Radio interference on maritime wireless communication due to solar farms and wind parks: Risks and mitigations

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Abstract

Renewable energy is developing at a very high pace. By 2030[1] 70%[2] of all electric energy in the Netherlands must be produced by sustainable energy sources like wind and solar farms. As the available landmass in the Netherlands for renewable energy decreases, not only wind farms, but also floating solar farms will be placed at sea.

The electrical energy generated by Solar and Wind power plants needs to be converted in order to match the electricity utility network. Electronics have been developed employing very fast switching circuits to accomplish this. A side effect of these fast switching circuits is *Electro Magnetic Interference* (EMI), which impacts the reception of wireless transmissions.

EU-regulations set limits to the EMI-levels which may be radiated, but these do not sufficiently protect the reception of wireless broadcast and communications. On the mainland, interference levels have increased, due to the vast numbers of electronic equipment and (domestic) solar panel installations and because the emission limits set in the various standards are too high.

EMI generating electronics in wind turbines are installed in the metal encapsulation of the mast, which acts as a Faraday cage, limiting the radiation of EMI.

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[1] Plans 2030-2050 | RVO.nl
[2] Elektriciteit | Klimaatakkoord

Solar panel power inverters installed on the mainland cause problems with the reception of broadcast (FM-broadcast, DAB+) and wireless emergency services (e.g.: C2000). In order to prevent a similar situation to occur at sea, it is paramount to prevent that the EMI from floating solar power installations causes interference on wireless communication. Without proper measures, maritime radio communication near solar parks may be severely disrupted. This may extend up to a kilometre around a floating solar power plant if no mitigating measures have been implemented.

Theoretically the ‘essential requirements’ of Annex I of the EU-regulations don’t allow EMI-levels that affect wireless communications, in practice these are not enforced. A general reduction of the EMI limits for all electronics would provide a much better solution for reliable wireless reception. In the long term that would mitigate the land-based interference situation as well.

Technically an abundance of mitigating solutions are available, such as: shielding, filtering of DC and AC lines, proper layout of the DC-power lines running to the solar panels, design improvements of the inverters. These may provide sufficient mitigation to prevent that a problematic man-made noise scenario which is now prevalent on many land locations, will arise on the North Sea as well.

Introduction

Renewable energy is developing at a very high pace. By 2030[3] 70%[4] of all electric energy in the Netherlands must be produced by sustainable energy sources like wind and solar farms. As the available landmass in the Netherlands for renewable energy decreases, not only wind farms, but also floating solar farms will be placed at sea.

The focus in this paper will be on the Electric Magnetic Interference (EMI)-effects of electric energy conversion techniques, and their impact on the ambient RF-noise environment (also referred to as “man-made noise”) with emphasis on the effects on marine communication. The build-up of this document is as follows:

- Short introduction on the generation of renewable energy
- An overview of wireless marine and public safety communications
- EMI and its impact on wireless reception
- Mitigating measures
- Conclusions and recommendations

The coexistence of wireless communication and switch-mode systems in general has become very challenging over the past decades. The EU Electro Magnetic Compatibility (EMC)-regulation[5]

[3] Plans 2030-2050 | RVO.nl
[4] Elektriciteit | Klimaatakkoord
[5] 2014/30/EU

(regarding CE approval) requires that all electronic equipment complies with EMC-standards. However, the authorized RF noise levels associated with these standards are such that virtually all receivers (part of any wireless communication systems) are negatively affected. Compliance of electronic equipment to EMC-standards does not guarantee absence of interference to wireless systems. To fight this RF-noise either a significant power increase of the associated transmitters is required, or a reduction of the EMI emitted by electronic equipment. Ignoring either measure will result in smaller coverage areas in which wireless systems can operate.

The EU EMC-regulation not only refers to the EMC-standards[6] for electronic equipment to comply with, but also has an appendix with "Essential requirements". These stipulate that electronic equipment *"the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended"*. These "Essential requirements" have often been ignored by manufacturers and authorities. In order to safeguard wireless communications, these ought to be enforced more strictly. Or better still: the maximum EMI-levels should be reduced.

Even though Wind Turbine Generators (WTGs) can be a source of EMI, in practice the generated EMI is of such a low level that the impact on wireless communication and broadcast services is marginal. The wind turbine industry has imposed upon itself stricter EMI-levels[7] than manufacturers of solar power inverters of similar power levels. Nacelles (the gondola) which contain the generator, controlling electronics and sometimes switching power electronics, are often shielded by an electric meshed network to safeguard it against lightning strikes. This wired mesh works in two directions, hence it also limits RF-radiation to escape from the nacelle. Furthermore, most wiring, which may act as radiating antennas, is locked inside the tube-like mast made of steel.

Solar panel installations and the associated inverters are specifically known to be high risk sources[8,9] of EMI and are deployed in large numbers on land. Floating solar farms are under development and are likely to be commercially exploited in the near future at sea[10,11,12].

