IMPLEMENTATION OF DIGITAL COMMUNICATION MODULATION TECHNIQUES IN DC-DC CONVERTERS FOR THE SUPPRESSION OF EMI AND ENCHANCEMENT OF GRID POWER QUALITY

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Abstract: *In the vital requirement of power quality and suppression of EMI in SMPS, two types of digital modulation techniques are proposed in dc-dc converter. The two direct-sequence modulation techniques namely Binary-Phase Shift keying modulation and Quadrature-Phase Shift Keying modulation are implemented for the first time in dc-dc converter to enhance the grid power quality. The proposed modulation techniques are executed through a Field Programmable Gate Array by writing a VHDL coding for each modulation technique. The coding written is verified by Model Sim tool through ISE Xilinx software to produce gate pulse for the switch in dc-dc converter. Instead of building modulator physically, the modulation logic is implemented through VHDL coding, thus reduces the cost and space. On utilising this proposed DSSS modulation techniques, the EMI is reduced by 12 dBm and 24 dBm by BPSK and QPSK modulation respectively, when compared with traditional PWM technique.*

Key words: *Binary-Phase Shift Keying modulation, CUK converter, Direct-Sequence Spread-spectrum modulation, Electromagnetic Interference, Power Quality, Quadrature-Phase Shift Keying modulation.*

1. Introduction

In recent times, switched mode power conversion has many advantages which make it desirable and even more necessary in some applications. Advancement in the design of power supply and manufacture need to keep pace with the advances of electronics systems. The portability requirements lead to the demand of more compact units with reduced losses. Besides, the regulations relating to Electromagnetic Compatibility (EMC) are becoming more stringent. Since Switched Mode Power Supplies (SMPS) are continually switching current, they are potential source of Electromagnetic Interference (EMI). The gate pulses of the power switching converter have steep rise and fall times to minimise the switching losses, but steeper the edges, the greater the harmonics and in turn larger the EMI noise because of high dv/dt and di/dt ratings. It is therefore necessary to design switched mode power converters with less EMI so that it should either get affected by the other electronic equipment or it should interfere with others. Hence the converter is designed so that it essentially meets the EMC standards [1].

Many types of dc-dc converters operating at high switching frequency are employed in SMPS for various applications. Usage of dc-dc converters with such high switching frequency although decreases the size of the inductors used but in turn extremely increases the level of EMI noise in the AC supply, also increases the harmonic content of the supply current, hence deteriorates the grid power quality which supplies SMPS. Implementation of conventional Pulse Width Modulation (PWM) in dc-dc converters increases the EMI noise and hence many modulation techniques were evolved to suppress the EMI.

To mitigate EMI, authors suggested the usage of filters, which increases the cost and volume of the circuit [2,3]. Later soft switching is suggested for the suppression of EMI [4], which again suffers from the drawback of improving the power quality of the grid. PCB layout design is a solution for the EMI mitigation [5] but that too suffered from the variation in frequencies. Hence forth, many modulation techniques such as Random Pulse Width Modulation (RPWM) [6,7], sigma delta modulation [8], chaotic modulation [9,10] and spread spectrum modulation [11-18] are employed in power converters for the suppression of EMI. However, the above literature failed to provide information about power quality indices such as power factor and THD. Hence an effort is made to implement the proposed Direct-Sequence Spread-Spectrum modulation (DSSS) techniques such as Binary-Phase Shift Keying (BPSK) modulation and Quadrature-Phase Shift Keying (QPSK) modulation in a dc-dc converter. The necessary grid power quality parameters such as Power factor, Total Harmonic Distortion (THD), FFT noise and EMI are measured and presented. These modulation techniques can be applied to all types of dc-dc converter employed in SMPS. In this work, CUK

converter is taken, as it has many applications in industrial drives and act as a power factor correction converter.

The paper is organised as follows: Section 2 presents the theoretical background of the proposed DSSS modulation techniques namely BPSK and QPSK and section 3 discusses the implementation of the conventional PWM technique and proposed modulation techniques in dc-dc converter through Field Programmable Gate Array (FPGA). The hardware results obtained for the proposed modulation techniques and the comparison of the same with the conventional PWM technique are presented in section 4. Finally the conclusion arrived by implementing the digital modulation techniques is discussed in section 5.

