MULTI-PULSE OVER-MODULATION AC-DC POWER CONVERTER DESIGN FOR MEDIUM VOLTAGE

Md. Habibur Rahaman[a,*], Dr. M.R.I. Sheikh[b], Shah Md. Rezwanul Haque Shawon[c]
[a]Dept. of Electrical and Computer Engineering
[b,c]Dept. of Electrical and Electronic Engineering
[a,b,c]Rajshahi University of Engineering and Technology, Rajshahi-6204, **BANGLADESH**
Email: [a]habibieee@yahoo.com, [b]ris_ruet@yahoo.com, [c]shawon.ruet08@gmail.com

ABSTRACT

The paper presents a details review about multipulse converter and a new approach to design, simulation and practical implementations of a multi pulse over-modulation ac-dc power converter. In these work different types of existing three phases, multi-pulse, multilevel converter performance at wide range of voltages has been analyzed and compared. A power converter has been designed newly with modified over-modulation topology in which different types of over-modulation block has been used to minimize harmonics instead of static capacitor bank. Only a small size super capacitor has been used to minimize harmonics on dc side. The proposed converter has been simulated in MATLAB/Simulink environment at wide range of voltage level. It has been found that THD is very low. Theoretical analysis has been carried out and simulated those converters for verification of theoretical concepts. It is guaranteed that the proposed converter performance is much better than others. It reduces costs, complexity, output voltage/current ripple and THD. The proposed multi-pulse over-modulation converter can be the best choice for medium voltage power conversion.

Keywords: Multi-pulse, Multilevel converter, PWM, Over modulation, DC Motor, Super capacitor, AC/DC converter, THD, MATLAB/Simulink.

INTRODUCTION

In modern power electronics converters, a three-phase converter is commonly used to convert power from ac to dc in HVDC power transmission system [1]. A lot of researches have been done worldwide to reduce harmonic contents in the utility line currents of different types of power converters [2-4].

In literature, voltage-source converters (VSC), which first appeared in HVDC in 1997 used transistors, usually the insulated-gate bipolar transistor (IGBT). Most of the VSC in HVDC systems has been built based on the two levels (half and full bridge) converter. The two level converters is the simplest type of three-phase voltage-source converter. Due to large harmonic contents (average 100% THD) in output line voltage and current those converters requires a large-size line filter so those cannot be used nowadays. Three level converters with space vector pulse width modulation (SV-PWM) with zero, three, four and seven state switching pattern has been introduced and developed in [5]. Due to high switching loses and high THD (average 65%) those converters became unfamiliar. Some special converters like application of new voltage dependent current order limiter (VDCOL) algorithm technique has been used for harmonic reduction also [6].

Multi-pulse converter like 6 pulses, 12 pulses, 18 pulses, 24 pulses, 36 pulses, 48 pulses, 60 pulses, and 84 pulses converters has been designed and analyzed their costs, switching losses, reliability [4,7–10]. Although, applying this technique THD can be reduced but those converters is very bulky (heavy), costly, complex in construction, large in size and needs more spaces to install [11]. Different multilevel converter topologies, such as the neutral point clamped (NPC), flying capacitor (FC) and modular multilevel converters has been considered for the design of an 11kV and 33 kV power system. The comparison is made in terms of the number of semiconductors, semiconductor cost and availability, THD, filter size, and control complexity of the converters. The investigation has shown that the 19 level MMC converter (THD is 4.48%) is the optimal choice for an 11 kV converter system and the 43 level topology (THD is 3.61%) is the optimal choice for a 33 kV inverter system. Both of the converters THD are lower than 5% which satisfied the IEEE and IEC standards [5]. In this paper, the overview of multipulse converter has been discussed in section 2, the over-modulation topology, and a complete proposed Multi-pulse over-modulation has been discussed in section 3. Performance analysis of proposed converter has been discussed in section 4, finally, comparison of different types of converter with proposed converter has been discussed in section 5.

Overview of Multipulse converter

In power system applications, ac–dc converters based on the concept of multipulses are used to reduce the harmonics in ac supply currents. For example, a 24 pulses converter is obtained by cascading two 12 pulse rectifier systems. The converters with more than 30 pulses are better to used practically.