Maritime communication, navigation (operating between 156 and 162 MHz) and UHF private communication systems often used for maintenance and public safety (e.g. DMR, TETRA/C2000) may experience deprecated radio coverage if solar plants in their vicinity only just comply to the EMC-standards and ignore the "essential requirements" of the EU EMC-regulation. Zones as large as 1 km around a floating solar farm may be affected due to the cumulative effects of multiple

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[6] EN55011:2016
[7] EMC IN WIND ENERGY SYSTEMS WORKING GROUP, C4.30
[8] Agentschap waarschuwt: zonnepanelen gevaar voor communicatie hulpdiensten (nos.nl)
[9] Voorkom storingen door zonnepanelen | Tips voor veilig gebruik van apparaten | Rijksinspectie Digitale Infrastructuur (RDI)
[10] Grootste offshore zonne-energiesysteem ter wereld ligt vanaf 2026 in de Noordzee | Change Inc.
[11] Drijvende zonnepanelen | TNO
[12] https://www.rvo.nl/onderwerpen/zonne-energie/water

inverters connected to wiring which acts as antennas, as will be demonstrated later in this paper (Figure 4).

Hence, the EMI-effects of a complete solar farm should be considered and be restricted to levels that safeguard all possible wireless communications in or near such a solar farm.

The scope of this paper has been limited to VHF and UHF (100 – 1000 MHz) given the specific types of communication equipment in a marine environment. The detrimental effects due to EMI on electronic equipment is not restricted to these frequencies and is also very prominently present below 100 MHz.

To date there is no measurement data available of man-made noise > 1000 MHz. Given the increased use of solid state switching technology, which results in EMI at higher frequencies, it is anticipated that negative effects will become noticeable on GNSS (1500 MHz) and other applications.

Two worlds…

The generation of sustainable electric energy has become a major contributor to the total electricity production in the Netherlands and many other European countries. Wireless (data)communication has also become integrated in society, as 5G, IoT, WiFi, DAB+, etc, etc have become an accepted and crucial part of today's way of working and living. Reliable wireless communication depends on being able to access the radio spectrum without being hampered by (non-intended) interference. The entanglement and intricacies of these two seemingly unrelated worlds will be explained here.

Generation of electric energy

Conventional production of electricity did not have any effect on wireless communications. Until the mid-nineties, electricity was generated by power plants using fossil fuels, nuclear and hydro kinetic energy. Except for hydroelectricity, energy is generated in the form of heat which is used to turn water into steam, propelling turbines which in turn drive electric power generators. Huge transformers are used to convert the relatively low voltages of a few hundred volts from the generators into mid (10 kV) or high range (> 100 kV) voltage levels, as solid-state devices are not yet capable to perform these functions.

Electric energy is transported from the power plants to municipalities at levels of tens to hundreds of kilovolts. The use of high voltages for energy transportation is solely to minimize transport losses, which decrease with increasing voltages. Down conversion to 230 VAC is performed with transformers, in a similar fashion as the up conversion at the power plants. Transformers can be large and may vary in size ranging from a few hundred kilograms to tens of metric tons.. The radiation of such a transformer is at very low frequencies and the magnetic field confined to several tens of metres from the source. There is virtually no interference with wireless communication equipment.

Contrary to conventional power plants, solar panels individually produce a DC voltage, around 40 to 50V per module, which are interconnected in series to strings that generate up to 1055 VDC. Large solar farms first convert the output voltage from the solar panels into a 3-phase AC voltage in the 400 - 800 VAC range, which then subsequently is upconverted using traditional transformers to the mid voltage range or even the high voltage range[13] to accommodate the electricity transmission network.

