EMC Inverter Effects Within ISM 2.4 GHZ Short-Range Radio Frequency Band

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***Abstract* - Due to raising popularity of renewable and hybrid grid tied power systems as well as commercialization of photovoltaic in residential market, power electronics is more widely used in preparation of grid parameters due to better performance during disturbances as well as reduced cost in maintenance and better failure predictions in large wind farm systems. Unfortunately, due to the switching nature of semiconductors, wave forms generated within 2.4 GHz ISM band can have significant impact on performance of such communication systems up to a point disabling them completely. Electromagnetic compatibility is mostly achieved by addressing the EMI source through techniques in the secondary environment, such as shielding and filtering but modern approach requires analysis and avoidance measure during component design phase. First, the model developed in Matlab was implemented at system power switching frequency with modifications for high frequency sampling and storage of data. The half-bridge and full-bridge inverter have been analyzed by using the developed model for up to 5 GHz sampling frequency of the output parameters in order to yield results for the targeted frequency within one period of base device frequency. Results are only presented in a narrow targeted frequency band due to limits of current software tools and the size of the sampled data.**

***Index Term*- grid-tied, converter, inverter, power electronics, radiated energy, bluetooth, wireless.**

I. INTRODUCTION

According to several international renewable agency investments in renewable energy are rising. [1], [2] Grid integration of renewable sources is becoming a necessity as increased sources are available and mature semiconductor technology for system integration is massively produced and widely available. Figure 1. show percentage of grid tied solar systems in the past few decades and a trend of integrating to the public electrical grid networks.

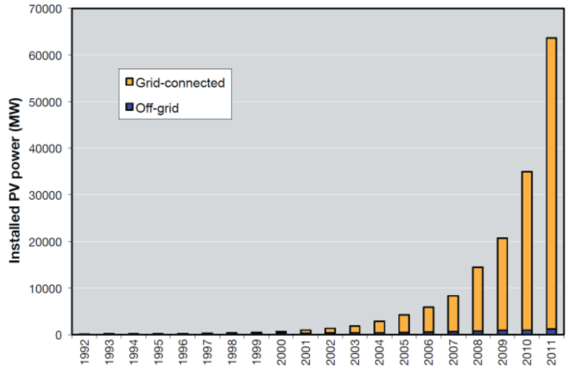

Fig. 1. Percentage of grid tied solar systems [1]

Power commonly found in renewable grid tied systems ranges from 2-10 kW for home PV systems up to 50 GW for wind farms. Availability of grid tied solar systems targeted for residential usage as a way of cost reduction especially in deregulated system with constantly changing energy prices, introduced continuous usage of inverters for creating sinusoidal parameters for network integration. Many of these systems do not have proper filtering capabilities as well as shielding in order to reduce electromagnetic interference.

Interference character depends on the frequency range of the disturbance and generally can be divided as a conducted or radiated interference. Figure 2. shows common frequency spectrum that can be observed when dealing with semiconductors in switching mode.

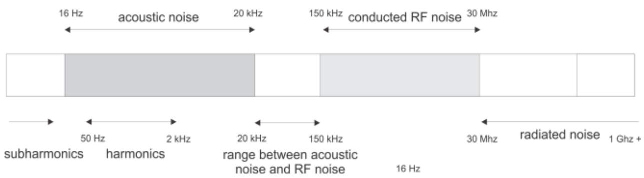

Fig. 2. Frequency spectrum disturbance clasification

Effects of radiated electromagnetic interference are usually not analyzed during the design process and commonly are treated with conventional shielding methods later. In the last decade, many modern communication technologies have been developed with device autonomy as a targeted feature which directly implied reducing the power output of the communication circuitry. Wide usage of ISM 2.4 GHz band expanded rapidly due to low cost hardware available almost in any modern communication device. In the last decade, power electronics also developed rapidly allowing higher power outputs which resulted in non-sinusoidal waves of current and voltage on the conductors in higher levels than before. Today, it is necessary to analyze those waveforms coupled with the geometry of devices in order to avoid ideal antenna wavelengths that can lead to almost perfect radiation of power teamed with devices which have their geometry ideal for that type of signal reception. Development in energy conservations, using smaller radiated power emissions for communication is almost mandatory in many developed technologies including almost all functioning at 2.4 GHz ISM band.