2. Direct-Sequence Spread-Spectrum (DSSS) modulation techniques

One of the most efficient modulation technique used in telecommunications to prevent the interference is Direct-Sequence Spread-Spectrum modulation. In DSSS modulation, pseudo-random noise is used for spreading the signal. The two types of DSSS modulation techniques employed in the proposed converter are Binary-Phase Shift-Keying (BPSK) modulation and Quadrature-Phase Shift-Keying (QPSK) modulation. These two types of modulation techniques are predominately used in the field of communication systems are recently used in power converters for the suppression of EMI. Spread spectrum techniques eliminates the bulky filter which is used to mitigate conducted EMI in the source side of the power switching converter maintaining near UPF operation.

The simplest form of direct-sequence spread spectrum is employing binary phase shift keying (BPSK) modulation in the converter. In BPSK modulation, the phase of the modulated signal, $S_d(t)$ is varied by the bit sequence generated by pseudo-random sequence generator.

The DSSS-BPSK modulation and the modulated carrier signal can be mathematically represented as

$$S_{bpsk}(t) = c(t) * S_d(t) \qquad (1)$$

$$S_d(t) = \sqrt{2P} \cos(\omega_o(t) + \theta_d(t)) \qquad (2)$$

where c(t) is the spreading code, P is the power of the modulated carrier with ω_0 as its frequency and $\Theta_d(t)$ is the phase of the modulation.

The power spectral density of the BPSK carrier signal [19-21] is obtained as

$$S_{bpsk}(t) = \frac{1}{2} PT_c \left\{ \begin{array}{l} \left[\sin c^2 \left([f - f_0] T_c \right) \right] \\ + \sin c^2 \left([f + f_0] T_c \right) \end{array} \right\} \qquad (3)$$

Where $\sin c f T_c = \dfrac{\sin \pi f T_c}{\pi f T_c}$, is used to modulate a co-sinusoid of frequency f_o and T_c is the duration of the spreading code signal.

In QPSK modulation method, two quadrature carriers are used for the modulation. The main advantage of this method is to improve the spectrum efficiency. The modulated signal $S_d(t)$ is placed on these two carriers to get QPSK modulated signal and the output of the QPSK modulator is given by,

$$S_{qpsk}(t) = \sqrt{P} \left[\begin{array}{l} C_1(t) \cos \left(\omega_0 t + \theta_d(t) \right) \\ -C_2(t) \sin \left(\omega_0 t + \theta_d(t) \right) \end{array} \right] \qquad (4)$$

Where $C_1(t)$ and $C_2(t)$ are in-phase and quadrature spreading waveforms respectively. Since the two signals are orthogonal, the power spectrum of the QPSK signal equals the sum of the power spectra of the two components. As seen from equations (3) and (4), in DSSS modulation, the power spectrum is spread over the frequencies of larger bandwidth for the suppression of EMI in adopting BPSK as well as QPSK modulation techniques in three-phase grid-connected inverters.

3. Implementation of modulation techniques in Power converter through FPGA:

A dc-dc Cuk converter shown in Fig.1.is built with the following specifications: V_{ac}=230 V, 50 Hz, single-phase, AC supply, V_{rect}=12 V, L_1=30mH, C_1=150µF, L_2=30mH, C_2=50µF, R_L=100 Ω, V_0=50 V, f_{sw}=25 kHz. The block diagram of hardware implementation of the modulation techniques using FPGA is shown in Fig. 2.

Initially, The entire system is designed in MATLAB Simulink and the various units like pseudo random sequence generator, saw tooth generator, BPSK / QPSK modulator and carrier wave generator are designed in SPARTAN FPGA 3E developer kit using VHSIC (Very High Speed Integrated Circuit) Hardware Description Language (VHDL) coding. The modulation techniques thus developed using VHDL in ISE XILINX platform is then simulated using Model-Sim. Later, the coding obtained by Xilinx software is burned in to FPGA to obtain gate pulse for the converter.

