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ANALYSIS OF EMI GENERATED BY ELECTRONIC SUPPLY SOURCES CAUSING DISFUNCTIONS IN SIGNAL PROCESSING SYSTEMS, MOBILE COMMUNICATIONS INCLUDED

EMI generation and propagation mechanism, high rates of of voltage and current change in fast switching power devices (such as using IGBT), modeling and identifying EMI (noise) sources and their coupling paths with the signal processing circuitry have been discussed. A practical EMI measurement system has been suggested to extract more information from noise through analysis in frequency and time-domains and test EMI emitting equipment to comply with electromagnetic compatibility (EMC) standards. Different filter topologies have been analiz0 ed for decreasing the EMI originated by negative effect exertion of high *dv/dt* and *di/dt* due to high frequency switching.

Keywords: electromagnetic interference, power devices, fast switching, EMI, noise, measurement system, power converters.

Not until recently in studying different kinds of EMI origination and quantitative estimation of negative effects immediately exerted on the signal processing devices was it very popular to believe a concept of separating evaluation conditioned by singly acting noise sources provided that they were all statistically independent on time domain. Eventually it resulted in overall RMS determination as an integral quantitative estimate of signal curruption changing the real *S/N* ratio achieved by simple summation of all calculated, *RMS*-s to a great extent additionally ignoring the spatial-domain belief. The thorough analysis of the same time-domain idea for solution of the task with respect to different spatial applications on a worldwide scale made it apparent that there was a sufficient discrepancy in existing systems for EMI estimations because, on one hand, the spatial domain has been ignored and on the other hand, the resultant estimate of EMI has been achieved without accepting EMI as multivariable vector with weighted components due to their specific particular correlations.

Keeping this end in view we found it to the point to start setting forth our vision of one of the important EMI component common for all operating devices and installations due to the character of closed block interaction immediately associated with the signal processing devices.

Electronic power converters are widely used in many applications including renewable energy generation, industrial equipment/motor drives, household appliances, bio-medical equipment and TV systems, computer power supplies and those for telecommunication equipment, etc. These power converters use fast power semiconductor switches, such as IGBT (Insulated Gate Bipolar Transistor) as the preferred switching devices of lower overall costs, losses, smaller sizes, i.e. resultant efficiency exceeding those of other ones. However, fast switching speed of new converter/inverter technologies has the potential to cause EMI due to high voltage and current time derivatives dv/dt, di/dt [1].

High-frequency switching operations in power electronic devices have improved the dynamic performance of AC installations but created unexpected problems such as motor bearing damage, breakdown of winding insulation, leakage currents and high levels of conducted EMI. It is proved that dv/dt as well as common mode voltage generated in AC drives are responsible for most of these problems [2]. In most of the previous papers some passive EMI filters were employed to reduce the effect of EMI (noise) and high dv/dt in power converters. However, in designing passive filters the compensating bandwidth is comparatively narrow and only a certain part of noise can be eliminated. The size, weight, temperature and reliability issues are significant design constraints. Active EMI filters provide alternative approaches to the problem [3]. Further intrusion into noise sources and coupling paths nowadays as always is desirable as well as more accurate identification of noise propagation mechanism in circuits, including all relevant parasitic elements if essentially required.

It is evident that a discussion on negative effects of EMI generated by electronic power switches, modeling EMI, their coupling paths and propagation mechanism have been presented, eventually resulting in EMI measurement systems adoption in time, and conventional frequency domains enables to extract more information on EMI quantitative reduction with the analytical techniques for noise characterization employed.

Problem station. The introduction of international regulations on electromagnetic compatibility (EMC) has prompted active research in the study of electromagnetic interference (EMI) emission from the abovementioned electronically operating and controlled power supply sources for renewable energy generation. For electronic circuits involved in the switching operation the high level of dv/dt performance in electronic power devices is widely believed to be a major source of EMI emission.

