ENHANCEMENT OF POWER QUALITY IN DISTRIBUTION SYSTEM USING HYBRID SEVEN LEVEL H-BRIDGE INVERTER BASED DPFC

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Abstract - *According to enrichment of electricity demand and enhanced the many numbers of non-linear loads in power grids needing an adept electrical power. In this article, improvement of power quality in distribution systems using hybrid seven level H-bridge inverter (HSLHBI) structure based distributed power flow controller (DPFC) is developed. A DPFC is one of the contemporary FACTS devices and its structure is similar to the unified power flow controller (UPFC). In spite of UPFC, in DPFC the common DC-link capacitor between the shunt and series converters is eliminated and the three-phase serial converter is divided to many single-phase series distributed converters through transmission line. This finally enables the DPFC to fully control all power system parameters. DPFC increases the reliability of the device and reduces its cost simultaneously. The HSLHBI is acts as voltage source converter (VSC). The MLIs are used for high power and high voltage applications. The HSLHBI output voltage produces a staircase output waveform, this waveform look like a sinusoidal waveform leads to reduction in Harmonics. The fuzzy logic controller (FLC), proportional-integral (PI) controller and multi-carrier sinusoidal PWM technique are designed for DPFC to controlling its parameters. The performance of the designed DPFC for distribution system is verified by construing the MATLAB/Simulink model. The results are presented to show the performance of the designed DPFC in distribution system with FLC.*

Index Terms - *FACTS, Power Quality, Multi Level Inverters, Intelligent Controller, Distributed Power Flow Controller.*

1. INTRODUCTION

An electrical fault in a power system network is almost impossible to avoid and it causes the electrical power quality issue has been the main concern of the power companies [1]. Main causes of power quality disturbances may be due to insulation failure, tree falling, bird's contact, lightning or a fault on an adjacent feeder [2]. The power quality disturbances may be in the form of voltage sag, swells, voltage imbalances, transients, interruptions and harmonics, which can affect the performance of electrical apparatus to the industries [3-4]. Out of these disturbances harmonics, voltage sags and swells are the major problems, because which can cause the malfunctioning or tripping the equipment [5-6]. Another important PQ problem is a poor power factor to the incoming utility. This is caused by the proliferation of induction motors, thyristor rectifiers and other nonlinear power electronic loads such as variable speed AC drives [7]. These undesirable voltage sags and poor power factor can be mitigated by connecting controlled devices either in series or in parallel to the load [8]. A variety of custom power devices are developed and successfully implemented to compensate various power quality problems in a distributed system [9-11].

These custom power devices are classified as the Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR) and Distributed Power flow controller (DPFC). A DVR is used in medium-to-low voltage levels to improve customer power quality [12]. The DSTATCOM is a shunt-connected device, which takes care of the power quality problems in the currents [15]. It consists of a DC capacitor, three-phase inverter (IGBT, thyristor) module, AC filter, coupling transformer and a control strategy [16-17]. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input DC voltage into a three-phase output voltage at the fundamental frequency. Inverter circuit is the heart of DSTATCOM and various inverter topologies can be utilized in applications of DSTATCOM such as: cascaded H-bridge, neutral point clamped and flying capacitor [18]. In particular, among these topologies, cascaded H-bridge inverters are being widely used because of their modularity and simplicity [19]. Various modulation methods can be applied to cascaded H-bridge inverters. Cascaded H-bridge inverters can also increase the number of output voltage levels easily by increasing the number of H-bridges. Fuzzy logic controller (FLC) for speed controller of induction motor drive through A.C chopper has been reported [20]. From the article, the performance of the motor parameter with FLC has well. Sliding mode controller (SMC), proportional integral (PI) controller, and SMC plus FLC for Luo-Converters has been presented [21-23]. Among these controllers, SMC plus PI controller has performed well for converters.

The DPFC is a new FACTS device, which its structure is similar to the unified power flow controller (UPFC) [13]. The main advantage offered by DPFC is eliminating the huge DC-link and instate using 3rd-harmonic current to active power exchange [14]. From the above pointed out problems are solved by designed hybrid seven level H-bridge inverter (HSLHBI) based DPFC in distribution system with FLC.

Therefore, in this article is to propose a HSLHBI based DPFC in distribution system with FLC. The performance of the designed is validated at different operating conditions using MATLAB/Simulink software platform.

2. DPFC PRINCIPLE AND MODELLING

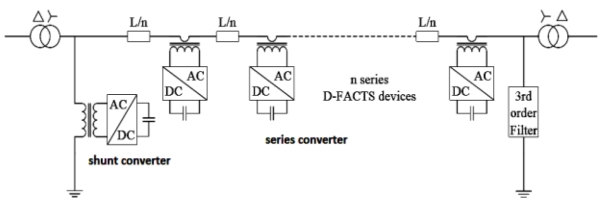


Fig. 1 Distributed power flow controller.