The total harmonic distortion is defined by

$$THD = \frac{\sqrt{I_a^2 - I_{a1}^2}}{I_{a1}}$$

(1)

The line current THD is a function of the fundamental current Ia_1[12]. Consider p *is* the number of pulses for a given multipulse converter, and k as any integer, relationships can be established for the p-pulse converter. The number (N_c) of 6 pulse converters is represented as follows:

$$N_c = p/6$$

(2)

The transformer phase-shift angle $\propto$ required for the p pulse converter is calculated as follows:

$$\alpha = \frac{360}{p}$$

(3)

In harmonic analysis theory [13], the characteristic harmonic orders n of the current generated by a p pulse converter is

$$n = k * p \pm 1$$

(4)

So, for a 6-pulse rectifier, it only generates the harmonic orders 5^{th}, 7^{th}, 11^{th} etc.

Design of proposed multi-pulse over modulation converter

An overmodulation concept has been taken from [12]. Fig.1 described the proposed power converter. Here two phase shifted transformer is used to supply power to IGBT bridges on which one is in 0^0 and another one is $+15^0$. First pulse generator containing a three phase locked loop (PLL) circuit arrangement to produce 12 pulses on which each pulses are 30^0 shifted that injected at first 12 pulses converter. Second 12 pulse converters is feeded by two output of 2 level PWM generator on which first PWM generator input voltage is U_{ref1} and

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second PWM generator input voltage is U_{ref2}. PWM generator input reference voltage is a sinusoidal wave $U_{abc}= U_{ref1}$ can be found as shown in Fig.7 on which frequency is considered as 50, phase angle is 0^0, magnitude of modulation indexed varies between 0.8 to 1.15 (exact value is 2/sqrt(3)=1.1547) at step size is 0.05. This converter can be designed considering over modulation technique and used a super capacitor.

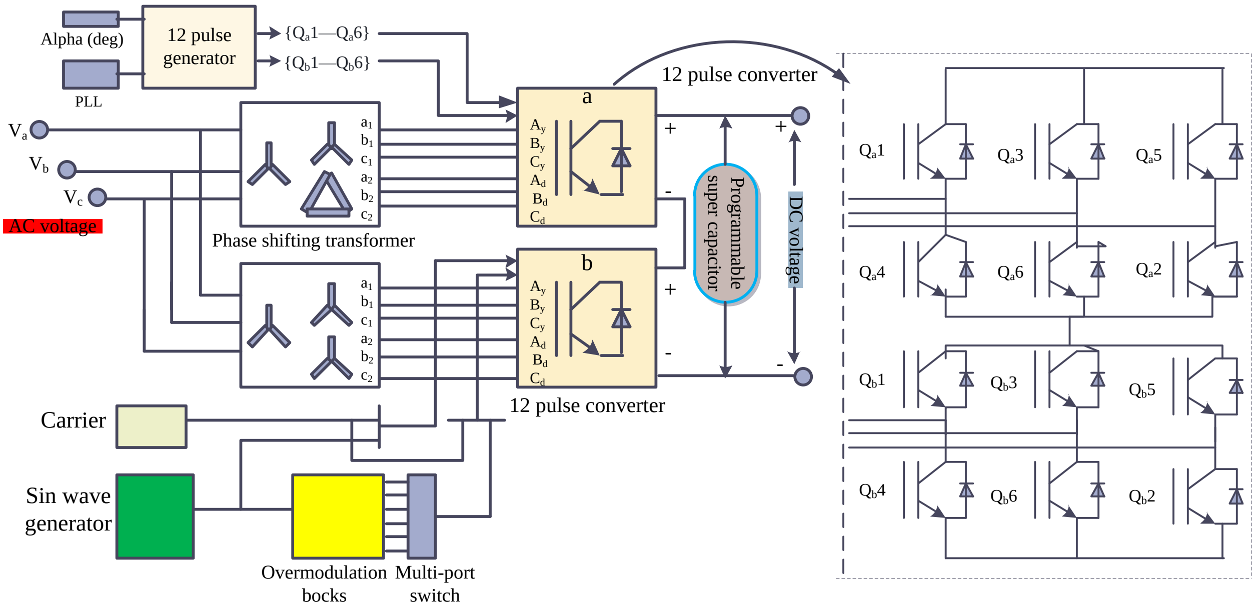

Fig. 1 Detailed network diagram of multi-pulse over-modulation power converter.