The use of electronic power converters is increasing very rapidly in application to clean energy (power) generating systems such as solar/wind power generation and electric vehicles, which are friendlier to the environment. According to the Electric Power Research Institute (EPRI), about 50...60% of the electric power is flowing through some kind of power electronics equipment, and eventually 100% will likely be doing the same in the near future. This trend is already ongoing in Europe, Australia, America and other continental areas because of the increasing demand for electric power to cater to the needs of the expanding industrial, commercial and residential sectors. As a result of the increasing proportion of electronically processed power, the EMI would increase in the coming years, too, unless well-thought-out EMC standards and proper mitigation techniques are introduced and enforced at an early design stage since failure to consider EMI pointed out at early phases of the design process may enevitably result in expensive modifications some later on. Due to strict EMC regulations, the EMI issue in power converters has recently become a topical area of research.

Modeling of EMI source, coupling path and propagation mechanism. The modeling of EMI (noise) sources and coupling paths in electronic power equipment is helpful for analyzing the EMI mechanism and for designers to improve EMC performance to satisfy national and international EMC standards. Designers may wish to characterize the EMI (noise) sources and identify the noise coupling paths through EMI simulations. However, modeling parasitic elements has been a very difficult task as they are difficult to identify and they may also be physically inaccessible inside the module package. Many methods are proposed in literature for parasitic modeling, such as three-dimensional finite element analysis, time-domain analysis and partial-element equivalent circuit method. These methods are all purely mathematical and they are developed based on computation and computer simulation and thus are very time-consuming because the circuit models are very complicated. Another fundamental limitation of these methods is that expensive instruments and sophisticated simulation tools are mandatory. For better prediction of EMI behavior without complicated circuit models and extensive calculation equivalent lumped circuit models (shown in Fig.1a) are proposed to characterize EMI (noise) from converter systems [4]. Although some EMI phenomena have been described and useful analyses have been reported the fundamental mechanisms by which the EMI or noise are excited and coupled have not been adequately investigated. Fig.1b shows a typical EMI source-band coupling paths model. In Fig.1a,b v_m is the voltage on the IGBT power switch, and i_D is the diode current in a chopper, and $V_{LISN\,1}$ and $V_{LISN\,2}$ are voltages of two resistors, with the Z_S in converter switch, Z_N in LISN (Line Impedance Stabilization Network), the voltage V_{LISN1} developed due to affection of i_D and V_{LISN2} originated by v_m.

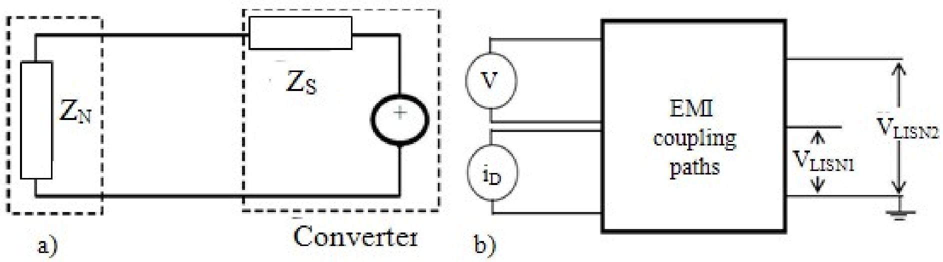

Fig.1. Simplified EMI noise lumped circuit model a), b) EMI sources and coupling paths

An emi measurement system. A practical, low cost EMI measurement system is suggested to captu--- EMI noise for frequency domain and time-domain analysis, and to test an equipment emitting EMI comply with Australian EMC Standards. The EMI measurement set-up typically requires a LISN, no: separator, spectrum analyzer, and computer as shown in Fig. 2. A LISN is required for capturing conduct EMI emission. The noise separator separates common mode (CM) and differential-mode (DM) no: components, with the former termed as "ground-included-loop" and the latter as "line-to-line" compone: The output of the noise separator is fed into a spectrum analyzer and the corresponding frequency spectrum can be obtained. Then the data is fed into a computer for analysing and designing the filters.

