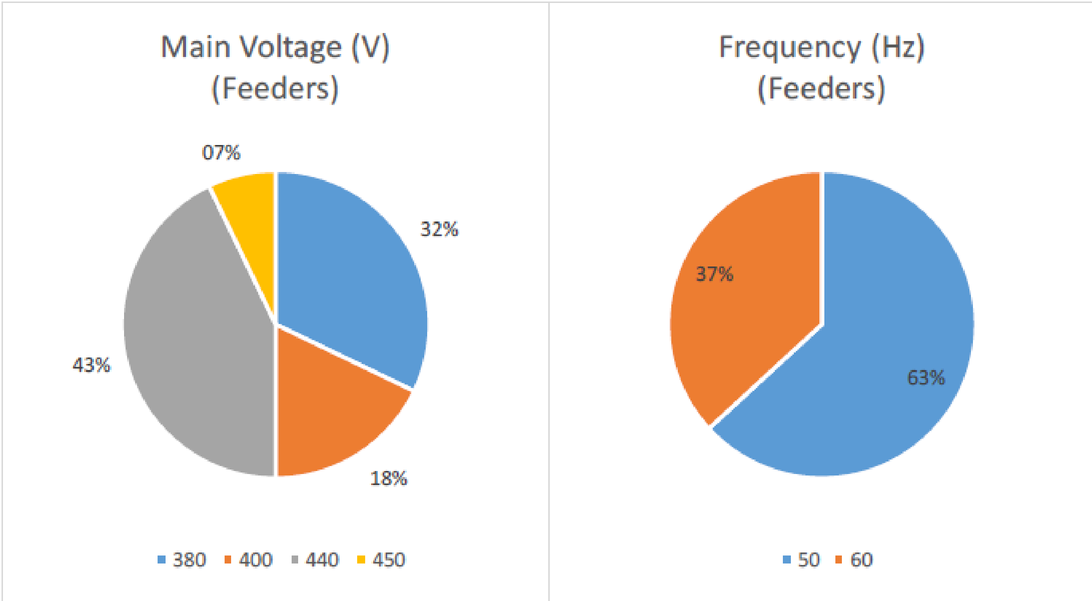


Figure 3.5 – Main voltage and frequency for feeders [1]

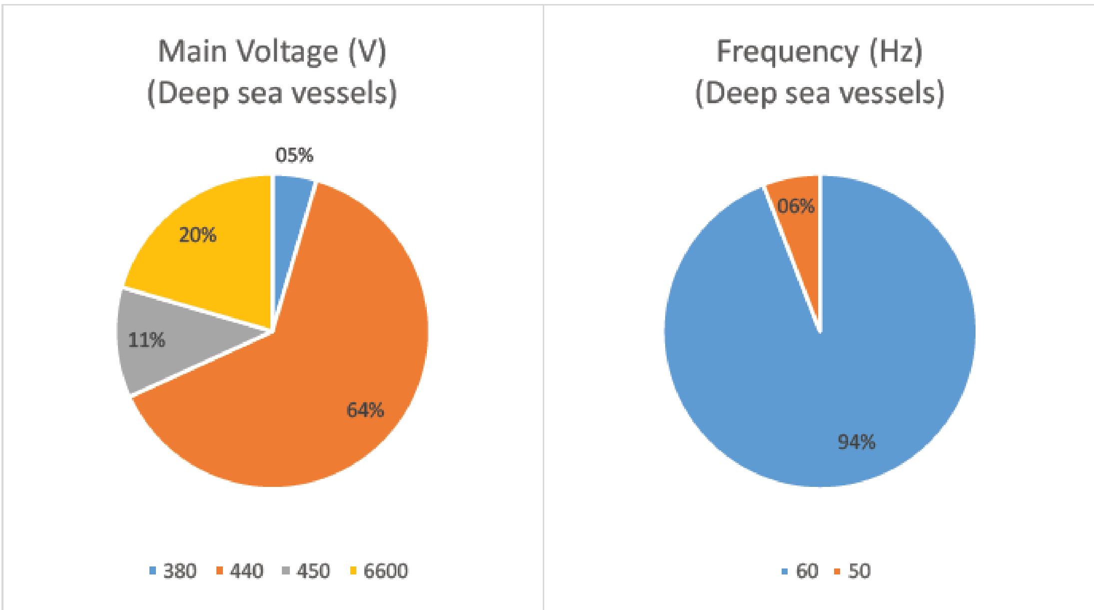


Figure 3.6 – Main voltage and frequency for deep sea vessels [1]

- <u>12 vessel dataset calculations</u>

The study of 12 vessel dataset was made in respect with more than 100 calls, TEU capacity, average and max hoteling load, total auxiliary system output, average and peak load factor for each vessel.

Results of the study are indicated on the following table and chart:

Table 3.7 – 12 containership data calculation [1]

TEU	Hoteling Load		Total D/G Output	Load Factor	Peak Load Factor
	Average	Max			
1068	344	616	3645	0.09	0.17
1810	518	796	5160	0.10	0.15
2240	857	2426	7832	0.11	0.31
3075	1236	3586	7760	0.16	0.46
4496	910	1262	6150	0.15	0.21
4496	751	1188	6150	0.12	0.19
4496	825	1161	6150	0.13	0.19
4824	1529	3431	8640	0.18	0.40
8850	1243	5938	12500	0.10	0.48
9662	1238	3099	14936	0.08	0.21
10484	1331	2146	9600	0.14	0.22
10484	1320	2122	9600	0.14	0.22
Average				0.13	0.27

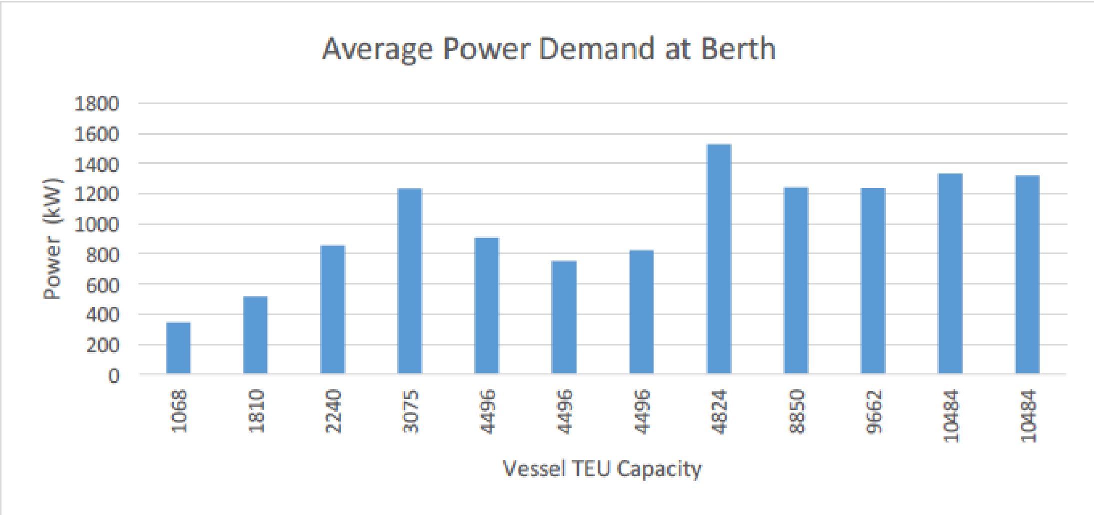


Figure 3.7 – Average power demand at berth [1]

Finally, Piraeus' containership berths will be designed according to the studies' results presented. The highest power demand was 6000-8000 kW and represented only to two out of 36 vessels, for this reason, only one berthing place will be designed with such a high power demand. By considering the rest of the presented results, the average berthing time and the traffic of these vessels in Piraeus port, designing of five more containership berthing places with significantly lower power demand presumed to be sufficient. Operating voltage will be set either in 6.6 kV or in 11 kV. To sum up, assuming a power factor value of 0.8 the following characteristics will be applied for the containership berthing places:

Table 3.8 - Containership berthing places maximum power demand for Piraeus port [1] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	3200	4
2	3200	4
3	3200	4
4	3200	4
5	3200	4
6	7200	9
Total	23200	29

3.2 Port of Killini case study

Port of Killini is located on the western Peloponnese region and its traffic is limited mostly to RoRo ferries. Five ferries are providing a connection of the shore with islands of Ionian Sea, including Zakynthos and Cephalonia.

Figure 3.8 – Port of Killini

The following description of Killini port case study is exclusively a result of Pantazopoulos Dionysios study [3] which will be briefly presented in this chapter.

Killini's port power demand analysis is much simpler than the one implemented for Piraeus port due to the less traffic and homogeneity between vessels' types which are berthing at it. Killini's port visiting vessels' information is indicated to the following table:

Table 3.9 –Killini's port visiting ferries' information [3]

	MARE DI LEVANTE	D. SOLOMOS	FIORE DI LEVANTE	NISSOS KEFALONIA	ZAKYNTHOS I
Voltage (ph-to-ph, V)	440	440	440	440	380
Frequency	60	60	60	60	50
Average power demand while in berth (kW)	250	250	250	200	150
Average power demand while in berth (kVA)	312.5	312.5	312.5	250	187.5
Fuel consumption while in berth (lt/hr)	60	80	80	90	12
Number of installed generators	3	3	4	3	3
Nominal generator ratings (kVA)	637,5	550	700	675	190
Nominal generator power factor	0,8i	0,8i	0,8i	0,8i	0,8i
Gross tonnage	4059	4309	9258	3924	2157
Length (m)	120,2	117	118,65	134	101,4

According to the operating characteristics of the five visiting ferries and the timetable information of the port, one berthing place of 0.44 kV voltage will be designed for the port of Killini with the following characteristics:

Table 3.10 – Killini's port berthing place power demand [3] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	400	0.5
Total	400	0.5

It is remarkable that Killini's port power demand is significantly limited comparing with this of Piraeus, a reasonable fact, since only five ferry vessels are visiting this port. Current's voltage is also limited at Medium Voltage (MV) values, counter to Piraeus design which included High Voltage (HV) current as well.

3.3 Port of Thessaloniki case study

Thessaloniki's port is the second largest port in Greece and one of the largest ports in Aegean Sea Basin. Port's traffic capacity contains 16 million tonnes (7 million tonnes dry bulk and 9 million tons liquid bulk). Container terminal has a total capacity of 4,696 TEUs and cargo terminal has a total storage area of 1,000,000 m^2. It also contains a gas & oil terminal with an annual traffic capacity of 9,000,000 tons per year and a passenger terminal serving the needs of thousands of native passengers and tourists annually.

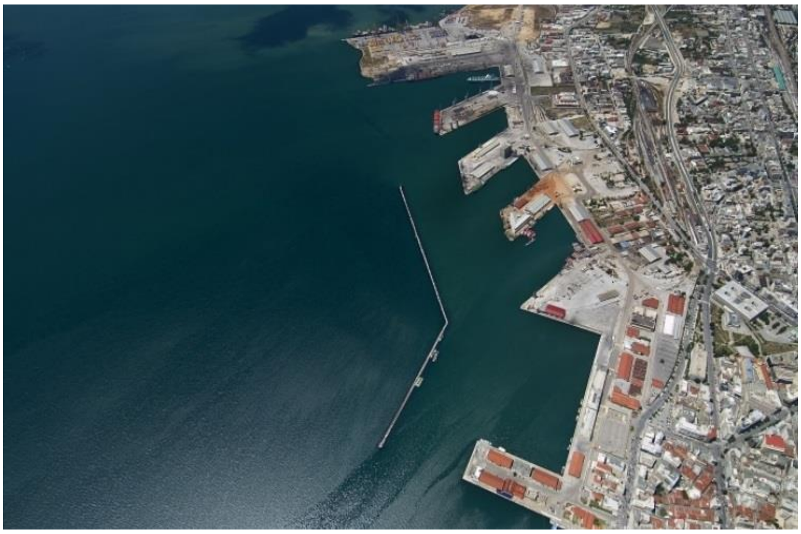


Figure 3.9 – Thessaloniki's port aerial view

Thessaloniki's port location is near the heart of city's center; therefore, an emission control perspective is high of importance for the national and local authorities and deserves a further study. This study was implemented by Kritikos Orfeas [2] and its contents will be briefly presented in this chapter.

Power demand analysis will be categorized once more by the vessel type.

3.3.1 Power demand analysis for Thessaloniki's Cruise vessels

22 cruise vessels which visited Thessaloniki's port on 2015 were included in this study. The following results describe the operating characteristics of these vessels and their length variation:

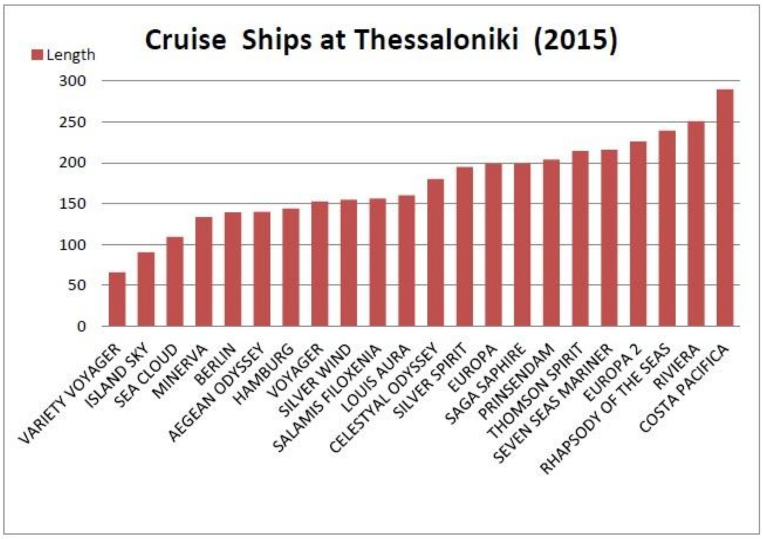


Figure 3.10 – Thessaloniki's port cruise vessels length variation [2]

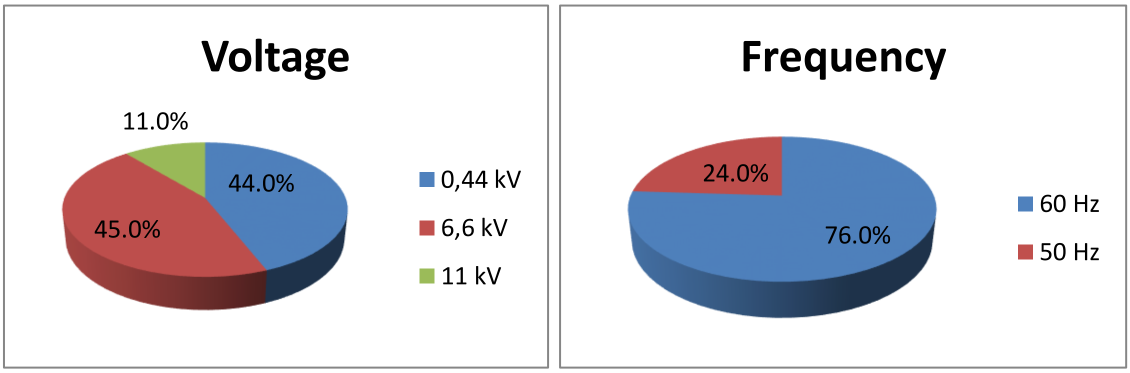


Figure 3.11 – Operating voltage and frequency of the 22 sample cruise vessels [2]

In the end, based on the aforementioned results, one berthing place will be generated for the Thessaloniki's cruise terminal with a voltage of 6.6 kV. Berthing place will have the following characteristics:

Table 3.11 - Cruise vessels' berthing place in Thessaloniki's port [2] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	8000	10
Total	8000	10

3.3.2 Power demand analysis for Thessaloniki's Bulk Carrier & General Cargo (GC) vessels

Out of 339 bulk carrier and GC vessels approaching Thessaloniki, 271 (80%) are less than 175 m. and 68 (20%) are larger. The following results describe the operating characteristics of these vessels and their length variation:

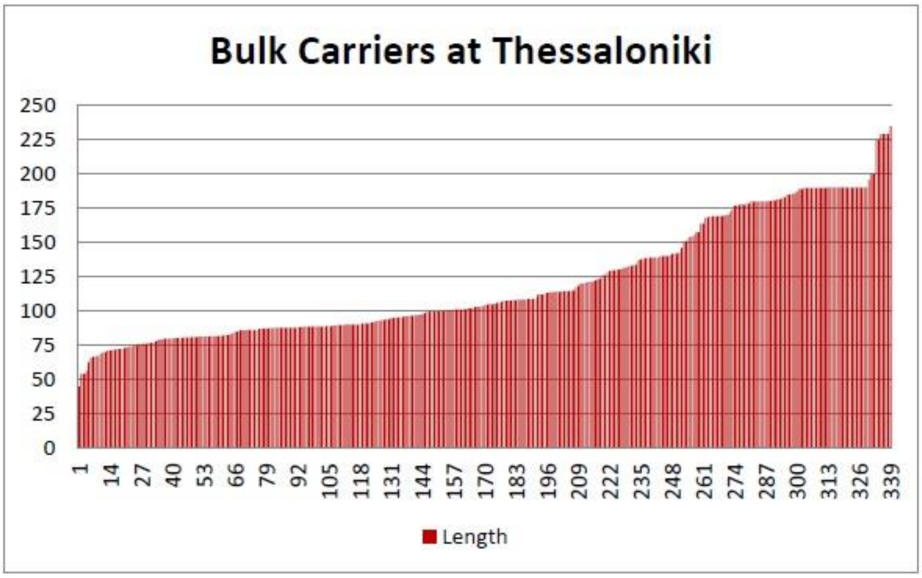
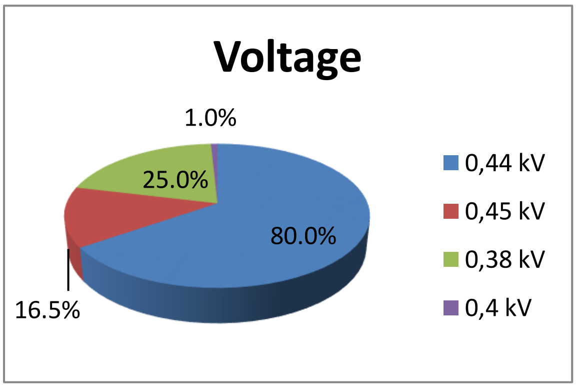


Figure 3.12 – Thessaloniki's port bulk carrier & GC vessels length variation [2]



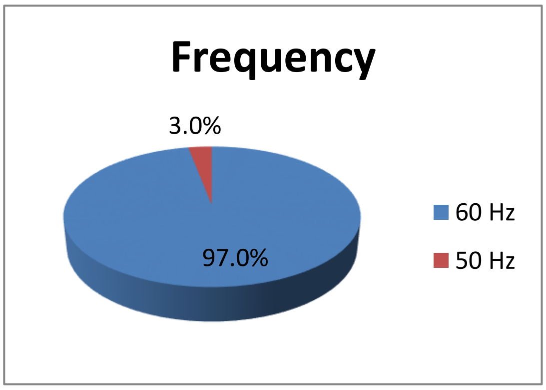


Figure 3.13 – Operating voltage and frequency of Thessaloniki's port bulk carrier & GC vessels [2]

Finally, based on the aforementioned results and that smaller vessels (<175 m), require an average mean power demand of 300 kW with a peak power demand of 1 MW while larger ships (>175 m) have mean and peak power demand approximately 1 and 3.5 MW respectively [2], three berthing places with lower power demand and 0.44 kV operating voltage and one berthing place with higher power demand and 6.6 kV operating voltage will be generated for the Thessaloniki's bulk carrier & GC vessels terminal. Berthing place will have the following characteristics:

Table 3.11 – Bulk carriers and GC vessels' berthing places characteristics in Thessaloniki's port [2] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	800	1
2	800	1
3	800	1
4	4000	5
Total	6400	8

3.3.3 Power demand analysis for Thessaloniki's Container vessels

68 container vessels which visited Thessaloniki's port were included in this study. The following results describe the operating characteristics of these vessels and their length variation:

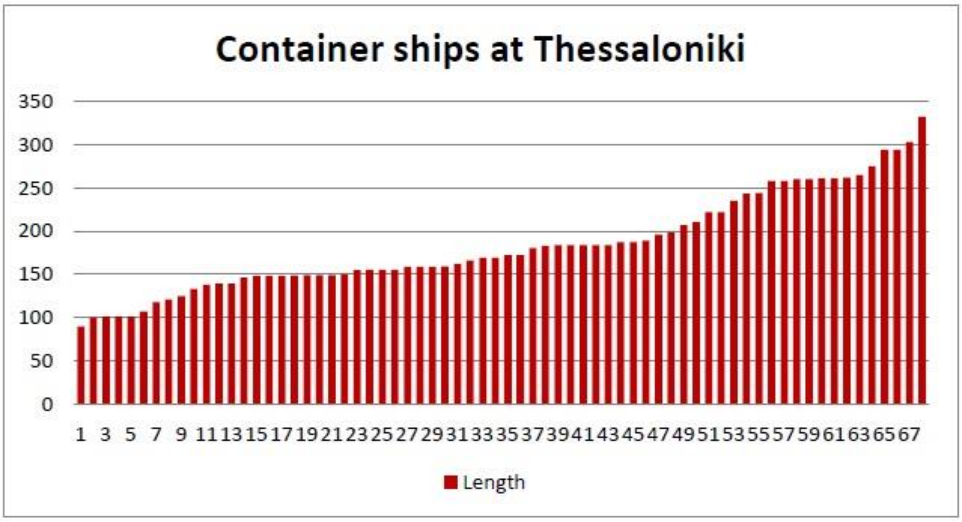
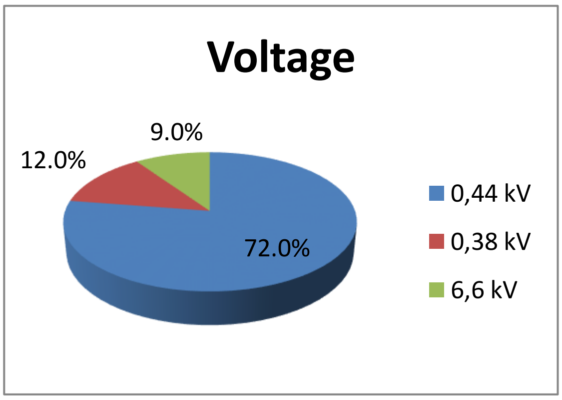


Figure 3.14 – Thessaloniki's port containerships' length variation [2]



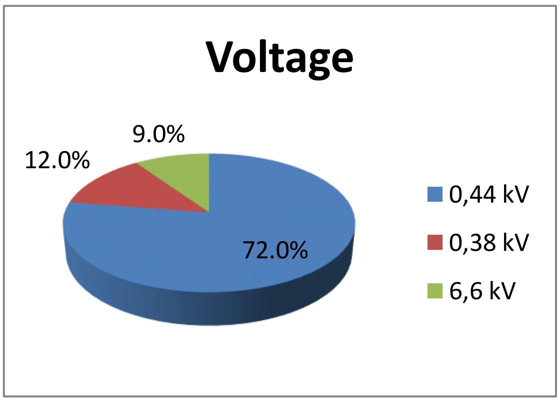


Figure 3.15 – Operating voltage and frequency of Thessaloniki's containerships [2]

13 vessels (19%) of the studied vessels were feeders, while 55 (81%) were deep sea container vessels. Based on the aforementioned results, two berthing places with high power demand and 6.6 kV operating voltage will be generated for the Thessaloniki's containership terminal. Berthing places will have the following characteristics:

Table 3.12 – Containerships' berthing places characteristics in Thessaloniki's port [2] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	6400	8
2	6400	8
Total	12800	16

3.4 Port of Patras case study

Port of Patras is a significant gateway for incoming and outgoing resources and passenger transportation through Ionian Sea. It consists of the northern part and the southern part. The southern part is used for the accommodation of the ships overnight and the northern for daily use.