II. DESCRIPTION OF SIMULATION SYSTEM

Transformerless photovoltaic grid-connected inverter was modeled.

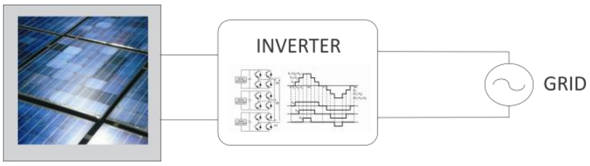

Fig. 3. Simplified block diagram od PV system

Simulation system is analyzed in following configurations:

1. Half-bridge inverter
2. Full-bridge inverter

The converters are built with the IGBT/Diode block. The IGBT/Diode block is a simplified model of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored. Voltage-sourced converters are controlled in open loop with the Discrete PWM Generator block available in the Extras/Discrete Control Blocks library. The two circuits use the same DC voltage (Vdc = 400V), carrier frequency (1080 Hz) and modulation index (m = 0.8) [3]. Figure 4 and figure 5 represent Matlab models of halfbridge and fullbridge inverters, respectively.

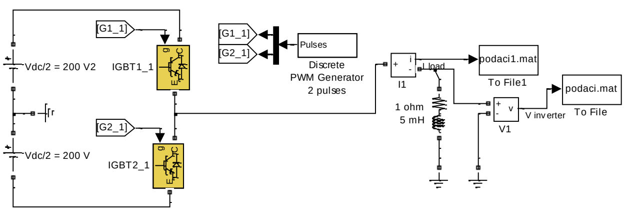

Fig. 4. Half-bridge inverter model

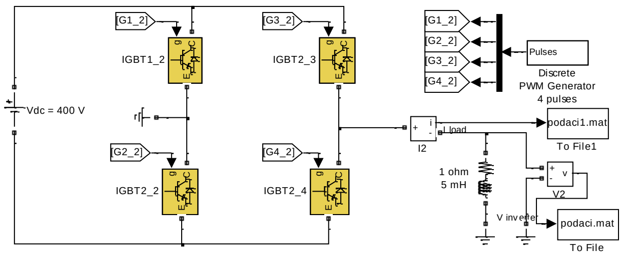

Fig. 5. Full-bridge inverter model

Both types of inverters our commonly found in such systems and their electromagnetic interference in this analysis is compared. DC voltage (Vdc = 400V) in a model represents stable source of voltage from photovoltaic system. In order to analyze frequency range od 2.3-2.5 GHz, Nyquist frequency, output must be sampled up to 5 GHz resulting in large sample since it is analyzes with base frequency of grid frequency of electrical power system.

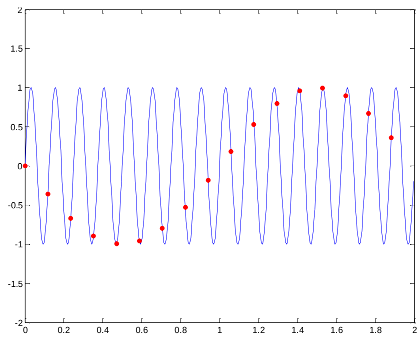

Fig. 6. Aliasing effect of undersampled signal

Discrete Fourier transformation was used for analysis to find high frequency components of base power system characteristic values, voltage and current.

$$x(t) = \sum_{n=0}^{\infty}\left(a_n \cos 2\pi n \frac{t}{T} + b_n \sin 2\pi n \frac{t}{T}\right)$$

$$a_n = \frac{2}{T}\int_0^T x(t)\cos\left(2\pi n \frac{t}{T}\right)dt$$

$$b_n = \frac{2}{T}\int_0^T x(t)\left(2\pi n \frac{t}{T}\right)dt$$

Where a_n and b_n represent Fourier coefficient's.
By discretizing the function (sampled voltage and current values)

$$X = \left(\frac{2\pi}{N}k\right) = \sum_{n=x}^{\infty} x[n]e^{-j2\pi kn/N}, \qquad k = 0,1,2,\ldots,N-1$$

numerical analysis can be applied with built in Matlab FFT functions. With mathematical formulation FFT analysis could be done using parallel computing or computing cluster speeding up independent calculations within application of the executable code or creating large scale cumulative analysis in systems consisting of higher of variable sources such as wind farms. It is necessary to implement such speed optimizations in order to evaluate any physical component in given circuitry which results in significantly large samples in every component output.

