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An Efficient Technique for EMI Mitigation in Fluorescent Lamps using Frequency Modulation and Evolutionary Programming

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***Abstract*—**Electromagnetic interference (EMI) is one of the serious problems in most electrical and electronic appliances including fluorescent lamps. The electronic ballast used to regulate the power flow through the lamp is the major cause for EMI. The interference is because of the high frequency switching operation of the ballast. Formerly, some EMI mitigation techniques were in practice, but they were not satisfactory because of the hardware complexity in the circuit design, increased parasitic components and power consumption and so on. The majority of the researchers have their spotlight only on EMI mitigation without considering the other constraints such as cost, effective operation of the equipment etc. In this paper, we propose a technique for EMI mitigation in fluorescent lamps by integrating Frequency Modulation and Evolutionary Programming. By the Frequency Modulation technique, the switching at a single central frequency is extended to a range of frequencies, and so, the power is distributed throughout the range of frequencies leading to EMI mitigation. But in order to meet the operating frequency of the ballast and the operating power of the fluorescent lamps, an optimal modulation index is necessary for Frequency Modulation. The optimal modulation index is determined using Evolutionary Programming. Thereby, the proposed technique mitigates the EMI to a satisfactory level without disturbing the operation of the fluorescent lamp.

***Keywords*—**Ballast, Electromagnetic interference (EMI), EMI mitigation, Evolutionary programming (EP), Fluorescent lamp, Frequency Modulation (FM), Modulation index.

I. INTRODUCTION

EXTENSIVE use of electric and electronic systems for household, industrial, communications and other applications makes it essential for circuits to operate on close proximity of each other. Often these circuits affect performance of other nearby circuits unfavorably by means of inadvertent coupling of their signals through near and far region by propagating EM fields. This interference is thus called Electro Magnetic Interference (EMI), rising to be a major problem for designers [1]. All Power equipments produce and emit the EMI, the unwanted signals that can direct performance degradation of other electrical/ electronic equipments [4]. EMI produce high frequency conducted and radiated EMI noise and sketch distorted line currents due to the sharp edges of the switching waveforms with high dv/dt [2]. Common examples of EMI include disturbances in television reception, mobile communication equipment, medical, military, and aircraft devices, in which interference could disturb or jam sensitive components, destroy electric circuits, and trigger explosions and accidents [5].

The occurrence of EMI in the home appliances is because of the ballast operation involved in the working of the fluorescent lamps. A fluorescent lamp belongs to the family of gas-discharge lamps that excite the mercury atoms in response to the electrical energy. The mercury atoms in the excited state generate ultra-violet light. The ultra-violet light then causes the phosphor to fluoresce, producing visible light. In comparison to the incandescent lamps, fluorescent lamps always require a ballast to regulate the flow of power throughout the lamp. The ballast can be defined as a device which is intended to limit the amount of current flowing in an electromagnetic circuit. The conservative usage of electromagnetic ballast in fluorescent lamps introduces harmonics into utility which leads to poor input power factor and low efficiency that result in the reduction of lifetime of the fluorescent lamps. To overcome these problems, electronic ballast comes in practice. Electronic ballasts for fluorescent lamps are extensively used because electronic ballasts have some advantages like high efficiency, light weight, and absence of flicker and audible noise as compared to electromagnetic ballasts [6].

Conventional electronic ballast for fluorescent lamps unites power factor correction circuits and harmonic restraint in one piece [7]. The electronic ballast drives the lamp at a much higher frequency, in the range of 20 kHz to 70 kHz. In electronic ballast, ballasting is attained by limiting the lamp’s current with a series reactive power element placed in series with the lamp. Since the lamp displays negative incremental resistance around the operating point, ballast is needed to guarantee stable operation [8]. The high frequency ballast is mainly a switching power supply and it has the potential for radiofrequency interference in the same way as any switched mode power supply. The output signal conditioning may include a few EMI countermeasures. However this is by no way universal, since the prime function of the output inductors is to limit the current supplied to the working lamps [9].