The several individual converters are combined together to form the structure of DPFC is depicting in Fig. 1 [6]. The converters linked in series to transmission line are known as series converters. The function of it has injected the controllable voltage at the fundamental frequency that can lead the power flow control in the transmission line. The converter arranged between the transmission line and ground is called as shunt converter. The main function of shunt converter is to supply the real power needed by the series converter and also, to compensate the reactive power to the grid. While there is no D.C link capacitor linking the shunt and the series converter, the real power is replaced by harmonics and through the ac network. The principle is depended on term of real power, which is product of the average values of the voltage and the current. At the same time, these voltage and current contains fundamental and harmonics. As the integrals of entire cross product of terms with various frequencies are null, the real power can be written as equation (1) [6]

$$P=\sum_{n=1}^{\infty} V_n I_n \cos\varphi_n \qquad (1)$$

Where,

Φ_n – phase angle between the voltage and the current of the n^{th} harmonics.

From equation (1) explains that real powers at various frequencies are separated from each other and its voltage and current in one frequency has no influence on other frequency components. The 3^{rd} order harmonic is select here to exchange the real power in the DPFC, because it can be easily filtered with help of star (Y)-delta (D) transformers.

A. *Steady State Analysis of DPFC*

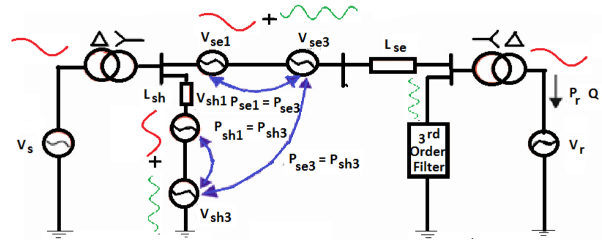


Fig. 2 Simplified equivalent circuit of DPFC in two bus power system.

Every converter is replaced with regulate the voltage sources in series with impedance, and produces the voltage at two various frequencies. From the Fig.2, the DPFC is located in a two bus power system with the sending end and receiving end voltages V_s and V_r, correspondingly.

The transmission line is represented with inductance 'L' and line current 'I'. The injected voltage of series converters are V_{se1} and V_{se3} at fundamental and 3^{rd} order harmonic frequency components, correspondingly. The shunt converter is connected to the sending end bus via. inductor L_{sh} and makes the voltages of V_{sh1} and V_{sh3} and also, the injected current of the shunt converter is represented by I_{sh}. The P_r and Q_r are receiving end real and reactive power flow and it can be engraved as equation (2)

$$P_r + jQ_r = V_r * I_1^* = V_r \left(\frac{V_s - V_r - V_{se1}}{jX_1}\right)^* \qquad (2)$$

Where,

$X_1 = \omega_1 L$ – indicates the line impedance at the fundamental frequency.

The power flow without DPFC compensation P_{ro} and Q_{ro} can be written as

$$P_{ro} + jQ_{ro} = V_r \left(\frac{V_s - V_r}{jX_1}\right)^* \qquad (3)$$

The power flow control range of the designed FACTS device can be written as equation (4)

$$P_{rc} + jQ_{rc} = V_r \frac{V_{se1}^*}{jX_1} \qquad (4)$$

Where,

P_{rc} and Q_{rc} – indicates the real and reactive power limit range of designed DPFC.

At fixed voltage at the receiving end and the transmission line impedance, the DPFC power flow control range is directly proportional to the peak voltage of the series converter, at the same time V_{se1}* shall be rotated over 360^0, so regulating the real and the complex power transfer via. the transmission line. Using the equations (2) and (3), the control ability of the DPFC is expressed as (5)

$$\left(P_r - P_{ro}\right)^2 + j\left(Q_r - Q_{ro}\right)^2 = \left(\frac{V\left|V_{se1}\right|}{X_1}\right)^2 \qquad (5)$$

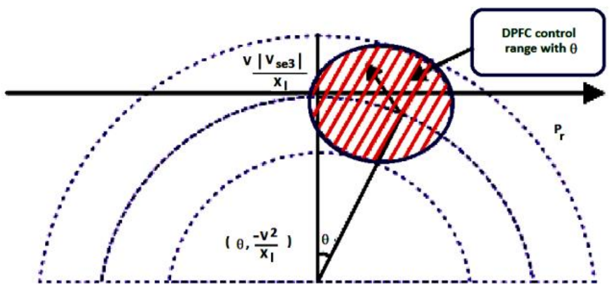


Fig. 3 DPFC real and reactive power control range using transmission angel.

The DPFC with its control range is represented the complex PQ plane in the form of circle as shown in Fig. 3. From this figure, it is clearly focused the locus of the power flow control without presence of the DPFC compensation f(P_{ro} , Q_{ro}) is a circle with radius of $|V^2|/|X_1|$ about its mid point (descried with coordinates P=0 and Q=$|V^2|/|X_1|$. Every point of this round circle offers P_{ro} and Q_{ro} ranges of the un-compensated system at the related θ. The possible boundary region for P_r and Q_r is arrived from a entire rotation of V_{se1} with their peak amplitude as mentioned in the Fig. 3. The V_{se1} at fundamental frequency is expressed by

$$V_{se1}=\frac{\left(S_r\text{-}S_{ro}\right)jX_1}{V_r} \tag{6}$$

Where,

S_r and S_{ro} – indicates the real power in compensated network and reactive power in non-compensated network.