3.1 conventional PWM technique:

The block diagram of implementation of the conventional PWM technique is shown in Fig. 3. In this technique, output voltage V_0 is compared with the reference voltage V_{Ref} to get the error signal V_{err}. This error signal is then compared with the saw tooth signal to get the gate pulse for the converter. Duty ratio D is adjusted only by a change in the output voltage, as the saw tooth waveform has fixed amplitude with fixed frequency. Hence, it is prone to create EMI noise in the supply side. In order to reduce this EMI emission, spread spectrum modulation technique is proposed. The simulated gate pulse obtained by Xilinx Model-Sim software is shown in Fig. 4.
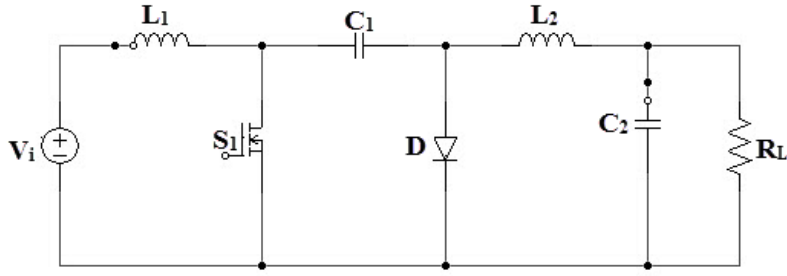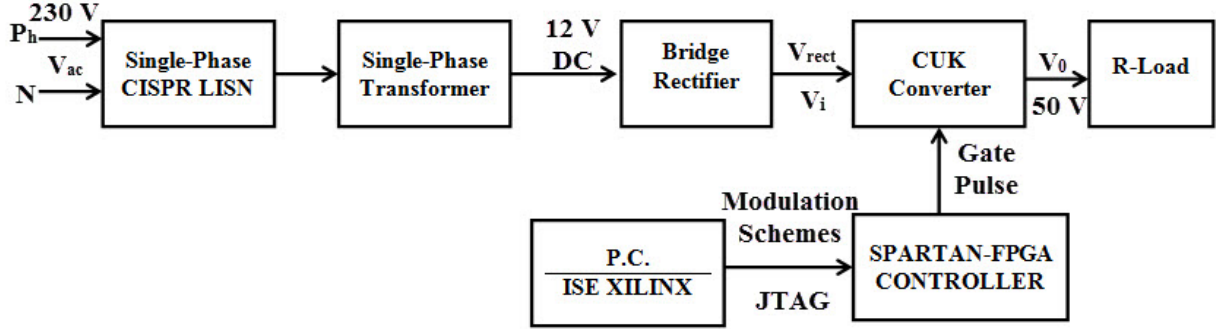
Fig. 1. Circuit diagram of CUK converter

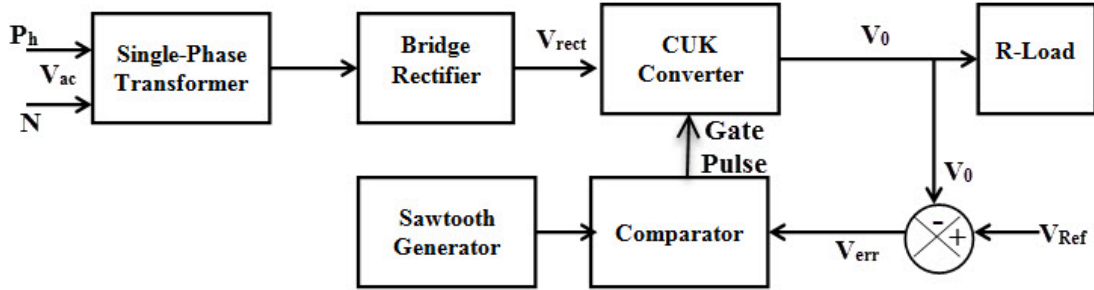Fig. 2. Block Diagram of hardware implementation of modulation schemes using FPGA.