[13] https://en.wikipedia.org/wiki/Photovoltaic_power_station

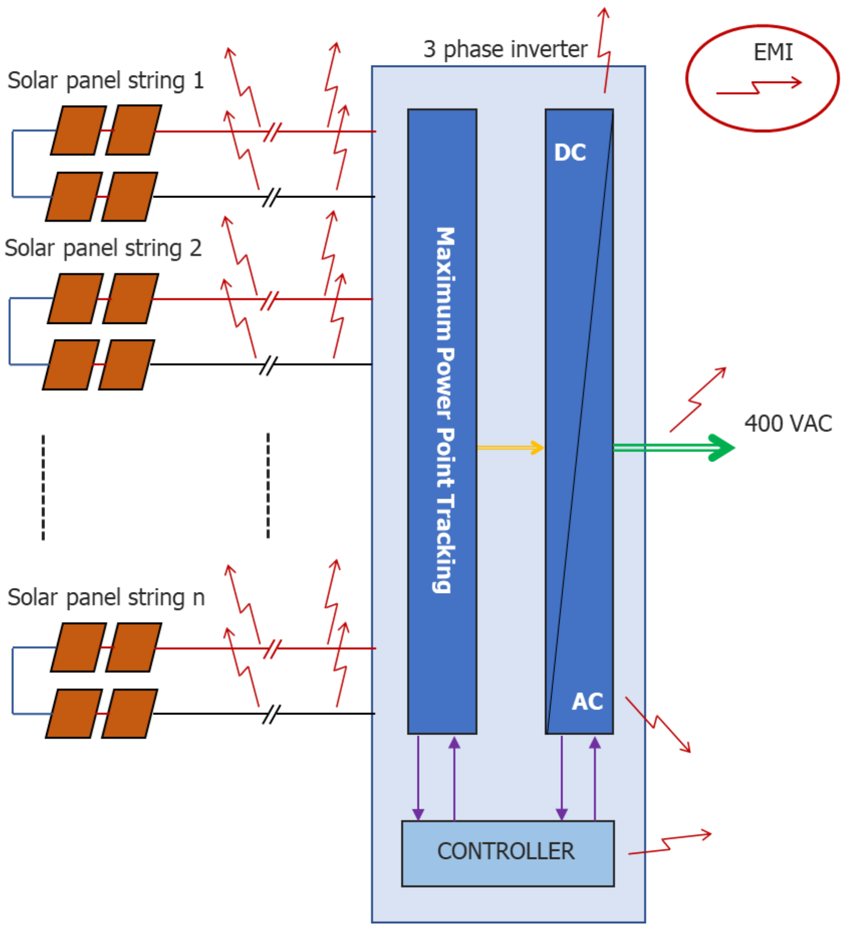

Figure 1 Potential sources of EMI for a high power three phase PV installation

In Figure 1 the principle of a three phase inverter is shown and the potential sources of EMI. The power levels of three phase inverters employed in large solar parks are usually more than 100 kW.

The transformation from DC- to AC-voltages is performed using to fast switching solid state technology. Residual effects from the switching process may radiate to the outside world, hence cause EMI. The wiring between inverter and solar panels may act as antennas and radiate this EMI.

Electromagnetic emissions (EMI)

Except for a 50 Hz electromagnetic field, traditional transformers do not produce additional electromagnetic fields which may cause interference in the RF spectrum.

The process of adapting from DC to AC and from low to high voltages, and vice versa, is called *power conversion*. Converting energy from a constant voltage (DC) to an alternating voltage (AC) is accomplished by chopping the DC-voltage in slices (Pulse Width Modulation “PWM”) and modulating it in such a way that the envelope is similar to a 50 Hz sine wave. The chopping requires the use of very fast solid state switching devices. A transformer is sometimes added to the final stage to transform into the desired AC output voltage range.

Solid state switches consume very little energy when they are either in an On or Off state. During the transition between these two states energy is lost as the switch transverses through a resistive state which results in the production of some heat, i.e.: loss of efficiency. Hence the wish to reduce the switch time as much as possible. This results in an excellent solution for energy conversion: an efficiency of often 90% or more.

The transitions of the solid state switch between open and closed and vice versa, may cause either short but intense currents, or voltage spikes. Currents as well as voltage spikes have properties similar to a "Dirac pulse". The properties of a true Dirac pulse are that it is infinitely short but with a high amplitude. The RF transmission properties of such a spike cause RF-noise across the entire RF spectrum. This explains why the EMI from switch mode electronics can be observed over large parts of the frequency spectrum, at least into the UHF-frequency range.

The used switching frequency (in the range of tens to a few hundred kHz) usually repeats itself hundreds of times[14] across the spectrum. Unless properly filtered, connecting circuitry, printed circuit traces and attached wiring, will act as antennas and radiate these signals to the outside world.

Wireless Communication and broadcast

Until 20 years ago, mainstream telephony was wired. In-house wireless extensions migrated from plain analogue FM (unsecure) to DECT, introducing a secure wireless experience. Subsequent technological advancements have led to GSM, Edge, 3G, 4G and 5G technologies which are available for the general public. A life without Bluetooth, Wi-Fi, etc. would be unimaginable to any adolescent today.

However, wireless communication has been around for much longer. Maritime radio (VHF marine communication "Marifoon", introduced in 1957[15]) and AIS (Automatic Identification System introduced in 2002[16]) both play a crucial role in the safety and guidance of ships at sea and on rivers and canals.

In addition, dedicated digital communication systems were developed for public safety like C2000, TETRA, DMR (the latter two mainly for commercial applications). C2000 is a crucial asset in life-threatening and hazardous situations, and it is used by law enforcement and emergency services. It

[14] RF spectra of the output pulse trains. | Download Scientific Diagram (researchgate.net)
[15] https://www.frequentieland.nl/geschiedenis/maritiem.htm
[16] https://globalfishingwatch.org/data/ais-brief-history/

is evident that fire squads and police forces should be able to rely on their radio equipment to contact their headquarters to obtain information or request for assistance.

A communication system can only function when it is able to properly receive a message from its partner transmitter. This may seem obvious, but it is not! Wireless communication, such as broadcasted (emergency) messages, but also FM-radio and DAB+, can only operate properly if the signal quality on the antenna is sufficient. *I.e.: the ratio between the intended signal and RF-noise (natural + man-made) should be adequate.* Interference from neighbouring systems and radio noise emitted by non-intended systems (Switch Mode Power Supplies, Solar Power Inverters, Ethernet networks, Computers, etc), may have a profound effect on the performance of wireless communication and broadcast systems. *Increases of the man-made noise (due to EMI) may render broadcast and communication useless.*

…working together?

Electro Magnetic Compatibility (EMC): Coexistence of transmitters with other electronic devices

Every wireless communication device contains a transmitter. In many instances the power levels are very low (for example, just a few milliwatt for Bluetooth), but higher power levels may be emitted by Personal Mobile Radios (PMR: 0.5 Watt) and smartphones (up to 2 Watt). Consumer and professional equipment should be capable to cope with the electromagnetic fields emitted by smartphones and other consumer grade transmitting devices up to at least 3 Volt/m[17]. In general, one may state that consumer and professional equipment have become more resilient to electromagnetic fields since the introduction of the EU EMC-directive.