In the direction of inject a 360◦ rotatable voltage, a real and complex power by the fundamental frequency has to be supplied to the series converter, even though the complex power is nearby offered to the series converter and the necessity of real power is supplied by the shunt converter at the 3rd harmonic frequency component via. the transmission line, and it is expressed as (7)

$$P_{se1}=\frac{X_1}{\left|V_r\right|^2}\left|S_r\right|\left|S_{ro}\right|\sin(\varphi_{ro}\text{-}\varphi_r) \tag{7}$$

Where,

φ_{ro} – indicates the power angle at the receiving end of the non-compensated system.

φ_r – indicates the power angle at the receiving end of the system with DPFC.

III. Control Methodology For DPFC

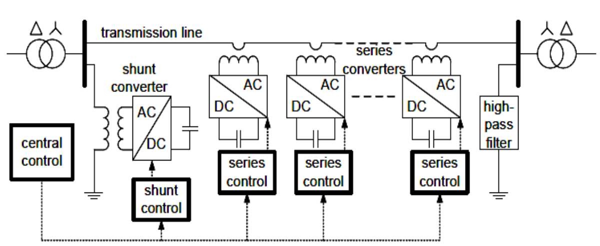


Fig. 4 Control block diagram of DPFC.

This section presents the controllers methodology for DPFC. Generally, the controllers for DPFC has three namely central control, shunt control and series control, rspectively. It is illustrated in Fig.4 [5-6].

A. Central Control

The central control unit (CCU) is produced reference signals and its generated reference signals are applied to both DPFC converters tenuously with help of the PLC communication technique. As per the system needs, the CCU makes the reference signal of V_{se1ref} for series control block and reference signal of q-component of $I_{sh1qref}$ for shunt control block at fundamental frequency.

B. Series Control

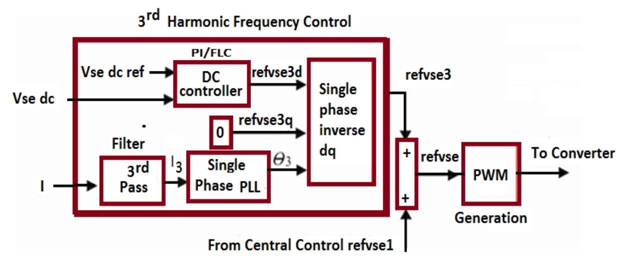


Fig. 5 Control block diagram of series converter.

C. Shunt Control

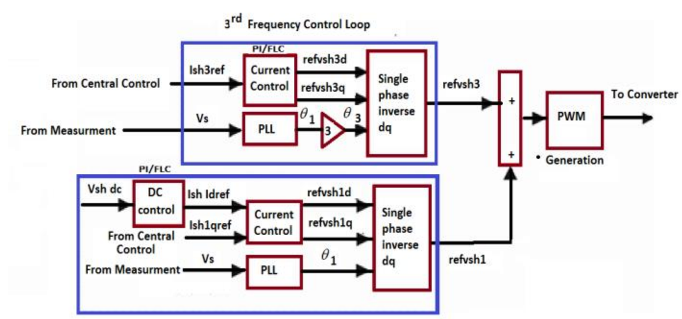


Fig. 6 Control block diagram of shunt converter.

The main function of this controller and its location were already discussed in the precious sections. The main control block of shunt converter of DPFC (see Fig. 6) has two namely fundamental frequency control loop (FFCL) and 3rd order frequency control loop (3rdFCL). Again, the FFCL consists of DC voltage control and current control. In FFCL, the bus voltage is chosen as rotation reference frame. The CCU and DC control is generated by the q component current and the d component reference signal. The current control is produces the desired control to the single-phase inverse parks transformation using PI controller and FLC. The 3rdFCL is generated the 3rd order harmonic component of shunt converter of DPFC, which is synchronized with bus voltage at fundamental frequency. A PLL is applied to follow the bus voltage frequency and the output signal which are multiplied with constant "3" to produce the decoupled double synchronous rotation reference frame for the 3rd harmonic current. The similar current control (PI control and FLC) is applied for 3rd harmonic frequency components. Both the frequency control loops are combined to offer the reference signal for shunt converter of DPFC to maintain the DC link voltage constant and constant 3rd harmonic current injected into the grid. Series converter rules and membership functions were applied for shunt converter also.

3. HYBRID SEVEN LEVEL H-BRIDGE INVERTER

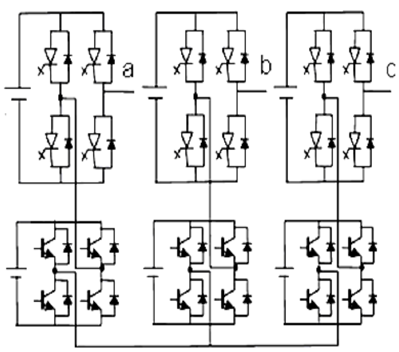


Fig. 1. Circuit diagram of Hybrid Seven Level H- Bridge Inverter.