The proposed power converter final output dc voltage has been found by adding in series with first and second universal twelve pulses IGBT based converter output dc voltage. Then found two terminals one is positive and another one is negative terminal finally on which dc motor drives has been connected. A 100Mvar super capacitor has been connected on output side of proposed power converter to reduce output voltage ripple and THD. As two six pulses was combined with two types of over modulated signal which reduces different types of harmonic with two level PWM two six pulses to fire power converters IGBT so proposed power converter topology can be called as multi-pulse over-modulation converter. Here, the operating principle of multiport switches can be described as follows: 1=No over-modulation, 2=Over-modulation (Third Harmonic), 3=Over-modulation (Fifth Harmonic), 4=Over-modulation (Eleventh Harmonic), 5=Over-modulation (Thirteenth Harmonic), 6=Over-modulation (Flat Top), 7=Over-modulation (Min-Max). The Z_{DC} Impedance Measurement block at output side measures the impedance and phase with respect to frequency.

Description of over-modulation topology for harmonic minimization

In this topology, third harmonic or more triplen harmonic zero-sequence signal can be added to three-phase signal instead of using large size filter capacitor bank. The over modulation block as shown in Fig. 2 and Fig. 3 respectively that increases the linear region of a three-phase PWM generator by adding a third harmonic or more triplen harmonic zero-sequence signal like $V_0 = U_{ref2}$ to the three-phase original reference signal of U_{ref1}. This zero-sequence signal does not appear in the line-to-line voltages [16].

The over modulation block implements three over modulation techniques like third harmonic, flat top and min max over-modulation technique but it can be extended to reduce higher order of harmonics that described below:

Third Harmonic over modulation technique: In this technique the third-harmonic signal U_{ref2} subtracted from the original signal is calculated [12] in equation 5.

$$U_{ref\,2} = \frac{|U_{ref\,1}|}{6} \times \sin[3.(\omega t + \angle U)]$$
(5)

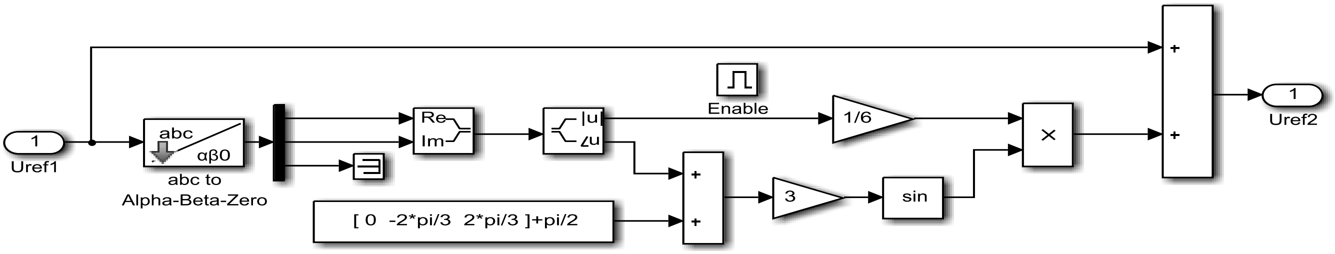

Fig. 2 Over-modulation block that reduces third harmonic distortion

Fifth Harmonic over modulation technique: In this technique the fifth-harmonic signal U_{ref2} subtracted from the original signal is calculated in equation 6.

$$U_{ref\,2} = \frac{|U_{ref\,1}|}{6} \times \sin[5.(\omega t + \angle U)]$$
(6)