Traditionally, electromagnetic interference (EMI) measurement is performed with conventional analogue EMI receivers operated in frequency domain. Measurement in the frequency domain takes a long time, of typically 30 minutes for a frequency band from 30 MHz to 1 GHz EMI receivers using a pre-selector to obtain the required dynamic range of 36 dB according to the standard by the International Special Committee on Radio Interference, CISPR 16-1. A time-domain EMI measurement system is suggested for measurement of EMI with a reduced number of accessories and cost to make the system more reliable and simple. This type of measurement system can provide both magnitude and phase information. Also, a number of other statistical virtual measurement systems can be used to simulate the conventional detection system (e.g. peak, average, RMS and quasi peak detector through digital signal processing). It should be noted that our aim is not to replace the conventional frequency-domain EMI measurement system but only to have a simple and efficient method of EMI measurement system that provides more information. Information obtained from both measurement systems can be used for accurate designing of EMI filters and performance testing. The EMI noise emitted from the equipment is captured from the line (L) and neutral (N) outputs of LISN. The EMI presence on the line and neutral phases has the following expressions:

$$V_L = V_{CM} + V_{DM}/2, \quad (1)$$

$$V_N = V_{CM} - V_{DM}/2, \quad (2)$$

where V_L is the positive line EMI and V_N is the negative line EMI voltage, V_{CM} and V_{DM} are the common and differential modes of EMI noise component voltages, respectively. The two signals given by (1) and (2) will be fed into the digital storage oscilloscope (DSO). Using the inbuilt features of oscilloscope such as sampling, adding and subtracting, the CM and DM components of EMI noise can be separated. The two channels of the DSO are added and subtracted in real-time and on-line to separate the CM and DM noise components (without using a noise separator as in frequency domain measurement system). It is as follows:

$$V_{CM} = (V_L + V_N)/2, \quad (3)$$

$$V_{DM} = (V_L - V_N)/2. \quad (4)$$

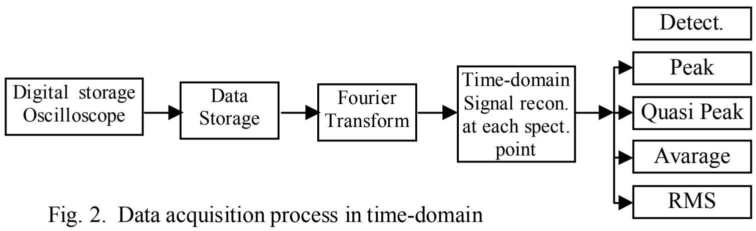

Fig. 2. Data acquisition process in time-domain

The data acquisition process for the time-domain measurement starts with the below sampling process of the oscilloscope. Then the spectra via the Fourier transform but (FT) are digitally computed. The errors due to the frequency characteristics of LISN, transmission line, amplifier, and anti-aliasing filter are corrected by signal procormessing. Next, the analysis of peak, RMS, average, and quasi-peak values of the EMI signal can be performed, as shown in Fig.2. For the measurement of EMI noise current a current probe with a very wide frequency bandwidth can be used.

Analytical Techniques for EMI Characterization and Identification. The high speed switching action (high dv/dt and di/dt) in a power converter emits both CM and DM components of EMI noise. The purpose of the EMI noise analysis is to investigate the fundamental mechanism of the conducted EMI noise generation from power device switching. The mechanism of EMI noise is analyzed through simplified time-domain models to predict the switching noise across the LISN of the measurement system. However, some domain proper models based on several assumptions, such as, the ideal EMI noise source, the ideal switching waveforms of power devices, etc. have been developed which in the first proximity though impair a great deal of accuracy of the model but in iterative approach make the model quite suitable to apply in practice due to limited amount of steps towards a sufficient accuracy rise. The switching transient in a power converter has traditionally been analyzed by modeling it as a single slope dv/dt and di/dt transients. Neither the diode reverse-recovery current effect nor the internal interconnect parasitic has been addressed. In reality, the switching transient of an IGBT has multiple slopes and shows complex switching behavior. The frequency domain model is also used to quickly predict the EMI spectrum, since it is based on the assumptions used for the simplified time domain model, the inherent drawbacks are apparent. The IGBT turn-on switching introduces a major change in device current i_c, di_c/dt which can be expressed as:

$$\frac{di_C}{dt}(\tau_{ON}) = \frac{g_m(V_g - V_{th})}{R_g C_{ies} + g_m L_s}, \tag{5}$$