Figure 3.16 - Patras port aerial view

A study was implemented about CI installation perspective in Patras' port by Daniil Antonis [4] and its contents will be briefly presented in this chapter. According to Patras port authority site, cruise ship calls are only a few, thus, cruise ships will not be part of this study.

3.4.1 Power demand analysis for Patras' RoRo ferry vessels

Available information about the power demand of the RoRo vessels' berthing in Patras' port was really limited [4]. Nonetheless, the present study was implemented with the assistance of other similar studies. The following information was obtained for the RoRo ferries power demand and electrical operating characteristics:

Table 3.13 – RoRo ferries power demand in Patras' port [4]

Ship name	DWT [tons]	Power demand [MW]
Hellenic spirit	6524	0.6
Olympic champion	6524	0.6
Asterion	7000	0.6
Euroferry Corfu	8111	1
Euroferry Olympia	11682	1.3
Superfast I	8500	2
Superfast II	7500	1.8

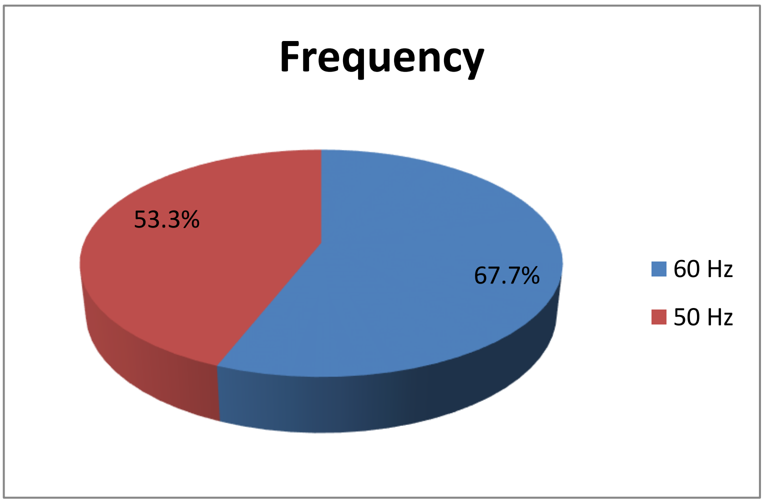


Figure 3.17 – Operating frequency for Patras' RoRo ferries [4]

From the scarce available information concerning operating voltage, it is defined that varies between 380 and 440 Volt.

Consequently, two berthing places for RoRo ferries were generated, operating on a 6.6 kV voltage with the following characteristics:

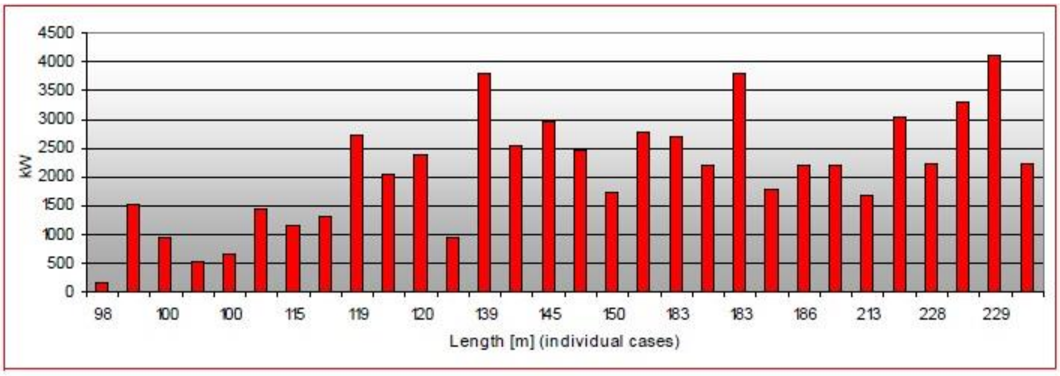
Table 3.14 – RoRo ferry vessels' berthing places' characteristics in Patras' port [4] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	3750	3
2	2500	2

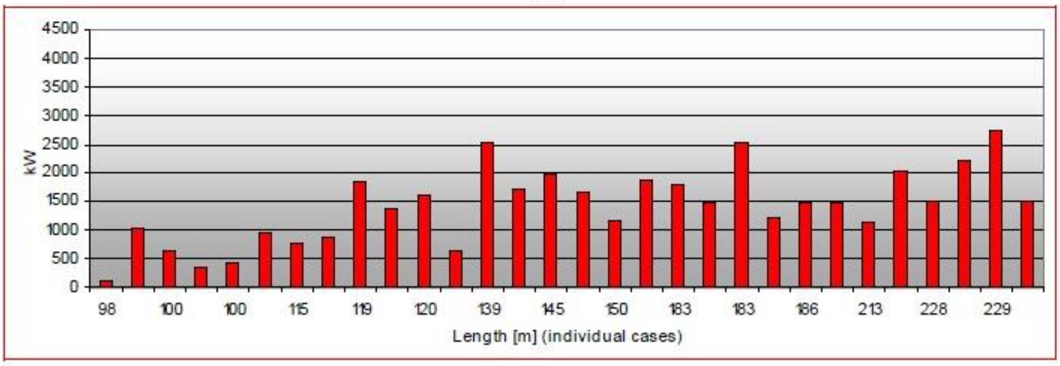
Total	6150	5

3.4.2 Power demand analysis for Patras' Tanker vessels

Information concerning power demand of the tanker vessels approaching port of Patras was not available for this study [4]; hence, general information for tankers was used, obtained by Patrick Ericsson and Ismir Fazlagić Master of Science Thesis [7]. The relevant information is indicated below:



(1)



(2)

Figure 3.18 – Tanker vessels' totally installed generation capacity onboard (1) and average power consumption at port (2) [7]

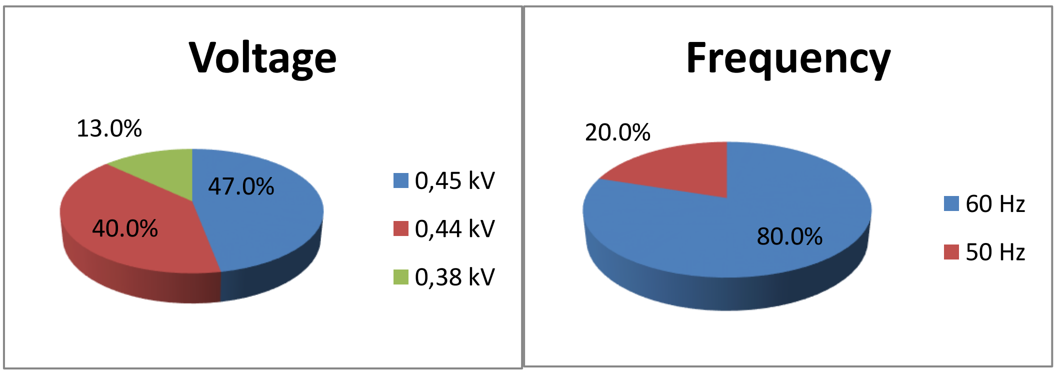


Figure 3.19 – Tanker operating voltage and frequency [7] used for Patras' port study [4]

According to the aforementioned analysis, one berthing place was designed for the accommodation of Patras' port tankers, operating in 6.6 kV voltage and the following power characteristics [4].

Table 3.15 – Tanker vessels' berthing place characteristics in Patras' port [4] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2500	2
Total	2500	2

3.4.3 Power demand analysis for Patras' Bulk Carrier and GC vessels

Voltage, frequency and mean/peak power demand references were made in this study [4] according to Thessaloniki's port case study [2], which is presented in Chapter 3.3.3.

Patras' port bulk carrier and GC vessel study concluded in the design of one berthing place operating in 6.6 kV voltage with the following power characteristics:

Table 3.16 – Bulk carrier & GC vessels' berthing place characteristics in Patras' port [4] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2500	2
Total	2500	2

3.5 Port of Heraklion case study

Heraklion city is located in central northern part of Crete's island. Heraklion port is one of the largest and busier ports in Mediterranean Sea. It contains five piers which service Container, General Cargo, Dry Bulk, Ferry and Cruise vessels.

Figure 3.20 – Port of Heraklion

A study was implemented about CI installation perspective in Heraklion's port by Pontikos Symeon [5] and its contents will be briefly presented in this chapter.

According to this study, the following vessels were registered berthing in the port of Heraklion:

Table 3.17 – Registered berthing vessels in Heraklion's port during this study [5]

Ship's name	DWT [tons]
RoRo Ferries	
KRITI II	5339
FESTOS PALACE	5493
KNOSSOS PALACE	7440
BLUE HORIZON	6005
CHAMPION JET 1	350
SUPERFERRY II	1029
HIGHSPEED 7	470
SUPERFERRY	1258
Bulk Carriers	
AQUAMARINE	10000
REECON EMIR	12513
DEMETRIOS B	5734
KRISTI I	3502
SEAVEN JOY	4753
ELIN POSEIDON	3842
AMETHYST	6375
Cruise vessels	
CELESTYAL OLYMPIA	5000
AEGEAN ODESSEY	4174
MSC LIRICA	6561
CELESTYAL CRYSTAL	1703
MARELLA DISCOVERY	5200
Tanker vessels	
EKO 3	3224
EKO 4	3224
EKO 5	3224

KARPATHOS	6247
ICE HAWK	15441
EVIA PETROL	2468

According to the registered vessels, a suggestion of 3 berthing places for RoRo ferries and one berthing place for bulk carriers & GC, cruise and tanker vessels respectively was composed during this study. A berthing place power demand analysis for each vessel will now follow.

3.5.1 Power demand analysis for Heraklion's RoRo Ferry vessels

A deadweight tonnage (DWT) – power demand relation can be formulated, showing that ships of high DWT will be expected to have a higher power demand, despite that, it doesn't mean that ships with similar DWT will have de facto adjacent power demand values. Since not abundant information for the power characteristics of RoRo ferry vessels was available, a combination of online research and previous researches for ships with similar dimensions concluded in the following results for the expected power demand of these vessels:

Table 3.18 – Power demand for RoRo ferries registered in Heraklion's port [5] (with a power factor = 0.8)

Ship's name	DWT [tons]	Power demand [MW]	Power output [MVA]
KRITI II	5339	1.4	1.75
FESTOS PALACE	5493	2.3	2.875
KNOSSOS PALACE	7440	2.3	2.875
BLUE HORIZON	6005	1.325	1.656
SUPERFERRY	1258	0.721	0.901
SUPERFERRY II	1029	0.721	0.901
HIGHSPEED 7	470	0.7	0.875
CHAMPION JET 1	350	0.968	1.21

Information concerning operating voltage and frequency of the RoRo ferry vessels approaching port of Heraklion was not available for this study [5], thus, general information for tankers was used, obtained by Patrick Ericsson and Ismir Fazlagić Master of Science Thesis [7]. The relevant information is indicated below:

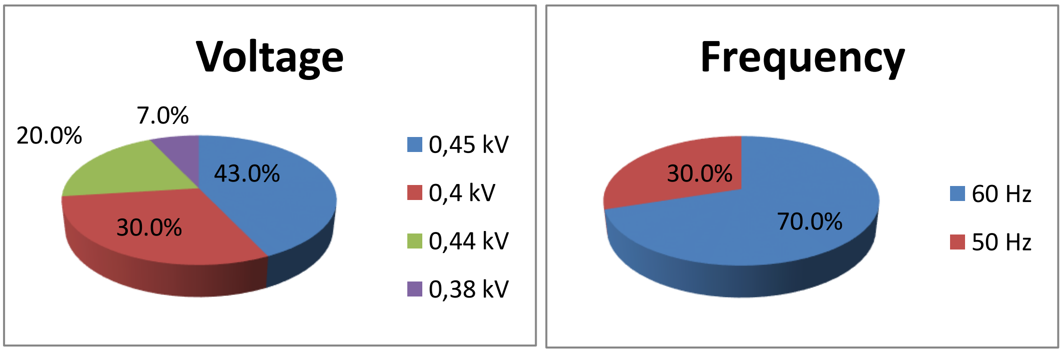


Figure 3.21 – RoRo ferry vessels' operating voltage and frequency [7] used for Heraklion's port study

According to port's timetable it was observed that mean berthing time for RoRo ferries in the port of Heraklion is 19 hours [5]. Consequently, three berthing places will be designed for RoRo ferry vessels, with one of them designed for the lowest power demand operating in 0.44 kV voltage, while the rest operate in 6.6 kV voltage. Results are indicated as follows:

Table 3.19 – RoRo ferries' berthing places power demand for Heraklion's port [5] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	1250	1
2	2500	2
3	3750	3
Total	7500	6

3.5.2 Power demand analysis for Heraklion's Bulk Carrier & GC vessels

Voltage and frequency analysis was made once again according to the Patrick Ericsson and Ismir Fazlagić Master of Science Thesis reference about product and oil tankers [7] which is indicated in Chapter 3.4.2. Power demand consideration for bulk carriers was made according to their length and DWT in a contiguous way of Thessaloniki's case study described in Chapter 3.3.2. Results are indicated as follows:

Table 3.20 – Bulk carrier & GC vessels' berthing places power demand for Heraklion's port [5] (with a power factor = 0.8)

Ship's name	DWT [tons]	Power demand [MW]	Power output [MVA]
REECON EMIR	12513	0.910	1.138
DEMETRIOS B	5734	0.951	1.188
KRISTI I	3502	0.964	1.205
SEAVEN JOY	4753	0.956	1.196
ELIN POSEIDON	3842	0.962	1.203
AMETHYST	6375	0.947	1.184

According to the abovementioned analysis, one berthing place for bulk carriers & GC vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

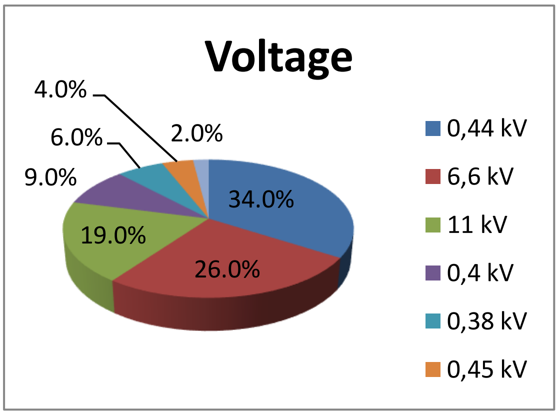
Table 3.21 – Bulk carrier & GC vessels' berthing place characteristics in Heraklion's port [5] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]

1	2500	2
Total	2500	2

3.5.3 Power demand analysis for Heraklion's Cruise vessels

Cruise vessels' power demand is related with the passenger capacity and their length. A Voltage and frequency analysis was made once again according to the Patrick Ericsson and Ismir Fazlagić Master of Science Thesis reference about cruise vessels [7]. It was observed that ships with length less than 200 m had significantly lower power needs. Concentrated results of this study are described as follows:



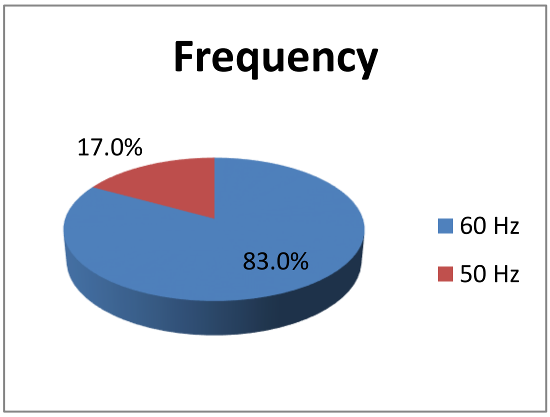


Figure 3.22 – Cruise vessels' operating voltage and frequency [7] used for Heraklion's port study

Power demand consideration for cruise vessels was made according to their length and DWT as follows:

Table 3.22 – Cruise vessels' berthing places power demand for Heraklion's port [5] (with a power factor = 0.8)

Ship's name	DWT [tons]	Power demand [MW]	Power output [MVA]
CELESTYAL OLYMPIA	5000	5	6.25
AEGEAN ODESSEY	4174	5	6.25
MSC LIRICA	6561	5	6.25
CELESTYAL CRYSTAL	1703	5	6.25
MARELLA DISCOVERY	5200	5	6.25

According to the abovementioned analysis, one berthing place for cruise vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

Table 3.23 – Cruise vessels' berthing place characteristics in Heraklion's port [5] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	12500	10

Total	12500	10

3.5.4 Power demand analysis for Heraklion's Tanker vessels

Voltage and frequency analysis was made once again according to the Patrick Ericsson and Ismir Fazlagić Master of Science Thesis reference about product and oil tankers [7] which is indicated in Chapter 3.4.2. Power demand analysis is described as follows:

Table 3.24 – Tanker vessels' berthing places power demand for Heraklion's port [5] (with a power factor = 0.8)

Ship's name	DWT [tons]	Power demand [MW]	Power output [MVA]
EKO 3	3224	0.812972	1.016215
EKO 4	3224	0.812972	1.016215
EKO 5	3224	0.812972	1.016215
KARPATHOS	6247	0.822041	1.02755125
ICE HAWK	15441	0.849623	1.06202875
EVIA PETROL	2468	0.810704	1.01338

According to the abovementioned analysis, one berthing place for cruise vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

Table 3.25 – Tanker vessels' berthing place characteristics in Heraklion's port [5] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2500	2
Total	2500	2

3.6 Port of Igoumenitsa case study

Figure 3.23 – Port of Igoumenitsa aerial view

City of Igoumenitsa is contained by two ports, the old port and the new one. A study was implemented about CI installation perspective in Igoumenitsa's new port by Mourkokosta Vasiliki [6] and its contents will be briefly presented in this chapter.

According to the information obtained by Igoumenitsa Port Authority S.A. (IPA – ΟΛΙ) Igoumenitsa's port traffic during 2017 was as described on the following table.

Table 3.26 – Igoumenitsa's port traffic in 2017 [6]

Month	Foreign Ferries	Local Ferries	Bulk Carrier & General Cargo	Transit	Cruise
January	231	473	109	1	0
February	223	455	108	1	0
March	244	530	94	0	0
April	244	658	112	0	0
May	232	633	89	0	2
June	245	830	64	0	1
July	318	1028	70	0	1
August	327	1142	102	0	2
September	271	1028	70	0	1
October	251	839	29	0	1
November	202	425	56	0	0
December	224	522	53	1	0
Total	3012	8593	956	3	8

Of the abovementioned traffic can be observed that RoRo ferries, bulk carriers/GC and cruise vessels are the ones worth for further examination of a CI installation perspective. Time spent in port for these vessels is indicated in the following table:

Table 3.27 – Time spent in Igoumenitsa's port in 2017 for study's vessels [6]

Ship's type	Different ships	Amount of berthing	Time spent in port [hours]	Average time [hours]
RoRo ferries	15	2990	8060.5	2.696
Bulk Carriers / General Cargo	5	21	657	31.29
Cruise	2	8	120.5	15.06

3.6.1 Power demand analysis for Igoumenitsa's RoRo Ferry vessels

Information for the power characteristics of RoRo ferry vessels approaching Igoumenitsa's vessel was obtained either by Greek shipping companies or from previous researches for ships with similar dimensions. A deadweight tonnage (DWT) – power demand relation can be formulated, showing that ships of high DWT will be expected to have a higher power demand. As a conclusion, the following results for the expected power demand of these vessels are available:

Table 3.28 –Igoumenitsa's port RoRo ferry vessels power demand and DWT [6] (with a power factor = 0.8)

#	Ship's name	DWT [tons]	Power demand [MW]	Power output [MVA]
1	SUPERFAST 1	8500	2	2.5
2	SUPERFAST 2	7500	1.8	2.25
3	SUPERFAST XI	6574	1.8	2.25
4	OLYMPIA CRUISE	8351	2.553	3.19125
5	CRUISE EUROPA	8351	2.23	2.7875
6	EUROFERRY OLYMPIA	11682	1.3	1.625
7	EUROFERRY EGNAZIA	10700	1.3	1.625
8	OLYMPIC CHAMPION	6524	1.8	2.25
9	ASTERION	7000	1	1.25
10	HELLENIC SPIRIT	6524	0.6	0.75
11	BARI	1490	0.9	1.125
12	RIGEL I	1775	0.9	1.125
13	GALAXY	1571	0.9	1.125
14	SUPERFAST XII	6578	1.8	2.25

Time spent in port for the vessels indicated in Table 3.28 varies from 1.5 to 4.5 hours daily. Operating frequency for the majority of the vessels is 50 Hz because they are constructed in Europe. Results of the operating frequency variation are indicated as follows:

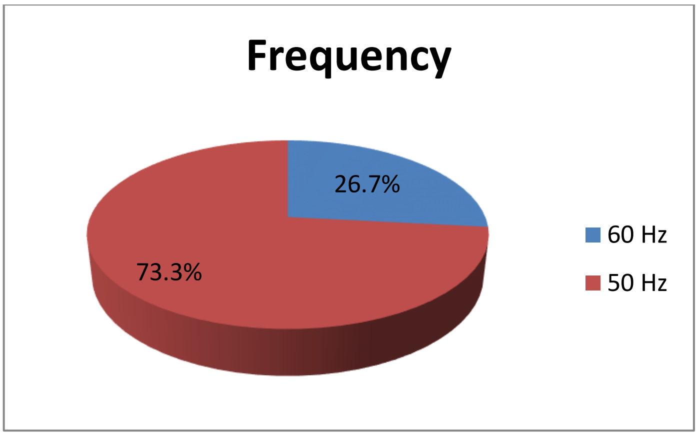


Figure 3.24 – RoRo ferry vessels' visiting Igoumenitsa's port operating frequency [6]

Operating voltage of the vessels indicated in Table 3.28 varies from 380 Volts to 450 Volts. According to the abovementioned analysis, two berthing places for RoRo ferry vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

Table 3.29 – Bulk carrier & GC vessels' berthing place characteristics in Igoumenitsa's port [6] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2500	2
2	3750	3
Total	6250	5

3.6.2 Power demand analysis for Igoumenitsa's Bulk Carrier & General Cargo vessels

Voltage and frequency analysis was made once again according to Kritikos Orfeas study for bulk carrier and GC vessels [2] which is indicated in Chapter 3.3.2. A list of the vessels approached Igoumenitsa's port at 2017 was obtained by IPA [6] and power demand analysis was made according to their DWT. Their berthing time varies from 15 hours to 4 days. Power demand is described as follows:

Table 3.30 –Igoumenitsa's port bulk carrier & GC vessels power demand and DWT [6] (with a power factor = 0.8)

#	Ship's name	DWT [tons]	Power Demand [kW]	Power output [MVA]

1	AMETHYST (CEMENT CARRIER)	6375	0.94725	1.18406
2	AQUAMARINE (CEMENT CARRIER)	6000	0.9495	1.18688
3	AMIRA LEEN	4652	0.95759	1.19699
4	EVIACEMENT IV(CEMENT CARRIER)	5016	0.9554	1.19426
5	NS MERMAID	2302	0.97169	1.21461

According to the abovementioned analysis, one berthing place for bulk carrier & GC vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

Table 3.31 – Bulk carrier & GC vessels' berthing place characteristics in Igoumenitsa' port [6] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	2500	2
Total	2500	2

3.6.3 Power demand analysis for Igoumenitsa's Cruise vessels

Cruise vessels' power demand is related with the passenger capacity and their length. A Voltage and frequency analysis was made according to Pontikos Symeon study [5] which was described in Chapter 3.5.3. A list of the vessels approached Igoumenitsa's port at 2017 was obtained by IPA [6] and power demand analysis was made according to their length and DWT. Their berthing time was approximately 13.5 hours. According to the abovementioned analysis, one berthing place for cruise vessels will be designed, with operating voltage of 6.6 kV and power characteristics as follows:

Table 3.32 – Cruise vessels' berthing place characteristics in Igoumenitsa' port [6] (with a power factor = 0.8)

Berthing Place	Power Demand [kW]	Power output [MVA]
1	12500	10
Total	12500	10

3.7 Summary of Greek port CI installation researches

A summary of the CI installation researches implemented for Greek ports is following. In most of the study cases a 6.6 kV selection was chosen for the design of the berthing places instead of 0.44 kV to reduce the cable amperage loading.