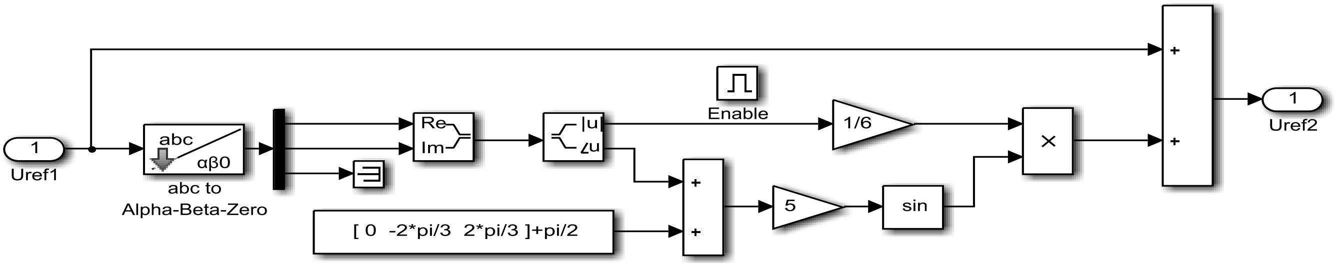

Fig. 3 Over-modulation block that reduces fifth harmonic distortion

Eleventh Harmonic over modulation technique: In this technique the eleventh-harmonic signal $V_0 = U_{ref2}$ subtracted from the original signal is calculated in equation 7.

$$U_{ref\,2} = \frac{|U_{ref\,1}|}{6} \times \sin[11.(\omega t + \angle U)]$$
(7)

Thirteenth Harmonic over modulation technique: In this technique the thirteenth-harmonic signal $V_0 = U_{ref2}$ subtracted from the original signal is calculated in equation 8.

$$U_{ref\,2} = \frac{|U_{ref\,1}|}{6} \times \sin[13.(\omega t + \angle U)]$$
(8)

Flat Top over-modulation technique: In this technique the portion of the three-phase input signal exceeding values +/−1 is computed. The three resulting signals are then summed and removed from the original signal Uref. The resulting modified signal Uref* is therefore a flat-top three-phase signal that contains zero-sequence triplen-harmonics. The block outputs a value between −1 and 1 as shown in Fig. 4.

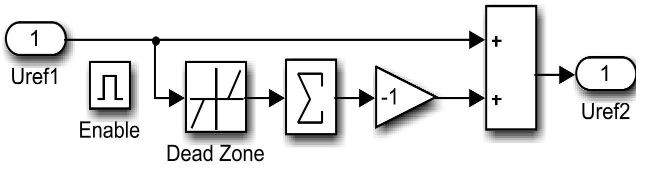

Fig.4 Flat Top Over-Modulation block

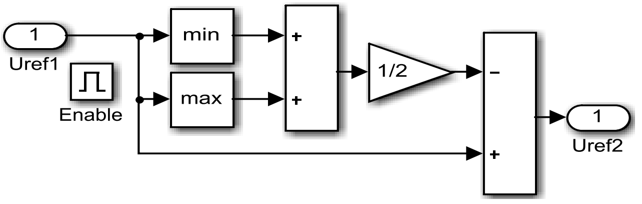

Fig.5 Min Max Over-Modulation block

Min-Max over-modulation technique: In this technique the minimum and maximum values of the three components of input signal Uref are summed and divided by two, and then subtracted from the input signal. The resulting modified signal Uref* also contains zero-sequence triplen-harmonics. The block outputs a value between −1 and 1 as shown in Fig. 5.

Description of super capacitor

Operating principle of super capacitor has been described in [17] and an ultra-capacitor has been discussed in [18]. Ultra capacitor is the latest capacitor in literature but it's cost is very high. So, in this research super capacitor has been used in proposed power converters.

Simulation Results

The proposed multi-pulse converter shown in Fig. 2 has been simulated in MATLAB/Simulink environment. This converter has been simulated at 33 kV, 132 kV. Evaluating performance at higher voltage it has been found that THD became 0.35% at 33 kV, 0.18% at 132 kV are shown in Fig. 6, Fig. 7 respectively. In this converter, IGBT has been used as switching devices in this converter and its standard and practical junction temperature with switching losses are shown in Fig. 8.