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Fluorescent lighting produces interference that is almost deterministic and periodic since the fluorescent light flicker at a constant rate determined by the lamp drive frequency [10]. A range of EMI mitigation schemes have been proposed over the years. They include filtering, soft-switching, and modified modulation schemes that shape the spectra of the switching function in order to lessen the EMI to within the FCC conducted EMI specifications [3]. Major drawback of the former methods was its hardware complexity in the circuit design. Due to the use of more parasitic circuit components in the circuit, power consumption is greatly increased. Therefore, excessive power dissipation takes place which results in either rapid heating or broken connection of circuit component. In addition, the usage of additional parasitic circuit components increases the overall cost. So as to avoid potential instability problems it is also necessary to design the additional parasitic circuit components of the circuit carefully. Concisely, the methods focus to provide additional circuitry to mitigate EMI incurs cost, weight, and complexity. On the other hand, Spread Spectrum Clock Generation (SSCG) is the effective approach for the mitigation of EMI. Still there also exists the possibility of a problem of deviation of the fluorescent lamp operation from its operating point; because the power consumption may be lesser than the actual power rating of the fluorescent lamp. Most of the researchers have their focus only on the minimization of EMI without considering other constraints such as cost, effective operation of the electronic equipment etc.

To overcome the above mentioned difficulties, we have developed a technique for the EMI mitigation in fluorescent lamp using FM incorporated with EP. By using the FM t, one of the important modulation techniques in telecommunication, the EMI level can be reduced heavily. But intensified decrease of EMI level may affect the fluorescent lamp operation as the probability of reduction in the power level for fluorescent lamp is more. The main objective of our work is to provide an optimal solution so that the EMI level can be mitigated satisfactorily without showing any inefficiency in fluorescent lamp operation. In order to provide an optimal solution, we have utilized the EP. Because of integrated work of both EP and FM, the distortions caused by EMI can be reduced reasonably without causing any disturbances to the operation of the fluorescent lamp. The remaining of the paper is organized as follows. Section II details some of the recent research works and Section III gives a brief introduction for EP. Section IV details the proposed EMI mitigation technique with necessary illustrations and mathematical formulations. Section V discusses the implementation results and Section VI concludes the paper.

II. RELATED WORKS

The research works that are concentrated over the emission of EMI and its mitigation are as follows. Wan-Rone Liou et al. [16] have presented a novel dual-mode step-up (boost) DC/DC converter. The converter will work in PFM mode at light load and in PWM mode at heavy load. The maximum conversion efficiency of this converter is 96%. The conversion efficiency was greatly enhanced when load current is below 100 mA. Furthermore, a soft-start circuit and a variable-sawtooth frequency circuit are proposed. The former was used to prevent the large switching current at the start up of the converter and the latter was utilized to reduce the EMI of the converter.

A numerical approach to the modeling of Electro-Magnetic Interference (EMI) from the emissions of integrated circuits (ICs) and printed circuit boards (PCBs), inside rectangular metallic enclosures of communication devices, was presented by Sotirios K. Goudos et al. [17]. The ICs are modeled as small magnetic dipoles, and their interaction with the enclosures are formulated by means of dyadic Green's functions. The EMI in a network switch and a network router are examined by means of sources-device models developed for each one of the devices. These models are based on data got from magnetic probe measurements in various types of network equipment. At last, the particle swarm optimization algorithm was utilized to show the optimal arrangement of ICs that results in significant reduction of the electric current density induced on the metallic walls.

R.Dhanasekaran et al. [18] have proposed a method to determine Common Mode (CM) and Differential Mode (DM) noise of a low power Switched Mode Power Supply (SMPS) using two-probe approach i.e. using one current probe as an injecting probe and other current probe as receiving probe, Common Mode (CM) noise was calculated between power line and ground. Differential Mode (DM) noise was measured between each power lines. EMI radiated emissions occur in the range of 150 KHz-30MHz. EMI filter was usually required in the input of the Switch Mode Power Supply (SMPS) to attenuate the noise. Their approach allows measurement of noise level in Switched Mode Power Supply without interleaving its normal operation. With proper set up calibration, their approach can be used to compute the noise level with reasonable accuracy. The noise level was measured from the frequency of 1MHz-3MHz using signal generator. The signal was induced in the injected probe and by means of receiving probe noise level was measured in db using spectrum analyzer.