Fig. 3. Blok diagram of implementation of conventional PWM technique

3.2 Direct-Sequence Spread-Spectrum (DSSS) modulation:

The block diagram of implementation of DSSS modulation in a power switching converter is shown in Fig. 5. In this method, primarily, a pseudo random sequence generator is used to generate a random sequence of 101101101. Secondly, the DSSS pulse is modulated according to the random sequence to get a DSSS modulated signal, $S_d(t)$. Later, this modulated signal is multiplied with the carrier signal to obtain a DSSS modulated carrier signal $S_{bpsk}(t)$. This high frequency carrier signal is then compared with the error signal to get the gate pulse for the converter. The Model-Sim output obtained from Xilinx software by implementing DSSS modulation is shown in Fig. 6.

4. Hardware Results:

The source side conducted EMI in each modulation technique is measured by connecting CISPR 50 Ω LISN network between the source and the converter. The measurements were taken keeping CISPR-11 as the limit line. The hardware results obtained by the conventional PWM technique and the proposed DSSS modulation techniques are presented and discussed.

4.1. Conventional PWM technique:

The experimental waveforms obtained by employing the conventional PWM technique are presented in Fig. 7. The line current THD obtained by this technique is 9.0% which is greater than the standard limit according to CISPR 11.
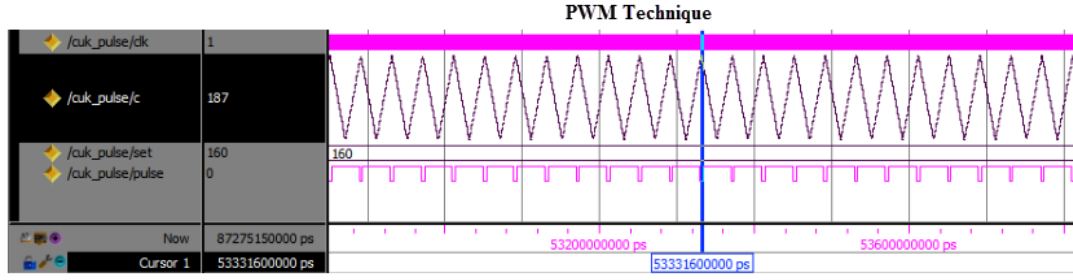
Fig. 4. Model-Sim output obtained from Xilinx software for PWM technique.
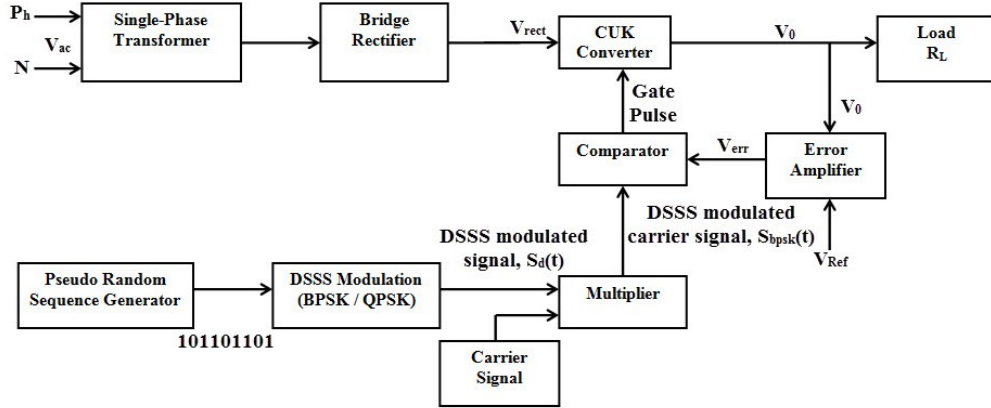