III. SIMULATION RESULTS

Several IEEE and IEC standards which target electromagnetic compatibility problems define maximum allowed interference up to first 50 harmonics for different classes of devices. The simulation results in his analysis will also include frequency range up to 3 kHz. Due to large number of harmonics analyzed and a density of visualization graph it was feasible to visualize targeted range of 2.3-2.45 GHz only which is presented in the paper.

1. Halfbridge inverter simulation results

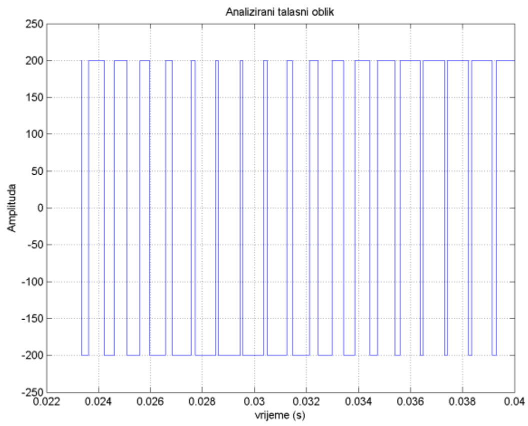

Fig. 7. Voltage waveform on the halfbridge inverter

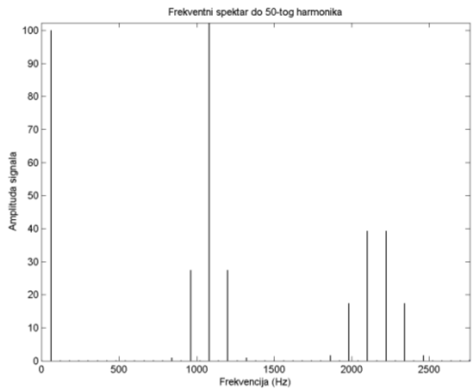

Fig. 8. Harmonic analysis of first 50 harmonics of voltage

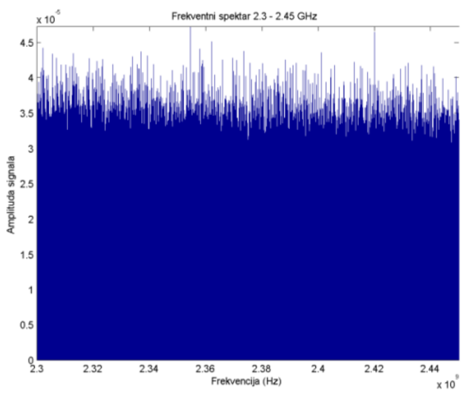

Fig. 9. Frequency components of voltage in 2.4 GHz range

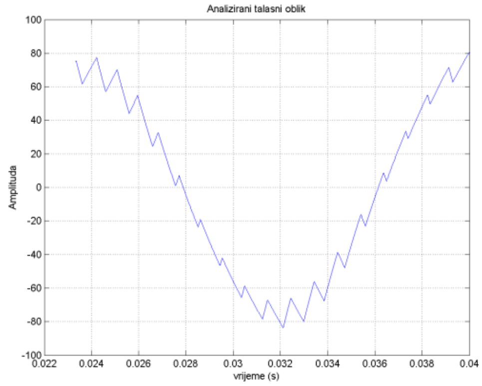

Fig. 10. Current waveform on the halfbridge inverter

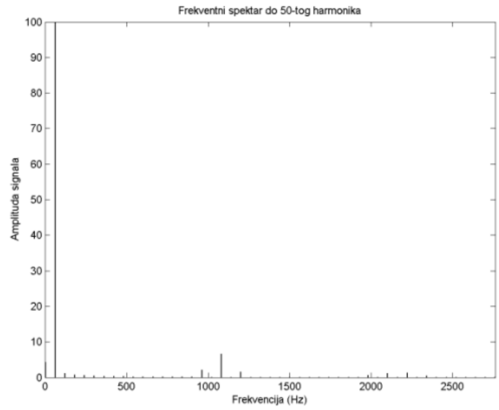

Fig. 11. Harmonic analysis of first 50 harmonics of current

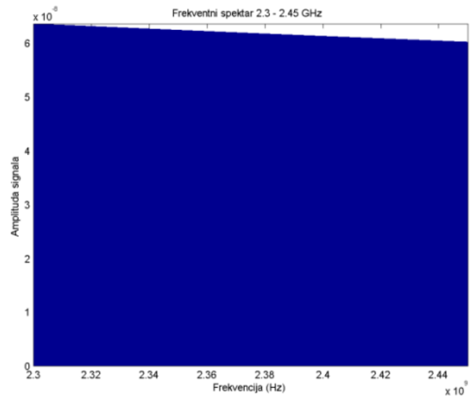

Fig. 12. Frequency components of current in 2.4 GHz range

2. Fullbridge inverter simulation results

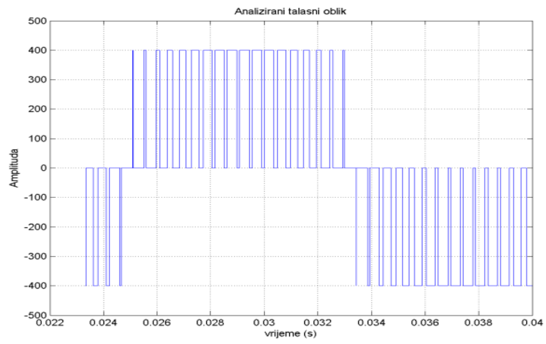