V. Sekar et al. [9] have proposed some of the prevailing tests and measurements which have the capability of plotting the EMI level in fluorescent lamps during ballast operation. The obtained level of EMI will be helpful in taking precautionary steps for reducing EMI.

Julia Paixao et al. [19] have investigated an EMI Reduction technique using two MOSFETs instead of a single MOSFET in a step-down converter. A circuit that employs this technique together with external capacitor control was designed and measurement results were compared against simulations. The switching element in the proposed circuit was an IRF7307 that consists of a p-channel and an n-channel MOSFET in the same package. The entire circuit also consists of an input circuit for the control pulses and a controller circuit accountable for optimizing the turn-on and turn-off of the p-channel MOSFET and n-channel MOSFET. The effect of difference in the threshold voltage between the two MOSFETs was controlled by external capacitances in a configuration referred to as capacitor control. The analyzes of simulations and measurement results have revealed that the symmetrical switching (or double MOSFET switching) technique can successfully be applied to lessen the RF emission in the low frequency and medium frequency range when compared to the single MOSFET switching.

K. M. Muttaqi et al. [2] have investigated the negative effects of electromagnetic interference (EMI) due to fast switching power devices (high dv/dt and di/dt) applied in power electronic converters and industrial equipment. Mitigation techniques have been surveyed to reduce EMI noise effectively. Corrective measures to reduce the risk of equipment malfunction and health risk due to EMI have been explored. EMI generation and propagation mechanism, high rates of change of voltage and current in fast switching power devices (such as IGBT), modeling and identifying EMI noise sources and coupling paths have been discussed. A practical EMI measurement system has been recommended to extract more information from EMI noise through analysis in frequency-domain and time-domain, and to check equipment emitting EMI to comply with electromagnetic compatibility (EMC) standards. Different filter topologies have been examined for minimizing EMI noise and effect of high dv/dt and di/dt due to high frequency switching.

Franc Mihalic et al. [20] have presented a comparative investigation of different random modulation schemes against the normal PWM for the DC motor drive with step-down chopper (buck) and half-bridge configuration. For this purpose, an experimental setup with DSP2 board has been built. The board consists of the signal processor TMS320C32 which was appropriate for validating the different modulations strategies. The effectiveness of randomization on spreading the dominating frequencies that normally exist in constant frequency PWM schemes was assessed by the power spectral density (PSD) estimations in the low-frequency range. In the end, one universal demo board with two power converters configuration (driven by the micro controller PICF16F876) has been used in EMI measurements to comply with the CISPR 25 (or EN 55025) regulations.

Min-woo Kim et al. [21] have put forth chip level techniques to enhance EMI characteristics of LCD-TV panels. In LCD- TV panels, a timing controller (TCON) employs over-driving algorithms to enhance the response time of liquid crystals (LC). This algorithm needs previous frame data and so external memory such as double data rate synchronous DRAM (DDR SDRAM) was widely used as a frame buffer. A TTL interface between the TCON and memory was used for read and write operations, producing EMI noise. For the lessening of this EMI, three methods were illustrated. The first method was to reduce the driving current of data I/O buffers. The second was to employ spread spectrum clock generation (SSCG), and the third was to use a proposed algorithm which reduces data transitions. EMI measurement of a 32” LCD-TV panel has revealed that these approaches are very efficient in the reduction of EMI, achieving 20 dB reductions at 175 MHz.

Kato, T.Inoue et al. [22] have proposed an elimination approach which was effective both to the leakage currents in a single-phase full-bridge PWM inverter. Their principle was so simple that the inverter was run only as complementary between two arms. This removes neutral voltage drifts of the load by maintaining the common-mode voltage as zero. Besides that, parasitic capacitor currents circulate only inside the inverter body because the switching times are synchronous between the two arms. This was applicable even when there are dead-times in arm switching. These effects are confirmed through simulation by Saber and experiment by a DSP-based system with switching frequency of 10 kHz.