Table 3.33 – Summary of the designed berthing places for Greek ports

Port	Vessel type						Power demand [MVA]
	RoRo Ferries	Cruise	Conteineships	Bulk Carriers & General Cargo Ships	Tankers	Total	
Piraeus	5	3	6	0	0	14	76.625
Thessaloniki	0	1	2	4	0	7	34
Patras	2	0	0	1	1	4	9
Kilini	1	0	0	0	0	1	0.5
Igoumenitsa	2	1	0	1	0	4	20
Heraklion	3	1	0	1	1	6	17

4. Program Presentation

4.1 Purpose of Implementation

Researches regarding CI installations have a growing rate over the last years. The reasons have been examined thoroughly in the previous chapters and the main goal which is staying foreground nowadays is the minimization of emissions while vessels are in port. A complete method of implementing such a research including quickness and simplicity over the tons of calculations is missing among the academic and enterprise communities. Hence, a computational application providing the majority of the techno-economical information needed for such a study seemed to be more than necessary. The main characteristics missing from regular computational methods (e.g. spreadsheet programs) for implementing such researches were the main purpose to be optimized during this dissertation.

4.2 Implementation process

The implementation process was made according to the already carried out CI installation researches referenced in this dissertation. Coding was made in Microsoft's Visual Basic.NET (VB.NET) programming language. VB.NET programming language uses a graphical user interface (GUI). VB.NET's GUI graphical construction renders the coding upon a manually constructed interface possible. Dynamic modification actions during runtime are controlled by a written code based on user's interaction with program's interface options. Microsoft's Visual Studio (VS) is an integrated development environment which was used for the code running and results' presentation. The combination of these two programmatic tools provided intelligence and clarity during their operation through the Visual Studio's IntelliSense (intelligent code completion) feature which facilitates the completion, mistake detection and correction of the code. Consequently a faster and comfortable procedure took place during the project's implementation.

Four steps were followed for the integration of this application. Firstly, an interface was designed according to the main concept and the requirements of the CI installation researches presented in Chapter 3. Options provided in this interface include data presentation among calculation procedures; thus, the second step was to import the required data - in a database form– to be displayed to the user and facilitate the selection procedure. A database of each port's berthing places (BPs) design was made as well as separate databases for equipment selection. Third step was the most challenging one because it did not contain only a coding procedure into which calculations will be executed, but it also contains multiple options of equipment selection according to user's perspective. Lastly, a techno-economic report was designed in a report form including the equipment selection and a financial division upon it.

A presentation of program's contents and functions through its interface, dataset's import data and program's calculation procedure will follow in Chapter 4.3. Any connection with Chapter 3 analysis will be done when required.

4.3 Program’s contents and functions

4.3.1 Initial page design

The initial page design introduces to the user the first functions of the program. A welcome message shows up when the user opens the program. When this message is closed by the user a couple of different tabs can be easily observed. User can navigate himself/herself by clicking each tab and get introduced with every tab purpose. Program’s initial page is depicted in the following figure.

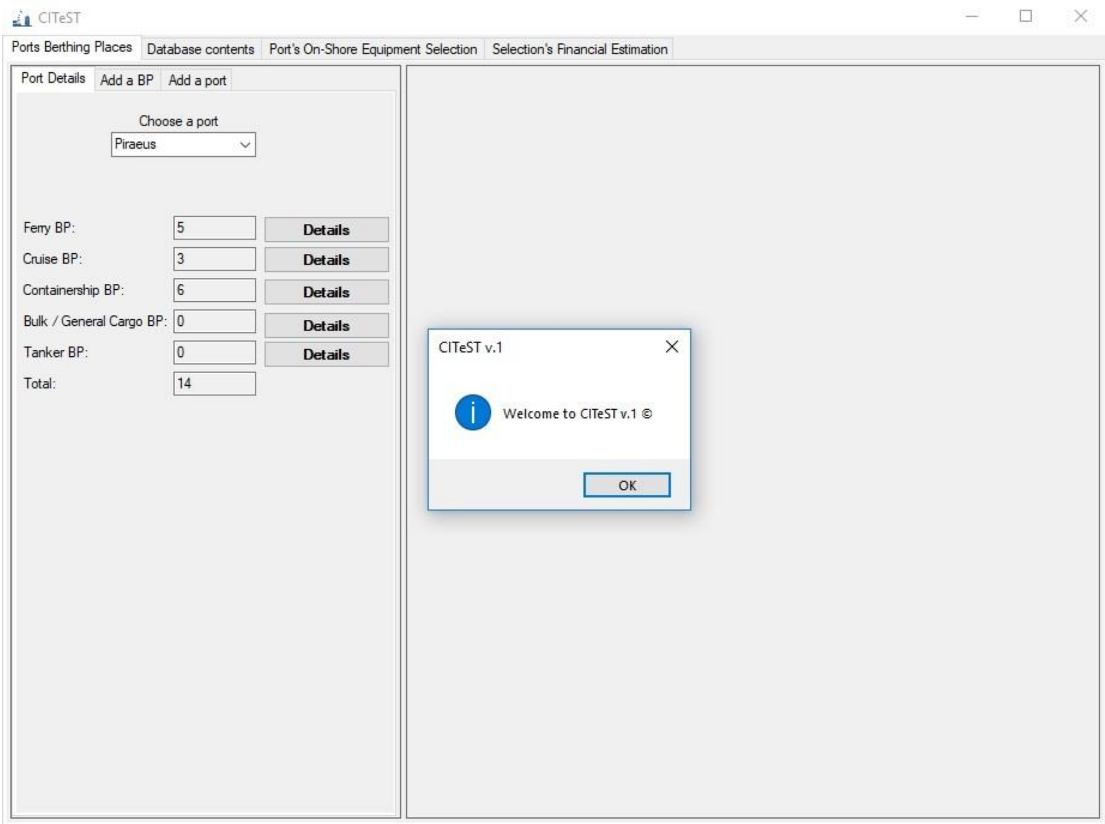


Figure 4.1 – Program’s initial page and welcome message

Program’s initial page contents are:

- “Port’s Berthing Places” tab, including:
  - “Port Details” tab
  - “Add a BP” tab
  - “Add a port” tab
- “Database Contents” tab
- “Port’s On-Shore Equipment Selection” tab including
  - “Main Substation” tab
  - “Primary Cable Arrangement” tab
  - “Shore-side Transformer Station” tab
  - “Shore-side Connection Arrangement” tab

- “Selection’s Financial Estimation” tab

4.3.2 “Port’s Berthing Places” tab

“Port’s Berthing Places” tab contents will be explained furthermore one by one.

4.3.2.1 “Port Details” tab

“Port Details” tab include information about each port’s designed berthing places. A scroll down menu was used to allow the user to change port selection. “Details” buttons are used to provide extended information about the chosen port and a specific ship type that was designed to be accommodated for SSP supply. Data import was made according to the analysis made in Chapter 3, based on already implemented studies, thus the following choices exist in port selection scroll down menu:

- Piraeus
- Thessaloniki
- Patras
- Killini
- Igoumenitsa
- Heraklion

In the same way, berthing places design option was made for the following ship types:

- Ferries
- Cruise vessels
- Containerships
- Bulk Carriers / General Cargo vessels
- Tankers

An example of clicking the “Details” button for Piraeus port Ferry BP is depicted on the following figure.

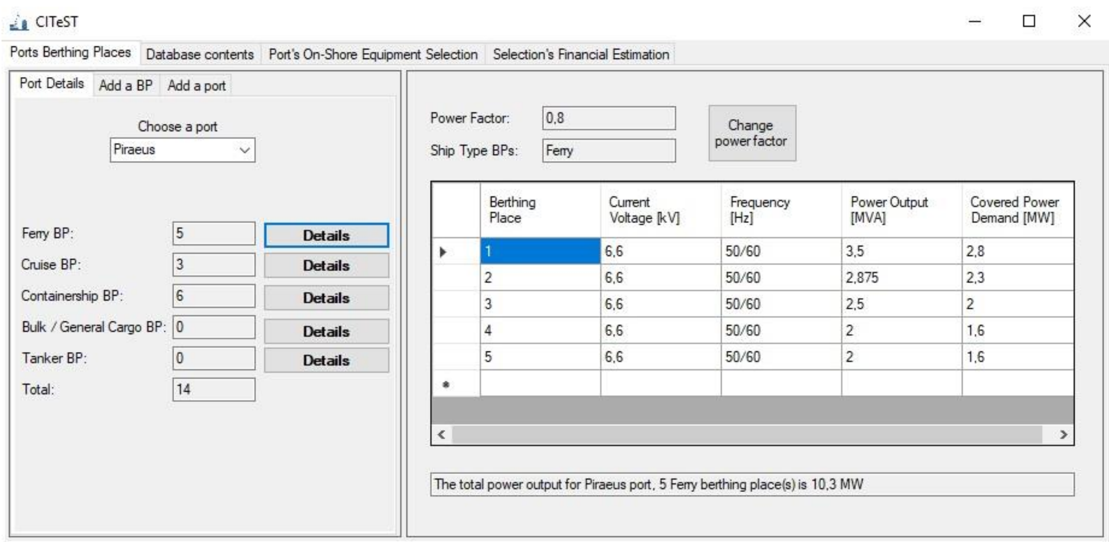


Figure 4.2 – 'Details" button click results example

Detailed information for each designed berthing place is given after the "Details" button is clicked, including:

- Berthing place's index
- Berthing place's operating voltage in kV
- Berthing place's operating frequency in Hz
- Berthing place's power demand coverage in MW
- Berthing place's power output in MVA

Berthing place's power demand coverage is a function of BP's power output and power factor. This function is described as follows:

$$Covered\ power\ demand\ [MW] = Power\ output\ [MVA] \cdot power\ factor$$

According to Chapter 3 analysis, representative results were taken by the usage of a 0.8 value for the power factor constant. Nevertheless, a power factor modification option is given through the "Change power factor" button which is depicted in Figure 4.2 as well.

A text box is used on the lower side of program's window to give a summary of the detailed information depicted right above it.

4.3.2.2 "Add a BP" tab

"Add a BP" tab is featured to allow the user to add a BP in a port's design. The required information for this function is the same depicted in Figure 4.2 for the already designed BPs, i.e. type of the ship serviced by this BP, current's voltage [kV], current's frequency [Hz] and power output [MVA]. An illustration of "Add a BP" is following in Figure 4.3.

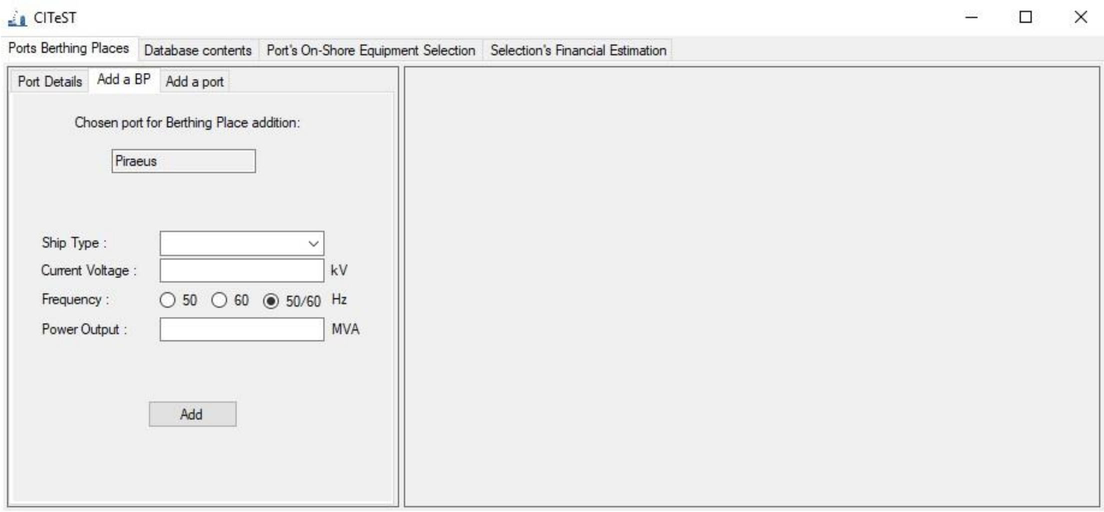


Figure 4.3 – "Add a BP" tab

As it can be seen in Figure 4.3, ship type specification is given through a scroll down menu and frequency values are given through VS's radio button option. This configuration not only facilitates user's input data practice, but also limits the input data between certain boundaries in which they must stay.

4.3.2.3 "Add a port" tab

"Add a port" tab is featured to allow the user to add a new port in program's database. Since the new port's name is typed by the user and "Proceed to BP addition for this port" button is clicked, a transition to a new window occurs where user can add the first BP for the recently added port. Configuration of this tab as well as the results of "Proceed to BP addition for this port" button click is depicted in Figure 4.4.

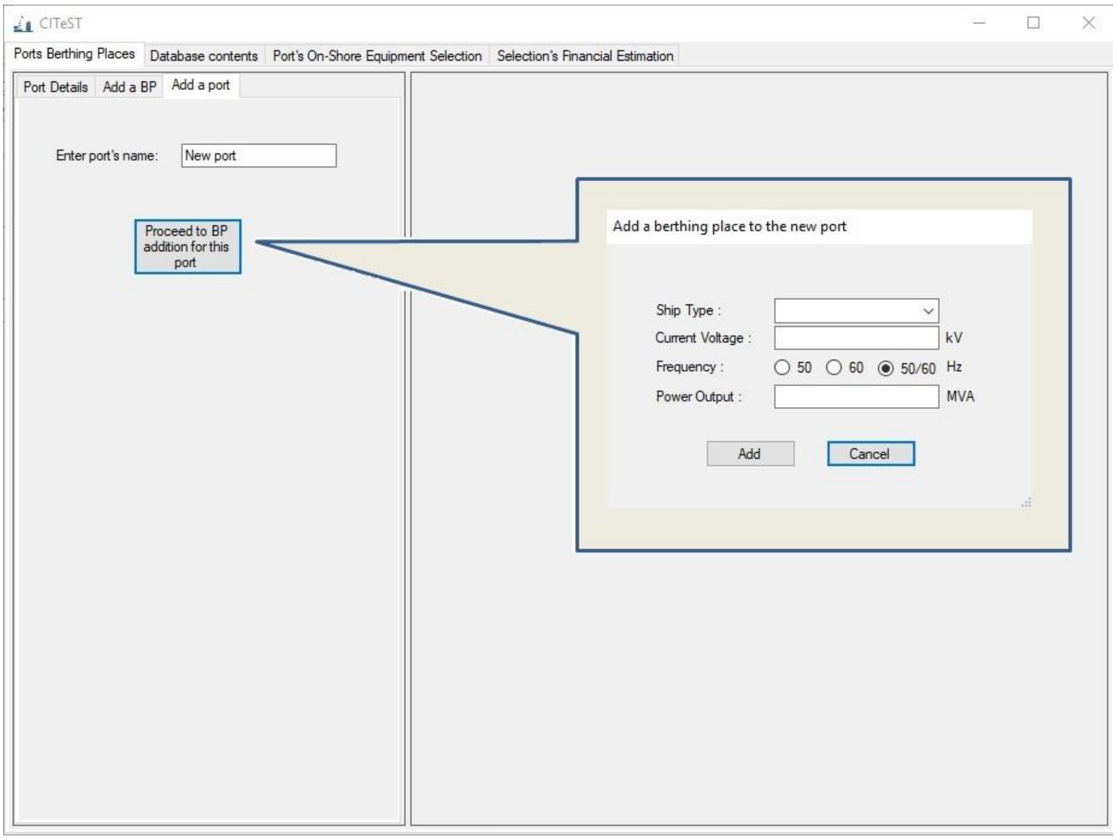


Figure 4.4 – "Add a port" tab and "Proceed to BP addition for this port" button click results

The required input data for the last emerged window for BP addition are the same with those in "Add a BP" tab.

4.3.3 "Database Contents" tab

"Database Contents" tab provides two options to the user, either to be informed about the data which are embedded in the program and/or to modify the already implemented design by removing a BP for a port of choice. “Database Contents” tab is illustrated in Figure 4.5 where configuration for BP removal can be observed.

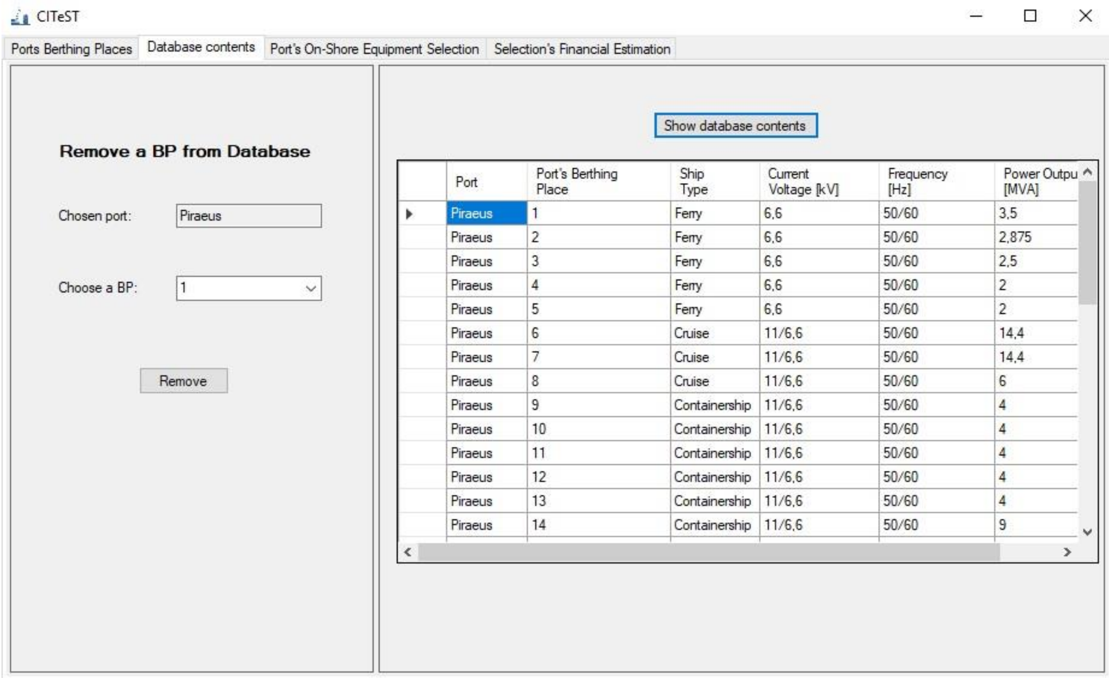


Figure 4.5 - “Database Contents” tab

Database contents are revealed after “Show database contents” button is pressed. Database contents include the following characteristics (see Chapter 4.4 also):

- BP’s port name
- Berthing place’s index (by port reference)
- BP’s ship type
- Berthing place’s operating voltage in kV
- Berthing place’s operating frequency in Hz
- Berthing place’s power output in MVA

Concerning the removal procedure, on the left side of the tab, a text box where the selected port is declared as well as a scroll down menu for the selection of BP’s index intended for removal have been placed.

4.3.4 “Port’s On-Shore Equipment Selection” tab

“Port’s On-Shore Equipment Selection” tab comprises four different tabs as described in Chapter 4.3.1. In every tab the major required equipment can be added in a port’s design for CI installation, so a complete financial approach for a selected port can be done afterwards. This tab is indissolubly linked with the equipment analysis made in Chapter 2 and Patrick Ericsson’s and Ismir Fazlagić’s Master of Science Thesis approach [7] of the equipment topic. A tab by tab analysis will follow to get the reader adapted with the function of each one of them.

4.3.4.1 "Main Substation" tab

"Main substation" tab is relevant with the equipment located in the main substation of the configuration described in Chapter 2.5. In this tab, a frequency converter addition is the main request for the user. Frequency converter cost was assessed based on its power output; hence, a concept of minimizing cost perspective was adopted for a suggested frequency converter addition option. This concept is applied when a generation button is clicked by the user. Nonetheless, a manual frequency converter selection option is also available. Configuration of this tab is illustrated in the following figure.

