NEKI PROBLEMI U KVALITETU SNAGE I
ELEKTROMAGNETSKOJ KOMPATIBILNOSTI
OOPREME ZA KGH

SOME POWER QUALITY AND ELECTROMAGNETIC
COMPATIBILITY ISSUES IN HVAC EQUIPMENT

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U radu se daje prelged autorovih istraživanja kvaliteta snage i elektromagnetske kompatibilnosti opreme za KGH u stambenom sektoru. Analizirane su niske i visoke frekvencije jedne klima-komore i toplane na gas. U oba slučaja prikazani su problemi kvaliteta u slučaju jakih interferenci visokih frekvencija. Uspešno su primnjene metode pasivnog filtriranja. Primena filtera elektromagnetnih interferencija uspešno je smanjivala ulazne i izlazne harmonike i elektromagnetne emisije.

Ključne reči: harmonici, elektromagnetna interferencija, emisije, gubici, prigušenja

The paper presents a review of some studies performed by the author on electrical power quality and electromagnetic compatibility in HVAC residential equipment, submitted before at different international conferences of power quality. In this paper an air handling unit and a gas heating central are analyzed from the viewpoint of low and high frequencies. Both of the cases presented in certain environmental conditions power quality issues along with high frequency electromagnetic interference (EMI). Passive filtering methods were successfully applied in both situations. Retrofitting of power electromagnetic interference filters led to the mitigation of the incoming and outgoing harmonics and of the electromagnetic emissions.

Keywords: harmonics, electromagnetic interference, conducted emissions, insertion loss, filter attenuation

1. Introduction

Nowadays, the interest in power quality has become more and more important for suppliers, manufacturers and customers. Suppliers are interested in the quality of their service, manufacturers have to build equipment compliant to a sum of standards and regulations with respect to power quality and finally, customers
want in their turn to have comfort and a quiet life in using electrically powered products.

Unfortunately, high speed semiconductor devices with fast switching capability and the emerging digital era in control and signal processing became the main enemies of electrical power quality.

On one hand, equipment need power quality, being less tolerant of voltage and current disturbances but, on the other, they represent the main source of electromagnetic perturbations in power lines.

In literature one can find plenty and sometimes conflicting definitions of power quality, related more or less to the performance of equipment or to the possibility of measuring and quantifying the performance of the power system (see the IEEE Standards and the IEC and EN Standards). For instance the Council of European Energy Regulators-Working Group on Quality of Electricity Supply speaks about voltage quality and includes the following disturbances: “frequency, voltage magnitude and its variation, voltage dips, temporary and transient overvoltage and harmonic distortion”, without mentioning explicitly “current quality”, which probably is implicitly considered where it affects the voltage quality. The viewpoint here is again that current quality is only a concern only if it affects the voltage quality. This difficulty of distinguishing between voltage and current disturbances is one of the reasons the term power quality is generally used. The term voltage quality is reserved for cases where only the voltage at a certain location is considered. The term current quality is generally used to describe the performance of power electronic converters connected to the power network.

In the author’s opinion, there is no power quality in the presence of electromagnetic interference, i.e. the process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths (or both). In this respect, every disturbance is a power quality issue, even the IEC and EN standards distinguish between an (electromagnetic) disturbance and (electromagnetic) interference: a disturbance is a phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. In power quality terms, any deviation from the ideal voltage or current can be considered as a disturbance. Interference is much stricter defined, being the actual degradation of a device, equipment or system caused by an electromagnetic disturbance.

Technical literature is abounding also in definitions of electromagnetic compatibility (EMC), but perhaps the most synthetic and eloquent one is that EMC consists is the absence of effects due to electromagnetic interference (EMI).

Since electric and electronic systems penetrate more deeply into all aspects of the society, both the potential for interference effects and the potential for serious EMI-induced incidents increase.

Finally, electromagnetic interference (EMI) is a serious and increasing form of environmental pollution. The threat of EMI is controlled by adopting the practices of electromagnetic compatibility (EMC), which has two complementary aspects: it describes the capacity of electrical and electronic systems to operate without inter-
Interference with other systems and also describes the ability of such systems to operate as intended within a specified electromagnetic environment.