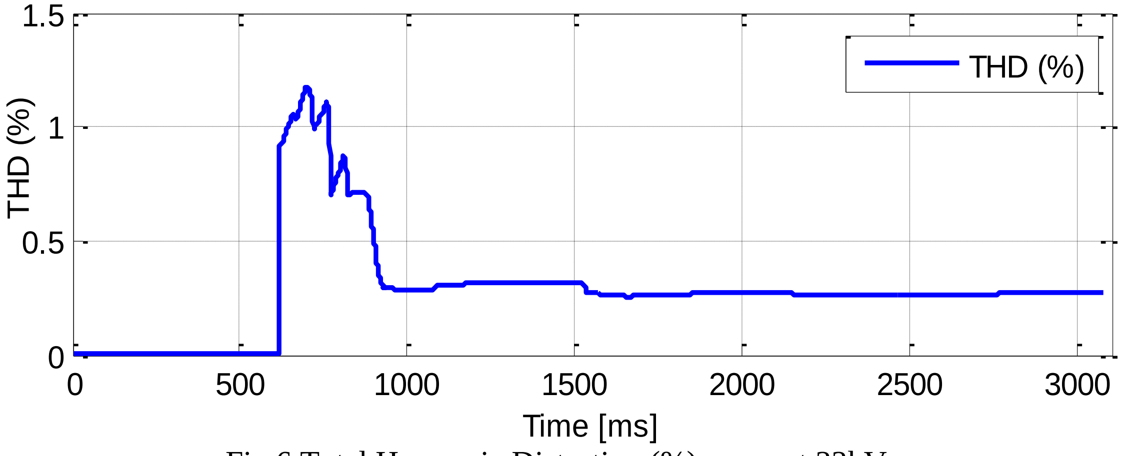

Fig.6 Total Harmonic Distortion (%) curve at 33kV.