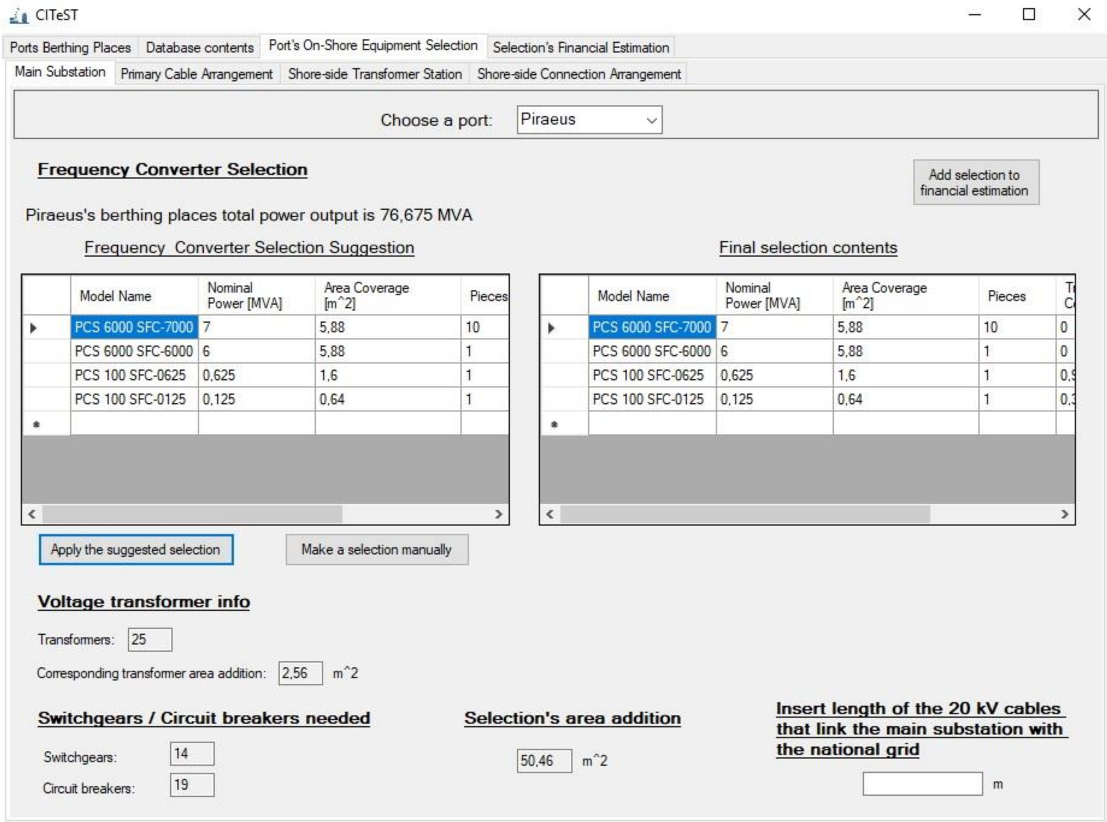


Figure 4.6 – "Main Substation" tab

As illustrated in Figure 4.6, this tab contains a few different topics which are linked with the frequency converter selection. "Main Substation" tab contains the following topics:

- "Frequency Converter Selection" topic
- "Voltage transformer info" topic
- "Switchgears / Circuit breakers needed" topic
- "Selection's area addition" topic
- "Final selection contents" topic
- "Insert length of the 20 kV cables that link the main substation with the national grid" topic

“Frequency Converter Selection” topic contains information about the program’s suggested selection. This suggestion is done for a frequency converter selection with the minimum power output that covers the power demand of a port’s main substation. In case the suggested selection is selected by the user by clicking the “Apply the suggested selection” button”, almost all the other topics’ information is automatically filled with the required equipment amount for the operational function of the main substation.

Program’s suggestion for frequency converter addition is not mandatory to be selected by the user; contrariwise, a manual selection option is available to be selected by the user. User can select manually the type and amount of frequency converter he/she wants to add on main substation’s configuration. Manual selection can be implemented be clicking the “Make a selection manually” button. When this button is clicked, a new window will emerge as illustrated in Figure 4.7.

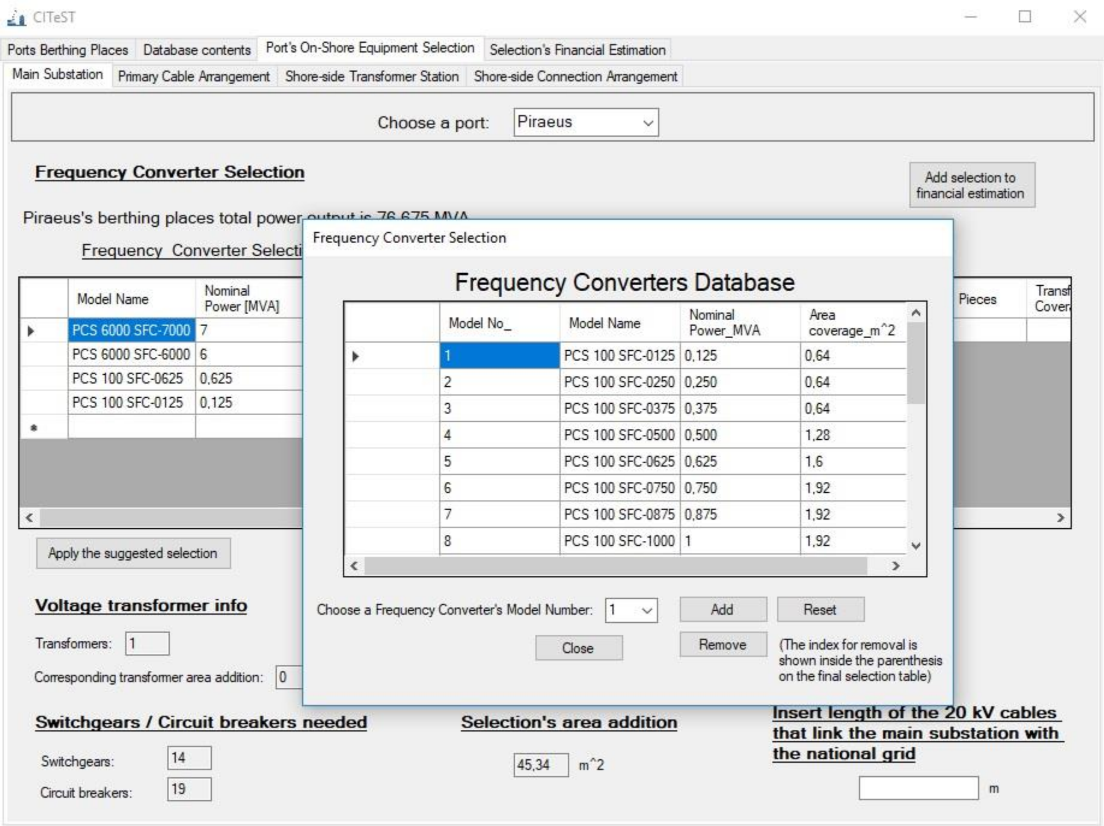


Figure 4.7 – Frequency converter manual selection option window

This window contains a list of frequency converters obtained by a frequency converter database (see Chapter 4.4 also). Database contents include the following characteristics:

- Frequency converter’s index number
- Frequency converter’s model designation
- Frequency converter’s power output in MVA
- Frequency converter’s area coverage

Area addition text boxes are filled with the additional area covered by the rest of the equipment including voltage transformers, switchgears and circuit breakers.

After the last topic's text box is filled with the length of the required cables destined for the connection of the main substation with the national grid, the user can dispose his/her selection for a financial estimation by clicking the "Add selection to financial estimation" button.

4.3.4.2 "Primary Cable Arrangement" tab

Chapter's 2.5 proposed configuration defines the connection of port's main substation with the shore-side transformer station with 20 kV cables. "Primary Cable Arrangement" tab allows the user to insert the required length of these cables between shore-side station of each ship type BPs and main substation. Configuration of this tab is illustrated in the following figure.

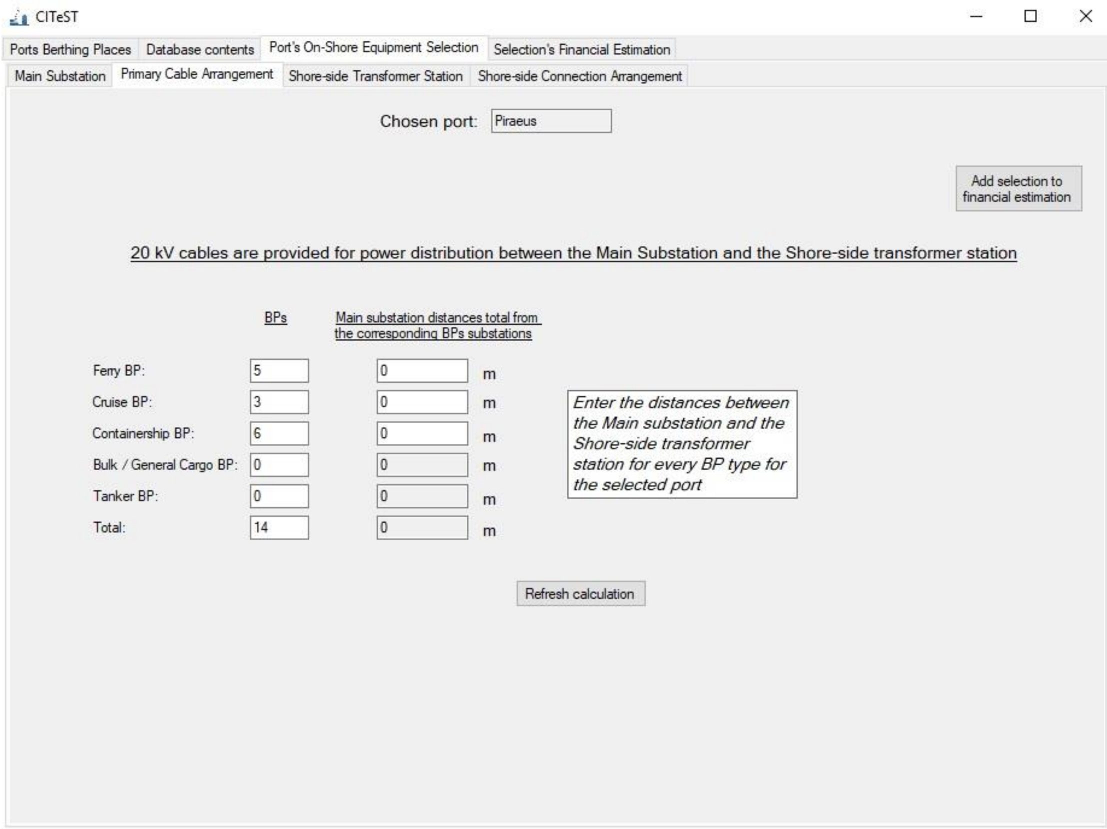


Figure 4.8 - "Primary Cable Arrangement" tab

When "Refresh calculation" button is pressed, results of the corresponding cable length for each BP's substation addition are shown in the last text box of the right column. Thereafter, the user can dispose his/her selection for a financial estimation by clicking the "Add selection to financial estimation" button.

4.3.4.3 "Shore-side Transformer Station" tab

"Shore-side Transformer Station" tab features the equipment needed for the operational function of the BP's shore-side transformer station. Configuration of this tab is illustrated in the following figure.

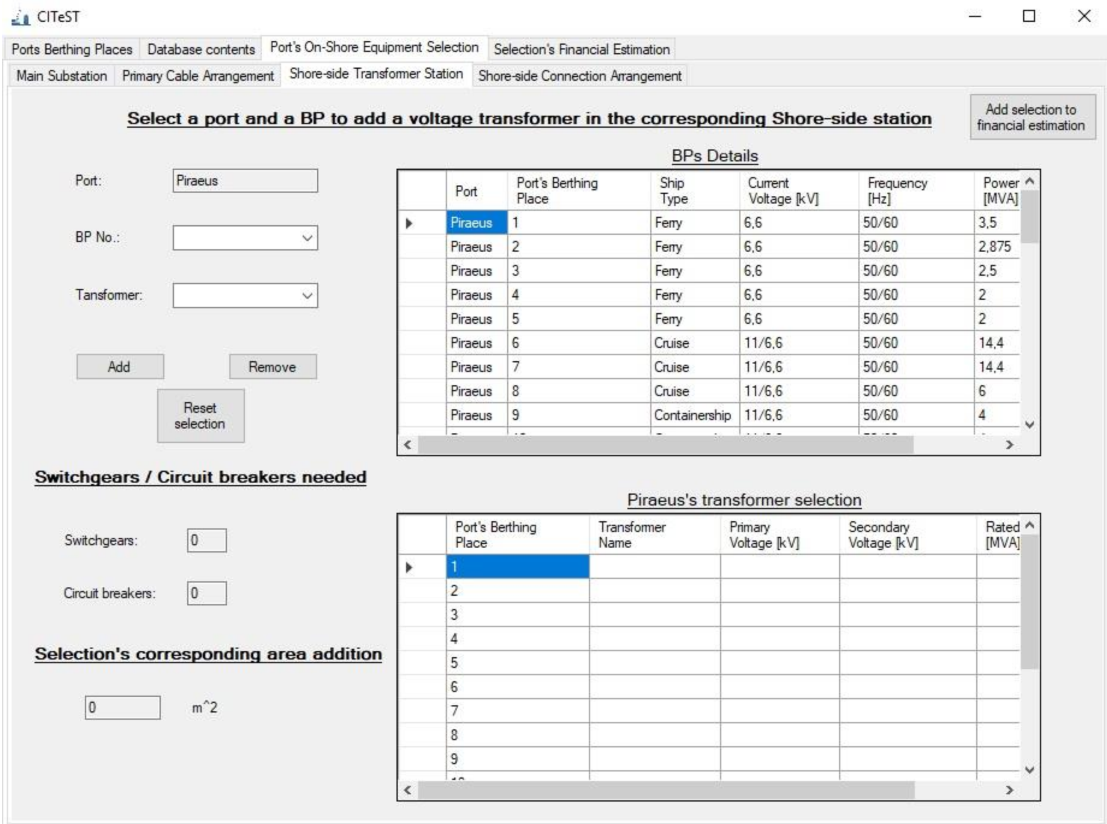


Figure 4.9 - "Shore-side Transformer Station" tab

As illustrated in Figure 4.8, this tab contains three different topics which are linked with the voltage transformer selection. "Shore-side Transformer Station" tab contains the following topics:

- "Select a port and a BP to add a voltage transformer in the corresponding Shore-side station" topic
- "Switchgears / Circuit breakers needed" topic
- "Corresponding area addition" topic

In this tab, program asks the user to add a transformer to each BP. Since the port selection has been defined in the previous tab, port's BPs' characteristics are illustrated in the "BPs Details" table on the upper part of the tab. User can choose a BP by clicking the "BP No" labeled scroll down menu and define the index shown on the "BPs Details" table for the desirable BP. When a BP is chosen, user can proceed to the voltage transformer selection for the corresponding BP by the "Transformer" labeled scroll down menu. Four voltage transformers are imported in the program as a selection option. Complete characteristics for these transformers are given in Appendix's Chapter 7.1.

Voltage transformer addition is completed when the user presses the “Add” button. Afterwards all the other topics’ information is automatically filled with the required equipment amount for the operational function of the shore-side station, including the port’s transformer selection table which is located in the lower part of the tab. Besides the addition option, a selection’s further manipulation is possible. A removal option exists by simply selecting the BP index in which voltage transformer is added and pressing the “Remove” button. Moreover, when “Reset selection” button is clicked, contents of port’s transformer selection table are eliminated and a new selection is possible.

Area coverage of each transformer is 2.85 m^2 for ABB SCR10-1000 transformer and 8 m^2 for the rest models (more information about used voltage transformer models can be found in Appendix’s Chapter 7.1). An extra area addition of 2.58 m^2 is taken into account for the cubicle that contains the switchgear and the circuit breaker for each voltage transformer.

In the end, the user can dispose his/her selection for a financial estimation by clicking the “Add selection to financial estimation” button.

4.3.4.4 “Shore-side Connection Arrangement” tab

“Shore-side Connection Arrangement” tab features the required equipment for the last step of the shore-to-ship connection. A cable arrangement has to be defined by the user with a similar way as in the “Primary Cable Arrangement” tab. Configuration of this tab is illustrated in the following figure.

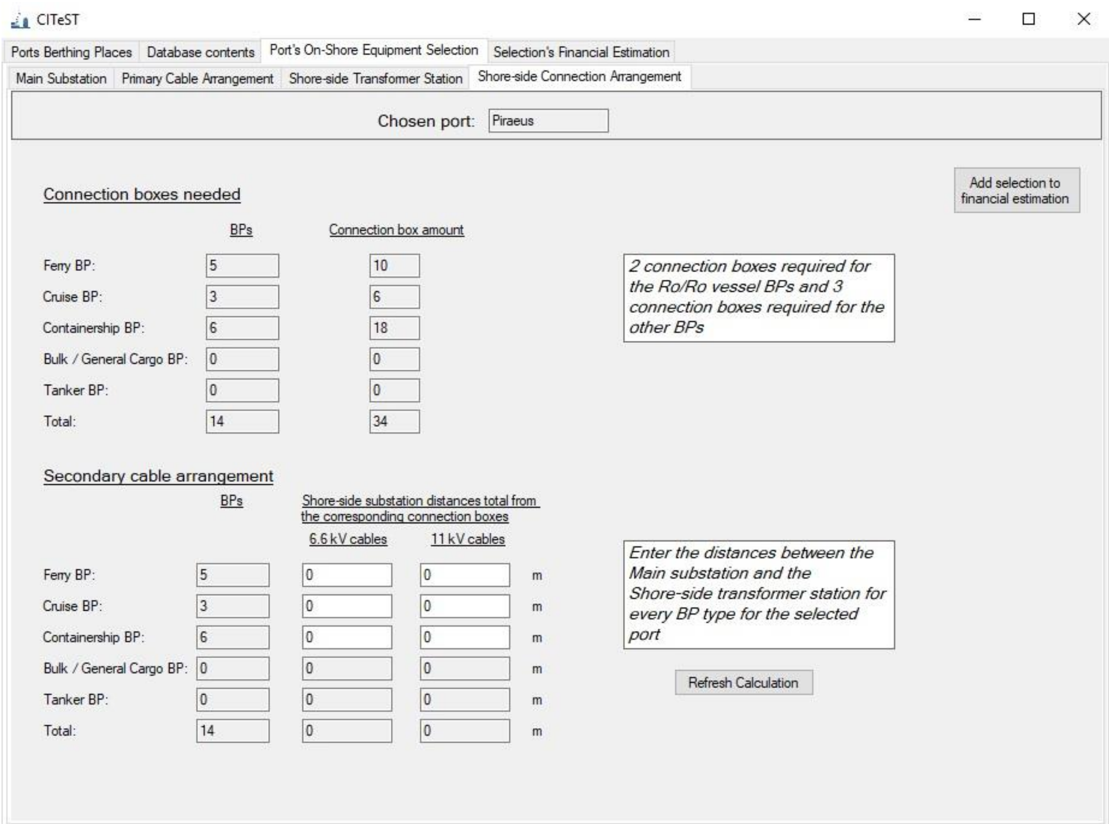


Figure 4.10 - “Shore-side Connection Arrangement” tab

Connection box amount is automatically calculated according to the type of the vessels for which each BP is destined to accommodate. Two connection boxes are added for the RoRo ferries and 3 for the rest. This happens because RoRo ferries have a more certain length variation and mooring position. This amount is updated when a BP is added to or removed from a port. Since existing CI installation researches select either a cable arrangement of 6.6 kV cables or 11 kV cables, it is up to the user to choose the length of the cables of each voltage which are required for the design.

When "Refresh calculation" button is pressed, results of the corresponding cable length for each BP's substation addition are shown in the last text box of the right column. Thereafter, the user can dispose his/her selection for a financial estimation by clicking the "Add selection to financial estimation" button.

4.3.5 "Selection's Financial Estimation" tab

"Selection's Financial Estimation" tab features the financial approximation of the equipment cost according to an implemented selection. In this tab a summary of the "Port's On-shore Equipment Selection" tab contents selection is illustrated including the cost for each selection. Configuration of this tab is illustrated in the following figure which depicts the results of a random equipment selection made for Killini's port.

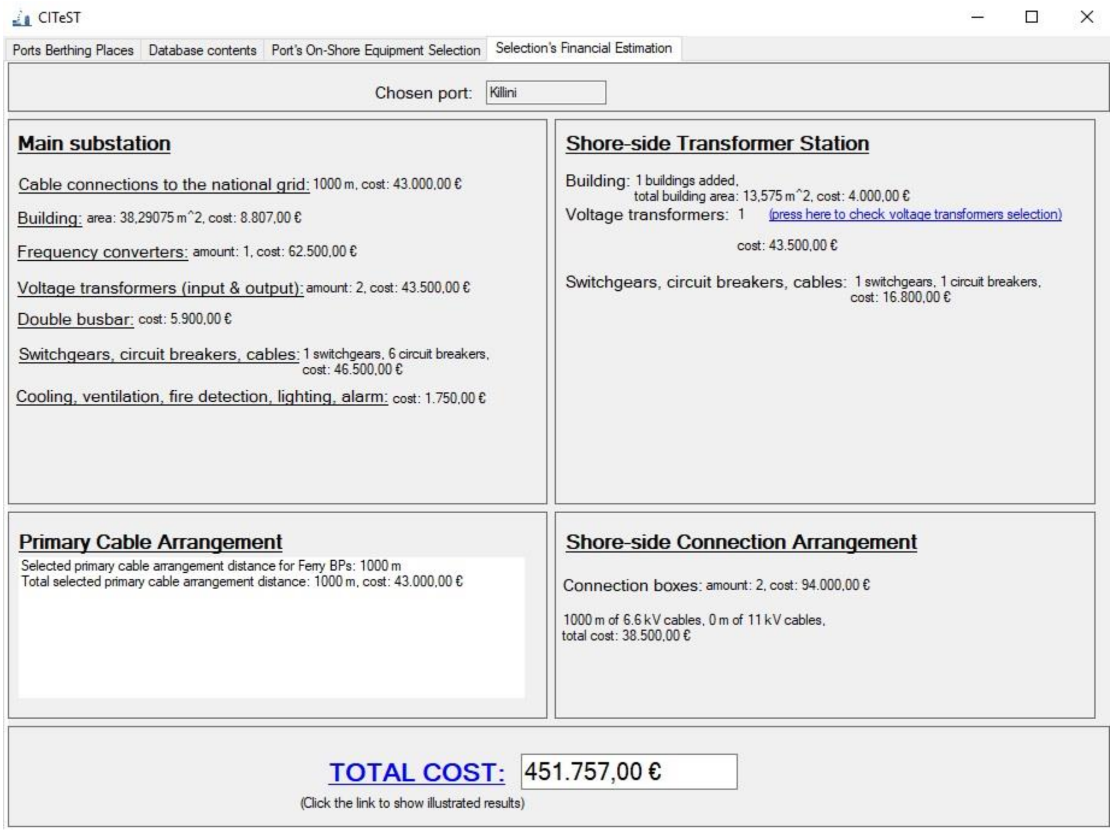


Figure 4.11 - "Selection's Financial Estimation" tab results for Killini's port instance

As depicted in Figure 4.11, results are categorized according to the selection tabs analyzed in Chapter 4.3.4. A concentrated view of the selected equipment is shown for every category. Port of selection is defined on a text box placed on the upper part of the tab while selection's total cost is defined on the lower part of the tab. A "(Click the link to show illustrated results)" indication appears right down of the "TOTAL COST" link label. When this link label is clicked a new window emerges containing tab's displayed results in graphs. This window is depicted in the following figure.

