SYNCHRONIZATION OF DIESEL-GENERATOR UNIT AND INLAND POWER NETWORK IN SHORE-TO-SHIP SYSTEMS

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Abstract
In the recent years, due to pollution emission by ships moored in ports, shore-to-ship power systems were introduced. Switch-over from ships' autonomous generator units to inland grid comes to carrying out automatic uninterrupted synchronization of both power sources. This task is burdened with several technological challenges, further complicated by lack of compatibility between electrical parameters of shore and marine power grids. These challenges, if not overcome, may disable the synchronization process or even lead to blackout on ship or emergency shutdown of shore-to-ship system. In this article, the author presents zero points synchronization method, which is usable in shore-to-ship systems based on power frequency converters. Proposed method leads to effective fail-free switch-over between ship and shore power sources.

Key words: *marine technology; zero crossing synchronization; power grid and generator synchronization; frequency converter.*

INTRODUCTION

Current environmental trends regarding pollution emission from marine vessels (*Directive 2005/33/EC of the European parliament and of the council, 2005*) made shore-to-ship (STS) systems increasingly popular solution installed in ports worldwide. In its premise STS system provides power, for moored ships, from inland power network, which allows ships' diesel-generator (DG) units to be shut down, thus reducing emitted pollution. Two problems must be solved in order to properly execute such process – first is matching electrical parameters of ship and inland power networks; second is synchronization of both networks and transfer of load to inland grid.

Mismatch of electrical parameters on ships and on the shore result from different voltage and frequency values in both systems. Inland grid structure forces installation of power transformers dedicated for STS systems, which makes problem of different voltage values negligible. Frequency incompatibility on the other hand is very common problem. Ship power systems use either 50 Hz (about 35% of ships) or 60 Hz (about 65% of ships) voltage (*Tarnapowicz, 2014*). High ratio of this values forces STS systems to provide voltages at both of these frequencies. In practice inland power grid of ports' country provides voltage at one of the frequencies and power frequency converters are installed to provide voltage of another, e.g. European continent utilises 50 Hz power grid, therefore to power 60 Hz ship frequency converter is required. Many ports (e.g. some of Swedish ferry terminals) have single high power frequency converter installed for all ships requiring frequency other than their regular inland grid provides. In cases like these synchronization of inland power grid to DG unit is done by modification of fuel rack settings on DG unit's diesel engine. Out voltages of both DG unit and frequency converter are used to control this process and determine moment of synchronization. Synchronization according to this procedure forces running DG network to match its' frequency with unloaded shore voltage source. This solution has following problems:

- Due to engine inertia loaded DG unit reacts to such change in nonlinear way (*Borkowski, 1990*). This increases the risk of triggering generator protection unit, which leads to blackout.
- Frequency change of running DG network affects every device connected to this network, this is especially important for electric motors powered by this network.
- STS systems with single frequency converter have another problem consequential to high sensitivity of converter protection units. While disconnecting from STS system ship's DG units must take on load. Frequency converter is however acts as ideal voltage source, so transfer of whole load from them to DG units is impossible. This forces automatic synchronization systems to disconnect ship from land while designated threshold of load is reached. Moment of disconnection is often interpreted, by converter protection unit, as occurrence of reverse pow-

er. This can lead to emergency shutdown of whole STS system, effectively creating blackout for all ships connected to it.

Solution to above problems is possible with different topology of STS system. Instead of single high power frequency converter multiple converters with smaller power output are used, one for each moored ship (*Borkowski & Tarnapowicz, 2014*). Implementation of this solution makes it possible to independently control output voltage of each converter, therefore inland network can be synchronized to ships' running network of DG units. While synchronized with ship's power network frequency converter will force its' parameters on DG units, because frequency converter behaves as ideal controlled voltage source. This predetermines use of synchronization method allowing fast correction of converter settings. Nowadays phase locked loop (PLL) method has been widely adopted for this purpose (*Tarnapowicz, 2013*). Method presented in this article, based on detection of DG unit's output voltage waveform crossing zeros, is an alternative to PLL method.