Fig. 5. Block diagram of implementation of DSSS modulation technique in dc-dc converter.
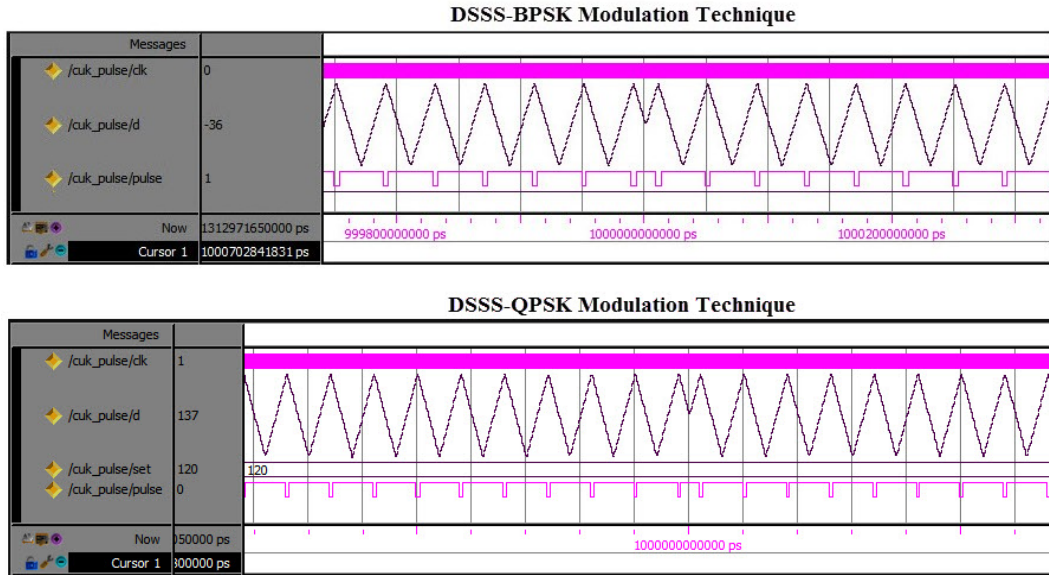

Fig. 6. Model-Sim output obtained from Xilinx software for DSSS modulation technique.

Also the FFT spectrum of the line current and EMI power spectrum of the source obtained by this technique are also a higher value which are -23.40 dB and 17 dBm according to the standard limits. Hence forth, the direct-sequence spread-spectrum modulation techniques are proposed to suppress EMI and to reduce THD and FFT noise of the line current with good power factor.