EMI: Influence of electronics on receivers

The EU EMC-directive also defines how much electromagnetic field is allowed to be emitted by electronic equipment. Oscillators in network switches, routers and fast switching devices like power supplies and solar inverters in particular are examples of devices which transmit either narrow band carriers and/or wide band RF-noise (the exact type of emissions are related to the type of clock source, switch mode, circuit design, etc. In practice often a mix of discrete carriers and wide band noise is emitted).

The Electro Magnetic Interference (EMI) of any electronic device must comply with emitting no more than the maximum *electric field strength* in order to obtain EU type-approval. When a new product is introduced, only a few devices are required to be tested by an approving body[18] in order to obtain CE approval by the EU. All subsequent products will be assumed to comply as well.

Field strengths are measured with specific qualified antennas and equipment at reference distances of 3, 10 or 30 metres from the Device Under Test (DUT). Required connecting wiring is *not* taken into consideration when EMI approval measurements are performed. However, in many instances cables need to be attached to this DUT in order to perform according to its designation. These cables may act as antennas, for example the DC-wiring which is connected between the inverter and solar panels and the AC-cabling from the inverter (the Device Under Test in this case) to the utility electricity network.

[17] NEN-EN-IEC 61000-6-1
[18] An organization which is certified to execute EMC measurements and to issue certificates of compliance.

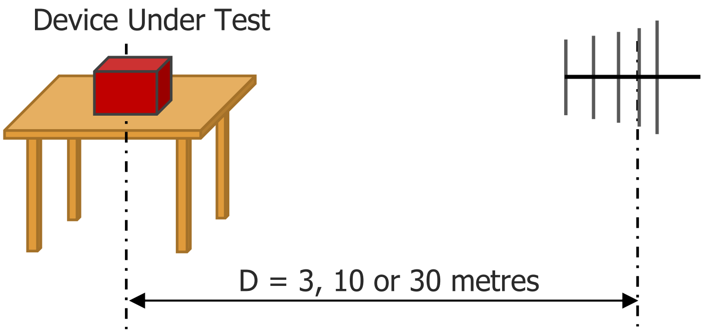

Figure 2 Standard test configuration with a DUT and measurement antenna.

The values shown in table 1 are for four situations. Three are based on the 2-ray propagation model which takes the surface into account. For short distances the actual propagation losses may be less than the Free Space model. The effects for three different receive antenna heights are shown versus distance.

1. 6 metre antenna height for ships.
2. 20 metres for operations on wind turbines
3. 60 metres for offshore platforms and large vessels.
4. The last situation shows the theoretical field strength versus distance for the free space propagation scenario. These values are used to explain the effects on communication in Figure 4. The actual values depend on the employed antenna heights and may be better or worse.

Table 1 the EMI field strength levels are given for high power industrial equipment (>20 kVA). "Industrial" in this respect is not necessarily a huge factory, but could be any equipment which consumes or produces more than 20 kW of electric power. A floating solar farm easily fulfils these requirements.

The levels shown are the maximum values in order to be compliant with the regulations. Compliance measurements are performed at distances of 3, 10 or 30 metres from a Device Under Test, but the electric field will of course expand into infinity. For every 10 fold increase in distance, the electric field strength will decrease by a factor of 10 (= 20 dB) as well (unless it is blocked by obstacles). An extrapolation of the field strength is shown in the table for several distances to show the possible field strengths at those distances.

The values shown in table 1 are for four situations. Three are based on the 2-ray propagation model[19] which takes the surface into account. For short distances the actual propagation losses may be less than the Free Space model. The effects for three different receive antenna heights are shown versus distance.

5. 6 metre antenna height for ships.
6. 20 metres for operations on wind turbines
7. 60 metres for offshore platforms and large vessels.
8. The last situation shows the theoretical field strength versus distance for the free space propagation scenario. These values are used to explain the effects on communication in Figure 4. The actual values depend on the employed antenna heights and may be better or worse.

Table 1 Class A, group 1, Industrial equipment (> 20 kVA). Based on the 2-ray propagation model. Solar panels and associated equipment installed at 3 m a.s.l.

Receive antenna height	**Electric Field strength[dBµV/m][20] vs. distance Values are applicable to the marine band (156- 162 MHz)**				
	10 m	**30 m**	**100 m**	**300 m**	**1000**
1. 6 m	50	40	31	12	-8
2. 20 m	50	40	35	22	2
3. 60 m	50	40	34	26	11
Field strength versus distance for the Free Space propagation situation					
4. Free Space	50	40	30	20	10

Wireless communication obeys the same principles as human voice interactions. When one is in a museum, whispering to one's neighbour will usually suffice to convey a message, while at a rock-concert, shouting out loud may not be sufficient to effectively communicate. The successful reception of wireless information also depends on the noise in the environment, but this time "Radio Frequency" (RF) noise. This RF noise usually increases with human activities (electric engines, cars, industrial activities, etc). The International Telecommunication Union has measured and published levels of background RF noise[21].