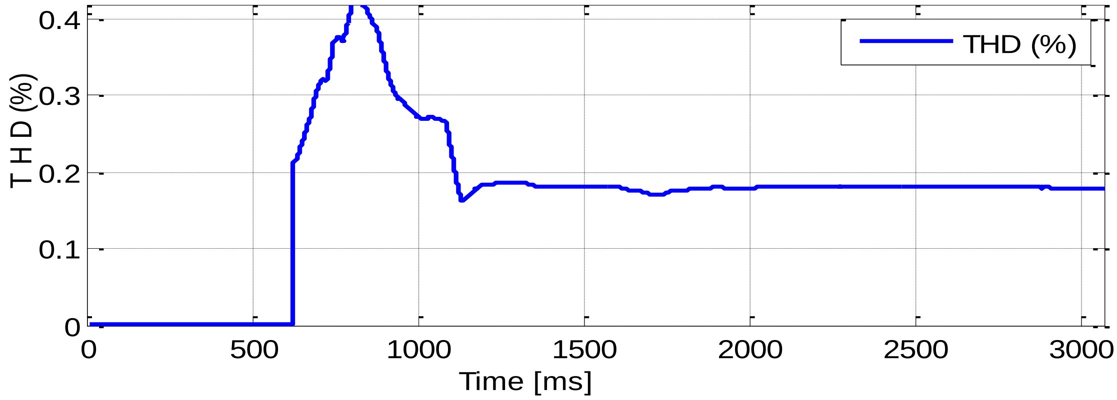

Fig. 7 Total Harmonic Distortion of proposed converter at 132 kV

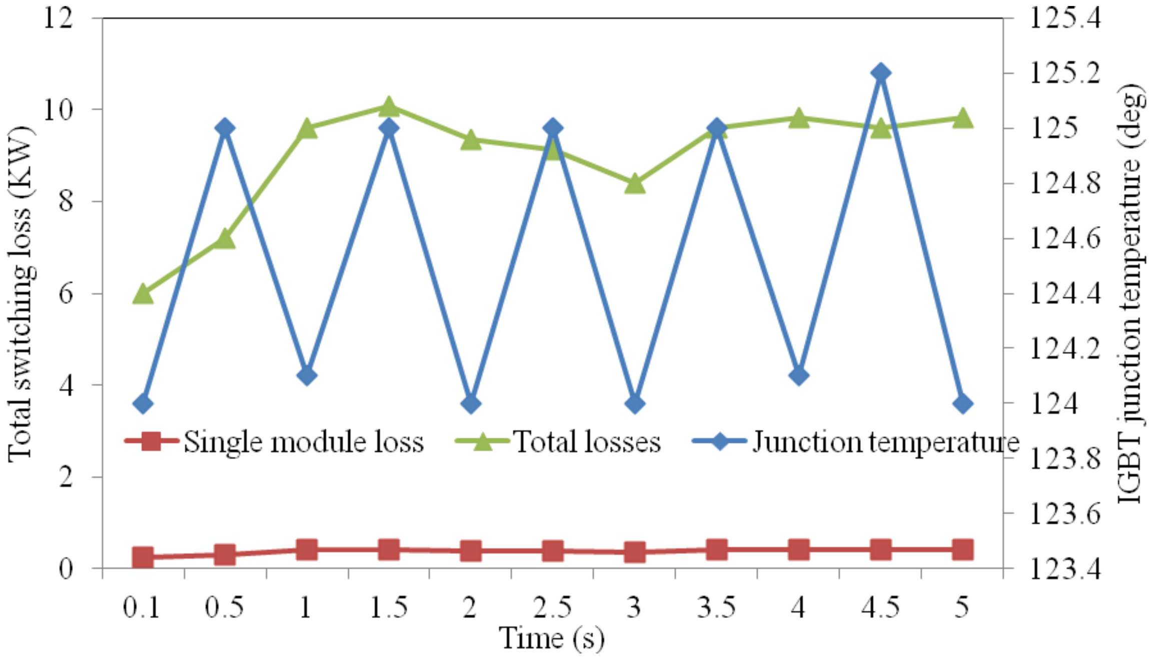

Fig. 8 IGBT's switching loss and junction temperature.

Analysis of research outcome

The proposed converter topology has been simulated at 33 kV to 132 kV. Because of large size capacitor banks, need large space to install, many transformer and IGBT requirements, and conventional multi-pulse converters are not suitable for power conversion nowadays. Multi-pulse over-modulation is a simplest type of robust power controller in which there is no use of input bulk filter capacitor bank only a 100Mvar super capacitor has been used at output side for harmonic reduction proposes. After simulating proposed model it is found that THD is very negligible at wide range of voltage and IGBT's switching losses is also negligible. In literature, it has been reviewed that if the level increase at multilevel or modular multilevel converter then the number of IGBT's and capacitor is also increased that means costs increase but capacitor lifetime, converter reliability is decreased besides that more space will be need to install those converter. For example, A 11 kV multilevel converter running at 21 level needs 120 no's of IGBT, 120 no's of capacitor and during 33kV operation at 55 level it needs 324 no's of IGBT, 324 no's of capacitor. Multi pulse converters like 48 pulses, 60 pulses, 84 pulses or more is not suitable. But in the proposed converter is a 24 pulses converter in which only one super capacitor has been used at output side and found better THD then other converters in literature.

DISCUSSION AND COMPARISON

In section 1 it has been discussed about different types of multi-pulse converter. It is investigated that if the level increase at multilevel or modular multilevel converter then the number of IGBT's and capacitor is also increased that means costs increase but capacitor lifetime, converter reliability is decreased besides that more space will be need to install those converter. Details comparison on graphical representation is shown in Table 1 and Fig. 9.

Table 1: Performance comparison of different multi pulse converter based on section 1

SI No.	Converter Name	Voltage Level	Name/No. of Level/ Pulse	THD (%)	No. of IGBT	Ref.
1	Single Phase	230V	Half Bridge	146	2	[5]
			Full Bridge	80	4	
			Space Vector PWM Technique	55		
2	Three Phase	440V to < 11kV	Zero State Switching Pattern	68	Not Mentioned	[5]
			Three State Switching Pattern	70		
			Four State Switching Pattern	65		
			Seven State Switching Pattern	66		
4	Multilevel Converter	11 kV	9 Level	9.8	48	[5]
			11 Level	9.5	60	
			15 Level	5.8	84	
			19 Level	4.8	108	
			21 Level	4.25	120	
		33 kV	15 Level	6.4	84	[5]
			23 Level	4.54	132	
			29 Level	4.12	168	
			43 Level	3.61	252	
			55 Level	3.47	324	
5	Multi-Pulse Converter	0.4kV to 33kV	6 Pulse	18	6	[4, 7-10]
			12 Pulse	15.22	12	
			18 Pulse	11	18	
			24 Pulse	7.38	24	
			36 Pulse	5	36	
			48 Pulse	3.8	48	
			60 Pulse	3.159	60	
			84 Pulse	2.358	84	