Fig. 13. Voltage waveform on the fullbridge inverter

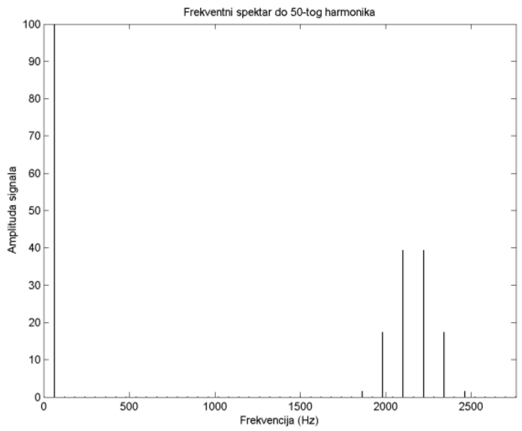

Fig. 14. Harmonic analysis of first 50 harmonics of voltage

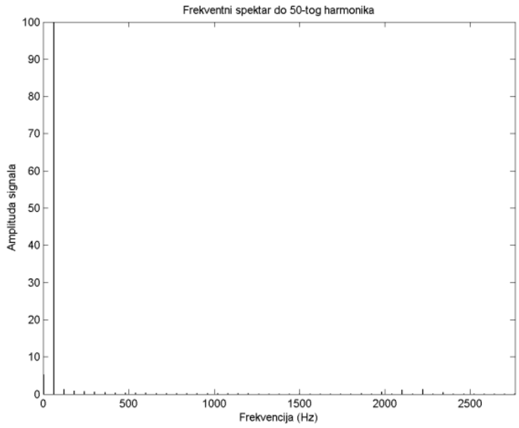

Figure 17. Harmonic analysis of first 50 harmonics of current

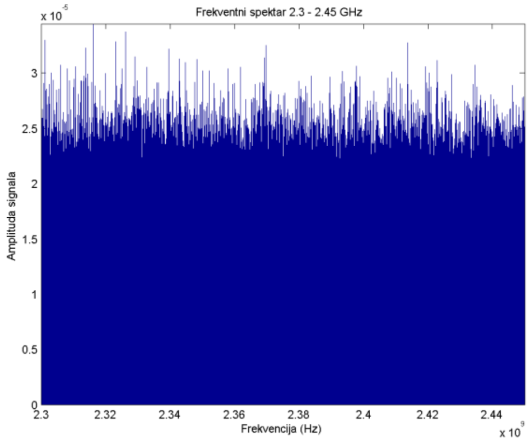

Fig. 15. Frequency components of voltage in 2.4 GHz range

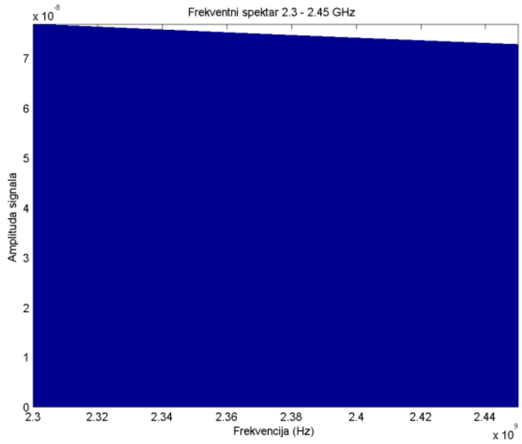

Fig. 18. Frequency components of current in 2.4 GHz range

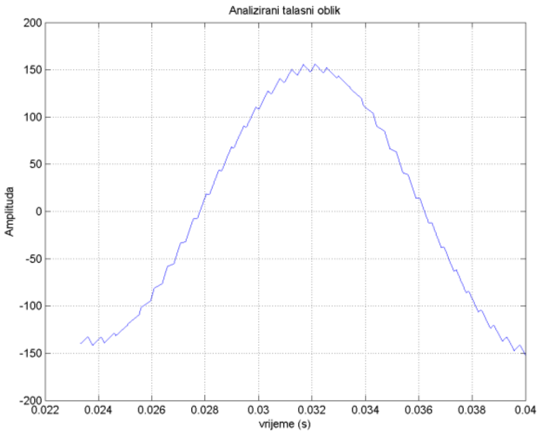

Fig. 16. Current waveform on the fullbridge inverter

Considering equations describing electrical far end fields around elementary doublet of conductor (imaginary elementary antenna):

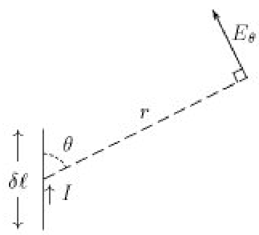

Fig. 19. Electrical far field of the electromagnetic wave radiated by each elementary doublet

$$dH_{\Phi} = \frac{I \cdot d \cdot l \cdot \sin\theta}{4 \cdot \pi \cdot r^2}(1+\gamma \cdot r)e^{-\gamma \cdot r}$$

$$dE_r = \frac{I \cdot d \cdot l \cdot \sin\theta}{4 \cdot \pi \cdot j\omega r_o} \cdot \frac{2\cos\theta}{r^3}\left[(1+\gamma r)e^{-\gamma r}\right]$$

$$dE_{\theta} = \frac{I \cdot d \cdot l \cdot \sin\theta}{4 \cdot \pi \cdot j\omega r_o} \cdot \frac{\sin\theta}{r^2}\left[(1+\gamma r+(\gamma r)^2\right]e^{-\gamma r}$$