[19] Two-ray ground-reflection model - Wikipedia, Wave propagation calculation tool (for free-space and 2 wave model) | technical tools | CIRCUIT DESIGN, INC. (cdt21.com)
[20] Industrial: CISPR11, edition 6.0, 2016-06.
[21] ITU Recommendation P.372-16

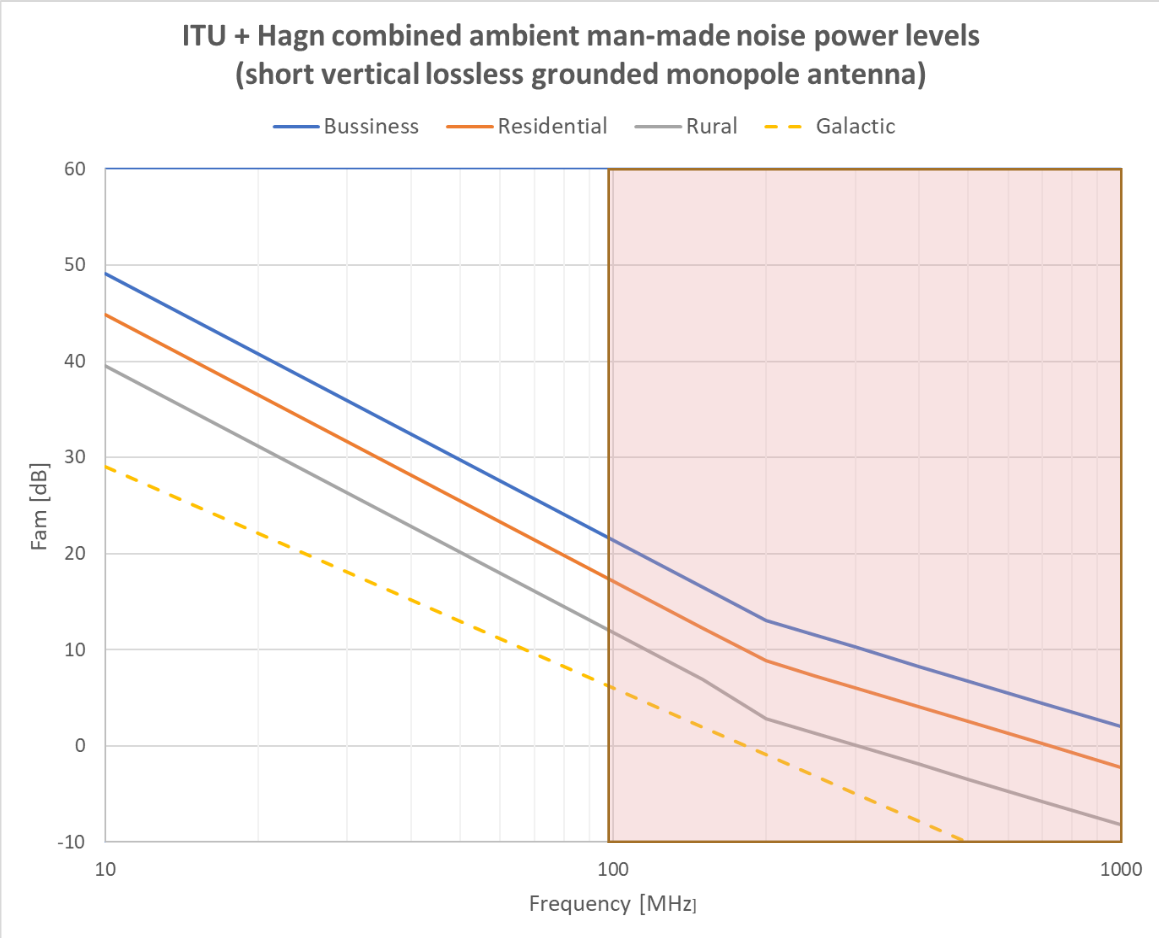

Figure 3 ITU measurement data of the RF noise level in different environments, taken prior to the introduction of wide scale solar panel systems and extrapolated to 1000 MHz[22]. The pink area represents the frequency range of interest where many wireless applications operate. F_{am} is the ambient noise referenced to 290 K (= 0 dB).

To put these background noise levels in perspective with the field strength emissions of solar panel inverters and the extrapolated EMI-level limits as referred to in the EU EMC-regulation, the *galactic* and *rural* noise levels in the right part (pink) of Figure 3 have been converted to field strength levels, which are presented in figure 4.

[22] ITU Recommendation P.372-16, page 100, up to 200 MHz. The graphs have not changed since 1994. Between 200 and 1000 MHz the formulas from: "Man-made radio noise and interference, G.H. Hagn", Agard-CP-420, 1987

Formulas to convert from Noise temperature as a ratio (F_{am}) to field strength (E) in dBμV/m:

F_{am} is the noise temperature, shown as a ratio in dB, with respect to 290 K.