Interference can propagate from a “source” to a “victim” via the mains distribution network to which both are connected. This is not well characterized at high frequencies, especially since connected electrical loads can present virtually any RF impedance at their point of connection.

On the other hand electromagnetic compatibility includes intra-system and inter-system electromagnetic interference. Difficulty arises when intra-system meets inter-system, when the two approaches are confused one with the other, or at the interface where they meet.

Further, the transfer of electromagnetic energy (with regard to the prevention of interference) is broken into four subgroups: radiated emissions, radiated susceptibility, conducted emissions and conducted susceptibility.

There are basically two classes of EMC requirements that are imposed on electric and electronic systems: those mandated by governmental agencies and those imposed by the product manufacturer.

The legal requirements are imposed in order to minimize the interference produced by the product. However, compliance with these EMC requirements does not guarantee that the product will cause no interference. On the other hand, EMC requirements that manufacturers voluntarily impose on their products are intended to result in customer satisfaction (in order of reliable). Compliance with both of these EMC requirements is critical to the success and the good reputation of the product in the marketplace.

Regulatory agencies impose limits on these conducted emissions because they are placed on the utility power system net of the installation.

The utility power distribution system in an installation is a large array of wires connecting the various power outlets from which the other electronic systems in the installation receive their AC power. It therefore represents a large “antenna” system from which these conducted emissions can radiate quite efficiently, causing interference in the other electronic systems of the installation. Thus the conducted emissions may cause radiated emission, which may then cause interference. Ordinarily, the reduction of these conducted emissions is somewhat simpler than the reduction of radiated emissions since there is only one path for these emissions that needs to be controlled: the unit’s power cord. However, it is important to realize that if a product fails to comply with the limits on conducted emissions, compliance with the limits on radiated emissions is a moot point. Therefore controlling conducted emissions of a product has equal priority with the control of radiated emissions.

For ease of measurement and analysis, in the commercial tests, radiated emissions are assumed to predominate above 30 MHz, while conducted emissions are assumed predominant below 30 MHz.

There is of course no magic changeover at 30 MHz, but typical cable lengths tend to resonate above 30 MHz, leading to anomalous conducted measurements, while measurements radiated fields below 30 MHz will of necessity be made in the
near field closer to the source giving results that do not necessarily correlate with real situations.

At higher frequencies, mains wiring becomes less efficient as a propagation medium, and the dominant propagation mode becomes radiation from the equipment or wiring in its immediate vicinity.

Perhaps the most important aspect of becoming effective at EMC design is to begin thinking of the nonideal behavior of electrical components in addition to the ideal behavior that we have been taught to keep in mind.

If one thinks only in terms of ideal behavior of electrical and electronic components, he will not be able to observe or anticipate the nonideal electrical paths and hence will not be able to consider other possible causes for conducted or radiated emissions. Therefore, will have inadvertently reduced the possibilities for correcting EMC problems and will not have the ability to see a schematic beyond its appearance.

However, an important problem still remains from the viewpoint of the frequency range. Power quality is confined in the low frequency range, i.e. from DC to maximum 3.5-5 kHz. Conducted interference is studied starting from 100-150 kHz. Consequently a large unexplored gap remains unexplored in the frequency range between 5 kHz and 100 kHz. In this latest range of frequency there are no standards and no measuring methods.

As a primary conclusion, there is no physical dichotomy between power quality, conducted and radiated interference. There is a chain reaction, phenomena turning one into the other. Power quality issues may determine conducted or even radiated interference and vice versa. The present approach will demonstrate, using two case studies, the multiple connections between them.

2. The case of a residential air handling unit

The energy efficiency of HVAC systems is considered as a vehicle for accomplishing energy savings. Many research efforts related to the modeling and optimization of HVAC systems have been reported in the literature. A typical simple air handling unit (AHU) is illustrated in a simplified schematic diagram (Fig. 1), depicting the two centrifugal fans, the heat exchanger, the heating (+) and the cooling (-) coils and the air flow directions. The supply air is at a specific temperature and flows at a specific rate to meet the heating or cooling load and ensure thermal comfort.