MATERIALS AND METHODS

Proposed method of synchronization relies on equalization of voltage waveform zero crossing time for both DG units and frequency converter being synchronized. Alternating current is a sine wave, therefore two zero crossings occur in one period, as presented in Fig. 1. Detection of these crossings comes to finding moments of sign change of voltage waveform. Time intervals between crossings are equal to length of half period of sine wave, thus voltage frequency can be calculated by equation (1)

$$f = \frac{1}{2t} \qquad (1)$$

where f is frequency (Hz) and t is time between transitions (s).

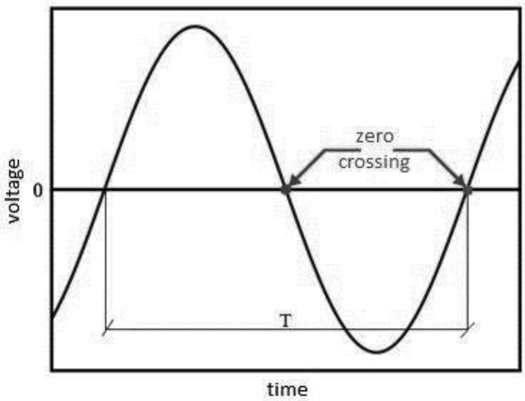

Fig. 1 One period of sine wave with marked zero crossings

Block for detection of zeros crossings is connected to STS system as presented in fig. 2.

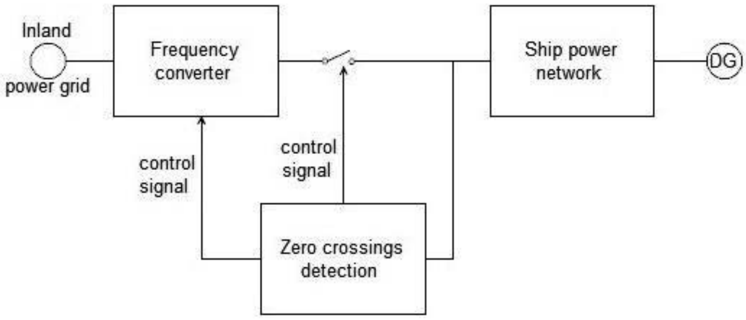

Fig. 2 STS system with block for detection of zero crossings

Detection block measures voltage in ship's power network and, when waveform's crossing of zero is detected, enables frequency converter in STS system and closes switch connecting both power networks. To prevent loss of synchronization, when DG unit's frequency fluctuations occur during load changes, zero crossings are measured constantly and adequate control signals for frequency converter are send. To increase precision of the method zero crossings are detected twice during each period – for both down and up slopes of sine wave.

RESULTS AND DISCUSSION

A simulation analysis of the synchronization of STS system's frequency converter and ship's DG units was performed with use of MATLAB-SIMULINK package. Following algorithm has been used for detection of waveforms crossing zeros:

- voltage signal is sampled at high frequency
- current sign is found by checking if value of the most recent sample is greater than zero
- current sign is compared with sign from the previous sample
- if signs differ crossing through zero occurred

In real-life cases digital signal processor would handle the high frequency sampling. To eliminate false data, coming from noises or lost samples, algorithm would test frame of samples (e.g. five most recent samples) and determine sign based on majority result.

Results of simulation are presented in fig. 3. Adjustment of frequency converter are seen at each zero crossing, with first synchronization occurring at 0,01 second.