$T = 290 \times 10^{F_{am}/10}$ T = Absolute temperature [Kelvin]

This quantity is converted to an absolute temperature using:

$Pn = T \times K \times B$

B = Field strength measurement bandwidth of 120 kHz

T = Absolute temperature [Kelvin]

K = Boltzmann's constant; 1.38 * 10^{-23} J/K

From the absolute temperature, the field strength is calculated as follows:

E = $\sqrt{(P_n \times 4\pi \times Z_0)/\lambda^2}$

E = Field strength [V/m]

λ = Wavelength [m]

Z_0 =Impedance of free space ≈ 377 Ω

$E_{dB} = 120 + 20 \times \log_{10} E$ E_{dB} = Field strength [dBμV/m]

An industrial rated system is allowed to produce an EMI-level as high as 50 dBμV/m at a distance of 10 metres. Assuming the free space propagation model, the associated EMI-levels at 100 and 1000 metres are 30 and 10 dBμV/m.

Note: For receiving objects close to the sea surface (i.e.: a few metres) the actual levels will be much less. However, for large ships, off-shore substations and platforms these levels are valid up to approximately 1 km from the EMI-source.

The required sensitivity levels of the receivers of communication and broadcast systems, such as marine radio and AIS, 4G/5G, DAB+, are denoted in their respective standards.

Error! Not a valid bookmark self-reference. In figure 4 these minimum sensitivity levels have been converted to equivalent field strength noise levels in order to make comparisons with EMI possible. The equipment sensitivity levels are indicated by the horizontal purple lines.

Radio planners will normally use the sensitivity levels as indicated in the system standards for the specific radio system "under planning" and the applicable ambient ITU noise levels (e.g.: rural, domestic, etc), to calculate radio coverage.

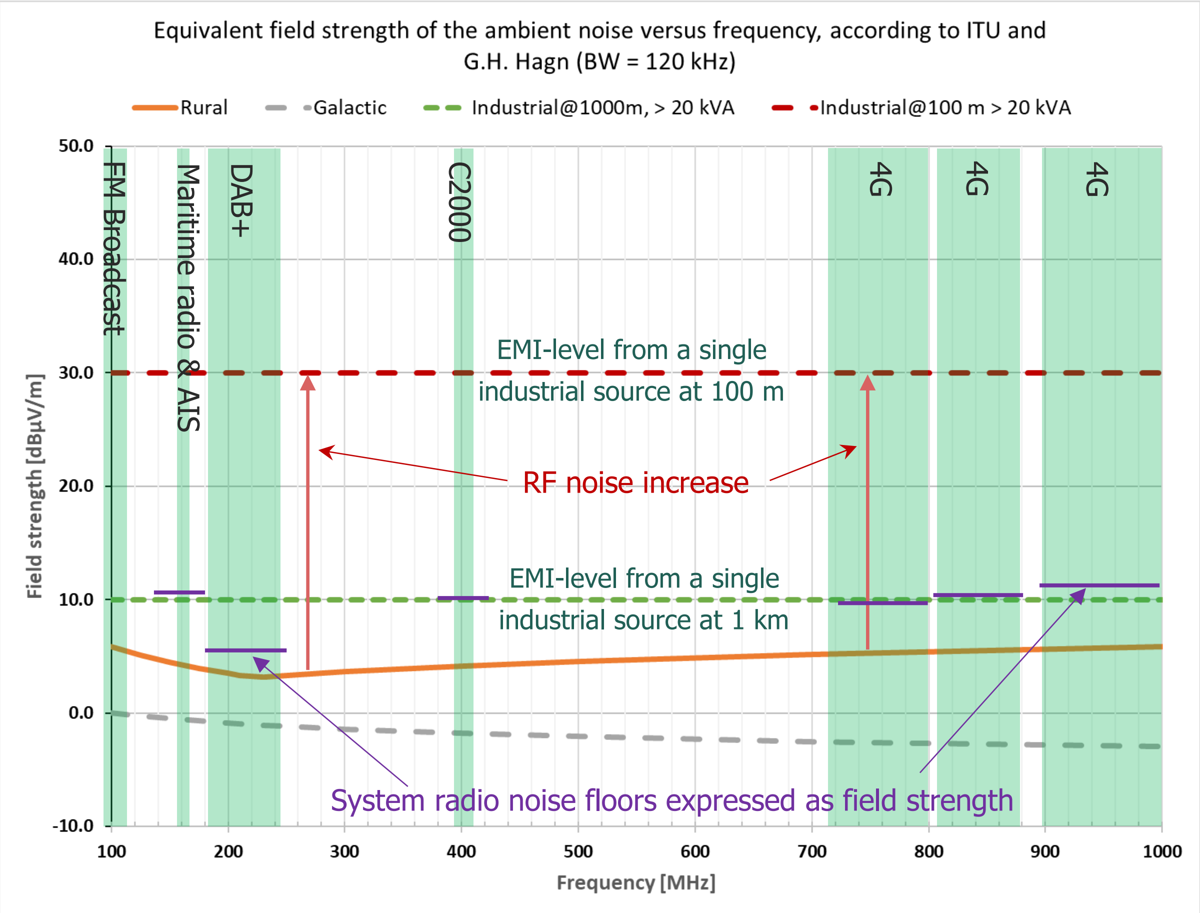

Figure 4 Systems operating in the frequency band between 100 and 1000 MHz which are affected by EMI. The ambient back ground noise (rural and galactic) is shown in relation to the RF-noise from a single industrial installation. Assuming the field strength values at 100 and 1000 metres as depicted in Table 1 for Free Space propagation. Actual values may be better or worse, depending on the exact circumstances.