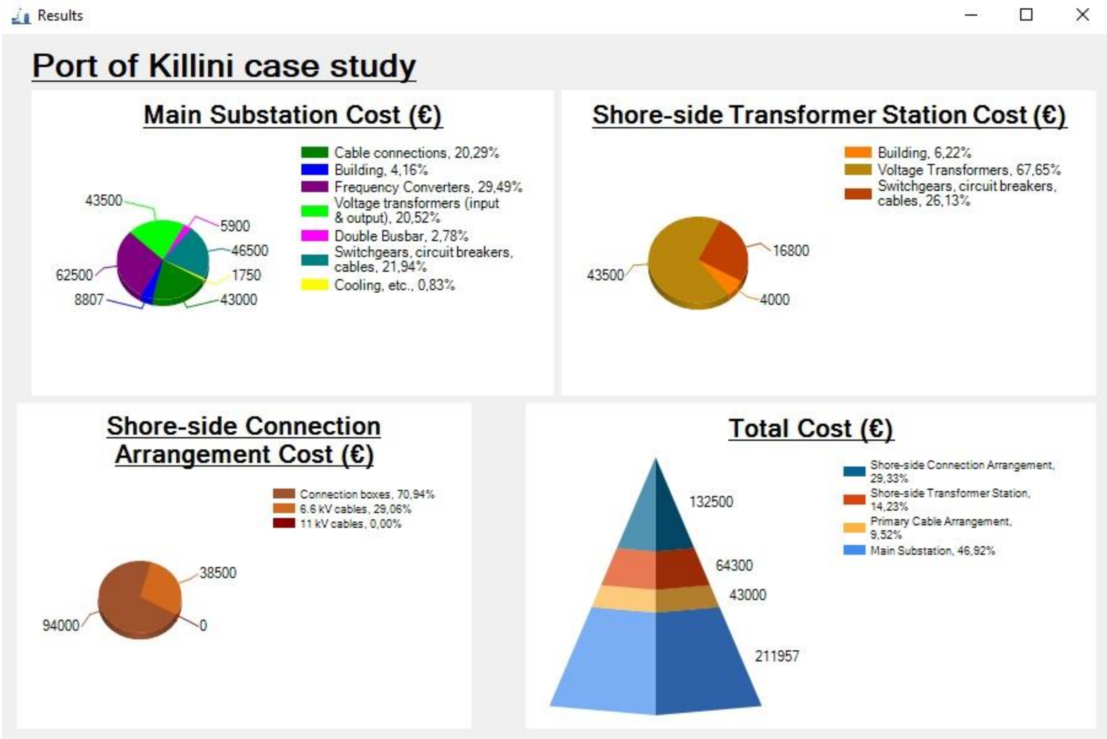


Figure 4.12 – Selection's results illustration in a graph view

Primary cable arrangement is a truly simple category concerning its costs due to its few contents (only 20 kV cables are costed); taking this into consideration and for space economy reasons, this category's results are not appeared in a graph view.

A factor which was difficult to be defined during the calculations made in this tab was the equipment's cost specification. This happens because equipment solutions for this type of installations are not always available for an immediate sale and its production is usually generated by specific orders' demand. Moreover, cost varies from the amount of each order and a constant unit cost prediction is hard to be made. As a result, cost prediction for each apparatus was made as an average from the case studies described in Chapter 3. More information about the equipment cost is given in Appendix's Chapter 7.2.

4.4 Database construction

Along with application's configuration, a database construction took place as well to support application's requirement for data storage. In Chapters 4.3.3 and 4.3.4.1 two cases of database were faced, a database containing the designed berthing places for each port and a database containing the frequency converter options respectively.

Another database was constructed to serve the needs of BP amount display in a concentrated way for each port. Databases were constructed with Microsoft SQL Server Management Studio 2017©, which is a software application used for configuring, managing, and administering all components within Microsoft SQL Server. This tool has the capability of creating a server in which an application configured in Visual Studio can link with and derive data. All databases were constructed in a table form. Microsoft SQL Server Management Studio program's configuration is depicted in the following figure which contains the database referenced in Chapter 4.3.3 as well.

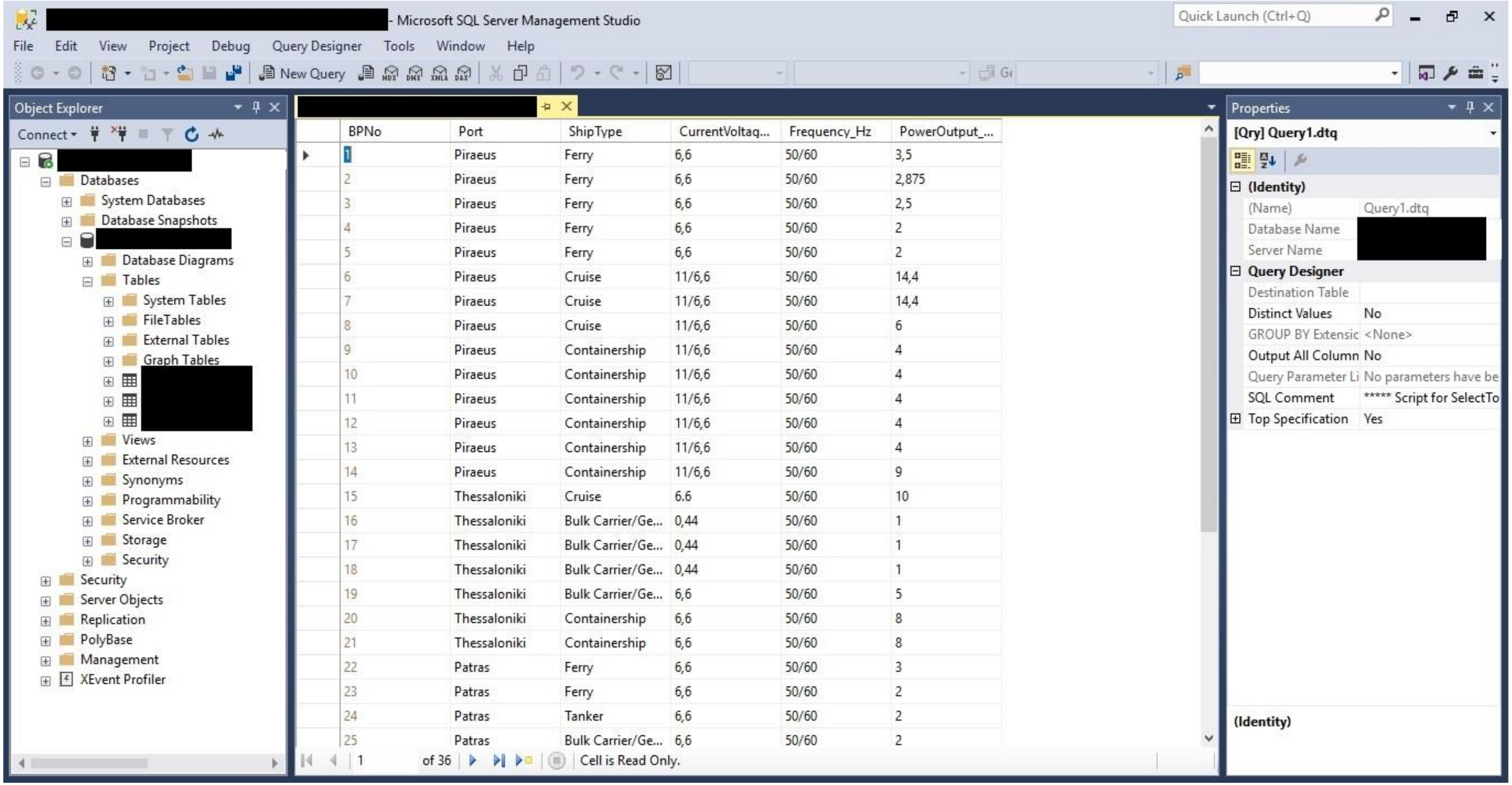


Figure 4.13 - Microsoft SQL Server Management Studio interface and Berthing places database

As it is shown in Figure 4.13, the following actions are some of those which can be made for manipulating the database:

- Add data to the database
- Delete data from the database
- Read data from the database
- Set passwords to secure database's connection with other applications
- Create new tables
- Edit created tables

The following two figures depict the rest of the tables constructed with this tool and imported as databases in the presented application.

	Model No.	Model Name	Nominal Powe...	Area coverage...	Transformer A...	Price_euro
	2	PCS 100 SFC-02...	0,250	0,64	0,64	31250
	3	PCS 100 SFC-03...	0,375	0,64	0,96	46875
	4	PCS 100 SFC-05...	0,500	1,28	0,96	62500
	5	PCS 100 SFC-06...	0,625	1,6	0,96	78125
	6	PCS 100 SFC-07...	0,750	1,92	0,96	93750
	7	PCS 100 SFC-08...	0,875	1,92	3,68	109375
	8	PCS 100 SFC-10...	1	1,92	3,68	125000
	9	PCS 100 SFC-11...	1,125	3,52	3,68	140625
	10	PCS 100 SFC-12...	1,250	3,52	3,68	156250
	11	PCS 100 SFC-13...	1,375	3,52	3,68	171875
	12	PCS 100 SFC-15...	1,500	3,52	3,68	187500
	13	PCS 100 SFC-16...	1,625	4,16	3,68	203125
	14	PCS 100 SFC-17...	1,750	4,16	3,68	218750
	15	PCS 100 SFC-18...	1,875	4,16	3,68	234375
	16	PCS 100 SFC-20...	2	4,8	3,68	250000
	17	PCS 6000 SFC-4...	4	5,88	0	500000
	18	PCS 6000 SFC-5...	5	5,88	0	625000
	19	PCS 6000 SFC-6...	6	5,88	0	750000
	20	PCS 6000 SFC-7...	7	5,88	0	875000
*	NULL	NULL	NULL	NULL	NULL	NULL

Figure 4.14 – Frequency converters table

	PortNo	PortName	FerryBP	CruiseBP	Containership...	Bulk_GeneralC...	TankerBP	Total
▶	1	Piraeus	5	3	6	0	0	14
	2	Thessaloniki	0	1	2	4	0	7
	3	Patras	2	0	0	1	1	4
	4	Killini	1	0	0	0	0	1
	5	Igoumenitsa	2	1	0	1	0	4
	6	Heraklion	3	1	0	1	1	6
*	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 4.15 – A table illustrating a summary of the existing design in the application

5. Results

A presentation of CITeST application working example will be featured in this chapter. Two different cases will be examined, one for an already examined Greek port and one for a random port.

5.1 Port of Igoumenitsa case example

Igoumenitsa's port case was selected as the first example for the presentation of CITeST's function. Firstly, the used input data will be presented. Afterwards a result presentation will follow and eventually, a comparison will take place with Igoumenitsa's port CI installation financial approach made by Mourkokosta Vasiliki [6] during her research which was briefly presented in Chapter 3.6.

5.1.1 Input data

A design for Igoumenitsa's port already exists in CITeST's database, hence, only the "calculator" part of this application will be used in this case. Input data for the "Main Substation" tab are depicted in the following figure.

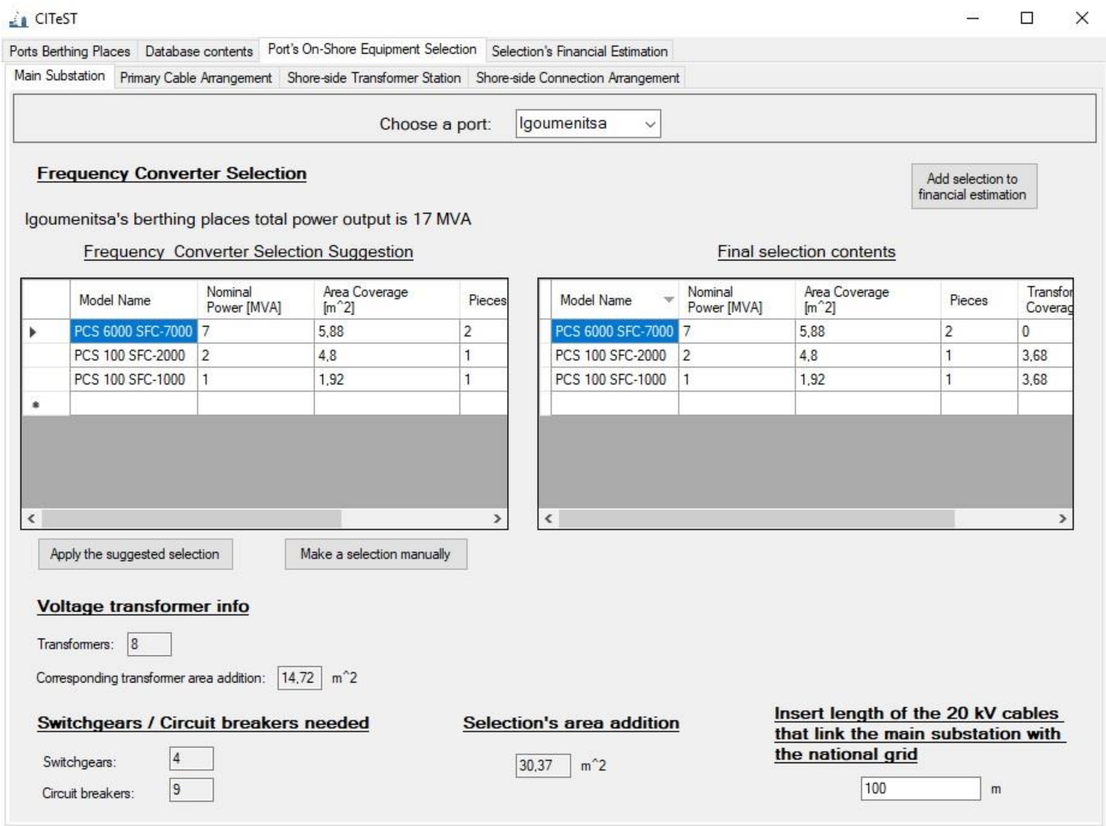


Figure 5.1 - Input data for the "Main Substation" tab

As it can be seen in Figure 5.1, Igoumenitsa's port was firstly selected on the scroll down menu which is located on the upper part of the tab. Afterwards, the "Apply the suggested selection" button was clicked and a selection of four frequency converters was accomplished, while a simultaneous selection of the rest of required equipment for the operational function of the main substation and an area needed for the building construction of the main substation was calculated as well. Finally, a cable length of 100 meters was set as the connection distance between the national grid and the main substation and the "Add selection to financial estimation" button was clicked.

Next step of the selection process is the input data in the "Primary Cable Arrangement" tab. Input data for the "Primary Cable Arrangement" tab are depicted in the following figure.

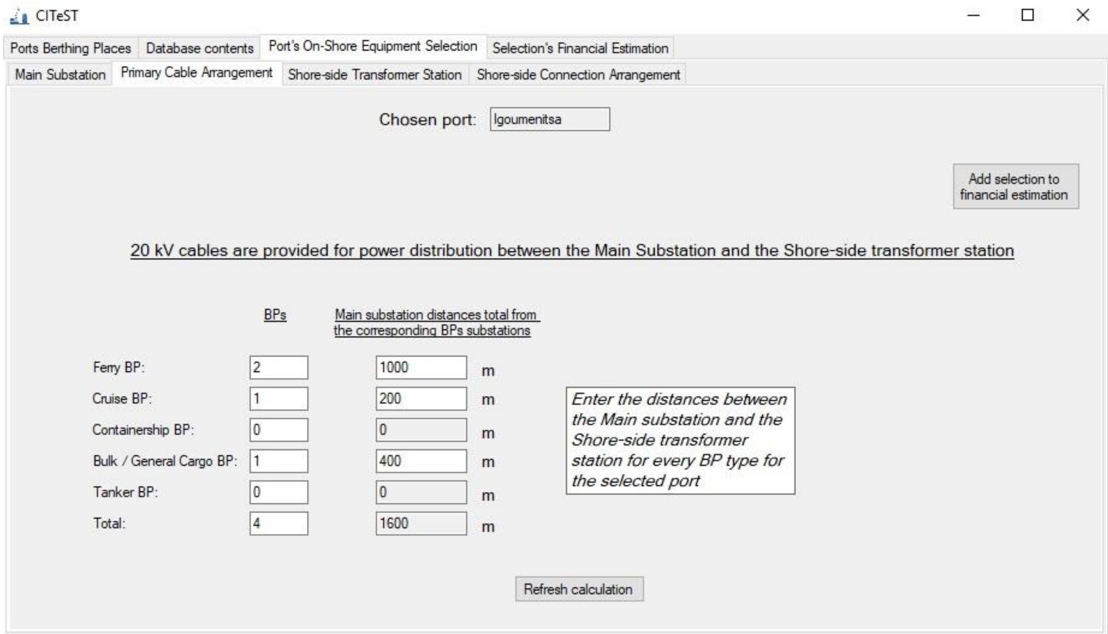


Figure 5.2 - Input data for the "Primary Cable Arrangement" tab

As it can be observed in Figure 5.2, cable lengths of 1000, 200 and 400 meters were set as the connection distances between the main substation and the Ferry, Cruise and Bulk Carrier/General Cargo BPs respectively. When "Refresh calculation" button was clicked a total distance of 1600 meters was calculated for the final selection and the selection was added for a financial estimation by clicking the "Apply the suggested selection" button.

Next step of the selection process is the input data in the "Shore-side Transformer Station" tab. Input data for the "Shore-side Transformer Station" tab are depicted in the following figure.

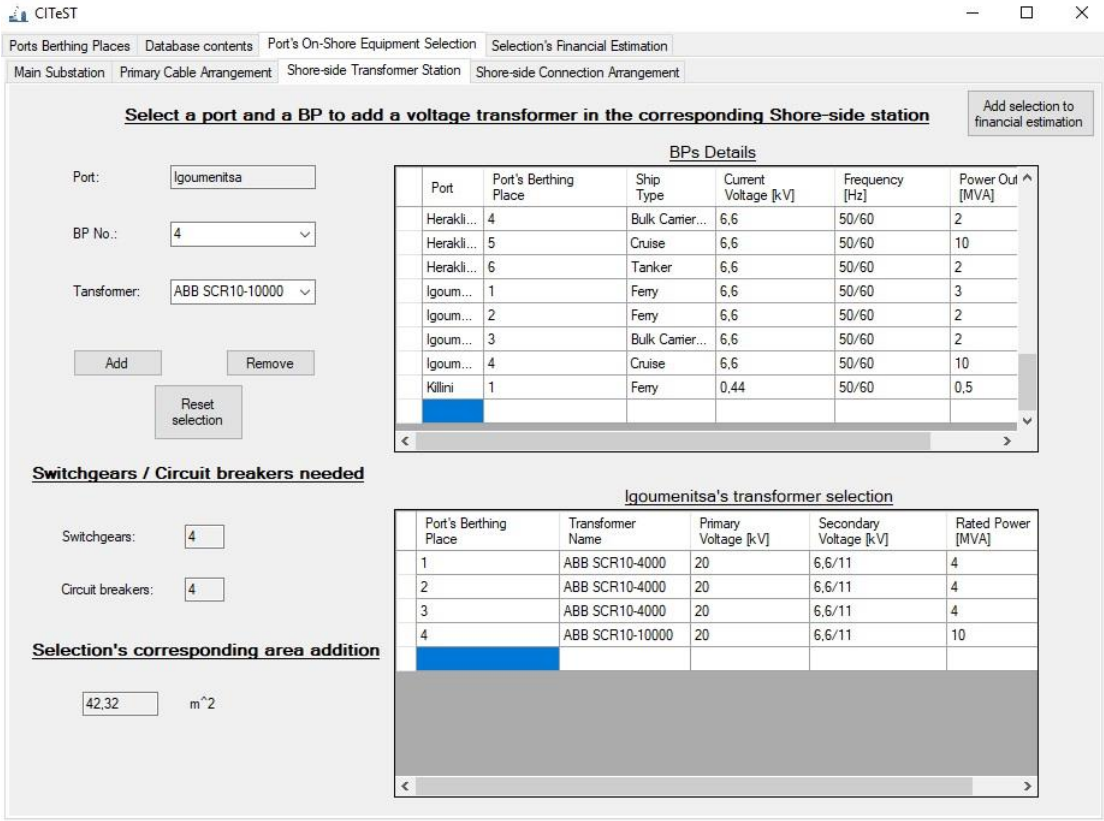


Figure 5.3 - Input data for the “Shore-side Transformer Station” tab

“Shore-side Transformer Station” tab input data were added by using the two scroll down menus indicating the BP index number and the voltage transformer model name. A simultaneous switchgear and circuit breaker addition was made with the insertion of each voltage transformer in the final selection table and an area needed for the building construction of the shore-side transformer station was calculated as well. Finally, the “Add selection to financial estimation” button was clicked and the selection proceeded for a financial calculation.

The final step of the selection’s process is the input data in the “Shore-side Connection Arrangement” tab. Figure 5.4 illustrates the input data for the “Shore-side Connection Arrangement”.