4.2. DSSS Modulation techniques:

The experimental waveforms obtained by implementing the DSSS-BPSK and DSSS-QPSK modulation techniques are presented in Fig. 8. and Fig. 9. respectively. Fig. 8 (a) and (b) shows the experimental gate pulse with output voltage obtained by BPSK and QPSK modulation. Fig. 8(c) and (d) shows experimental THD and power factor obtained by BPSK and QPSK modulation techniques.
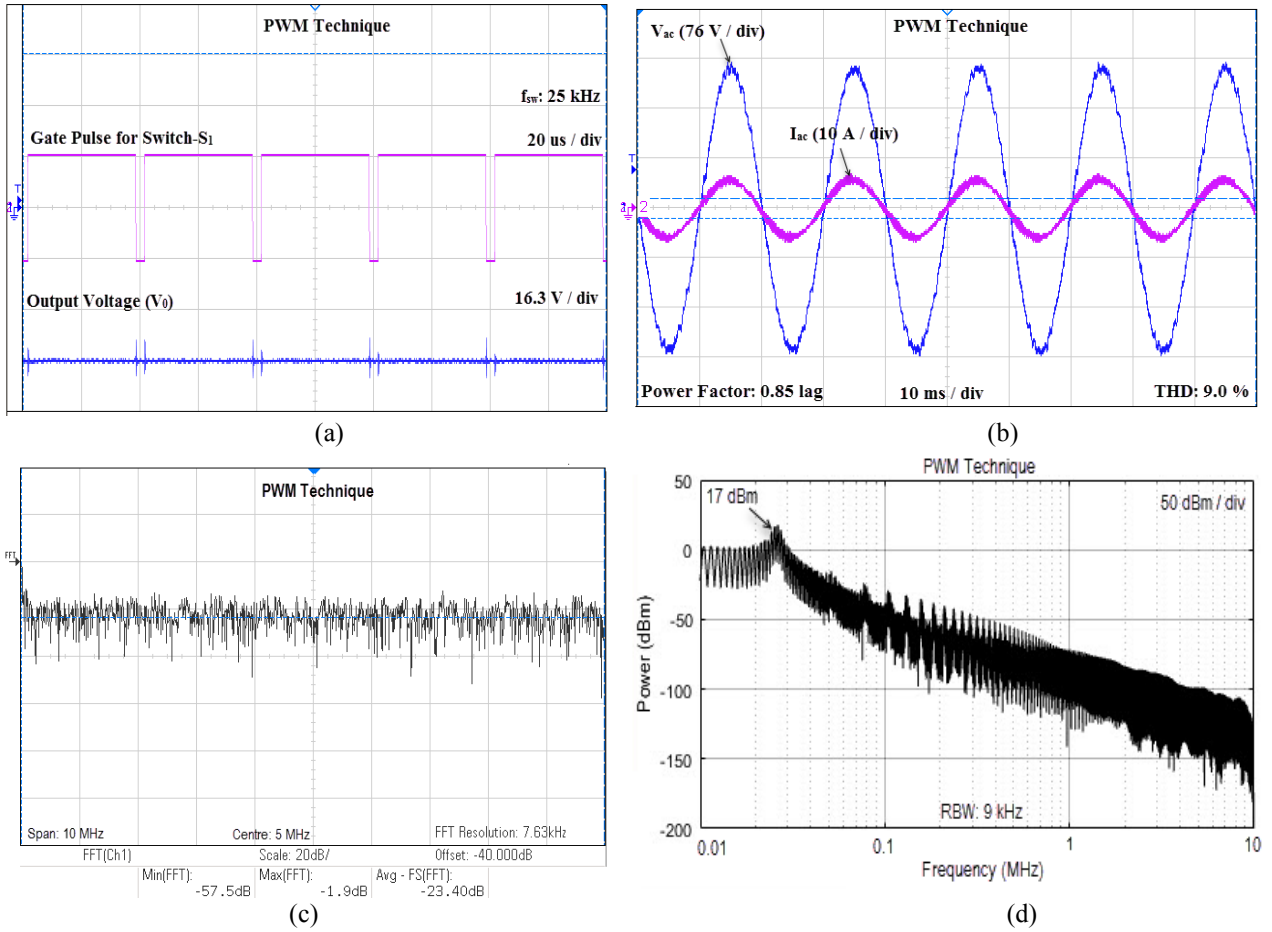
Fig.7. Experimental waveforms obtained by PWM technique (a) Gate pulse with output voltage, (b) PF and THD measurement, (c) FFT spectrum of the line current and (d) EMI power spectrum.
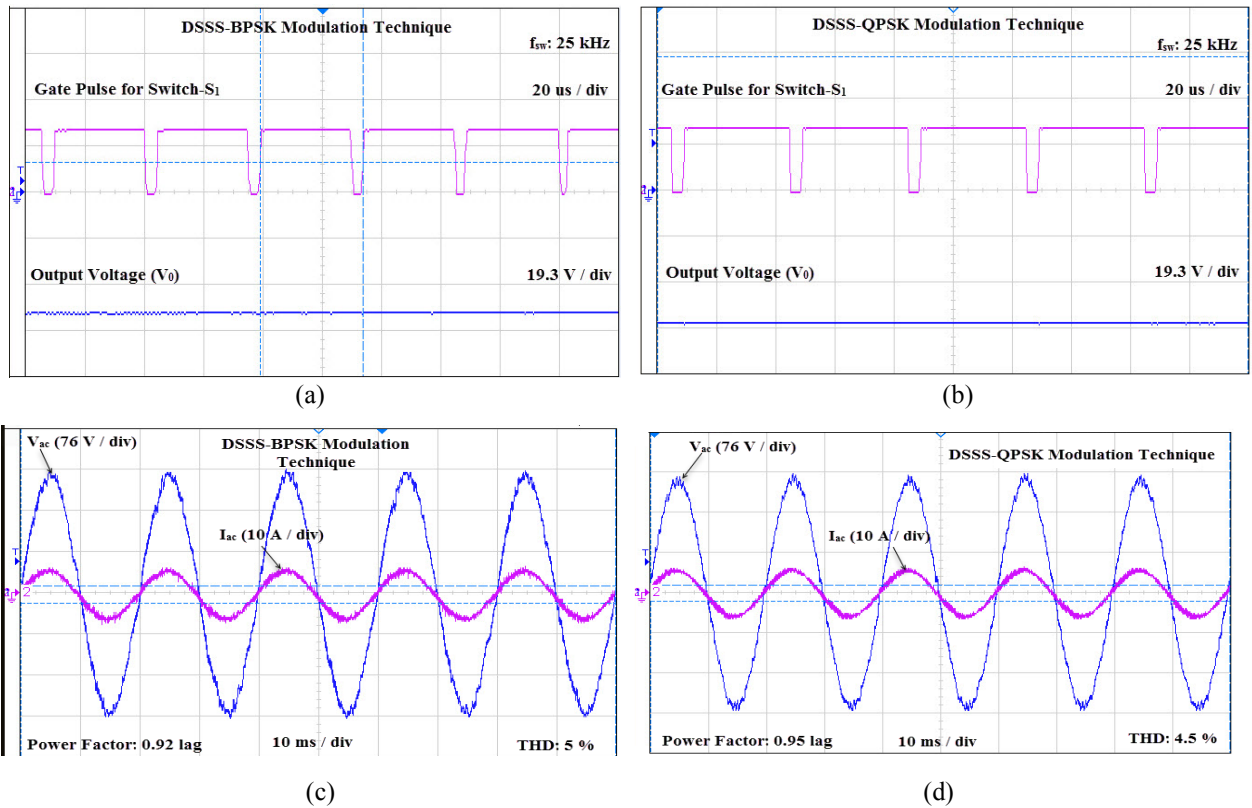