Outdoor air mixes with the return air, and the mixed air passes through cooling coils, heating coils, and the supply fan. Chilled water in the cooling coils cools the mixed air and hot water or steam in the heating coils heats the mixed air to maintain the desired temperature of the supply.

Besides, air handling units are provided with temperature sensors for the return and outside air, dampers for fresh and exhaust air, making sure that there will be airflow only if the fans are running, pressure difference switches that monitor the airflow in the ducts and generates an alarm in case there is a conflict between the fan
run status and airflow status. Also, air handling units are usually provided with CO₂ and humidity sensors.

The main features of the centrifugal fans provided with external rotor brushless DC motor, an inside-out motor (i.e. the rotor appears outside of the stator) are: nominal voltage 230 Vac at 50/60 Hz, maximum current draw 1.35 A, power input 170 W, variable speed drive at maximum speed value of 2100 rot⁻¹, maximum airflow of 350 m³/h.

Obviously the inside-out motor construction has some disadvantages in the generation of losses in the part of the motor most difficult to cool, but in this specific case, due to the reduced load (i.e. the fan blades), small commutation currents are involved.

It is well-known that brushless DC motors (BLDC) are considered as high performance motors due to their high reliability, versatility, adequate torque and speed and low maintenance cost. They are rotating self-synchronous machines provided with a permanent magnet rotor and with known rotor shaft positions for electronic commutation. The advantage of brushless configuration in which the rotor (field) is inside the stator (armature) is simplicity of exiting the phase windings. Due to the absence of brushes, motor length is reduced as well. The disadvantages of the brushless configuration relative to the commutator motor are increased complexity in the electronic controller and need for shaft position sensing.

The main advantages of BLDC motor drives are high efficiency, low maintenance and long life, low noise, control simplicity, low weight, and compact construction. On the other hand, the main disadvantages of the BLDC motor drives are high cost of the permanent magnet materials, the problem of demagnetization, and limited extended speed, constant power range (compared to a switched reluctance machine).

Two main classes of PM motor drives have been developed, depending on the shapes of their respective back-electromotive force (EMF) waveforms, sinusoidal or trapezoidal. Brushless DC motors are typically characterized as having a trapezoidal back (EMF) and are typically driven by rectangular pulse currents. This mimics the operation of brush DC motors.
Excitation waveforms for BLDC motors take the form of square-wave current waveforms. The nature of the excitation waveforms permits some important system simplifications compared to sinusoidal PMAC machines. In particular, the resolution requirements for the rotor position sensor are much lower with BLDC motors since only six commutation instants per electrical cycle must be sensed. In addition, the BLDC motor drive only requires a single current sensor in the inverter DC link.

However, the simplicity of a BLDC motor drive is responsible for determining an additional source of ripple torque, known as commutation torque, taking the form of torque spikes or dips, generated at each discrete time instant when any of the square-wave current excitation waveforms change levels.

The terms “energy-saving” and “quiet-running” are becoming very important in the world of variable speed motor drives. For low-power motor control, there are increasing demands for compactness, built-in control, and lower overall-cost. An important consideration, in justifying the use of inverters in these applications, is to optimize the total-cost-performance ratio of the overall drive system. In other words, the systems have to be less noisy, more efficient, smaller and lighter, more advanced in function and more accurate in control with a very low cost.

In order to meet these needs, several companies have developed new series of compact, high-functionality, and high efficiency power semiconductor devices called Smart Power Modules (SPMs). SPM based inverters are nowadays considered an attractive alternative to conventional discrete-based inverters for low power motor drives, specifically for appliances such as air-conditioners, water pumps, etc.

Smart power modules, based on fast-recovery MOSFET (FRFET) technology as a compact inverter solution for small power motor drive applications are composed of six FRFET, and three half-bridge high-voltage integrated circuits (HVICs) for FRFET gate driving. They provide low electromagnetic interference (EMI) characteristics with optimized switch speed. Moreover, since it employs FRFET as a power switch, it has much better ruggedness and larger safe operation area (SOA) than that of an FRFET-based power module or one-chip solution. MCU, DSP can control IGBT/MOSFET by HVIC directly without photo coupler. By adding bootstrap circuit outside of HVIC, high side and low side can supplied with a signal power source. It can make system miniaturization.