Table 1. Switching Pattern between a and b of inverters

Command Signal (Desired Output)	GTO Inverter	IGBT Inverter
Between -400V and -300V	-300V	0 ↔ -100V
Between -300V and -100V	-300V	0 ↔ 100V
Between -100V and -0V	0.0 V	0 ↔ -100V
Between 0V and 100V	0.0 kV	0 ↔ 100V
Between 100V and 300V	300V	0 ↔ -100V
Between 300V and 400V	300V	0 ↔ 100 V

Generally, the voltage jamming ability of high speed switching devices namely Insulated Gate Bipolar Transistors (IGBT), and Gate Commutated Thyristors (IGCT) is obtained to be limited [16]. With a modular H-bridge topology [16], apprehension of MLIs with a hybrid approach involving IGBTs and IGCTs operating in synergism is achievable. Hybrid MLI topologies have been reported for high power applications [17-18]. The topology addressed in [18] combines a Gate Turn-Off (GTO) thyristor based inverter, and an IGBT inverter, similar to that Fig.1. It can be validated that with a combination of 300V and 100V DC bus voltages in this topology, it is achievable to produce stepped waveforms with seven voltage levels via. -400V, -300V, -100V, 0, 100V, 300V, 400V at the every phase leg output of the designed MLI. From the Fig. 1, the higher voltage levels (±300V) are synthesized using GTO inverters while lower voltage levels (±100V) are synthesized with IGBT inverters. However, it is well known that switching ability of GTO thyristors is restricted at high frequencies [17]. Therefore, a hybrid modulation strategy that incorporates stepped synthesis in combination with changeable pulse width of the consecutive steps is offered. The switching pattern of the designed MLI at every state is addressed in Table 1 and its corresponding simulated responses are illustrated in Fig.2.

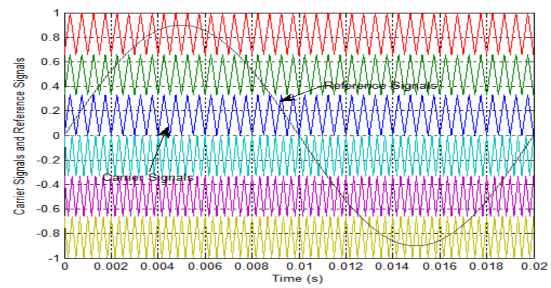


Fig. 2. Multi-carrier sinusoidal PWM technique for Hybrid Seven Level H-Bridge Inverter.

4. DESIGN OF FLC

The FLC is designed for controlling the parameters of DPFC system such as D.C link capacitor voltage, series converter voltage and shunt current. The design of FLC is choosing the right inputs and outputs and designing each of the four components of the FLC shown in Fig. 3. The FLC is activated only in the transient period and once the value of the dc link voltage settles down, the controller gains are kept fixed at the constant state value [20, 23].

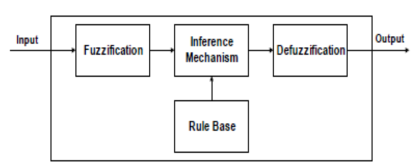


Fig.3 FLC for DPFC.

A. Fuzzification

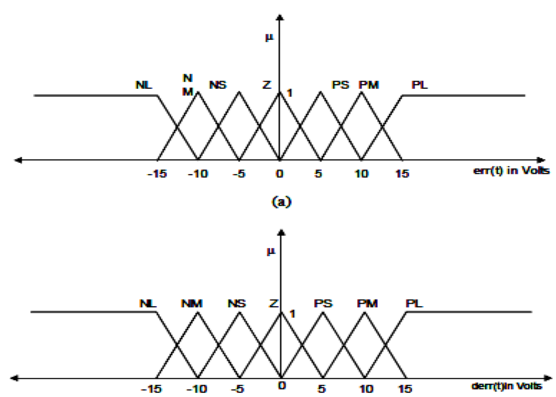


Fig.4 Membership functions for error input. (b) Membership functions for change in error input.

The fuzzification interface modifies the inputs to a form in which they can be used by the inference mechanism. It takes in the crisp input signals and assigns a membership value to the membership function under whose range the input signal falls. Typical input membership functions are triangular trapezoidal or exponential. Seven triangular membership functions (MFs) have been chosen: NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive Large) for both error (err) and change in error (derr) . The input MFs are shown in Fig. 4. The tuning of the input MFs is done based on the system characteristics. Each MF has a membership value belonging to [-15 15]. It can be observed that for any value of error or change in error, either one or two MFs will be energetic for each.

B. Inference Mechanism

The two main operations of the inference mechanism are:

- Based on the active MFs in error and the change in error inputs, the rules that utilize for the current state are calculated.
- Once the rules which are on are evaluated, the faith of the control exploit is ascertaining from the membership values. This is called as premise quantification. Therefore, at the end of this process, it have a set of rules each with a certain certainty of being applicable. The database containing these rules is present in the rule base from which the control action is found. The rule base will be discussed in the next section. The terms PL and PM are the MFs for error and for change in error respectively.

C. The Rule Base

Designing the rule base is a major role in designing the FLC. It is significant to realize how the rule base has been derived. The points involved in the design of the rule base is mainly depends on error of the system response. Table 2 gives a rule base matrix for designed DPFC.