Jalakas, T.Molder et al. [23] have focused on EMI reduction problems in high voltage power converters with 6.5 kV IGBTs. The generation process of electromagnetic interference was concisely explored and some EMI reduction methods are presented. Theoretical analysis, computation and experimental results of selecting the snubber circuit for minimization of parasitic ringing were explained. The effect of EMI suppression circuit was also experimentally analyzed on output rectifier of described power converter.

III. EVOLUTIONARY PROGRAMMING

Over the past few decades, researchers have presented many novel nature inspired heuristic methods such as the evolutionary algorithms (EA) for optimization design based on specific domain knowledge. Two well-developed techniques belong to the class of EA are Genetic Algorithms (GA) and Evolutionary Programming (EP) [12]. EP was first designed as an evolutionary approach to artificial intelligence. It is also very proficient in solving numerical and combinatorial optimization problems [13]. As a powerful and general global optimization tool, EP looks for the optimal solution by evolving a population of candidate solutions over numerous generations or iterations [14]. Commonly, the EP algorithm for global optimization contains four parts: initialization, mutation, competition, and reproduction [11]. According to the problem each step can be modified and configured in order to obtain the optimal result. EP starts with the population of randomly generated candidate solution and evolves a better solution over a number of generations or iterations. It is more suitable to handle non-continuous and non-differentiable function effectively [15]. The steps for finding the optimal solution using EP are detailed below.

Step1: Initialize the population size, and survivors of the population values by random values within the limit.

Step2: Determine the fitness value for each of the survivors of the population.

Step3: Select the best survivors and mutate them to produce new children.

Step4: Determine the fitness for the newly produced children

Step5: Check for the termination criteria. If it is satisfied, select the best survivors as the optimal solution, else, go to Step 3.

This is the common procedures of EP used in finding the solution for any optimization problem. The EP is utilized as one of the major part of the proposed EMI mitigation technique and the proposed EMI mitigation is discussed in the next section.

IV. PROPOSED EMI MITIGATION TECHNIQUE BASED ON FM AND EP

As discussed earlier, for EMI mitigation in fluorescent lamps, we are utilizing the combination of FM technique, one of the significant techniques in the area of communication as well as EP, one of the significant optimization techniques. This combined performance leads to efficient fluorescent operation with satisfactory EMI mitigation rather than using the FM solely. It is known that the EMI is generated because of the high frequency switching of the electronic ballast used in the fluorescent lamps. Instead of using a single central frequency for switching, switching over a range of frequencies avoids the EMI mitigation. In order to accomplish this, the FM technique is used. Let, $V_S(t)$ be a sine voltage termed as modulating voltage which can be given as

$$V_S(t) = V_S \sin(2\pi \; f_s t) \tag{1}$$

where, V_S is the amplitude of the voltage and f_s is the supply frequency. The usual ballast operation is nothing but the switching of the low frequency supply and so that the low frequency supply is converted into high frequency supply. In order to accomplish this, a pulse train of high frequency is generated within the ballast circuit so as to activate the 'ON' and 'OFF' status of the switching operation. In the proposed technique, a sine voltage of A.C. supply frequency is used as the modulating signal for the FM and a carrier of high frequency f_c is generated. Then the FM modulated voltage is obtained as follows

$$V_{FM}(t) = V_c \sin\left(2\pi \left(f_c + \frac{f_d}{V_S} \right) V_S(t) \right) t \tag{2}$$

where, $V_{FM}(t)$ is the FM modulated voltage,

V_c is the carrier voltage,

f_d is the frequency deviation, a significant parameter in the FM.

The power is distributed throughout a range of frequencies because of the usage of FM. This range of frequency is little deviated from the chosen f_c and this deviation is decided by f_d . Generally, the f_d is based on the modulation index δ chosen for the FM technique and the relation between the δ and f_d is given as $\delta = \frac{f_d}{f_s}$

When δ increases, then the power is distributed throughout a wide range of frequencies. So, power peaking at the carrier frequency decreases which leads to the mitigation of EMI. But, the operation of fluorescent lamp is disturbed as well as the ballast is operated beyond the range of operating frequency. So, it is essential to determine the optimal δ in order to minimize the EMI up to a reasonable level without any intrusion for the fluorescent lamp operation. Hence, it is proposed that the optimal δ can be determined by utilizing the EP, one of the evolutionary algorithms and it is described in the following section.