**Harmonic limits check**

The centrifugal fan has been tested in conformity with the standard EN 61000-3-2: 2006 (+A1+A2), using the general purpose programmable power source California Instruments 15003iX-CTS, which is a complete IEC AC power test system that covers many of the IEC regulatory test standards involving AC and/or DC powered equipment, providing precise, isolated and low distortion AC power at the user specified frequency and voltage.

The EN 61000-3-2 standard categorizes products in one of four product classes. Using the correct class is important as the harmonic current limits for each class are different. The air handling unit is a Class A equipment. Equipment belonging to
Class A are all motor driven equipment, most “domestic” appliances and virtually all 3 phase equipment (<16 A rms per phase). Evaluation of current harmonics is always done using the transitory method so no user selection is provided.

The newer standard allows Class A test to exceed 150% limit and less than or equal to 200% of the applicable limits under the following conditions, which apply all together: the EUT belongs to Class A for harmonics, the excursion beyond 150% of the applicable limits lasts less than 10% of the test observation period or in total 10 min (within the test observation period), whichever is smaller, and the average value of the harmonic current, taken over the entire test observation period, is less than 90% of the applicable limits.

The centrifugal fan passed the tests according to the standard EN 61000-3-2. However, for several low order harmonic components (especially for the 9th, 11th, 13th, 15th order components), the values are very close to the limits imposed by the standard (see Fig. 2, where the low order components of the test report are presented). The warnings to be reckoned are colored in yellow, while the virtual ones in green.

The result is quite pessimistic, taking into account that in real conditions, in which the impedance of the system is variable and unknown, the harmonic components of the current drawn by the fan could easily exceed the maximum limits. Even being provided with an input EMI filter, the results were not optimistic, because the air handling unit operates simultaneously with two centrifugal fans, parallel connected and the effect of the two fans THDi’s could be cumulative. As it was expected, the equipment failed the harmonic test. The harmonic tests performed on the air handling delivered the results depicted in the test report presented in Fig. 3, for the low order harmonic components.
It can be observed that the presumption made was even too optimistic, because operating in full speed with two motors, the air handling unit failed the test. Note that there are overcame limits until the 23rd order harmonic component and the 25th order harmonic is very close to the limit as well.

Fig. 4 depicts the waveform of the current drawn by the air handling unit, supplied by a clean 230 Vac sine wave, while in Fig. 5 is presented the FFT chart of the complete test report, until the 50th order harmonic component.

The result was an expected one, because the current drawn by the bridge rectifier is generally a discontinuous one and the common mode choke of the EMI filter placed at the input of the board is not sufficient to smooth the current waveform. In situations like that, a line reactor or other countermeasures are compulsory.

**Conducted electromagnetic interferences check**

As it was stated in the introductory section, in most situations, harmonics determine inevitably conducted interferences. Due to the presence of high harmonics content, it is expected that the high frequency conducted electromagnetic interference would also appear.

The main purpose of the conducted emission tests consisted in evaluating noise currents that exit the product’s AC power cord conductors and the compliance with the standard EN 55014-1:2006 (+A1+A2).

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*Fig. 4 Supply voltage and current drawn by the AHU*
In order to record conducted electromagnetic interference at the mains supply voltage, a line impedance stabilization network (LISN) and a spectrum analyzer have been used.

The two major objectives of the LISN are: to present constant impedance (50Ω) between the phase conductor and the safety wire and between the neutral conductor and the safety wire and to prevent external conducted noise on the power system net from contaminating the measurement. These two objectives are to be satisfied only over the frequency range of the conducted emission test (150 kHz – 30 MHz). Another requirement for the LISN is to allow the 50Hz (60Hz) power required for the proper product’s operation.

For measurements with a Spectrum Analyzer/EMC Receiver, the EMC signal is available after having passed a high pass filter.

In order to perform the conducted interference tests, a HM 6050-2 LISN and a HM 5014 spectrum analyzer (both manufactured by HAMEG Instruments) were used. The schematic setup is presented in Fig. 6.