If we are considering far end fields we can assume:

$$\lambda \langle\langle r \rightarrow H_r \cong 0 \qquad H_\theta \cong \omega^2 \frac{I\Delta S}{4\pi C^2}\frac{e^{-\gamma\cdot r}}{r}\sin\theta$$

$$\lambda \langle\langle r \rightarrow E_\varphi \cong \omega^2 \frac{Z_w I\Delta S}{4\pi C^2}\frac{e^{-\gamma\cdot r}}{r}\sin\theta$$

Power of radiation in this case can be:

$$\vec{P} = \vec{E} \wedge \vec{H}^{\,*} \rightarrow W_r = \oiint_{Sfera} \vec{P}\,\frac{\vec{r}}{r}\,dS$$

$$\lambda \langle\langle r \rightarrow W_r \cong 2\pi Z_w \left(\frac{\omega^2 I\Delta S}{4\pi C^2}\right)^2 \int_0^\pi (\sin\theta)^3 d\theta$$

We can analytically solve these equations for vacuum

where $Z_w = \sqrt{\frac{\mu_o}{\varepsilon_o}}$

$$W_r = R_r I^2 \qquad R_r = Z_w \frac{\pi}{2}\left(\frac{\Delta S}{\lambda}\right)^2$$

For far end field we can notice that the current and wavelength play major role energy radiated from the conductor. Results of both simulation shows that at given frequency range both devices are giving $6\cdot 10^{-8}$ and $7\cdot 10^{-8}$ amplitude of initial amplitude of current at power system base frequency.