The traditional ambient noise at sea is less than the "rural" ambient noise conditions on land (orange line) and in practice close to the galactic noise line (dashed grey line). Comparing the EMI generated noise (see Table 1) with "rural" back ground level, shows that at a distance of 100 metres (dashed red line in Figure 4) 23 to 27 dB higher levels can be expected when industrial equipment, which just complies with EMI regulations, is used! For high elevated objects (≥ 60 m above sea level (asl)) there has to be a separation of at least 1 km from such a source of EMI to have its effects more or less mitigated.

When the ambient noise (natural or from man-made sources) reaches the same level as the radio noise floor, the sensitivity of that receiver will be degraded by 3 dB. Hence the radio noise floor and the interference noise level for a 3 dB sensitivity degradation are the same and indicated by the same purple lines. A 3 dB degradation is clearly noticeable in most applications, but generally still manageable to cope with (this does not apply to e.g. satellite communication which often relies on very low signal levels and margins).

It is demonstrated in figure 4 that the EMI from a single industrial inverter, at a distance of 100 metres, may be (much) higher than deemed acceptable to limit receiver sensitivity degradation to 3 dB. Even at a distance of 1 km there may still be performance degradation. And that's for <u>one</u> inverter. **A scenario with a single industrial power device, and an EMI-level exactly compliant to the EMC regulations, will have a marked interference up to 1 km distance, hence possibly impacting the reliability of communication and broadcast within that range.**
On the mainland there may be enough margin for broadcast, as extra losses apply due to buildings, trees and other structures which induce extra signal loss of the EMI source. Such a situation is much less applicable at sea.

The levels in Figure 4 are applicable for a single industrial rated system. The effect of multiple inverters (and the associated wiring), as may be found on solar farms, will have cumulative effects which may increase the levels substantially above the 30 dBμV/m at 100 metres and 10 dBμV/m at 1 km as depicted in Figure 4. Hence, a much larger region may be affected in practice.

Maritime navigation and communication in a man-made noise environment

The development and deployment of large solar farms in the North Sea has given rise to concern of the susceptibility of the communication and navigation networks to interference generated by the associated inverters and wiring.

Impact of floating solar farms on maritime communication: Sensitivity

The minimum sensitivity of marine radio and AIS receivers is defined by international standards and is rather low (i.e.: the radios are not particularly sensitive). In a sense this is a positive aspect when it comes to susceptibility to increased (man-made) noise, negative effects are manifested at a higher noise level than for a sensitive receiver. However, this does not eliminate the effects of EMI, but at best mitigates it. The cumulative effects of many inverters on a floating solar farm may still be such that large areas of several km^2 around (and inside!) the farms are affected.

The situation on land has already become problematic, as long-distance VHF communications (i.e. more than a few kilometres) in domestic areas are often severely hampered on sunny days. The vast numbers of solar panel installations on rooftops create a blanket of EMI, which swamps all weak signals. C2000 has been one of the affected systems. There is no defence against EMI other than a vast increase of (C2000) base stations or a reduction of the sources of EMI.

With the right measures and a (self-imposed?) more strict policy of lower EMI-levels than the EMC regulations ordain, and actually adhering to the 'essential requirements' in appendix I of the EU-EMC regulation, it is possible to avoid that a similar problematic man-made noise situation arises in the maritime setting.

Contrary to the situation on land, there are no alternatives for wireless communication when hazardous situations arise at sea. Wireless communication provides the only means of communication.

Mitigating measures

Shielding and filtering the circuitry which generates the EMI, has and will be the best way to decrease the amount of interfering RF that escapes from switch mode devices. The filter aspect is perhaps even more important than shielding of the switch mode hardware, as it will prevent RF to escape over the wiring which may act as an antenna, and be radiated into the outside world. The layout of the DC lines to and from the DC panels can mitigate this antenna effect but will not completely prevent it. Suppressing the conducted RF to reach the power lines is one of the most effective ways to prevent harmful EMI.

EMI originates at the power inverter: the switching devices which convert DC to AC. Over the past decade design and solid-state circuitry[23] have been developed that inherently diminishes the amount of radiated and conducted EMI.. The implementation of such technology would cost tens of Euros, only a small fraction of the present investment costs of an offshore solar park. In a worst-case scenario where shielding, technology and EMI filtering is required, the estimated additional costs to produce a (very) low EMI power inverter is likely in the order of 20% (or less) of the price of the inverter. High power inverters are usually encapsulated in a metal enclosure and fitted with EMI-filters. Hence, relatively small improvements of the RF shielding quality and improved or additional EMI-filters, can provide substantial reductions of the radiated EMI of a solar park. Given the high costs of investment for an offshore solar park, this is just a very small fraction.

Some methods for mitigating EMI can be applied quite affordably. To prevent the wires which are attached to the solar panels to act as antennas, they need to be mounted in close proximity to each other and placed inside a metal gutter. This will effectively cancel common mode radiation to a substantial extend. See Figure 5.