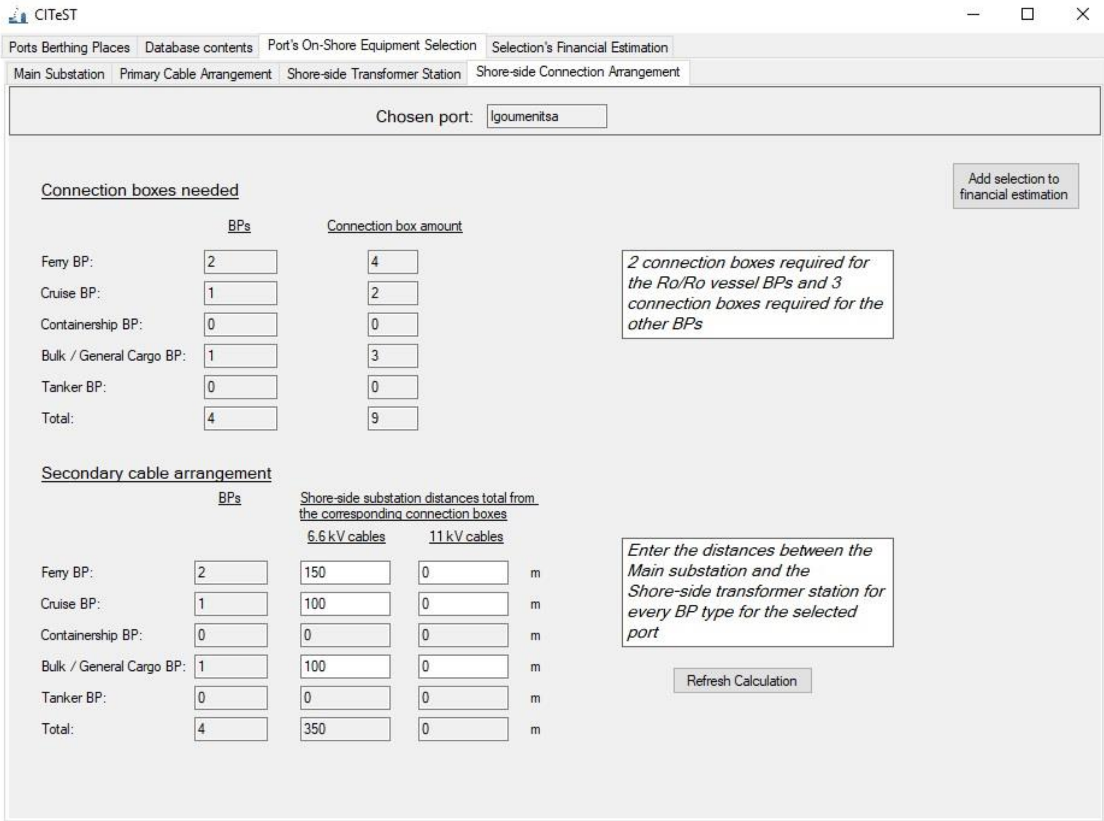


Figure 5.4 - Input data for the “Shore-side Connection Arrangement” tab

As it can be seen, cable lengths of 150, 100 and 100 meters were set as the connection distances between the shore-side station and the Ferry, Cruise and Bulk Carrier/General Cargo BPs’ connection boxes respectively. When “Refresh calculation” button was clicked a total distance of 350 meters was calculated for the final selection and the selection was added for a financial estimation by clicking the “Apply the suggested selection” button. Connection boxes amount is calculated automatically according to the type of the vessels serviced by each designed BP.

5.1.2 Example’s results

Since the selection’s input data were added and all the selected equipment proceeded for a financial calculation it’s time to have a look at the results indicated in “Selection’s Financial Estimation” tab. The results are depicted in the following figures. Figure 5.5 contains the “Selection’s Financial Estimation” tab overview while Figure 5.6 contains the illustrated version of the selection’s financial approach results which was given after “TOTAL COST” link label was clicked.

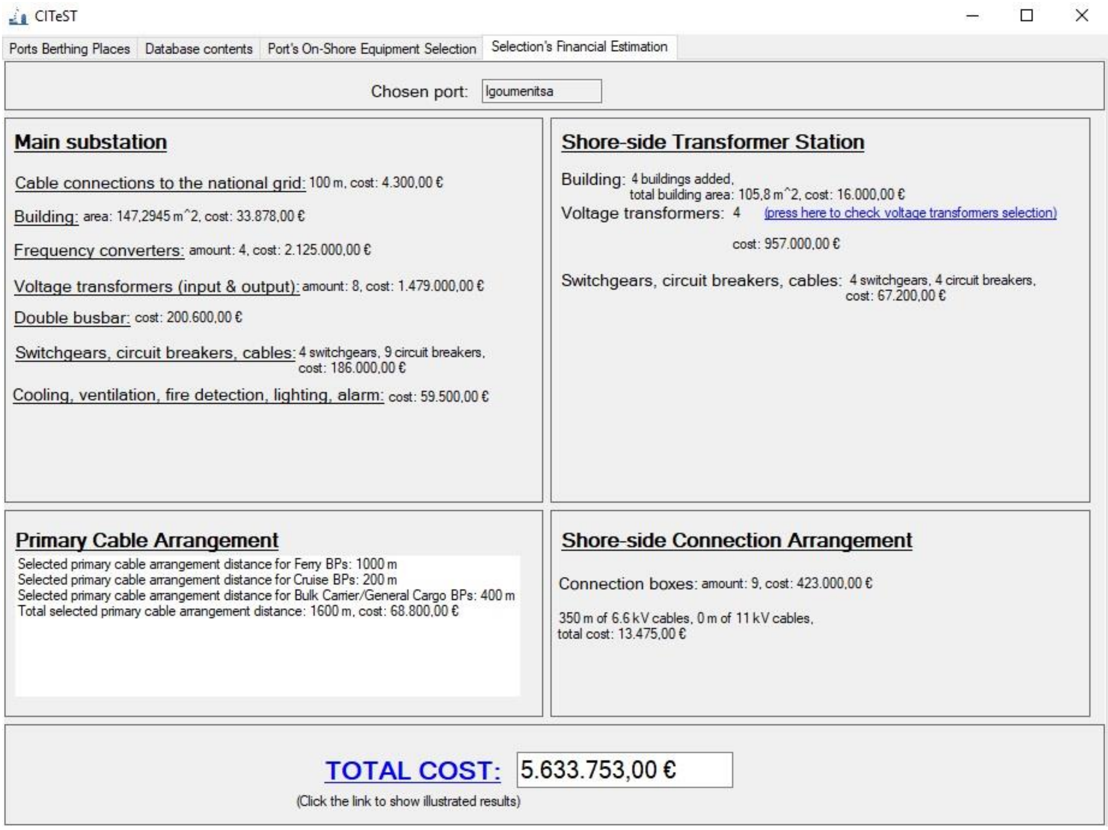


Figure 5.5 – Results indicated in “Selection’s Financial Estimation” tab

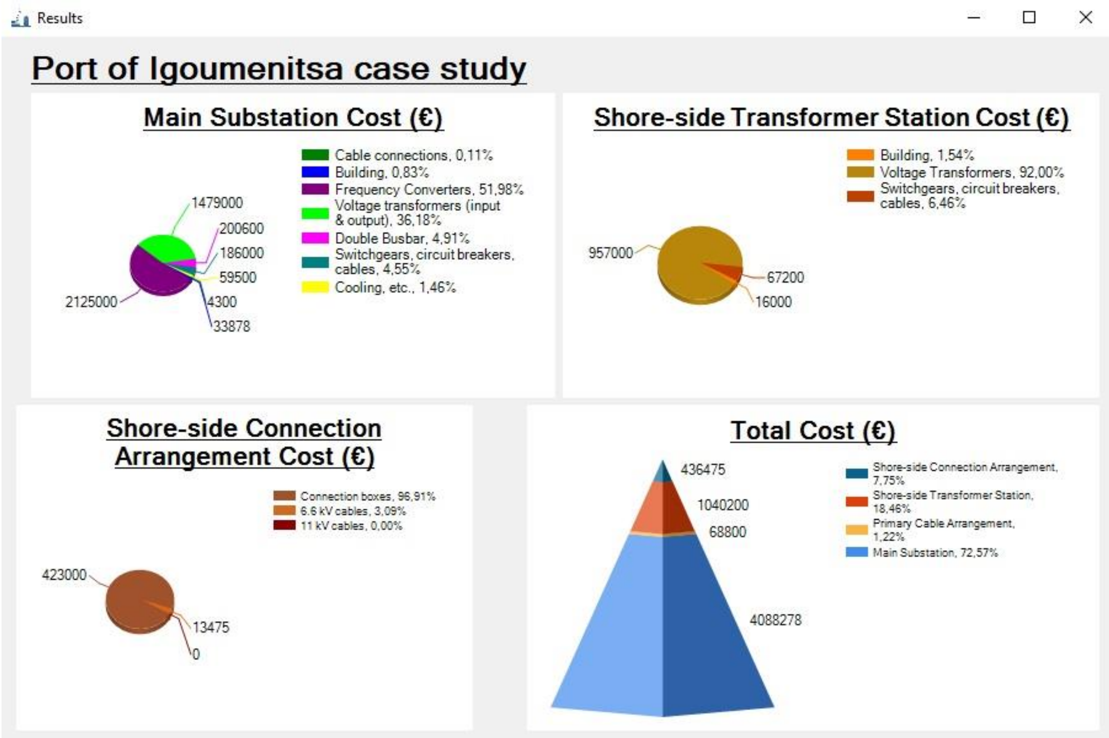


Figure 5.6 – Illustrated results indicated in “Results” window after clicking the “TOTAL COST” button

5.1.3 Results Comparison

A comparison between CITeST results and V. Mourkokosta's research [6] results for Igoumenitsa's port case study will follow in this chapter. Both of them are indicated in the following table.

Table 5.1 – V. Mourkokosta [6] and CITeST results for Igoumenitsa's port case study

	V. Mourkokosta's research results			CITeST results		
Main substation						
	€		%	€		%
Building	20000		0,34	33878		0,60
Frequency Converters	2 x 7 MVA & 2 x 1.5 MVA	2140000	36,09	2 x 7 MVA, 1 x 2 MVA & 1 x 1 MVA	2125000	37,72
Voltage Transformers (input & output)	4 x 7 MVA & 4 x 1.5 MVA	1744000	29,4	4 x 7 MVA, 2 x 2 MVA & 2 x 1 MVA	1479000	28,91
Double Busbar	150000		2,53	200600		3,56
Switchgears, circuit breakers, cables, etc.	150000		2,53	186000		3,30
Cooling, etc.	40000		0,67	59500		1,06
Cable Arrangement						
20 kV	1700 m	67500	1,14	1700 m	73100	1,30
6.6 KV	350 m	15750	0,27	350 m	13475	0,24
Shore-side Station						
Buildings	4	16000	0,27	4	16000	0,28
Voltage Transformers	2 x 2 MVA, 1 x 3 MVA & 1 x 10 MVA	750000	12,65	3 x 4 MVA & 1 x 10 MVA	957000	16,98
Connection boxes	8	375000	6,32	9	423000	7,13
Switchgears, circuit breakers, cables, etc.	250000		4,22	67200		1,19
Crane truck	212000		3,57	-		
Total	5930250		100	5633753		100

Comparison's main observation is the 5.26% higher total cost which was calculated in the calculation without the CITeST application. This difference is plasmatic, since a crane truck acquirement is not part of CITeST functions, thus, total cost difference can be presumed as a 1.5 % for real. This difference was expected and can be described as quite normal; since in CITeST methodology equipment's cost approximation has been made according to the average costs of six different researches - the researches which were briefly described in Chapter 3 – it is expected for a slight divergence to exist in the results.

5.2 "V port" case study, a random case example

A random case study will be presented in this chapter for a non-existing port. The major reason for this is to present the application's port and BP addition functions which are very useful tools for the implementation of new researches.

5.2.1 "V port" addition input data

Port addition tool has already been mentioned in Chapter 4.3.2.3 as the "Add a port" tab description. In this tab, CITeST application gives the chance for a new port addition to the user by typing the new port's name in the appropriate text box. Since the addition is confirmed, user is requested to add the first BP for this port. Input data for these actions on this random port case study are presented in the following figure.

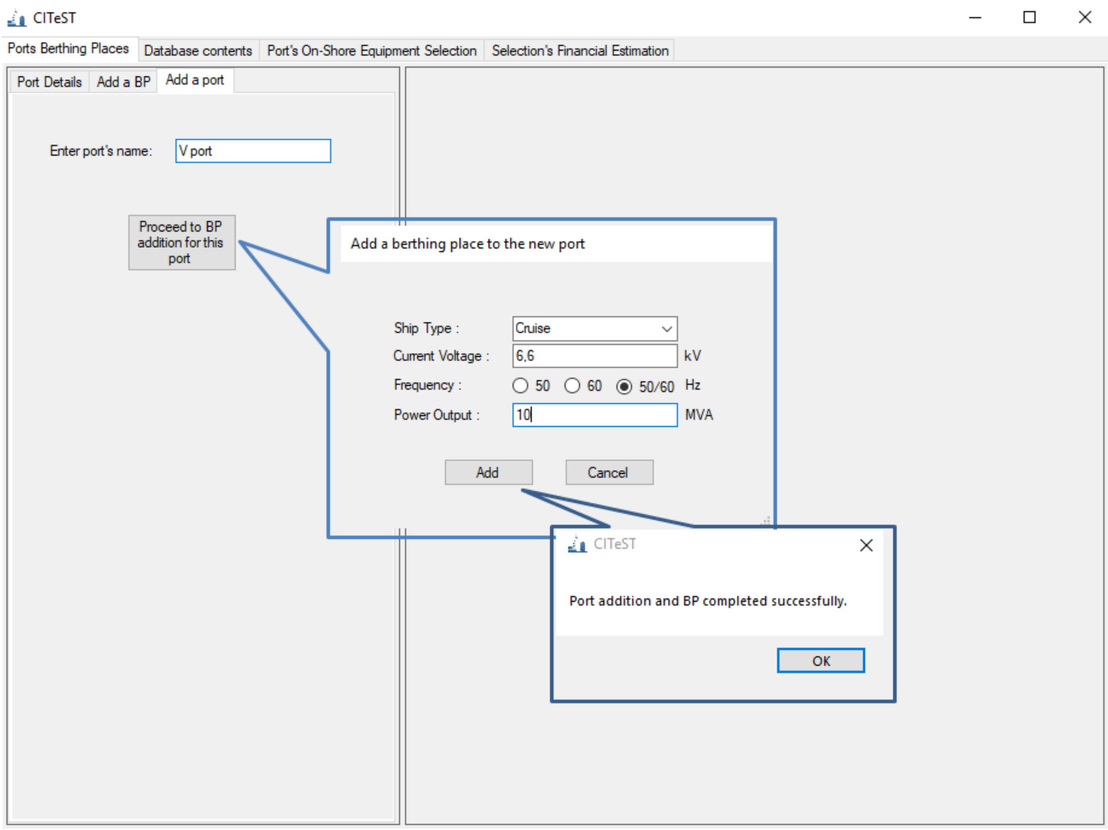


Figure 5.7 – Port addition procedure example

As it can be seen in Figure 5.7, input data were typed firstly on the “Add a port” tab. After the “Proceed to BP addition for this port” button was clicked, a new window emerged requesting the required information for a BP addition. Input data for the BP addition were randomly chosen and a BP for Cruise vessels’ accommodation with 6.6 current’s voltage, 10 MVA power output and a 50/60 Hz frequency option was determined. Thereafter, “Add” button was clicked on the last window and a message confirming the successful port and BP addition showed.

In the following figure the refreshed database is depicted including V port’s new BP which appears in the “Database contents” tab.

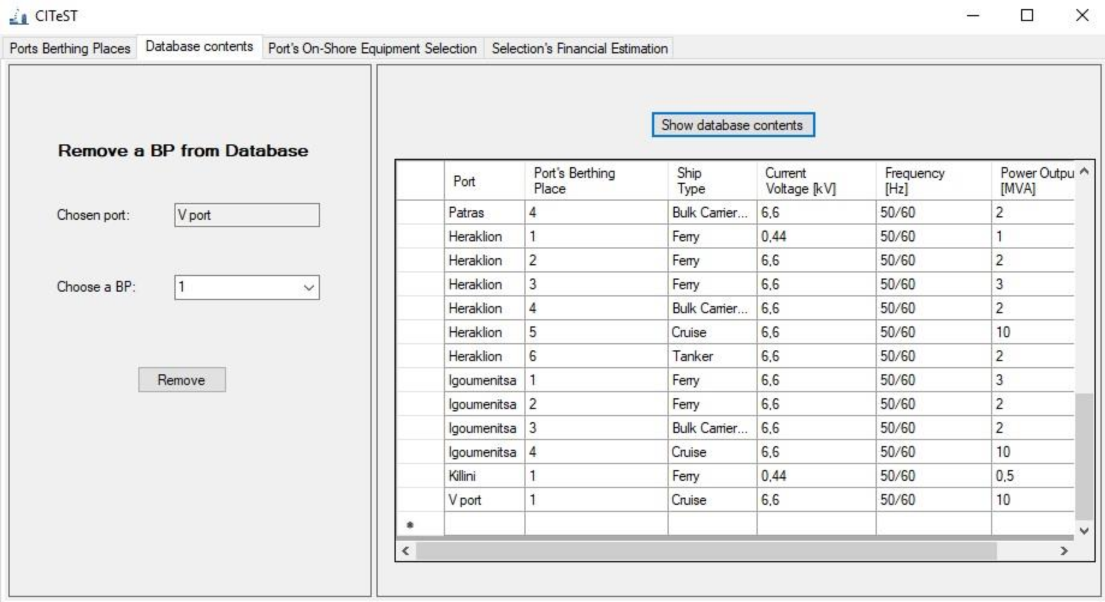


Figure 5.8 – Database contents after the V port’s BP addition

Next step will be to add an extra BP for the V port case study. For this quest the BP addition tool will be used which is located on the “Add a BP” tab described in Chapter 4.3.2.2. Input data for V port’s second BP addition were once again randomly chosen and a BP for Containerships’ accommodation with 11/6.6 current’s voltage option, 5 MVA power output and a 50/60 Hz frequency option was determined. Input data for V port’s second BP addition are depicted in the following figure.

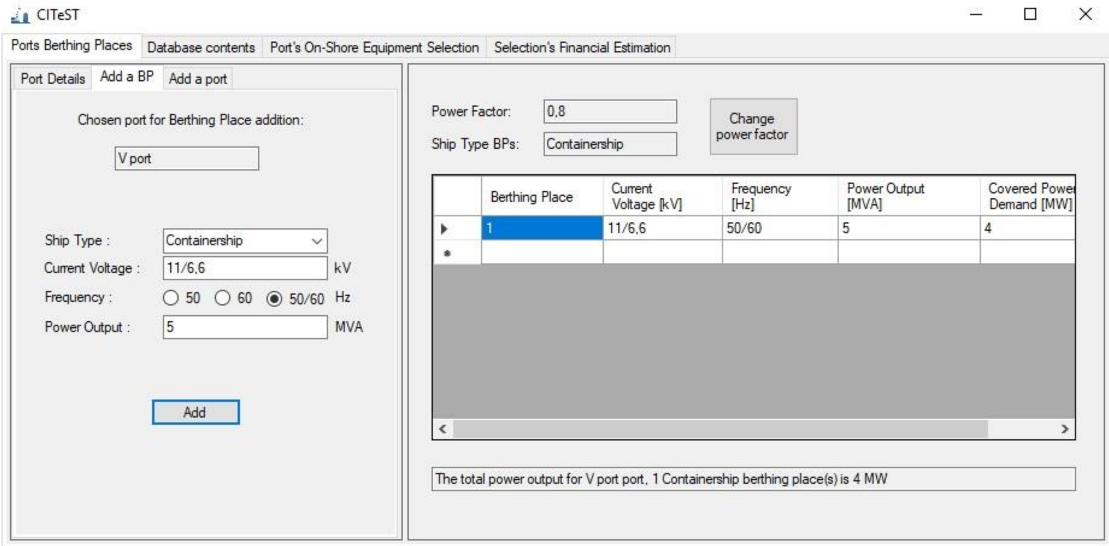


Figure 5.9 – V port's second BP addition

When "Add" button was clicked on "Add a BP" tab, detailed information about V port's Containership BPs showed on application's right hand side indicating the successful BP addition. After the second BP addition, equipment selection can be implemented for the existing BP design.

5.2.2 "V port" equipment selection

Equipment selection methodology will follow the same syllogism as in the Igoumenitsa's port example. Nevertheless, a manual frequency converter selection on the "Main Substation" tab will be chosen.

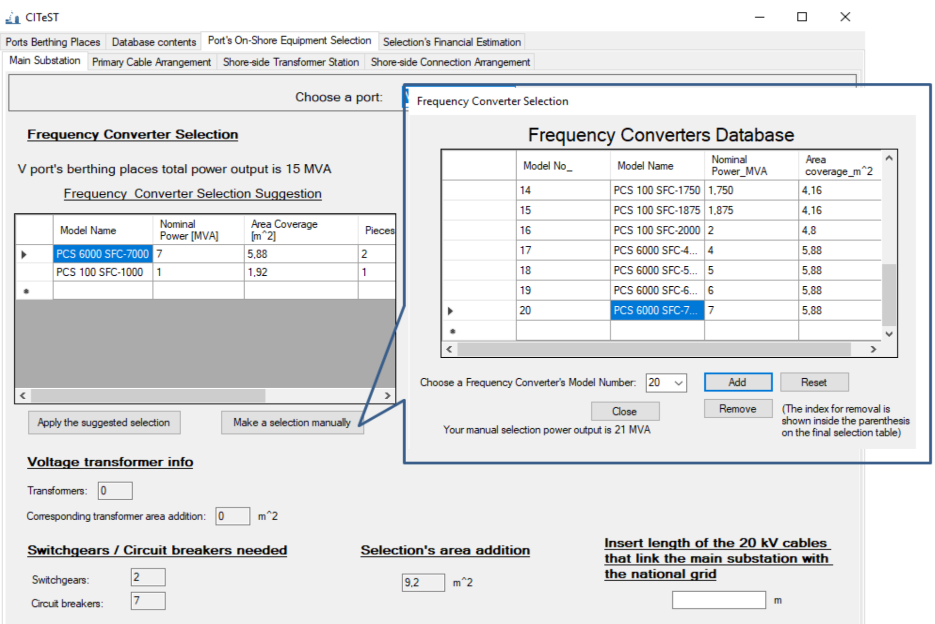


Figure 5.10 – Frequency converter manual selection for V port's equipment selection

As shown in Figure 5.10, the suggested selection was to add two pieces of PCS 6000 SFC-7000 of 7 MVA nominal power output each and one piece of PCS 100 SFC-1000 of 1 MVA nominal power output. A total of 15 MVA power output will be achieved with this selection. However, in V port case study we presume that a future perspective of power output retrofit is under investigation so ships with higher power demand can be accommodated in the port. Thus, manual selection tool was chosen and an addition of three PCS 6000 SFC-7000 frequency converters with a total power output of 21 MVA was implemented. Final selection for the "Main Substation" tab is depicted on the following figure.