The conducted interference spectrum conducted in the line wire is depicted in Fig. 7 (in linear scale, where high frequencies are better noticeable) and in Fig. 8 (in logarithmic scale, where low frequencies are expanded, so better noticeable). The sample (green line), the average value (blue line) and the quasi-peak value (red line) are presented.
One can easily observe that both the average and quasi-peak values of electromagnetic interference exceed the limits imposed by the standard EN 55014-1:2006 (+A1+A2) in the range from 150 kHz up to almost 17 MHz. Especially for the quasi-peak value there is an overcoming of almost 17 dBµV. The standard average limits are depicted in blue line and the quasi peak limits are depicted in red line.

For the both problems (i.e. harmonics and electromagnetic interference) a combined filtering solution may be adopted, and that will be the retrofitting of a passive EMI filter.

3. The case of a residential gas home heating system

The second case study is devoted to the 24 kW residential gas home heating system.

In general, any residential equipment, electrical grid connected is provided with a power EMI filter in its input stage. Fig. 9 presents the input power filter of the gas home heating system.

One can see the lack of the common mode capacitors, coupling the line and the neutral to the electric protection conductor (PE), which could be a great handicap in mitigating common mode incoming and outgoing electromagnetic conducted emissions.
Fig. 9 The EMI filter of the gas home heating system.

Fig. 10 Typical topology of a power EMI filter

Fig. 10 presents a typical commercial EMI filter that are the balanced Π type. Although they seem mainly common mode in appearance, they include components to block both common mode and differential mode components.

The common mode choke L consists of two identical windings on a single high permeability toroidal core, configured so that differential (line-to-neutral) currents cancel each other. This allows high inductance values, typically 1–10mH, in a small volume without fear of choke saturation caused by the mains frequency supply current. This is because the common mode inductor is wound on ferrite cores having high $L_A$ values.

Capacitors $C_Y$ attenuate common mode interference, while the $C_X$ capacitor attenuates differential mode only.

The attenuation characteristics of the filter in differential (Fig. 11) and in common mode (Fig. 12), in logarithmic scale, are obtained using the spectrum analyzer HM 5014 and its embedded tracking generator.

Fig. 11 The transfer characteristics of the filter in differential mode

One can see that in differential mode the features of the characteristics are better than in common mode, but in normal conditions the attenuation is good enough, for stopping the incoming or outgoing electromagnetic emissions.

However, in some particular environmental conditions a few power quality issues occurred, due mainly to the presence in the neighborhood of two radio broadcasting stations (amplitude modulated, with the carrier frequencies $f_1=1152$ kHz, $f_2=909$ kHz, and the corresponding output powers $P_1=400$ kW, $P_2=200$ kW). Be-
cause of the vicinity of the stations, the electronic circuitry of the gas heating cen-
trals installed in the nearby residences, presented malfunctions, giving error messag-es on the interface display.

According to the European and the Romanian specifications, the maximum allowed RF noise level injected in the public low voltage network in the frequency range 150 kHz -30 MHz, must be situated below 52dBμV. The measurements re-
vealed a RFI noise spectrum exceeding 72 dBμV (20 dBμV in plus), at the frequency of the carrier and its odd harmonics, both on the L and the N conductors (Fig. 13).

![Graph showing RF conducted emissions](image)

Fig. 13 RF conducted emissions injected on the public mains network by the radio broadcasting stations.

4. Conclusions

In both cases the solution consisted in retrofitting EMI power filters. The differential and common mode characteristics of an EMI filter printed using the tracking generator are depicted in Figs. 14 and 15.

One can see the almost ideal shape and the high attenuation of both character-
istics.

After retrofitting filters in both cases, the results were within the standardized limits. They are depicted in Figs. 16 and 17.

Some of the reasons for the development and use of block mains EMI filters are:

• Mandatory conducted emission standards concentrate on the mains port
• Safety approvals for the filter have already been achieved
• Many equipment designers are not familiar with RF filter design
In fact, the market for mains filters really took off with the introduction of regulations on conducted mains emissions, compounded by the rising popularity of the switch-mode power supply. With a switching supply, a mains filter is essential to meet these regulations and as we have seen, sometimes, in special conditions, it may be necessary an extra EMI filtering cell.

References