Table 2. Rule base for designed DPFC

Ce/e	NL	NM	NS	Z	PS	PM	PL
NL	PL	PM	NS	NS	Z	Z	Z
NM	NS	Z	Z	Z	Z	Z	NL
NS	Z	NM	NS	PL	NM	Z	Z
Z	Z	Z	Z	Z	PS	PM	PL
PS	NM	NS	PS	PM	PL	NL	Z
PM	PS	PM	PL	NM	NS	PS	Z
PL	PM	PL	NM	Z	Z	PM	NS

D. Defuzzification

The inference mechanism provides us with a set of rules each with a $\mu_{premise}$. The defuzzification mechanism considers these rules and their respective $\mu_{premise}$ values, combines their effect and comes up with a crisp, numerical output. Thus, the fuzzy control action is transformed to a non fuzzy control action. The 'center of gravity' method has been applied for this DPFC. However, the resultant crisp output of this method is sensitive to the entire active fuzzy outputs of the inference mechanism.

5. SIMULATION RESULTS

In this part FLC based DPFC with HSLHBI or voltage source converters (VSC) is discussed. The main aim of intelligent power flow controller will be increased the power quality of the transmission line in the power system. The MATLAB/Simulink model of the designed system is shown in Fig. 5 and its specifications are listed in Table 3.

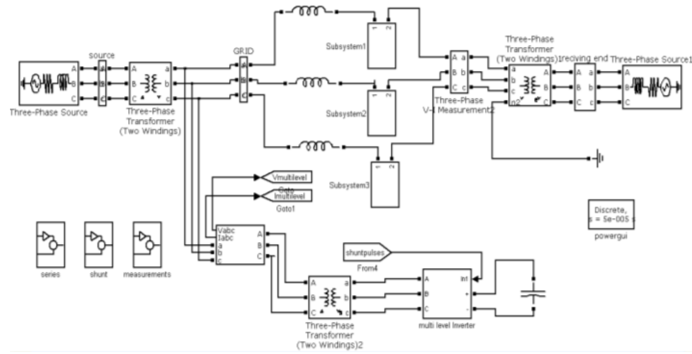
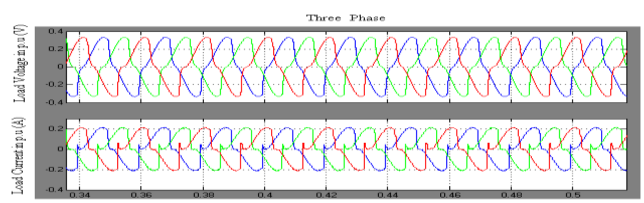


Fig. 5 MATLAB/Simulink model of FLC based DPFC for distribution system.

Table 3. Specifications of DPFC in distribution system

Sl. No.	Parameters Name	Values
	Shunt Converter	
1	Three Phase Shunt Transformer Details Winding 1 (star)	735KVA
2	Winding 2 (Delta)	315KVA
3	D.C link capacitors	3000 µF
4	D.C link voltage	300
	Series Converter	
1	Single Phase Series Transformer Details Winding 1 (delta)	1KV
2	Winding 2 (star)	100kV
3	Switching frequency	6kHz



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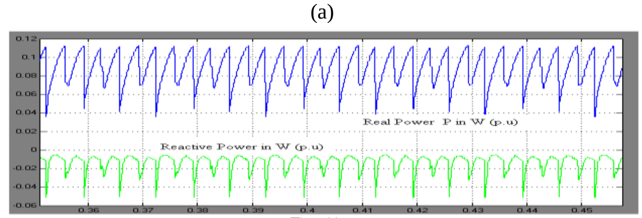
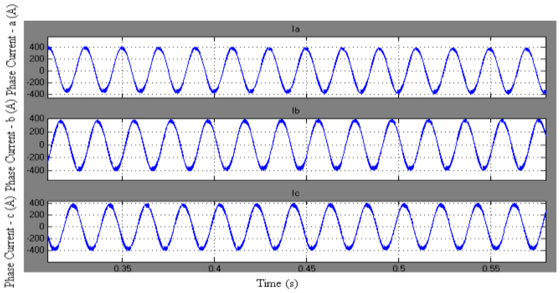


(b)

Fig. 6 Performance of the power system without DPFC in p.u values, (a). Three phase load voltages and currents and (b) Three phase load real and reactive power.



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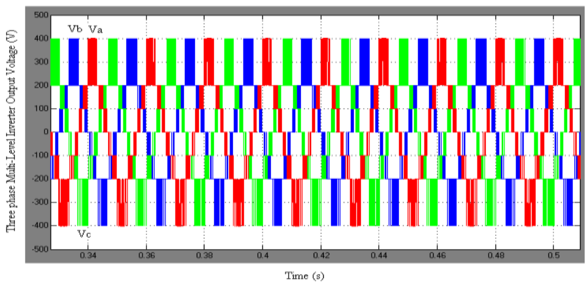