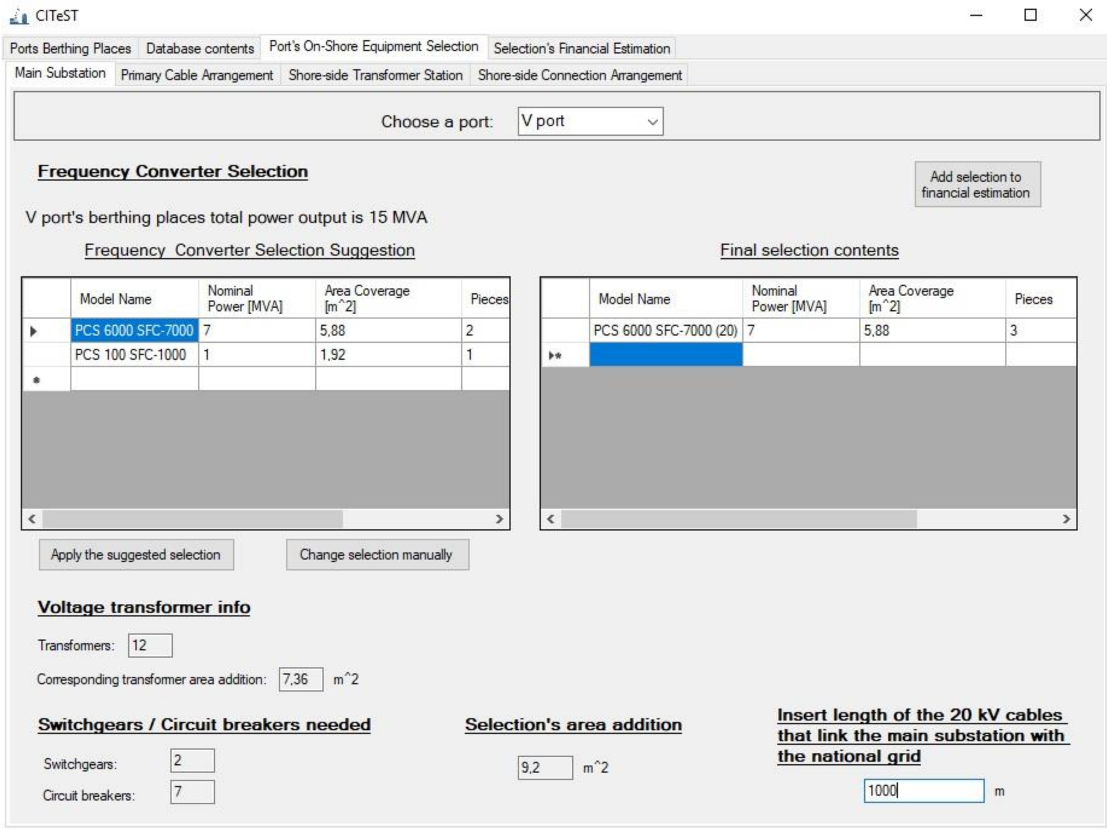


Figure 5.11 – "Main Substation" tab final selection

Finally, a cable length of 1000 meters was set as the connection distance between the national grid and the main substation and the "Add selection to financial estimation" button was clicked.

Next step of the selection process is the input data in the "Primary Cable Arrangement" tab. Input data for the "Primary Cable Arrangement" tab are depicted in the following figure.

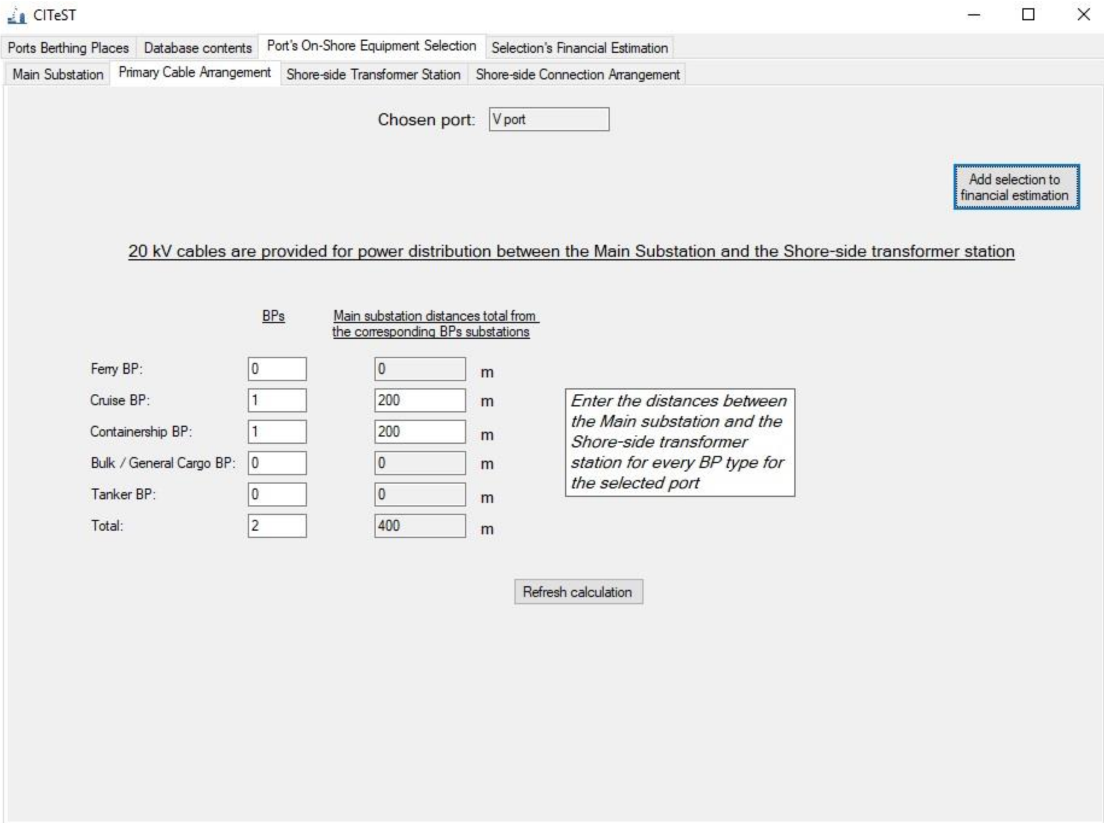


Figure 5.12 – "Primary Cable Arrangement" tab final selection

As it can be observed in Figure 5.2, cable lengths of 200 meters were set as the connection distances between the main substation and the Cruise and Containership BPs respectively. When "Refresh calculation" button was clicked a total distance of 400 meters was calculated for the final selection and the selection was added for a financial estimation by clicking the "Apply the suggested selection" button.

Next step of the selection process is the input data in the "Shore-side Transformer Station" tab. Input data for the "Shore-side Transformer Station" tab are depicted in the following figure.

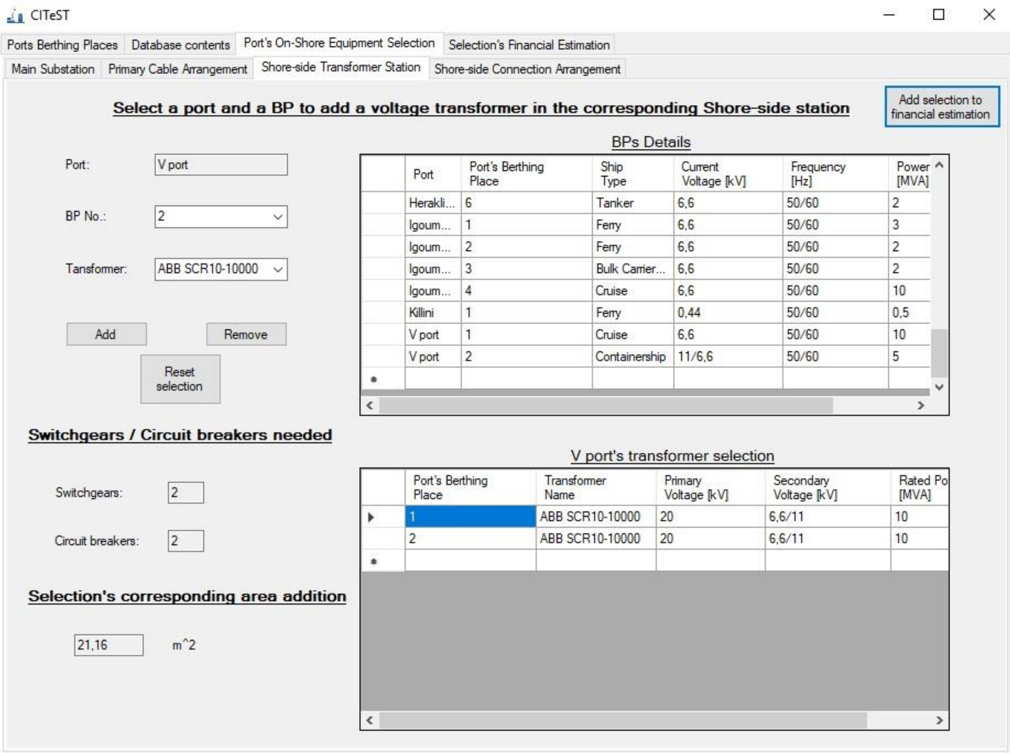


Figure 5.13 – “Shore-side Transformer Station” tab final selection

The final step of the selection’s process is the input data in the “Shore-side Connection Arrangement” tab. Figure 5.4 depicts the input data for the “Shore-side Connection Arrangement”.

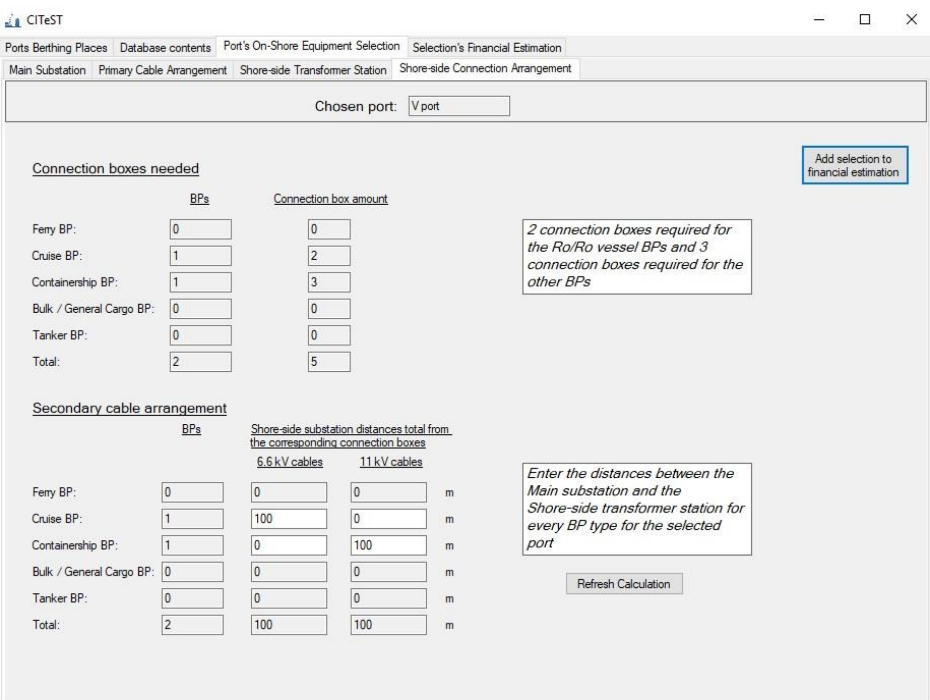


Figure 5.14 – “Shore-side Connection Arrangement” tab final selection

As it can be seen, cable lengths of 100 meters were set as the connection distances between the shore-side station and Cruise and Containership BPs' connection boxes respectively. When "Refresh calculation" button was clicked total distances of 100 meters of 6 kV cables and 100 meters of 11 kV cables were calculated for the final selection and the selection was added for a financial estimation by clicking the "Apply the suggested selection" button. Connection boxes amount is calculated automatically according to the type of the vessels serviced by each designed BP.

5.2.3 "V port" case study results

Since the selection's input data were added and all the selected equipment proceeded for a financial calculation it's time to have a look at the results indicated in "Selection's Financial Estimation" tab. The results are depicted in the following figures. Figure 5.15 contains the "Selection's Financial Estimation" tab overview while Figure 5.16 contains the illustrated version of the selection's financial approach results which was given after "TOTAL COST" link label was clicked.

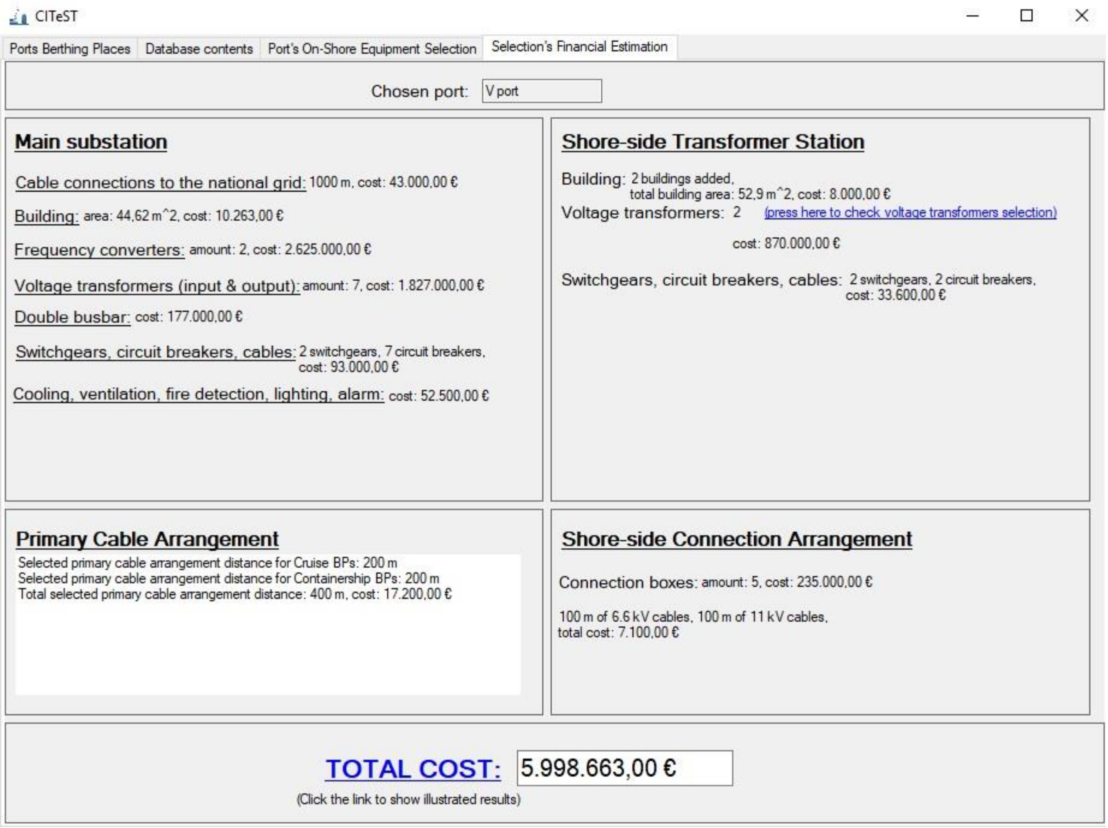


Figure 5.15 – Results indicated in "Selection's Financial Estimation" tab

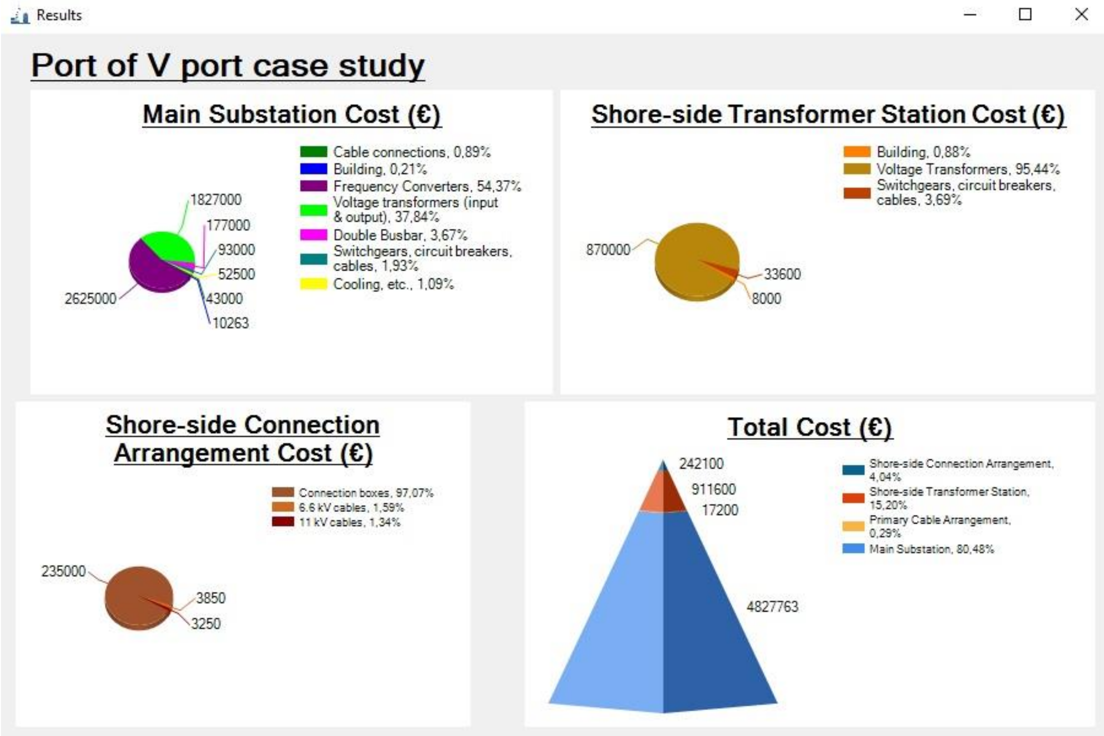


Figure 5.16 – Illustrated results indicated in “Results” window after clicking the “TOTAL COST” button

6. Conclusions and Recommendations

6.1 Conclusions

- A powerful application using a plethora of tools for CI installation perspective study was successfully implemented.
- A comparison with an already implemented research showed that application's results are plausible and reliable, along with the used methodology which was determined as well-defined.
- A useful database has been constructed and it is carried by the present application to keep a record of the already implemented CI installation studies.
- A tool for the addition of more CI installation designs and retrofitting of the existed is available.
- CITeST v.1 ©offers an intelligent interface and an interactive environment that makes its handling simple and convenient even for beginner users concerning technical matters.
- Calculation speed for CI installations is now at great level
- An elegant and comprehensible result presentation facilitates the user for an immediate assessment.

Considering the abovementioned conclusions for CITeST v.1 ©, a few recommendations for upgrade perspective are indicated in the next chapter.

6.2 Recommendations for further investigation

CITeST v.1 © application implementation lead to the adoption of significant advantages concerning the available tools for a CI installation perspective research. A few ideas will be presented as a closure of this dissertation, for further investigation and/or a potential upgrade of CITeST v.1 © application:

- Since equipment prices are updated along the years, a new window for equipment cost manipulation will be a useful addition for a better total cost approximation.

- Besides the already useful databases, a voltage transformer database could be also constructed to offer a wider range of options

- A comparison tool of a specific port equipment selection would be useful for an all-around assessment.

- Multiple result presentation windows and/or their direct extraction as picture files would be convenient for keeping a result record.

- Since an assessment of a studied CI installation via CITeST v.1 © application may lead to further investigation and attract relevant stakeholders, a calculator for a techno-economic feasibility study of function and maintenance of such an installation would be undoubtedly useful.

Implementation of such actions might lead to the upgrade CITeST v.1 © and why not to the adoption of another application including more tools.

7. Appendix

7.1 Equipment data

SCR10（20 kV）

Technical data for SCR10 series distribution transformer (20 kV)

Rated power (kVA)	Voltage combination: HV (kV)	Tapping range of HV (%)	LV (kV)	Connection symbol	No-load loss (W)	On-load loss 75℃(W)	No-load current (%)	Short circuit impedance (%)	Sound pressure dB	Sound power (dB)
SCR10-315	20 22	± 2*2.5%	0.4	Dyn11 或 or Yyn0	970	3550	1.3	6	50	63
SCR10-400					1150	4220	1.1		51	64
SCR10-500					1350	5040			52	65
SCR10-630					1530	5970	1.0		53	66
SCR10-800					1750	7200			54	67
SCR10-1000					2070	8480	0.85		54	68
SCR10-1250					2380	10000			56	69
SCR10-1600					2790	12000			57	70
SCR10-2000					3240	14200	0.7		57	71
SCR10-2500					3870	16800			58	72

SCR10（35 kV）

Technical data for SCR10 series distribution transformer (35 kV)

Rated power (kVA)	Voltage combination: HV (kV)	Tapping range of HV (%)	LV (kV)	Connection symbol	No-load loss (W)	On-load loss 75℃(W)	No-load current (%)	Short circuit impedance (%)	Sound pressure dB	Sound power (dB)
SCR10-315	35 38.5	± 2*2.5%	0.4	Dyn11 或 or Yyn0	1170	3930	1.3	6	51	64
SCR10-400					1370	4720	1.1		52	65
SCR10-500					1620	5790			53	66
SCR10-630					1860	6700	1.0		54	67
SCR10-800					2160	7950			55	68
SCR10-1000					2430	9060	0.75		56	69
SCR10-1250					2830	11000			57	70
SCR10-1600					3240	13400			58	71
SCR10-2000					3820	15800			59	73
SCR10-2500					4450	19000			60	74

SCR10（35 kV）

Technical data for SCR10 series power transformer (35 kV)

Rated power (kVA)	Voltage combination: HV (kV)	Tapping range of HV (%)	LV (kV)	Connection symbol	No-load loss (W)	On-load loss 75℃(W)	No-load current (%)	Short circuit impedance (%)	Sound pressure dB	Sound power (dB)
SCR10-3150	35 38.5	± 2*2.5%	3.15 6 6.3 10 10.5 11	Dyn11 Yd11 YNd11	6030	24500	0.7	8	59	76
SCR10-4000					7020	29400			60	77
SCR10-5000					8370	34900	0.6		61	78
SCR10-6300					9900	40800			62	79
SCR10-8000					11300	46000	0.5	9	62	80
SCR10-10000					12900	55500			63	81
SCR10-12500			6 6.3 10 10.5 11		15700	64600	0.4		64	82
SCR10-16000					19300	76000			65	83
SCR10-20000					22900	85500	0.35	10	65	84
SCR10-25000					27100	101000			66	85

Figure 7.1 – ABB RESIBLOC SCR10 series voltage transformers' characteristics [20]

Four transformer models were added as an embedded choice for voltage transformer addition in a design in "Shore-side Transformer Station" tab. These models are SCR10-1000, SCR10-4000, SCR10-10000 and SCR10-16000. Basic information about their function is given in Figure 7.1. Their operating characteristics can be modified since –

according to company's relevant product brochure is stated that [20] - no moulds are required for manufacturing RESIBLOC transformers, their windings can be individuallydimensioned to take into account customer's specific requirements.