Fig. 8. Experimental waveforms of gate pulse with output voltage obtained by (a) DSSS-BPSK and (b) DSSS-QPSK modulation, PF and THD measurement obtained by (c) DSSS-BPSK and (d) DSSS-QPSK modulation techniques.

From the results obtained, it is observed that in DSSS-BPSK modulation the THD of the source current attained is 5 % which is less than the CISPR limit. Further by employing this technique the experimental FFT spectrum of the line current obtained is shown in Fig. 9(a). It is observed that 11 dB reduction is obtained when compared with PWM technique. Also, EMI power spectrum is presented in Fig. 9(c) is observed as 5 dBm which is 12 dBm less compared with PWM technique.

when compared with both PWM and BPSK modulation techniques.

The values of the power quality parameters obtained by the various modulation techniques are listed is Table-I. From the table, it is proved that, the experimental values obtained by DSSS modulation particularly QPSK modulation is superior to the conventional PWM and BPSK modulation technique.
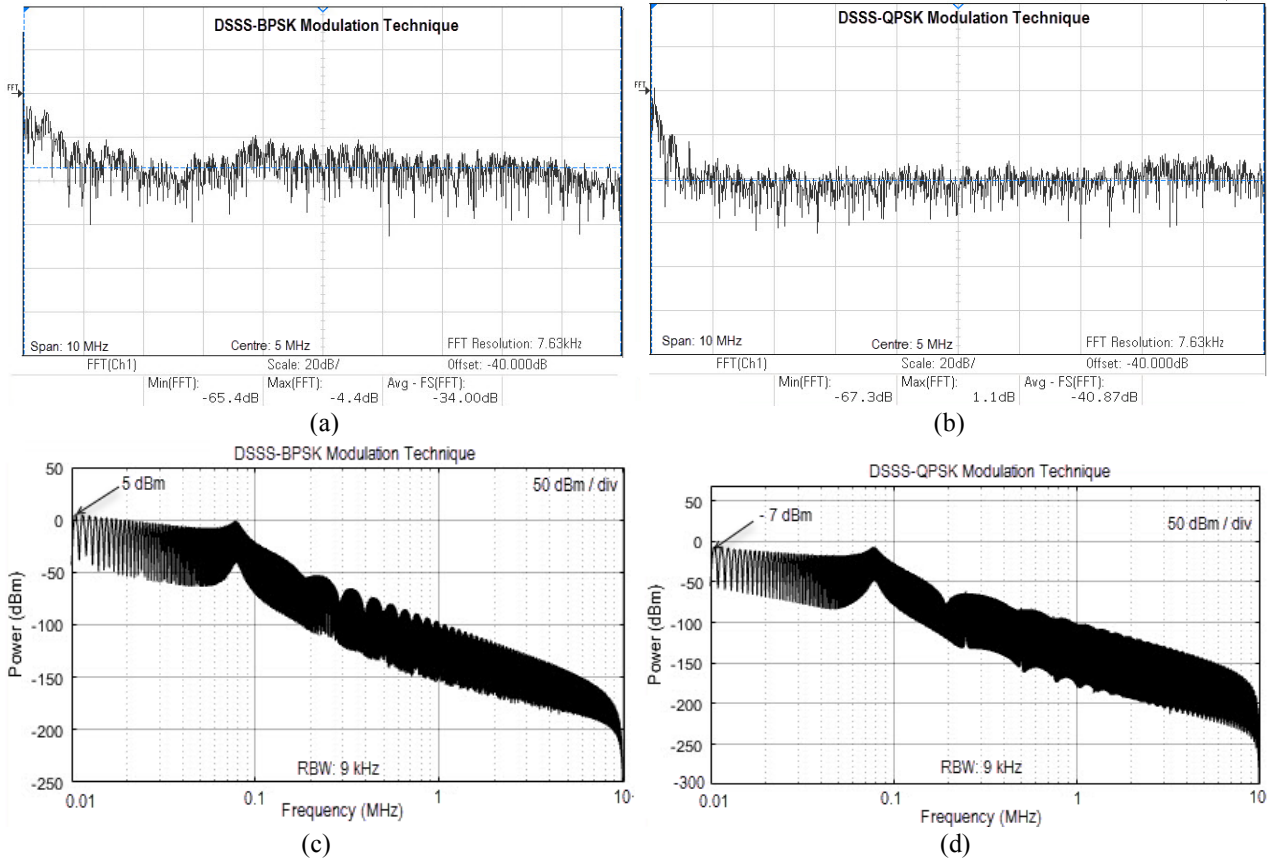