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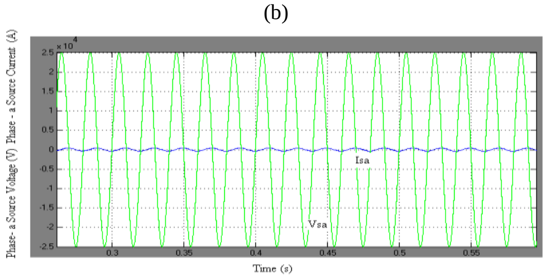

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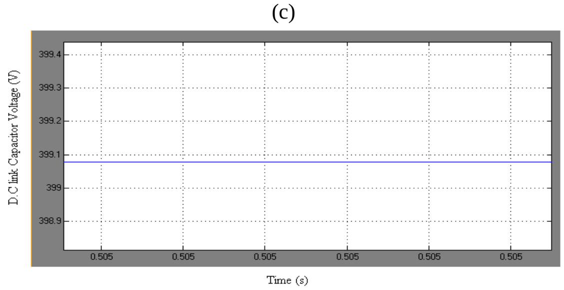

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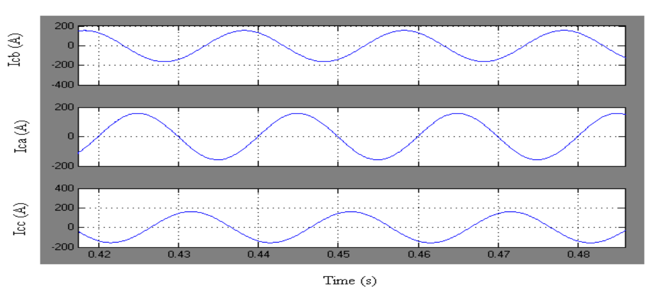
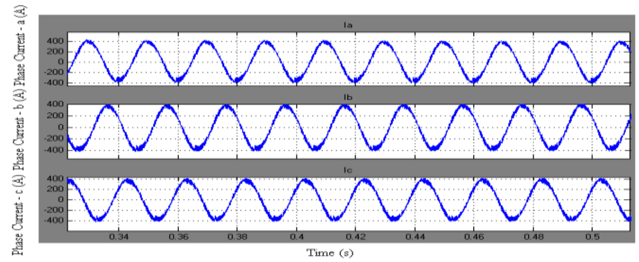


(e)

Fig. 7 Performance of the PI controller based seven level VSC DPFC for power system, (a). Three phase source current, (b). Three phase output voltage of ML VSC, (c). Source voltage and current, (d) D.C link capacitor voltage and (e) Three phase compensation current.



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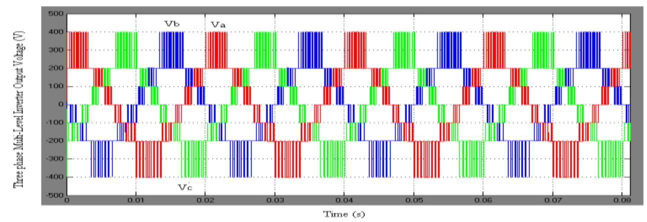

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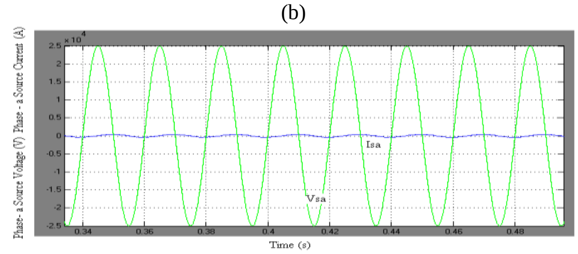

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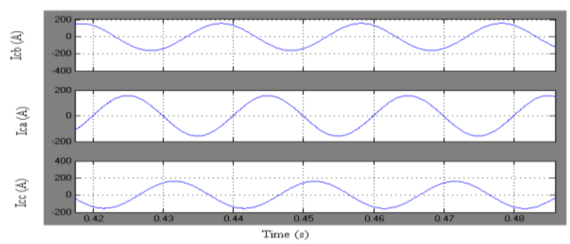

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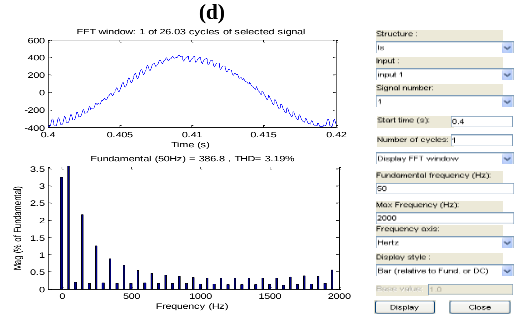
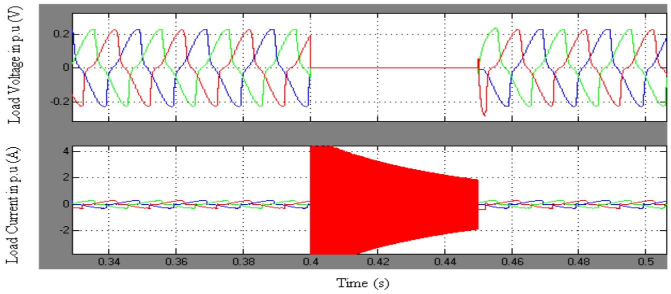


(e)

Fig. 8 Performance of the FLC based seven level VSC DPFC for power system, (a). Three phase source current, (b). Three phase output voltage of ML VSC, (c). Source voltage and current, (d) Three phase compensation current and (e) Source current THD.