7.2 Cost values approach

Equipment cost approximation followed the CI installation researches implemented for Greek ports criteria. Prices for voltage transformers, cables, buildings construction, double busbar system, switchgears, circuit breakers, connection boxes and cooling/other systems were taken as average values from the already implemented researches for Greek ports. Frequency converter prices showed a significant divergence from study to study, thus, prices were taken into account according only to D. Pantazopoulos' research [3] which appeared to be the most regular for these devices. Final costs for CITeST's equipment selection are viewed on the following table.

Table 7.1 – Equipment prices

	Main substation	Shore-side station	Shore-side connection arrangement	Units
Frequency converters	200000	-		€/MVA
Voltage Transformers	43500		-	€/MVA
20 kV cables	43		-	€/m
11 kV cables	-		40	€/m
6.6 kV cables	-		38,5	€/m
Building	230 €/m^2	4000 €/BP	-	
Double busbar system	11800	-		€/MVA
Switchgears, circuit breakers, extra cables	46500	16800	-	€/BP
Cooling, etc.	3500	-		€/MVA
Connection boxes	-		47000	€/unit

It is noted that the required area for the main substation's building was calculated as the addition of the area covered by each device housed in it and multiplied by an increment factor which value is 4.85. This approximation was done to comply with a monetary unit per square meter syllogism which appears to be the most trustworthy.

7.3 Algorithm

A few parts of the composed algorithm for CITeST application implementation will be presented in this chapter.

7.3.1 Information for each designed berthing place ("Ports Berthing Places" tab)

Detailed information for each designed berthing place is given after the "Details" button is clicked on "Ports BP" tab for each BP type. Coding details for "Details" button is as follows.

```
Private Sub DetailsBtn_Click(sender As Object, e As EventArgs) Handles DetailsBtn.Click
    Try

        Dim BPnumber As Integer = BPTextBox.Text
        Dim check1 As Boolean = abovezero(BPnumber)
        Dim check2 As Boolean

        If check1 = True Then
PowerFactorEdit:
            If pfcondition = False Then

                TextBox4.Text = "[redacted]"
                Label2.Visible = True
                TextBox1.Visible = True
                Label13.Visible = True
                TextBox4.Visible = True
                PFchangeButton.Visible = True
                pf = TextBox1.Text

                check2 = boundaries(pfdown, pfup, pf)
            Else
                check2 = True
                pf = newpf
            End If
            pfcondition = False

            If check2 = False Then
                MsgBox("Power factor must be >=0 and <=1")
                GoTo PowerFactorEdit
            End If
        Else
            MsgBox("No Ferry berthing places are available for this port")
        End If

        If check1 = True And check2 = True Then

            DataGridView1.Columns.Clear()
            DataGridView1.Rows.Clear()
            DataGridView1.Visible = True
            DataGridView1.Columns.Add("Berthing Place", "Berthing Place")
            DataGridView1.Columns.Add("Current Voltage", "Current Voltage [kV]")
            DataGridView1.Columns.Add("Frequency", "Frequency [Hz]")
            DataGridView1.Columns.Add("Power Output", "Power Output [MVA]")
            DataGridView1.Columns.Add("Covered Power Demand", "Covered Power Demand [MW]")

            Dim shiptype As String = "[redacted]"
            Dim Num As Integer = position(shiptype, ComboBox1.Text)
            Dim i As Integer = 1
            Dim CurrentVol As String
            Dim Freq As String
            Dim PowerOut As String
            Dim PowerDemCover As Single
            Do While i <= BPnumber

                CurrentVol = [redacted].Rows(Num).Item(3)
                Freq = [redacted].Rows(Num).Item(4)
                PowerOut = [redacted].Rows(Num).Item(5)
                PowerDemCover = PowerOut * pf
                DataGridView1.Rows.Add(i, CurrentVol, Freq, PowerOut, PowerDemCover)

                sum = sum + PowerDemCover
                i += 1
                Num += 1

            Loop
            TextBox5.Visible = True
            TextBox5.Text = "The total power output for " & ComboBox1.Text & " port, " & BPnumber & " " &
                shiptype & " berthing place(s) is " & Math.Round(sum, 3) & " MW"
            sum = 0
        End If
    Catch ex As Exception
        MsgBox(ex.Message)
    End Try
End Sub
```

When “Details” button is clicked, the code indicated right above runs. Firstly, a check for the amount of port’s according BPs is done. If no BP is designed for this port – ship type, a relevant informing message appears. A second check is done in respect with power factor’s value. Power factor is requested until its value is between certain boundaries. Finally, if both checks are successful information for this design is copied from the Database to “Port’s Berthing Places” tab’s table and a message of design’s total power output appears.

7.3.2 BP addition (“Ports Berthing Places” tab)

BP addition is described in Chapter 4.3.2.2. In this chapter, the code which runs when “Add” button is clicked on “Add a BP” tab will be presented.

```
Private Sub AddBPBtn_Click(sender As Object, e As EventArgs) Handles AddBPBtn.Click
    Try
        Dim check1 As Boolean
        If notemptytext(TextBox2, False) = True And notemptytext(TextBox3, False) = True Then
            check1 = True
        Else
            MsgBox("Fill all the required boxes")
        End If


        If selectionadditionbtnclick = True Then
            VerificationForm.ShowDialog()
            If calcelimverification = False Then
                check1 = False
            End If
        End If


        If check1 = True Then

            Dim i As Integer = portno(ComboBox1.Text)
            Dim j As Integer = shiptypeno(ComboBox3.Text)

            If [redacted].Rows(i).Item(j) > 0 Then

                Dim position1 As Integer = position(ComboBox3.Text, ComboBox1.Text)
                Dim k As Integer = position1 + [redacted].Rows(i).Item(j)
                Dim z As Integer = count("bps") - 1
                [redacted].Rows.Add()


                Do While z >= k

                    [redacted].Rows(z + 1).Item(1) = [redacted].Rows(z).Item(1)
                    [redacted].Rows(z + 1).Item(2) = [redacted].Rows(z).Item(2)
                    [redacted].Rows(z + 1).Item(3) = [redacted].Rows(z).Item(3)
                    [redacted].Rows(z + 1).Item(4) = [redacted].Rows(z).Item(4)
                    [redacted].Rows(z + 1).Item(5) = [redacted].Rows(z).Item(5)

                    z -= 1
                Loop

                [redacted].Rows(k).Item(1) = ComboBox1.Text
                [redacted].Rows(k).Item(2) = ComboBox3.Text
                [redacted].Rows(k).Item(3) = TextBox2.Text
                If RadioButton1.Checked = True Then
                    [redacted].Rows(k).Item(4) = RadioButton1.Text
                ElseIf RadioButton2.Checked = True Then
                    [redacted].Rows(k).Item(4) = RadioButton2.Text
                Else
                    [redacted].Rows(k).Item(4) = RadioButton3.Text
                End If
                [redacted].Rows(k).Item(5) = TextBox3.Text
```

```
                [redacted].Rows(i).Item(j) = [redacted].Rows(i).Item(j) + 1
                [redacted].Rows(i).Item(7) = [redacted].Rows(i).Item(7) + 1

                btnclick(j, sender, e)
            Else
                Dim j1 As Integer = j
                j = 2
                Do Until j = 7
                    If [redacted].Rows(i).Item(j) > 0 Then
                        Exit Do
                    End If
                    j += 1
                Loop
                If j = 7 Then
                    MsgBox("Database data should be fixed")
                    Exit Sub
                End If

                Dim shiptype As String = shiptypename(j)
                Dim position1 As Integer = position(shiptype, ComboBox1.Text)
                Dim k As Integer = position1 + [redacted].Rows(i).Item(j)
                Dim z As Integer = count("bps") - 1
                [redacted].Rows.Add()


                Do While z >= k

                    [redacted].Rows(z + 1).Item(1) = [redacted].Rows(z).Item(1)
                    [redacted].Rows(z + 1).Item(2) = [redacted].Rows(z).Item(2)
                    [redacted].Rows(z + 1).Item(3) = [redacted].Rows(z).Item(3)
                    [redacted].Rows(z + 1).Item(4) = [redacted].Rows(z).Item(4)
                    [redacted].Rows(z + 1).Item(5) = [redacted].Rows(z).Item(5)

                    z -= 1
                Loop

                [redacted].Rows(k).Item(1) = ComboBox1.Text
                [redacted].Rows(k).Item(2) = ComboBox3.Text
                [redacted].Rows(k).Item(3) = TextBox2.Text
                If RadioButton1.Checked = True Then
                    [redacted].Rows(k).Item(4) = RadioButton1.Text
                ElseIf RadioButton2.Checked = True Then
                    [redacted].Rows(k).Item(4) = RadioButton2.Text
                Else
                    [redacted].Rows(k).Item(4) = RadioButton3.Text
                End If
                [redacted].Rows(k).Item(5) = TextBox3.Text

                [redacted].Rows(i).Item(j1) = 1
                [redacted].Rows(i).Item(7) = [redacted].Rows(i).Item(7) + 1

                btnclick(j1, sender, e)
            End If

            DataGridView2.Visible = False

            ComboBox6.SelectedIndex = -1
            DtGrdVAdd(DataGridView5)
            TransfDtGrdVAdd(True, True)
        End If

    Catch ex As Exception
        MsgBox(ex.Message)
    End Try
End Sub
```

Firstly, a check if the required boxes are filled is done. A second check takes places to investigate if an already implemented design has proceeded for a financial estimation prior to the addition process; in this case, a new window appears to ask the user if he/she wants the implemented financial estimation to be erased. Since the user is eager to procced to this action, the new BP of this ship type for the specified port is added right next to the already existing BPs in the database. The addition is done on a right position of the database to keep database's contents in port and ship type sequence so a neat database presence is guaranteed. In the end, details for the ship type of the new added BP are showed on the "Port's Berthing Places" tab's table.

7.3.3 Port addition ("Ports Berthing Places" tab)

Port addition is described in Chapter 4.3.2.3. In this chapter, the code which runs when "Add" button is clicked on "Add a Port" tab will be presented.

```
Private Sub AddPortBtn_Click(sender As Object, e As EventArgs) Handles AddPortBtn.Click
    If notemptytext(PortAddTxtbx, True) = True Then
        newport = PortAddTxtbx.Text
        Dim portnum = portno(newport)
        Dim portexistancecheck As Boolean
        If portnum <> -1 Then
            portexistancecheck = True
        End If
        If portexistancecheck = False Then
            PortAddition.ShowDialog()
        Else
            MsgBox("Port name already exists, select a different one.")
        End If
    End If
End Sub
```

Firstly, a check if the required box for the new port's name is filled is done. A second check is done if a port with the same name already exists. If both checks are successful a new window appears to request the user the input data for the first BP of the new port. When BP addition is completed according the same syllogism presented in Chapter 7.3.2, port addition is completed as well.

7.3.4 "Main substation" tab's equipment selection addition for financial estimation ("Port's On-Shore Equipment Selection" tab)

"Main substation" tab's equipment addition for financial estimation is described in Chapter 4.3.4.1. In this chapter, the code which runs when "Add selection to financial estimation" button is clicked on "Main Substation" tab will be presented.

```
Private Sub MainSubSelAddBtn_Click(sender As Object, e As EventArgs) Handles MainSubSelAddBtn.Click
    Dim mainsubcablelength As Double
    Dim mainsubvoltransfamount As Integer
    Dim mainsubcbamount As Integer

    Dim check As Boolean
    If notemptytext(TextBox17, False) = True Then
        check = True
    End If

    Dim check1 As Boolean
    If manualselbtnclick = True Then
        check1 = True
    End If

    If check = True And (applybtnclickcheck = True Or check1 = True) Then
        mainsubcablelength = TextBox17.Text
        mainsubfreqconandswitchamount = TextBox7.Text
        mainsubvoltransfamount = TextBox9.Text
        mainsubcbamount = TextBox8.Text

        MainSubGridConCableCostLbl.Visible = True
        mainsubcablecost = mainsubcablelength * 43
        MainSubGridConCableCostLbl.Text = "" & mainsubcablelength & " m, cost: " & Format(mainsubcablecost, "Standard") & " €"

        MainSubBuildingCostLbl.Visible = True
        mainbuildingcost = Format(TextBox13.Text * 4.85 * 230, "0")
        MainSubBuildingCostLbl.Text = "area: " & TextBox13.Text * 4.85 & " m^2, cost: " & Format(mainbuildingcost, "Standar

        FreqConCostLbl.Visible = True
        FreqConCostLbl.Text = "amount: " & mainsubfreqconandswitchamount & ", cost: " & Format(freqconvcost, "Standard") & " €"

        MainSubVoltTransfCostLbl.Visible = True
        MainSubVoltTransfCostLbl.Text = "amount: " & transfnum & ", cost: " & Format(maintransfunitcost * 2, "Standard") & " €"
```

```
            DoubleBusCostLbl.Visible = True
            doublebusbarcost = poweroutput1 * 11800
            DoubleBusCostLbl.Text = "cost: " & Format(doublebusbarcost, "Standard") & " €"

            MainSubSwitchCBCablesCostLbl.Visible = True
            mainswitchandcbcost = TestDBDataSet2.PortsBP.Rows(portno(ComboBox6.Text)).Item(7) * 46500

            MainSubSwitchCBCablesCostLbl.Text = "" & TextBox7.Text & " switchgears, " & TextBox8.Text & " circuit breakers,
cost: " & Format(mainswitchandcbcost, "Standard") & " €"

            MainSubExtraApparatusCostLbl.Visible = True
            coolingetccost = poweroutput1 * 3500
            MainSubExtraApparatusCostLbl.Text = "cost: " & Format(coolingetccost, "Standard") & " €"

            totalequipmentcost = totalequipmentcost + mainsubcablecost + mainbuildingcost + freqconvcost +
                maintransfunitcost * 2 + doublebusbarcost + mainswitchandcbcost + coolingetccost
            TotalCostTxtbx.Text = "" & Format(totalequipmentcost, "Standard") & " €"

            MsgBox("Selection added successfully.")
            selectionadditionbtnclick = True
        Else
            MsgBox("Fill the required boxes to add your selection.")

            If blinker.Focus() Then
                Timer1.Enabled = False
                Timer2.Enabled = False
                blinker.BackColor = SystemColors.Window
            End If
        End If

    End Sub
```

Firstly, a check if the required boxes are filled is done. Afterwards, a second check for either the suggested or a manual frequency converter selection is made is done. Since both checks are successful, the required financial calculations are implemented for the added equipment (frequency converters, voltage transformers, 20 kV cables, building construction, double busbar system, switchgears, circuit breakers and cooling/other systems). Results along with the amount of the added equipment are added in the "Selection's Financial Estimation" tab to be presented. Respective utilized prices for these calculations are explained in Appendix's Chapter 7.2. Lastly, a window indicating the successful addition appears.

7.3.5 "Primary Cable Arrangement" tab's equipment selection addition for financial estimation ("Port's On-Shore Equipment Selection" tab)

Equipment added for financial estimation in "Primary Cable Arrangement" tab is described in Chapter 4.3.4.2. In this chapter, the code which runs when "Add selection to financial estimation" button is clicked on "Primary Cable Arrangement" tab will be presented.

```vb
Private Sub PrimCableArrSelBtn_Click(sender As Object, e As EventArgs) Handles PrimCableArrSelBtn.Click
    PrimCableArrLstbx.Items.Clear()
    PrimCableArrLstbx.Visible = True
    If abovezero(FerryBPTextBox1.Text) Then
        PrimCableArrLstbx.Items.Add("Selected primary cable arrangement distance for Ferry BPs: " & FerryDistTxtbx.Text & " m")
    End If

    If abovezero(CruiseBPTextBox1.Text) Then
        PrimCableArrLstbx.Items.Add("Selected primary cable arrangement distance for Cruise BPs: " & CruiseDistTxtbx.Text & " m")
    End If

    If abovezero(ContainershipBPTextBox1.Text) Then
        PrimCableArrLstbx.Items.Add("Selected primary cable arrangement distance for Containership BPs: " & ContainDistTxtbx.Text & " m")
    End If
```

```vb
    If abovezero(Bulk_GeneralCargoBPTextBox1.Text) Then
        PrimCableArrLstbx.Items.Add("Selected primary cable arrangement distance for Bulk Carrier/General Cargo BPs: " & BulkDistTxtbx.Text & " m")
    End If

    If abovezero(TankerBPTextBox1.Text) Then
        PrimCableArrLstbx.Items.Add("Selected primary cable arrangement distance for Tanker BPs: " & TankerDistTxtbx.Text & " m")
    End If

    primcablearrtotalcost = TotalDistTxtbx.Text * 43
    PrimCableArrLstbx.Items.Add("Total selected primary cable arrangement distance: " & TotalDistTxtbx.Text & " m, cost: 
Format(primcablearrtotalcost, "Standard") & " €")

    totalequipmentcost = totalequipmentcost + primcablearrtotalcost
    TotalCostTxtbx.Text = "" & Format(totalequipmentcost, "Standard") & " €"

    MsgBox("Selection added successfully.")
    selectionadditionbtnclick = True
End Sub
```

Firstly, a check for which BPs' shore-side stations connection cables with the main substation are added is done. Thereafter, distances covered by the added cables proceed for presentation in "Selection's Financial Estimation" tab. Finally, required calculations are implemented for the 20 kV cables' cost and total cost proceeds as well in the "Selection's Financial Estimation" tab. Respective utilized prices for these calculations are explained in Appendix's Chapter 7.2.

7.3.6 "Shore-side Transformer Station" tab's equipment selection addition for financial estimation ("Port's On-Shore Equipment Selection" tab)

Equipment added for financial estimation in "Shore-side Transformer Station" tab is described in Chapter 4.3.4.3. In this chapter, the code which runs when "Add selection to financial estimation" button is clicked on "Shore-side Transformer Station" tab will be presented.

```
Private Sub SSideStationSelBtn_Click(sender As Object, e As EventArgs) Handles SSideStationSelBtn.Click

    Dim transformersneeded As Integer = DataGridView6.Rows.Count - 1
    Dim i As Integer
    Dim transfpowout As Double
    Dim transformersadded As Integer
    Do While i < transformersneeded
        If DataGridView6.Item(4, i).Value <> "" Then
            transformersadded = transformersadded + 1
            transfpowout = transfpowout + DataGridView6.Item(4, i).Value
        End If

        i += 1
    Loop

    If transformersadded > 0 Then
        SsideStatBuildingCostLbl.Visible = True
        ssidebuildingcost = [redacted].Rows(portno(ComboBox6.Text)).Item(7) * 4000
        SsideStatBuildingCostLbl.Text = "" & [redacted].Rows(portno(ComboBox6.Text)).Item(7) & " buildings added,
total building area: " & TextBox12.Text * 2.5 & " m^2, cost: " & Format(ssidebuildingcost, "Standard") & " €"

        VolTransfLinkLbl.Visible = True
        ssidetransfcost = transfpowout * 43500
        SsideStatVoltTransfCostLbl1.Visible = True
        SsideStatVoltTransfCostLbl1.Text = transformersadded
        SsideStatVoltTransfCostLbl2.Visible = True
        SsideStatVoltTransfCostLbl2.Text = "cost: " & Format(ssidetransfcost, "Standard") & " €"

        SsideStatSwitchCBCablesCostLbl.Visible = True
        ssideswitchandcbcost = [redacted].Rows(portno(ComboBox6.Text)).Item(7) * 16800
        SsideStatSwitchCBCablesCostLbl.Text = " " & TextBox10.Text & " switchgears, " & TextBox11.Text & " circuit breakers,
cost: " & Format(ssideswitchandcbcost, "Standard") & " €"

        totalequipmentcost = totalequipmentcost + ssidebuildingcost + ssidetransfcost + ssideswitchandcbcost
        TotalCostTxtbx.Text = "" & Format(totalequipmentcost, "Standard") & " €"

        MsgBox("Selection added successfully.")
        selectionadditionbtnclick = True
    Else
        MsgBox("Transformer selection is empty.")
    End If

End Sub
```

Firstly, a definition of the selected voltage transformer amount takes place. If this amount is above zero, cost calculations are executed and equipment amount along with calculated costs proceed for presentation in "Selection's Financial Estimation" tab. In the end, a window indicating the successful addition appears. Respective utilized prices for these calculations are explained in Appendix's Chapter 7.2. In contrary, if no selection is made, a window indicating a relevant message appears.

7.3.7 "Shore-side Connection Arrangement" tab's equipment selection addition for financial estimation ("Port's On-Shore Equipment Selection" tab)

Equipment added for financial estimation in "Shore-side Connection Arrangement" tab is described in Chapter 4.3.4.4. In this chapter, the code which runs when "Add selection to financial estimation" button is clicked on "Shore-side Connection Arrangement" tab will be presented.

```
Private Sub SSideConArrSelBtn_Click(sender As Object, e As EventArgs) Handles SSideConArrSelBtn.Click
    Dim ssidecabletotalcost As Double

    SSideConArrConBxLbl.Visible = True
    conboxcost = TotalBPsConBoxTxtBx.Text * 47000
    SSideConArrConBxLbl.Text = "amount: " & TotalBPsConBoxTxtBx.Text & ", cost: " & Format(conboxcost, "Standard") & " €"

    SsideConnArrLbl.Visible = True
    sside6_6kVcablecost = Val(TotalDistTxtbx1.Text) * 38.5
    sside11kVcablecost = Val(TotalDistTxtbx2.Text) * 40
    ssidecabletotalcost = sside6_6kVcablecost + sside11kVcablecost
    SsideConnArrLbl.Text = "" & TotalDistTxtbx1.Text & " m of 6.6 kV cables, " & TotalDistTxtbx2.Text & " m of 11 kV cables,
total cost: " & Format(ssidecabletotalcost, "Standard") & " €"

    totalequipmentcost = totalequipmentcost + conboxcost + Val(TotalDistTxtbx1.Text) * 38.5 + Val(TotalDistTxtbx2.Text) * 40
    TotalCostTxtbx.Text = "" & Format(totalequipmentcost, "Standard") & " €"

    MsgBox("Selection added successfully.")
    selectionadditionbtnclick = True
End Sub
```

It is mentioned before that connection boxes are added automatically with the port selection according to each port's BPs and ship type. In the code depicted right above, firstly, connection boxes proceed for cost calculation according to their defined amount. Afterwards, a cost definition for 6.6 and 11 kV selected cables according to the distances chosen to cover by the user is done. Finally, all the aforementioned calculated data proceed for a presentation in "Selection's Financial Estimation" tab.

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