where g_m is the trans-conductance of the IGBT, V_g is the IGBT gate voltage, and V_{th} is the IGBT threshold voltage. The i_c rise during time τ_{on} causes v_{ce} to fall down because of the stray inductance L_s. The change in v_{ce} can be given as:

$$\Delta_{ce} = -L_S \frac{di_C}{dt(\tau_{ON})}. \tag{6}$$

The change in device voltage, dv_{ce}/dt during τ_{on} can be written as:

$$\frac{dv_{ce}}{dt}(\tau_{ON}) = -L_S \frac{\left(\frac{di_C}{dt}\right)\tau_{ON}}{\tau_2}, \tag{7}$$

where τ_2 is the time required by the collector current (i_c) to change from peak value to steady state value as shown in Figure 4.

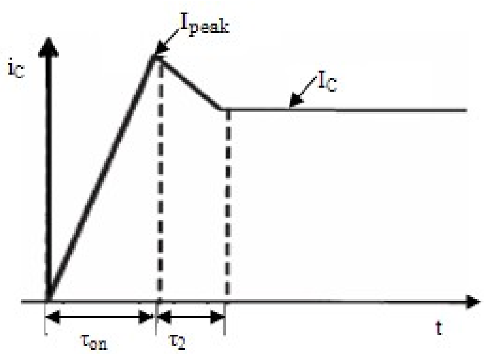

Fig. 3. Turn-on waveform of IGBT with inductive load

The di_c/dt during the current rise has a direct impact on the reverse-recovery current (Irr) of the freewheeling diode. The relation between di_c/dt and I_{rr} is given by:

$$I_{rr} = \sqrt{2\tau_{LT} I_L \frac{di_C}{dt(\tau_{ON})}}, \tag{8}$$

where τ_{LT} is the minority carrier lifetime of diode. It has been revealed that large reverse-recovery current increases the EMI level. A larger turn on *di_c/dt* leads to a higher *dv_{ce}/dt.* High *dv/dt* and *di/dt* during switching of power devices is related to switching frequency and conducted EMI level.

Mitigation of EMI (Noise) Generated From Power Converters. Filters can be designed and used to reduce EMI emission from power converters. Fig. 4 shows the simulation model for the investigation of EMI on a pulse width modulated (PWM) IGBT-inverter fed AC motor drive.

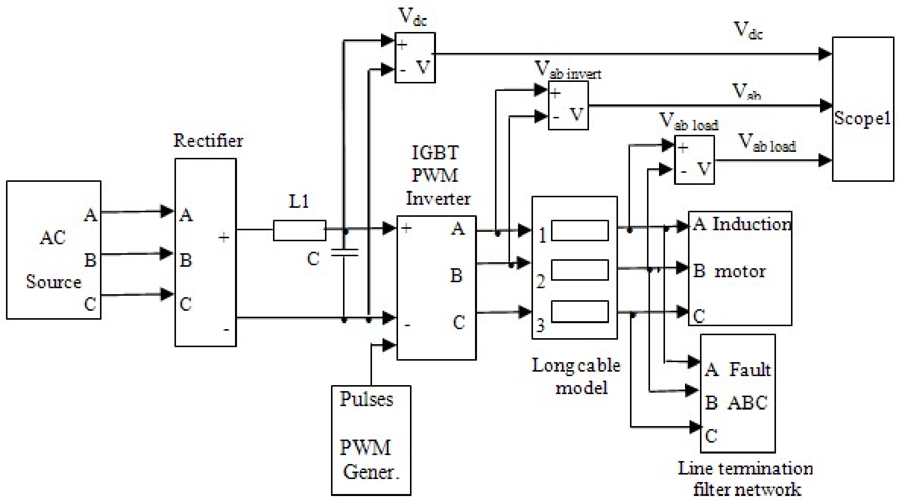

Fig. 4. EMI investigation on a pulse width modulated IGBT-Inverter fed AC

Fig.5a shows a typical PWM inverter output voltage. Fig.5b shows overvoltage at the motor end due to EMI and high dv/dt value.