A. Selection of Optimal modulation Index by EP

The core of the proposed approach is to recognize the optimal modulation index δ for the FM signal, which is generated for the pulse train so as to drive the ballast operation. The modulation index decides the range of frequency to be deviated in the FM signal from the carrier. Hence by using EP, the optimal δ is determined and the steps for determining the optimal δ are depicted in the Fig. 1.

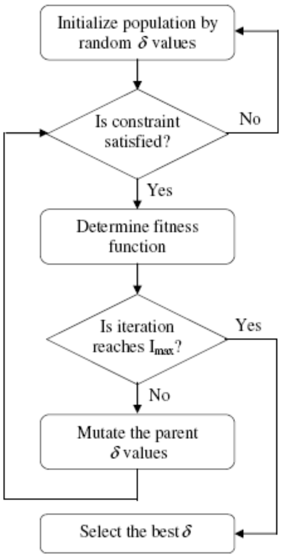


Fig. 1 EP steps for determining the optimal δ

Initially, a population of random values is generated by uniformly distributed numbers as

$$p_i = r_1 \,\%\, \delta_{\max} \qquad ; 0 \le i \le n_p - 1 \tag{3}$$

where, n_p is the population size, r_1 is the random integer which is distributed uniformly in the interval $(0,1)$, $\delta_{\max}$ is the maximum value of the modulation index of the FM systems and p_i is the initial population generated for the selection of optimal modulation index.

From the initially generated population, best survivors are selected by calculating the fitness of the existing survivors of the population. The fitness function used to determine the best survivors of the population is given by

$$F_i = \arg\min_{p_i}\left(1 - \frac{f_d^{(i)}}{f_d^{\max}}\right) \tag{4}$$

with the constraint,

$$\left[S_{xx}\left(V_{FM}(f)\right)\right]_{f_d^i} \geq \left[S_{xx}\left(V_{FM}(f)\right)\right]_{f_d^{\max}} \tag{5}$$

In (4), $f_d^{(i)}$ is the frequency deviation because of the p_i which are generated using the (3), $f_d^{\max}$ is the maximum acceptable frequency deviation in the supply which is generated by the ballast. The fitness is determined only for the survivors of the population if the $f_d^{(i)}$ of the corresponding p_i satisfies the constraint given in the (5). The constraint is to check whether the chosen δ leads to any reduction in the power used to drive the fluorescent lamp. In (5), $\left[S_{xx}\left(V_{FM}(f)\right)\right]_{f_d^i}$ and $\left[S_{xx}\left(V_{FM}(f)\right)\right]_{f_d^{\max}}$ are the power spectrum of the FM signal with a frequency deviation of $f_d^{(i)}$ and power spectrum of the FM signal with a frequency deviation of $f_d^{\max}$, respectively. The power spectrum $S_{xx}\left(V_{FM}(f)\right)$ can be determined as

$$S_{xx}\left(V_{FM}(f)\right) = V_{FM}(f)V_{FM}^{*}(f) = \left|V_{FM}(f)\right|^2 \tag{6}$$

where, $V_{FM}^{*}(f)$ is the complex conjugate of $V_{FM}(f)$ and $V_{FM}(f)$ is the Fourier transform of $V_{FM}(t)$ which can be given as

$$V_{FM}(f) = F\left\{V_{FM}(t)\right\} = \int_{-\infty}^{\infty} V_{FM}(t)e^{-j2\pi ft}dt \tag{7}$$

where, f is the frequency used for analyzing. Hence, n_b number of best survivors are chosen from the population pool based on the fitness values (which has minimum fitness) from the population pool and they are mutated as follows

$$p_k^{child} = \frac{\left(p_j^{parent}\right)^2 + 1}{p_j^{parent}} \tag{8}$$

where, $0 \leq j \leq n_b - 1$, $n_b \leq k \leq 2n_b - 1$ and p_k^{child} is the children obtained from the mutation. By the given mutation as in (8), n_b number of children for the best n_b parent survivors is obtained. Then the fitness is determined for the children using the (4) as similar as done earlier and the children are added to the population pool along with the best survivors. From the population pool, n_b number of survivors are selected and the process is repeated again from mutation. Repeating the process until it reaches a maximum iteration count of $I_{\max}$, a best δ is obtained. Based on this best δ, FM modulated voltage is generated which laid the cornerstone for EMI mitigation technique without any disturbance of the fluorescent lamp operation. With the aid of the FM voltage, a pulse train is generated for switching operation of the ballast.