Fig. 6 show the simulated load voltages, currents, real and reactive power results of designed power system without DPFC. It is evident that the designed power system without DPFC has contains more harmonics in the its load voltages and currents. Also, the real power of 20kW and reactive power of 4kW for the power system without DPFC. Fig. 7 show the simulated performance parameters of HSLHBI DPFC for power system using classical PI controller. From these results, it is clearly found that designed system with PI controller has produced good performance such as source current THD of 3.31%, ripple of D.C link capacitor voltage ML VSC of 0.0001V, good voltage regulation, source current and voltage should be in phase and seven level output of VSC without voltage stress.



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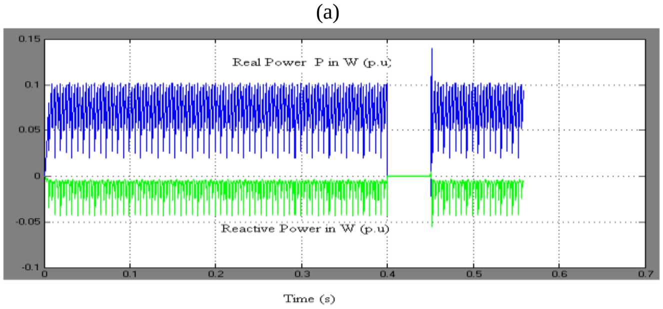

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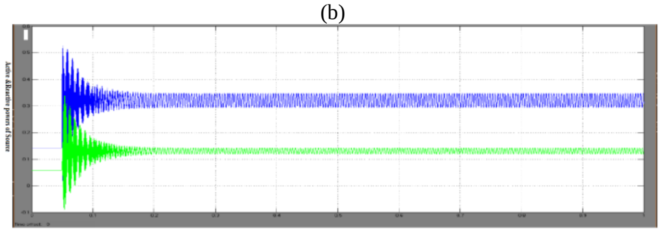

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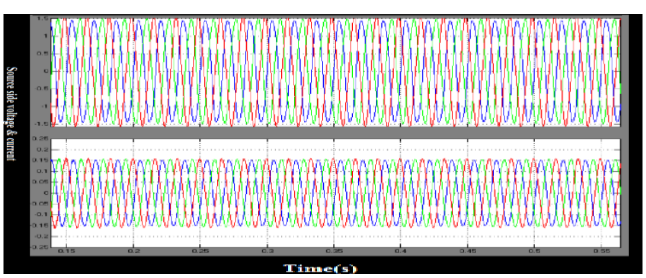

(d)

Fig. 9 Performance of power system in three phase fault in p.u values, (a). Three phase load voltage and current, (b). real and reactive power in load side without FLC based seven level VSC DPFC, (c). real and reactive power in load side with seven level VSC DPFC and (d) Three phase source current and voltage.

Fig. 8 show the simulated performance factors of seven level VSC DPFC for power system with FLC. It is clearly observed that designed system with FLC has maked good performance such as source current THD of 3.1%, ripple of D.C link capacitor voltage ML VSC of 0.00001V, profcient voltage regulation, source current and voltage should be in phase and no voltage stress of seven level output of VSC.

Fig. 9 show the simulated performance parameters of power system in three phas faulty conditons with/without designed DPFC model. It is clearly obtained that the power system with designed DPFC has performed well during the three phas fault conditon.

6. CONCLUSION

In this article FLC based HSLHBI DPFC for distribution system has been investigated in MATLAB/Simulink software platform. The designed DPFC has proficiently regulated active and reactive power flow in the power system. The results of source current THD value of the designed power system with developed DPFC have produced very less. Here, the series converter of the DPFC employs the D-FACTS concept, which uses multiple converters instead of one large-size converter. The reliability of the DPFC is greatly increased because of the redundancy of the series converters. The total cost of the DPFC is also much lower than the UPFC, because no high-voltage isolation is required at the series converter part and the rating of the components are low. Also results show the valid improvement in power quality with designed seven level VSC DPFC.

7. REFERENCES

[1] K Chandrasekaran, P A Vengkatachalam, Mohd Noh Karsiti and K S Rama Rao, “Mitigation of Power Quality Disturbances”, Journal of Theoretical and Applied Information Technology, Vol.8, No.2, pp.105-116, 2009.

[2] Priyanka Chhabra, “Study of Different Methods for Enhancing Power Quality Problems”, International Journal of Current Engineering and Technology, Vol.3, No.2, pp.403-410, 2013.

[3] Bindeshwar Singh, Indresh Yadav and Dilip Kumar, “Mitigation of Power Quality Problems Using FACTS Controllers in an Integrated Power System Environment: A Comprehensive Survey”, International Journal of Computer Science and Artificial Intelligence, Vol.1, No.1, pp.1-12, 2011.