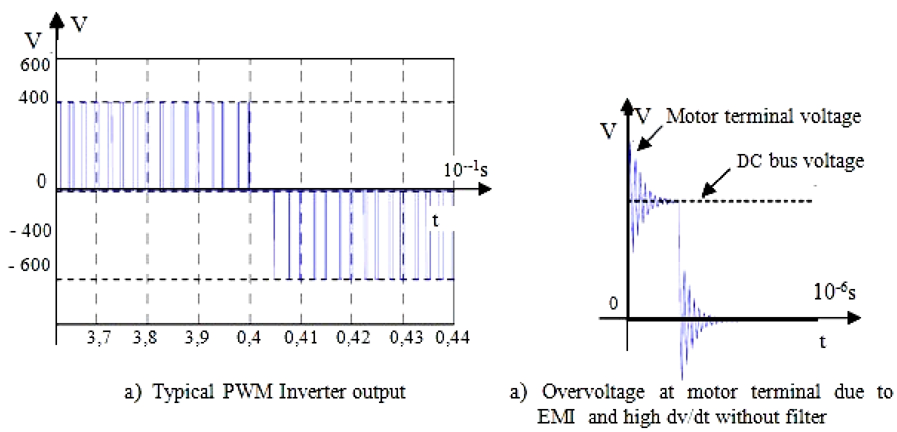

Fig. 5. Overvoltage at the motor terminal due to EMI

Another point of a fact which can be caught a sight of as the matter of significantly suppressed EMI occurrence caused due to different types of RC or LC filters applications is presented in Fig.6. It comes out as a comparabely shaped a reduction in oscillations with an exponentially decreasing amplitudes coresponding to short time intervals within transient processes in time domain for the cases mentioned above concerning Fig.5.

One can obviously accept that such EMI can affect a lot of disfunctions in many telecommunication equipment.units and even speech codecs included if not properly reduced.

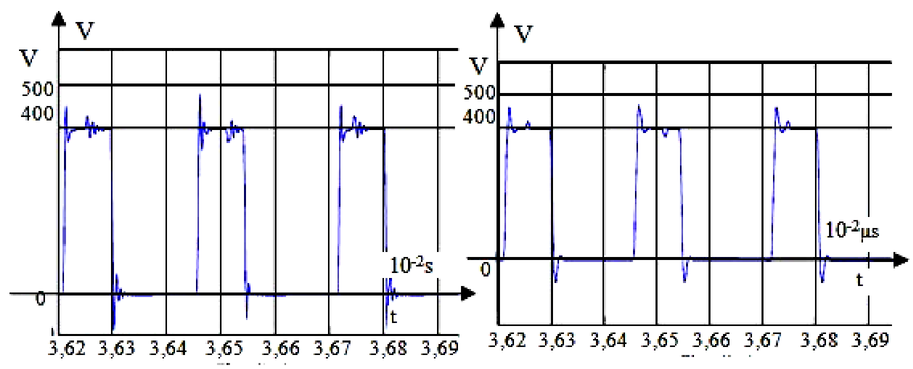

Fig. 6. EMI mitigation using filters

Conclusions. The impact of EMI noise generated from power electronic switches due to fast switching (high dv/dt and di/dt) is investigated. EMI noise modeling, coupling path and propagation mechanism issues are also discussed. A time domain measurement technique is suggested together with the conventional frequency domain measurement system as reference for collecting more information for EMI noise characterization. The suggested EMI measurement system will be able to capture EMI noise for frequency-domain and time-domain analysis, and to test equipment emitting EMI to comply with electromagnetic compatibility (EMC) standards. Mitigation techniques for the effect of EMI are discussed. From simulation results it can be revealed that the effect of EMI can be reduced significantly with the help of properly structured filters of simple topologies.