B. Generation of pulse train for switching

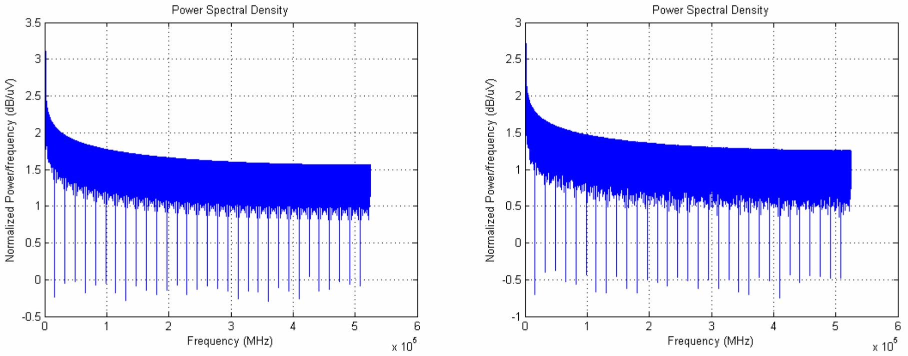
The pulse train required to perform the switching operation of ballast is generated using the FM voltage as follows

$$V_p(t) = \begin{cases} V_1; \ if \ \ V_{FM}(t) > 0 \\ V_2; \ else \end{cases} \tag{9}$$

where, V_1 represents ‘ON’ state and V_2 represents the ‘OFF’ state. Thus generated pulse train has the two levels of amplitude but the frequency is similar to that of the $V_{FM}(t)$. Using the generated pulse train, the usual ballast switching operation is performed. Hence, the frequency of the mains supply is changed as per the frequency of the pulse train and so the power is distributed throughout the frequency of $(f_c - f_d^{best})\ to\ (f_c + f_d^{best})$ with a range of $2f_d^{best}$, where, $f_d^{best} = \delta_{best}\ f_s$. Instead of supplying voltage with a constant high frequency, in the proposed technique, the ballast is supplying a voltage whose frequency is deviated by up and down from the central high frequency. This indirectly means that the obtained δ provides sufficient frequency deviation for satisfactory EMI mitigation so that the frequency range are not deviated away from the ballast operating frequency as well as its output power. Thus generated supply voltage for fluorescent lamp is sufficient enough to drive the fluorescent lamp. Hence the ballast operation is also made efficient because of the optimal selection of δ and so the mitigation of EMI is achieved up to a satisfactory level. Eventually, the fluorescent lamp operation is not being disturbed; meanwhile, the EMI is also mitigated to certain extent.