[23] Only DC – DC conversion, but it shows what can be achieved given the right hardware. Silent Switcher® Technology | Analog Devices

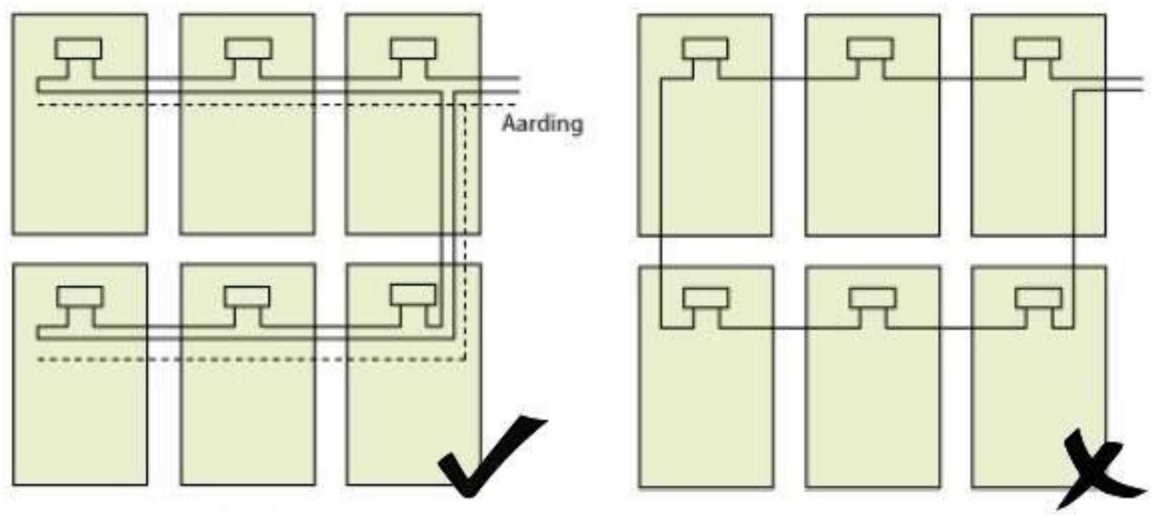

Figure 5 Installation guidelines of solar panels and wiring (source:ISSO handboek Zonne-Energie 2016)

Summarizing the mitigating measures

Improved shielding, proper EMI filters on all in- and outputs of the inverter and minimizing antenna effects of the wiring by placing the + and - wires of each solar panel in close proximity of each other, can provide a serious reduction of the ambient EMI generated by solar panel power inverters. These recommendations are valid for any solar panel system: domestic, on-land and floating at sea.

Conclusions

Floating solar farms at sea provide an important contribution to make the energy transition possible. However, with the current EU-EMC regulations, the EMI generated due to the transformation of electric power from solar panels from DC to AC, poses a serious threat to all wireless communication which operates within the vicinity of 1 km or less from solar farms. This includes C2000, DAB+ and maritime radio. The latter is the most important means of communication between ships and ship to shore.

On land the electronic smog has resulted in serious limitations to wireless communications, including systems used for public safety. Given the popularity of the North Sea for transport, fishing and leisure activities, it is paramount to prevent that a similar situation will arise on the North Sea.

To what level should the EMI-field strength be limited in a nautical environment in order to safeguard communication, navigation and broadcast against harmful degradation? In theory that depends on the actual signal levels of the transmitter in a two-way communication scenario. If the transmitter is nearby, one can accept more EMI than when a system operates at the verge of the coverage area. One should however aim for a worst-case scenario, i.e. signal levels could be low, whether due to normal circumstances (sailing at edge of coverage area, which may change dynamically) or to safeguard communication in emergency situations where signal margins may be non-existent. Accumulation of EMI due to the unfolding of multiple floating solar power plants must be prevented.

A safe target EMI level for industrial grade installations should be a total emission reduction of at least 20 dB with respect to the current EMC regulations.

DC to AC inverters used at solar power plants can be produced generating substantially less EMI than set by EMC-standards. Essentially this is just a matter of design and good EMI practice, at a slight cost increment. Additionally, proper layout of the DC-wiring between inverters and solar panels, shielding and additional RF-filtering may provide sufficient mitigation to prevent that a problematic man-made noise scenario which is now prevalent on many land locations, will arise on the North Sea as well.

Theoretically the 'essential requirements' of Annex I of the EU-regulations don't allow EMI-levels that affect wireless communications, in practice these are not enforced. A general reduction of the EMI limits for all electronics would provide a much better solution for reliable wireless reception. In the long term that would also mitigate the land-based interference situation.

Abbreviations

AC	Alternating Current
AIS	Automatic Identification System
ASL	Above Sea Level
Bluetooth	Short range communication (2.4 GHz)
C2000	Communication 2000. Based on the TETRA standard.
DAB+	Digital Audio Broadcast
DC	Direct Current
DECT	Digital Enhanced Cordless Telecommunications
DMR	Digital Mobile Radio
EMC	Electro Magnetic Compatibility

EMI	Electro Magnetic Interference
GNSS	Global Navigation Satellite System
Marifoon	Marine radio (156 – 162 MHz)
PMR	Personal Mobile Radio
PWM	Pulse Width Modulation
RF	Radio Frequency
TETRA	Terrestrial Trunked Radio
UHF	Ultra-High Frequency (300 – 3000 MHz)
VHF	Very High Frequency (30 – 300 MHz)
Wi-Fi	Wireless Fidelity (2.4, 5, 6 GHz)