Fig. 9. Experimental waveforms of FFT spectrum of the line current obtained by (a) DSSS-BPSK and (b) DSSS-QPSK modulation, EMI power spectrum obtained by (a) DSSS-BPSK and (b) DSSS-QPSK modulation techniques

Furthermore, the experimental values of FFT and EMI noise obtained by BPSK modulation are under the standard limit. In order to further improve the power quality of the grid, DSSS-QPSK modulation technique is applied in the power converter using FPGA. Upon utilising this technique the THD is further reduced to 4.5% which is shown in Fig. 8(d). The FFT of the source current and EMI power spectrum obtained by QPSK modulation is shown Fig. 9(b) and (d) respectively.

It is noticed from the above figures that, both the values are further reduced substantially and well within the standard limit. The power factor of the grid is also improved to noticable value than the conventional PWM technique. The experimental power quality parameters obtained by QPSK is found to be improved

Table 1
Comparison of power quality parameters obtained by various modulation techniques

Modulation Techniques	Power Factor	THD %	FFT spectrum dB	EMI (Peak) dBm
PWM	0.85 lag	9.0	-23.40	17
DSSS - BPSK	0.92 lag	5.0	-34.00	5
DSSS - QPSK	0.95 lag	4.5	-40.87	-7

5. Conclusion:

In this paper, two different DSSS modulation techniques namely BPSK and QPSK modulation techniques are implemented for the first time in dc-dc cuk converter to improve the power quality of the grid. In order to emphasize the finer performance of the proposed modulation techniques, the power quality parameters obtained is compared with the traditional PWM technique. All the modulation techniques are realized using a low-cost FPGA. In the traditional PWM technique, it is seen that the power quality parameters measures are all above the standard limits. But, on making use of the proposed DSSS modulation techniques, the power quality parameters are improved. When compared with PWM technique, DSSS-BPSK and DSSS_QPSK modulation techniques reduced the line current THD by 4% and 4.5% respectively with a notable improvement in the power factor. Also the FFT noise in the source current is also reduced by DSSS-BPSK and DSSS-QPSK modulation techniques by 10.6 dB and 17.47 dB, when compared with PWM technique. Correspondingly, the EMI power of the source is also reduced by 12 dBm and 24 dBm by DSSS-BPSK and DSSS-QPSK modulation, when compared with PWM technique.

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