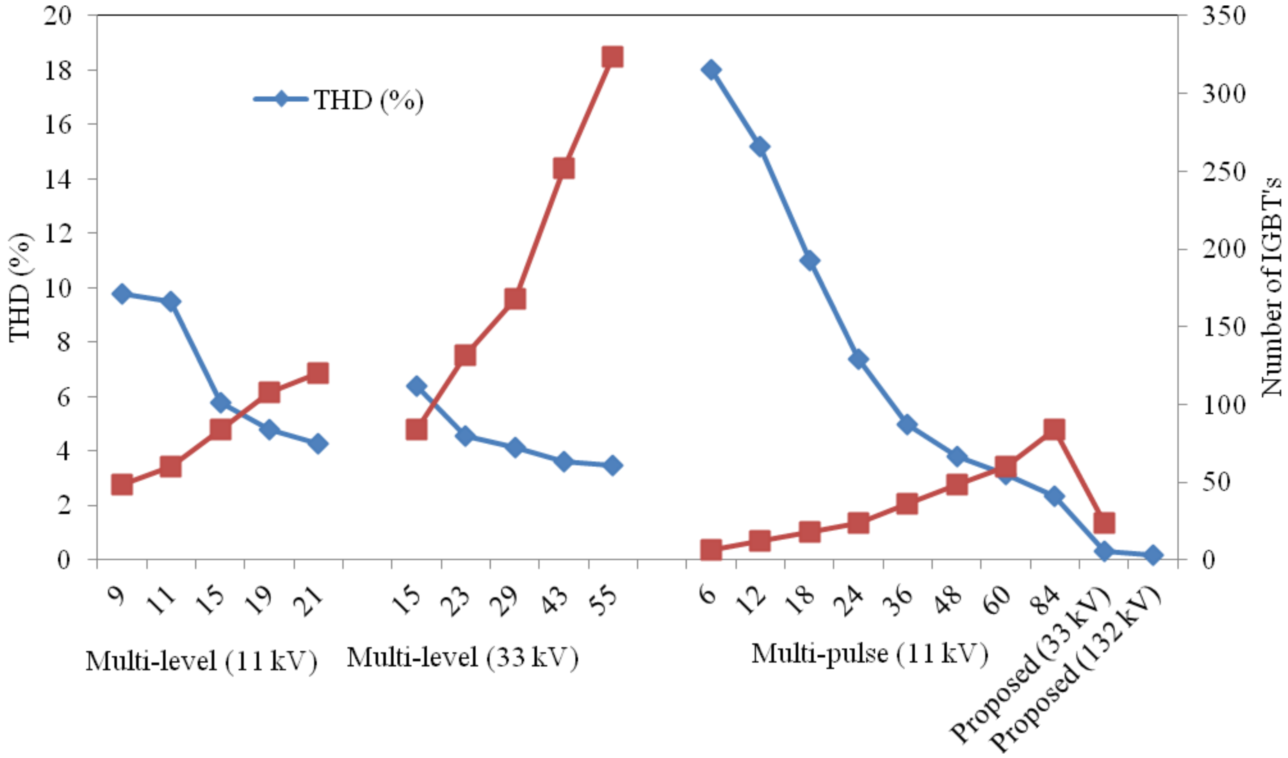

Fig. 9 Performance comparison of different converters with proposed converter [4] [5] [7-10]