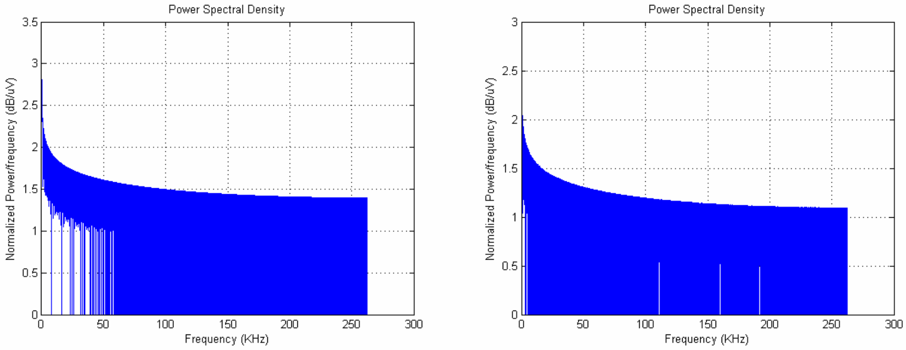
V. RESULTS AND DISCUSSION

The proposed FM and EP based technique for EMI mitigation has been implemented in the working platform of MATLAB (version 7.8). Before implementing the proposed EMI mitigation technique, the EMI emission levels in the usual ballast operation have been simulated. The mains voltage of 230V A.C. and frequency of 50Hz supply is applied to the ballast for fluorescent lamp operation. Because of switching at high frequencies, the fluorescent lamp emits EMI of both conducted and radiated type emissions. The switching operation is simulated in the MATLAB and the corresponding EMI emission levels are visualized and plotted in the Fig. 2 and Fig. 3. The EMI emission levels are tested for two cases. One is by setting the switching frequency at 1 MHz and another by setting the same at 150 KHz. For the two different switching frequencies, the EMI emission levels are observed from the plot provided by the program. This EMI emission level is compared with the level obtained for the proposed EMI mitigation technique. The emission levels estimated without any EMI mitigation techniques and the emission levels estimated after the utilization of the proposed EMI mitigation technique are plotted in the Fig. 2 and Fig. 3.



(a) (b)

Fig. 2 The estimated emission level in the switching pattern of frequency 1 MHz (a) without any EMI mitigation technique and (b) with the proposed EMI mitigation technique



(a) (b)

Fig. 3 The estimated emission level in the switching pattern of frequency 150 KHz (a) without any EMI mitigation technique and (b) with the proposed EMI mitigation technique

Fig. 2 (a) and Fig. 3 (a) illustrates the EMI emission level without any EMI mitigation technique at the switching frequency of 1 MHz and 150 KHz respectively. Fig. 2 (b) and Fig. 3 (b) shows the EMI emission level using the proposed technique at the switching frequency of 1 MHz and 150 KHz respectively. As discussed earlier, we have utilized FM for the EMI mitigation; however, EP plays a significant role in obtaining the δ value which decides the range of deviation of frequency in the FM. The major reason behind the usage of EP for the selection of δ is that the chosen δ should not violate the operating parameters of the fluorescent lamp and the ballast by any means. The chosen lamp is of the type 40T12 which requires the ballast having the specifications of 100V as output voltage and 39 KHz of output frequency with a tolerance value of up to 5%. For EP, initially a population of size '5' (i.e. $n_p = 5$) has been generated, the $\delta_{\max}$ has been set to '5' and the $I_{\max}$ to '100'. For every iteration, the fitness of the survivors has been determined and the parents were mutated to form children. At the end of the $I_{\max}$, a best δ has been obtained. As the two different switching frequencies, 1 MHz and 150 KHz have been utilized as two test cases; two different d values have been obtained from the EP. Based on the δ, FM has been performed and so the switching operation has been done. Then the estimated levels of EMI emissions have been plotted in the Fig. 2 (b) and Fig. 3 (b). Moreover, the voltage applied for the fluorescent lamp after the mitigation is approximately 134V (i.e. operating voltage is 130V approx.). Hence, it can be observed that the EMI emissions are mitigated to a considerable level without any disturbance for the fluorescent lamp operation by providing the sufficient operating voltage.

VI. CONCLUSION

The proposed EMI mitigation technique based on FM and EP has performed well in the reduction of EMI without adding any operating difficulties to the fluorescent lamp. As the interference is due to the high frequency switching operation of the electronic ballast, the proposed technique drives the ballast to switch over a range of frequencies. For the purpose of switching, we have utilized the FM and for determining the optimal δ for FM, we have utilized EP. The obtained results have claimed that the EMI is reduced to a considerable level with the usage of the proposed EMI mitigation technique. Because of this considerable EMI mitigation, the operating limit of the parameters of the fluorescent lamp and the ballast considered, have not exceeded. This in turn, can be asserted that the proposed EMI mitigation technique using FM and EP mitigates the EMI without disturbing the operation of the fluorescent lamp. Succinctly, the technique not only achieves effective EMI mitigation, but also, assures uninterrupted operation of the fluorescent lamp.

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