According to ERC/REC/ 70-03 short range radars, wideband communication devices and RFID (Radio-frequency identification) components have allowed power outputs ranging from 25mW up to 4W.

TABLE I
ERC RECOMMENDATION 70-03 RELATING TO THE USE OF SHORT RANGE DEVICES (SRD) WITHIN 2.4 GHZ RANGE

Freq. range (MHz)	**Power output**	**Typical usage**
2483.5 – 2500	10 dBm e.i.r.p	Low Power Active Medical Implants and associated peripherals
2400.0-2483.5	10 mW e.i.r.p.	Telemetry,Telecommand, Alarms and Data in general
2400.0-2483.5	100 mW e.i.r.p.	Wideband Data Transmission Systems and Wireless Access Systems including Radio Local Area Networks (WAS/RLANs)
2446-2454	500 mW e.i.r.p.	Automatic vehicle identification systems for railways including Automatic Vehicle Identification for Railways (AVI)
2400.0-2483.5	25 mW e.i.r.p.	SRD radiodetermination applications including SRD radar systems, Equipment for Detecting Movement and Alert
2446-2454	≤500 mW – 4W e.i.r.p.	Radio frequency identification (RFID)

Due to power saving features typical usage usually starts from 1mW (class 3 Bluetooth). With currents in solar grid tied systems ranging from 20 A up to 100 kA in high power renewable sources integration currents of 2.4 GHz component are significant enough to be coupled with parasitic capacitance and inductance parameters on lines (including the grounding installations) to significantly impact performance or even bring these systems to a halt. At best considerable drop of communications device range, as well as increased number of errors during transmisson is present. Considering wavelengths at these frequencies is close to 125 mm it is not uncommon to find these lengths as well as half-length open conductors in such power electronics devices, which can lead to almost ideal transmission expected in modern antenna device applications.

IV. CONCLUSION

Considering fundamentals of electromagnetic compatibility (EMC), there are no significant differences between communication systems and power electronic based devices. From EMI point of viwe the switching frequency in an electrical system is much lower than in a communication system, but with much higher operation voltage, current, and power. However, from an application point of view, the electromagnetic Interference (EMI) problem in power devices is very different in a view of normal operation and desired effects. EMI problems can manifest themselves as errors or failures toward other equipment working with low power communications. During diagnostics other hardware or software problems may be suspected and investigated which are typical for usage of this type of communication devices and the wideness of its public usage. Considering effects with parasitic inductance and capacitance in the circuit’s emissions can be significant to bring communication systems to a halt. This problem becomes more obvious considering current trends of electrical drivetrain in automotive industries, renewable resource popularity with grid integrations, as well as reduction of power in the mobile devices, wireless networks, home entertainment and control, wireless sensor networks, medical data collection, building automation and generally all low power devices using the 2.4 GHz ISM band for operation. Semiconductor device manufacturers additional cost due to shielding and filtering could be reduced at design level.

Current power delivery standards are analyzing parameters up to first 50 harmonics as the ones most important for power system functions (protections, fault detection, measurements etc.) and are actually encourage higher switching frequency which gives better results in terms of power quality criteria. Due to higher switching frequency of power electronics even higher levels of high frequency signals are found in power system integration parameters which contribute EMI in bands typically regulated within communication industry.

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Jasna Hivziefendić was born in 1972. She graduated Faculty of Electrical and Mechanical Engineering in Tuzla 1998. and received a M.Sc degree in 2003. Her research interest include application of stochastic medthods in problem of control and planning of distribution networks as well as EMC of powerlines and distribution stations.