[4] J Ganesh Prasad Reddy and K Ramesh Reddy, “Power Quality Improvement Using Neural Network Controller Based Cascaded H-Bridge Multilevel Inverter Type D-STATCOM”, International Conference on Computer Communication and Informatics, 2012.

[5] Lin Xu and Yang Han, “Effective Controller Design for the Cascaded H-bridge Multilevel DSTATCOM for Reactive Compensation in Distribution Utilities”, Elektrotehniski Vestnik, Vol.78, No.4, pp.229-235, 2011.

[6] Subhro Paul,SujaySarkar, SurojitSarkar, Pradip Kumar Saha and Gautam Kumar Panda, "By Dynamic Voltage Restorer for Power Quality Improvement", International Journal of Engineering And Computer Science, Vol.2, No.1, pp.234-239, 2013.

[7] Aarti Rai, "Enhancement of Voltage Stability & reactive Power Control of Distribution System Using Facts Devices", International Journal of Scientific Research Engineering & Technology, Vol.1, No.9, pp.1-5, 2012.

[8] S Suresh, N Devarajan, M Geetha and V Rajasekaran , "Investigation on D-STATCOM Operation for Power Quality Improvement in a Three Phase Three Wire Distribution System with a New Control Strategy", Control Theory and Informatics, Vol.1, No.2, 2011.

[9] D Mohan Reddy and T Gowrimanohar, "Cascaded Multilevel Inverter Based DSTATCOM for Restructured Power Systems to Compensate the Reactive Power and Harmonics Using Shift Carrier Techniques", IOSR Journal of Electrical and Electronics Engineering, Vol.4, No.3, pp.39-48, 2013.

[10] Shailesh M Deshmukh and Bharti Dewani, "Overview of Dynamic Voltage Restorer (DVR) for Power Quality Improvement", International Journal of Engineering Research and Applications, Vol.2, No.6, pp.1372-1377, 2012.

[11] A Boudaghi and B Tousi, "DSTATCOM Based Five-Level Cascade H-Bridge Multilevel Inverter for Power Quality Improvement", International Journal on Technical and Physical Problems of Engineering, Vol.4, No.3, pp.110-117, 2012.

[12] Veeraiah Kumbha and N Sumathi, "Power quality improvement of Distribution lines using DSTATCOM under various loading conditions", International Journal of Modern Engineering Research, Vol.2, No.5, pp-3451-3457, 2012.

[13] Kiran Kumar Pinapatruni and Krishna Mohan, "DQ based Control of DSTATCOM for Power Quality Improvement", International Journal of Electrical, Electronics and Communication Engineering, Vol.2, No.5, pp.207-227, 2012.

[14] Tapajit Ghosh, "The Role of DSTATCOM for Power Quality Improvement In Distribution Networks, International Journal of Engineering Research and Applications, Vol.2, No.3, pp.3218-3222, 2012.

[15] Mehdi Hosseini, Heidar Ali Shayanfar and Mahmoud Fotuhi-Firuzabad, "Modeling of Static Series Voltage Regulator (SSVR) in Distribution Systems for Voltage Improvement and Loss Reduction", Leonardo Electronic Journal of Practices and Technologies, pp.61-82, 2008.

[16] P. K. Steimer, H.E. Gruning, J. Wuninger, E. Caroll, S.Klaka, S. Linder,;"A New Emerging Technology for High Power, Low Cost Inverters", IEEE-IAS'98 Conference Proceedings, pp.1592-1599, 1998.

[17] H. Gruning, "Power Electronics Circuit Arrangement having Plural Power Converters", U.S. Patent No. 5,805,487, 1998.

[18] M.D. Manjrekar, T.A. Lipo "A Hybrid Mulilevel Inverters Topology for Drive Applications", IEEEAPEC'98 Confernce Proceedings, pp. 523-529, 1998

[19] V. Agelidis, M. Calais,;"Application specific harmonic performance evaluation of multicarrier PWM techniques", IEEE-PESC'98 Conference Record, pp. 172-178, 1998.

[20] J. Gayathri Monicka, Dr. N.O.Guna Sekhar, K. Ramash Kumar," Performance Evaluation of Membership Functions on Fuzzy Logic Controlled AC Voltage Controller for Speed Control of Induction Motor Drive", International Journal of Computer Applications, ISSN (0975 – 8887) Volume 13– No.5, January 2011.

[21] Kuppan Ramash Kumar, Seenithangam Jeevananthan," Sliding mode control design for current distribution control in Paralled Positive Output Elementary Super Lift Luo Converters", Journal of Power Electronics (JPE) Korea, Vol.11, No.5, September 2011, pp. 639-654.

[22] K. Ramash Kumar, S. Jeevananthan, "Analysis, Design and Implementation Of Hysteresis modulation sliding mode controller for negative output elementary boost converter", Journal of Electric Power Components and Systems, 40:3, 292-311, 2012.

[23] K. Ramash Kumar, S. Jeevananthan, S. Ramamurthy" Improved Performance of the Positive Output Elementary Split Inductor-Type Boost Converter using Sliding Mode Controller plus Fuzzy Logic Controller, WSEAS TRANSACTIONS on SYSTEMS and CONTROL, Volume 9, 2014, pp. 215-228.