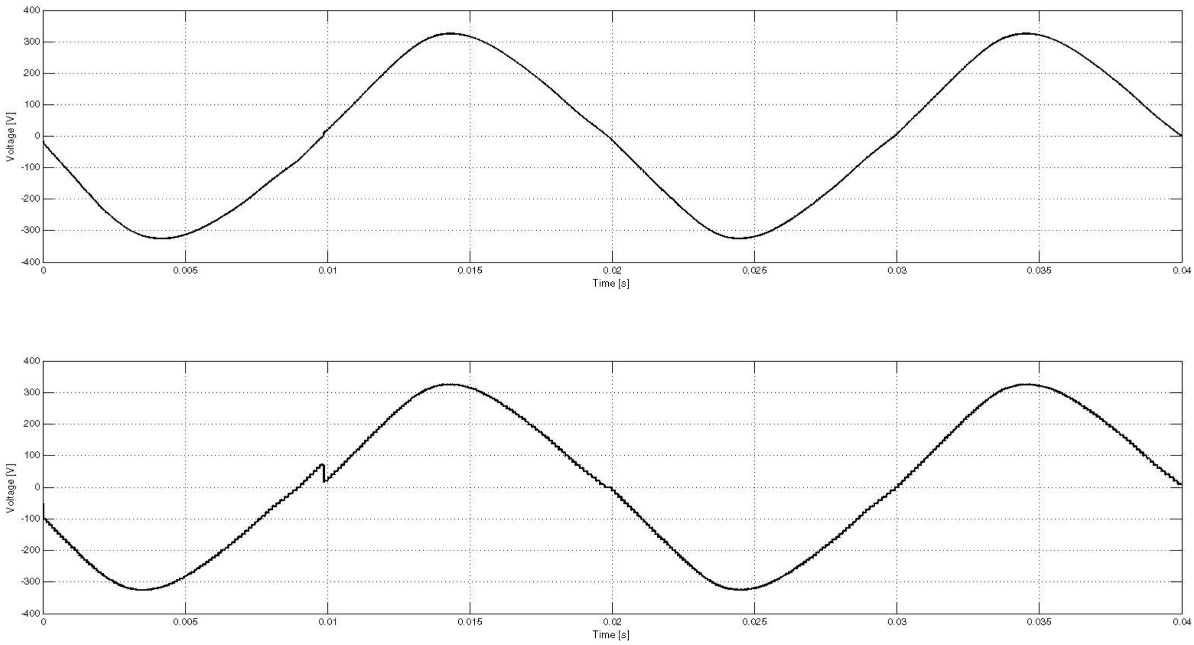

Fig. 3 Voltage outputs of ship's DG units (above) and STS frequency converter (below)

Difference between ship's DG voltage and STS voltage output is presented in fig. 4. After first synchronization measured differences mostly consist of the voltage distortions typical for frequency converter output. All distortions are in the same range as analogous measurements for PLL synchronization method, therefore distortion levels for both method are basically identical.

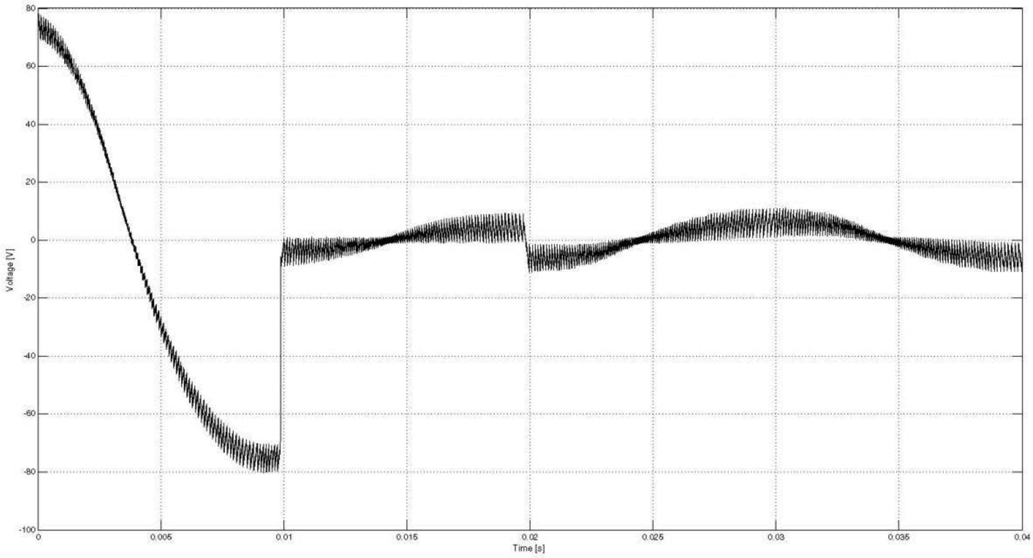

Fig. 4 Difference between voltage from ship's network and STS system

CONCLUSIONS

Method of voltage synchronization based on detection of DG unit's output voltage waveform zero crossings is good solution for STS systems. Detection of zero crossing with use of digital signal processor is simple, as is control over frequency converter's start signal. Proposed method requires STS system with independent frequency converters dedicated for each ship. This should not be a problem in the future, because this topology of STS systems is growing in popularity, due to fact that it solves other technological and quality of power problems. Most of future STS systems in European ports are supposed to have such topology.

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