References

1. **Haque M.E., Bokhari A.A.** and **Alolah A.I.** Simulink modeling of the problem associated with fast switching PWM IGBT-inverter fed AC motor drive with long cable and its remedies // IEEE Intl. conference on Systems, Signals & Devices.- Sousse-Tunisia, March, 21-24, 2005.
2. Analysis of anew PWM method for conducted EMI reduction in a field oriented controlled induction motor / **L.H. Kim, N.K. Hahm, W.C. Lee** et al // Proc. of IEEE Applied Power Electronics Conference and Exposition (APEC '06), 19-23 March, 2006. - P 204-210.
3. **Chen W.**, **Yang X.** and **Wang Z.** An active EMI filtering technique for improving passive filter low-frequency performance // IEEE Trans. On Electromagnetic Compatibility.-Feb., 2006.- Vol. 48, N. 1.-P.172-177.

4. Noise source lumped circuit modeling and identification for power converters / **J. Meng, W. Ma, Q. Pan** et al // IEEE Trans. Industrial Electron.- Dec., 2006.- Vol. 53, N.6.-P.1853–1861.

State Engineering University of Armenia (Polytechnic).The material was received 07.02.2011.

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ԱԶԴԱՆՇԱՆՆԵՐԻ ՄՇԱԿՄԱՆ՝ ՆԵՐԱՌՅԱԼ ՇԱՐԺԱԿԱՆ ԿԱՊԻ ՀԱՄԱԿԱՐԳԵՐԻ ՍՆՈՒՑՄԱՆ ԷԼԵԿՏՐՈՆԱՅԻՆ ՍԱՐՔԱՎՈՐՈՒՄՆԵՐԻՑ ԱՌԱՋԱՑԱԾ ՖՈՒՆԿՑԻՈՆԱԼ ԽԱՓԱՆՈՒՄՆԵՐ ՀԱՐՈՒՑՈՂ ԷԼԵԿՏՐԱՄԱԳՆԻՍԱԿԱՆ ԽԱՆԳԱՐՈՒՄՆԵՐԻ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆ

Դիտարկված են ԷՄԽ-ի առաջացման և տարածման մեխանիզմը, լարման և հոսանքի փոփոխության մեծ արագությունները արագագործ շարունակական անցողիկ ընթացքներով բնութագրվող սնուցման սարքավորումները, ԷՄԽ-ի աղբյուրների մոդելավորող և նույնականացնող, ինչպես նաև ազդանշանների մշակման ենթակառուցվածքների հետ դրանց կապող շղթաները: Ընտրված և առաջարկված է իբրև հենակային տարբերակ՝ մի գործնական սխեմա էլեկտրամագնիսական համատեղելիության պահանջները բավարարելու նպատակով նշված ԷՄԽ-ի մասին՝առավել լիարժեք տեղեկատվություն քաղելու և բացասական ազդեցություններն էապես նվազեցնելու կամ վերացնելու միտումով՝ դրանց հնարավոր պատճառների միարժեք նույնականացումը իրագործելու համար

Առանցքային բառեր. էլեկտրամագնիսական խանգարումներ, սնուցման էլեկտրոնային սարքավորումներ, արագ փոխանջատում, աղմուկ, հզորության կերպափոխիչներ, էլեկտրամագնիսական խանգարումներ:

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АНАЛИЗ ЭМП, ГЕНЕРИРУЕМЫХ ПОД ВОЗДЕЙСТВИЕМ ЭЛЕКТРОННЫХ УСТРОЙСТВ ПИТАНИЯ И ВЫЗЫВАЮЩИХ ДИСФУНКЦИИ В СИСТЕМАХ ОБРАБОТКИ СИГНАЛОВ, ВКЛЮЧАЯ СИСТЕМЫ ПОДВИЖНОЙ СВЯЗИ

Приведены результаты анализа процессов возникновения и распространения электромагнитных помех (ЭМП). В качестве базового образца предложена измерительная система, обеспечивающая наиболее полное извлечение информации из процесса образования помех и их эффективное подавление, а также тестирование генерирующего ЭМП оборудования для проверки его соответствия стандартам электромагнитной совместимости. Рассмотрены топологии различных типов фильтров для уменьшения ЭМП, порождаемых вредным воздействием больших скоростей изменения напряжений и токов, обусловленных большой частотой переключения.

Ключевые слова: электромагнитные помехи, гибридные полевые-биполярные транзисторы, электронные устройства питания, топология, фильтры, электромагнитная совместимость.