CONCLUSION

In this research, different types of power converter performance have been compared. Different types of multi pulse converter, multilevel or other three phase converter has been analyzed and compared their performance specially compared their THD, output dc voltage and current ripple at output, reliability and cost of installation. A new technique has been implemented to design the proposed converter combining with multipulse and over-modulation topology here and analyzed its operation, cost, THD, output ripple etc. It has been investigated that using filter capacitor at input side of multi-pulse converter, THD and ripple decreases but power rating, cost of converter became higher including installation, maintenance complexity. After simulating and analyzing, it has been found that it is much better than any other multi-pulse or multilevel converter. Although some multi-pulse and multilevel converter's THD became lower then IEEE and IEC standard but the proposed power converter is very cheap, simple in construction, easy to install containing very lower THD, voltage and current ripple which also can operate at wide range of transmission voltage. So the proposed robust power converter is the best choice as ac to dc power conversion for medium voltage line and for industry purpose.

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Author's Biography

Md. Habibur Rahaman received the B.Sc & M.Sc. Engineering degree in Electrical and Electronic Engineering department from Rajshahi University of Engineering and Technology (RUET), Bangladesh in 2012 & 2017 respectively. He received Bangladesh President and Prime Minister's Gold Medal award for achieving outstanding result. He is now pursuing his M.Sc Engineering degree in Electrical and Electronic Engineering department on the same university. In 2012, He taught some private universities in Bangladesh as a lecturer. In May 2013, He joined as a lecturer in Electrical and Electronic Engineering department at Pabna University of Science and Technology (PUST), Pabna, In April 2014, He joined as an assistant engineer in Dhaka Electric Supply Co. Ltd (DESCO). Currently, He is working as an Assistant Professor in Electrical and Computer Engineering department at RUET, Bangladesh. His research field is power system stability and control, FACTS devices, Power converter and Inverter design, Renewable Energy. He published several papers on peer reviewed recognized journal and IEEE conference papers on this field [Email: habibruet1@gmail.com].

Professor Dr. Md. Rafiqul Islam Sheikh received the B.Sc. Engineering degree in Electrical and Electronic Engineering in 1990 from BIT, Rajshahi, M.Sc. Engineering on same department in 2001 from BIT Rajshahi and Doctor of Engineering in EEE 2010 Kitami Institute of Technology (KIT), Japan. From 1994-1999, He served as a lecturer, From 1999-2006, He served as a Assistant professor , From 2006-2011, He served as a Associate professor, Since 2011, He is working as a professor of EEE department at Rajshahi University of Engineering and Technology (RUET), Bangladesh. Besides this he served as an additional duty as syndicate member, registrar, member, CASR, Dean, head of EEE, ETE departments. Presently he is working as Vice-Chancellor of this University. He organized IEEE international conference named ICECTE and ICEEE conference in RUET, Bangladesh. He is an editor/reviewer of IEEE Transection on Power and Energy Society, IEE/IET Transection on Renewable Power generation, Int. journal of Renewable and Sustainable Energy (Elsevier), and European transection on Electrical Power, Indonesian Journal of Electrical Engineering, and Some journal on Springer or Elsevier covering power system /renewable energy. He supervised at least five hundred of undergraduate level, thirty Master's level and four PhD level of research work. He received best paper award from ICEMS international conference, Tokyo, Japan and IEB Electrical Engineering division on 2002, Bangladesh. He published total number of four text books, at least fifty papers on peer reviewed recognized journal and One hundred fifty papers on different international/IEEE conferences organized in national and International level. His field of research interest on Smart grid, Renewable (Wind, Wave and Solar) Energy , FACTS and Energy storage devices, Stability augmentation techniques, Power Converter, Inverter design, Load frequency control [Email: ris_ruet@yahoo.com].

Shah Md. Rezwanul Haque Shawon received the B.Sc Engineering degree in Electrical and Electronic Engineering department from Rajshahi University of Engineering and Technology (RUET), Bangladesh in 2013. Currently, He is working as an Assistant Engineer in Dhaka Power Distribution Company ltd., Bangladesh. His research field is power system stability and control, FACTS devices, Power converter and Inverter design, Renewable Energy. He published another paper on peer reviewed recognized journal on this field [Email: shawon.ruet08@gmail.com].