ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 3, Issue 9, September 2017

Power Quality Enhancement in Power System using STATCOM by Fuzzy Logic Controller Technique

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Abstract:-- **:- This paper exhibits another multilevel specific consonant disposal beat width tweak (MSHE-PWM) system based transformer-less Static Synchronous Compensator (STATCOM) system utilizing cascaded H-bridge inverter (CHI) setup. The MSHE-PWM strategy improves both the DC voltage levels and the switching angles, empowering more harmonics to be wiped out without influencing the structure of the inverter circuit. The strategy gives consistent switching angles and direct example of DC voltage levels over the balance list extend. This in turns wipes out the monotonous strides required for controlling the disconnected ascertained exchanging points and in this way, facilitating the usage of the MSHE-PWM for dynamic frameworks. In spite of the fact that the strategy depends on the accessibility of the variable DC voltage levels which can be acquired by different topologies, in any case, the quick development and advancement in the field of energy semiconductor gadgets prompted deliver high proficiency DC-DC converters with a generally high voltage limit and for simplicity, a buck DC-DC converter is considered and also Fuzzy Logic Controller is used in this paper. Current and voltage shut circle controllers are executed for both the STATCOM and the buck converter to take care of the reactive power demand at various stacking conditions. and also Fuzzy Logic Controller technique is used in this paper, then the MSHE-PWM technique and Fuzzy Logic Controller technique these two comparing the outputs of Total Harmonic Distortion (THD) will reduces the THD values of voltages and currents. The adequacy and the hypothetical investigation of the approach are checked through both reenactment and test contemplates.**

Index Terms- Cascaded H-Bridge Inverter (CHI), MSHE-PWM, STATCOM, Reactive power (VAR) Compensation.

INTRODUCTION:

The huge infiltration of inexhaustible sources, which are characteristically indeterminate and exceedingly factor by nature as a viable methods for control era has emerged new difficulties to existing force systems. Nonlinear loads, for example, single-stage air conditioning pulling forces frameworks make the system to work under undesired conditions (i.e. contorted, uncontrolled responsive power), confining the greatest dynamic power exchange and huge unbalance requirement [1]. The fast advancement of the power gadgets industry then again has opened up open doors for enhancing the operation and administration of energy framework systems by means of adaptable AC transmission framework (FACTS) controllers, for example, static synchronous compensator (STATCOM) to improve neighboring utilities and areas for more prudent and solid trade of energy [2]-[18]. At first, the customary voltage source inverters (VSI) based STATCOM framework have demonstrated their common sense also predominance as the best answer for VAR pay over the customary thyristor-

based compensators (i.e. Static VAR Compensator (SVC)) because of their capacity to adjust for a more extensive scope of receptive power in part of cycles. Moreover, multilevel inverters have as of late demonstrated their capacity to beat issues related with the regular two-level inverters and in this way have gotten a broad explore in the last few rots. There are different topologies of multilevel inverters that have been and announced in the open writing. Among all these, the Multi-level fell H-connect inverter (CHI) has been an appealing topology for STATCOM framework because of its particularity, extensibility and control effortlessness [2]-[4]. The inspiration driving supplanting the regular VSIs with multi-level inverters is to dispose of the cumbersome, overwhelming, and expensive line recurrence transformer. For instance, it has been accounted for] that the heaviness of a three-stage line recurrence transformer appraised at 6.6 kV and 1 MVA ranges from 3000kg to 4000kg, while the heaviness of the three-stage CHI with the same voltage and current appraisals may run from 1000kg to 2000kg. It was additionally appeared in that the transformer weights about half of the 360kVA D-STATCOM framework. Moreover, these transformers speak to around 70% from the aggregate power misfortunes of the MVA rating of the STATCOM framework [3].

Then again, the decision of the regulation method assumes an imperative part in a STATCOM control framework as it has a high effect on its remuneration goals, transient and also enduring state exhibitions. In this manner, a few heartbeat width tweak (PWM) systems have been explored, and archived in the writing; including transporter based PWM (CB-PWM), multilevel space vector tweak (SVM), stair case adjustment, and specific consonant end PWM (SHE-PWM). CB-PWM is by a wide margin the easiest strategy to produce the required multilevel heartbeat through the convergence of a key reference waveform with the committed air bearer. There are three surely understood demeanor strategies, specifically elective stage manner (APOD), in stage mien (IPD), and stage inverse aura (Case). Relative assessments of these techniques in view of THD execution for multilevel inverter topologies regarding the quantity of levels, exchanging frequencies, and adjustment lists have been accounted for in a few articles. Zero succession infused IPD CB-PWM, or else known as the switch recurrence ideal (SFO) PWM method, with minor THD change is displayed to additionally improve the THD execution in bring down tweak records with extra exchanging moments. In spite of its effortlessness, the CB-PWM method does not offer any immediate control over the consonant substance and moreover, displays high changing misfortunes because of high exchanging frequencies; making its work into high power applications is a major concern where high misfortunes are terrible. SVM, then again, can be utilized to control music at low tweak lists and keep up wanted execution attributes of multilevel inverter in low exchanging frequencies. Despite the fact that endeavors have been made to expand the operation of multilevel inverters under SVM into the over modulation locale, be that as it may, as the quantity of levels builds, the quantity of inverter's states additionally definitely increments bringing about trouble to process the obligation cycles, determination of the correct exchanging states, and decide the division in which the reference vector lies in. Promote endeavors to destroy these issues have been endeavored to improve the calculation what's more, control. In any case, as the quantity of level reductions. The blunder regarding the produced vectors concerning the reference will be higher and thus causing an expansion in current swell, which influence the capacitor lifetime.

The goal of this work is to abuse the components of the recently created MSHE-PWM control procedure which proposed by the creators into STATCOM framework. The STATCOM intends to adjust for the variety in the receptive power at the purpose of regular coupling to adapt to the adjustments in the heap conditions, which in swings has a tendency to amend the source control factor.
The commitments of the displayed work are abridged as takes after:

1. Presents a without transformer STATCOM framework in view of fell multilevel converters (i.e. five-level in this work, be that as it may, the procedure is relevant regardless of the quantity of levels) empowering the disposal of cumbersome, overwhelming, and expensive line recurrence transformer that adds to just about 70% of the aggregate power misfortunes per a MVA rating [3].
2. The MSHE-PWM strategy builds the quantity of opportunities and consequently the sounds that can be disposed of, prompting better symphonious profile and more extensive converter's data transfer capacity. It was additionally ready to discover the arrangement of the exchanging plots for a significantly more extensive scope of the balance list when contrasted and the settled voltage DC levels case.
Moreover, the technique gives steady exchanging edges and direct example of DC voltage levels over the full scope of the tweak record, which thus facilitates the execution of the MSHE-PWM for dynamic frameworks, for example, STATCOM.
3. The operation with low-exchanging recurrence (i.e. the viable exchanging recurrence is just 1.6 kHz) when contrasted with SPWM based STATCOM, where the exchanging recurrence extends between 5 kHz and 10 kHz. Hence, less misfortunes and less cooling and influence scattering necessity is required, which will significantly lessen the volume and weight of the general framework and thus increment its dependability and execution.
4. The framework requires variable DC voltage and for straightforwardness DC/DC buck converter which worked at moderately low exchanging recurrence of 2 kHz (rather than 5 kHz and 50 kHz) is considered in this work. Moreover, the quick development in the power semiconductor gadgets and the propelled materials with a normal proficiency of 97%

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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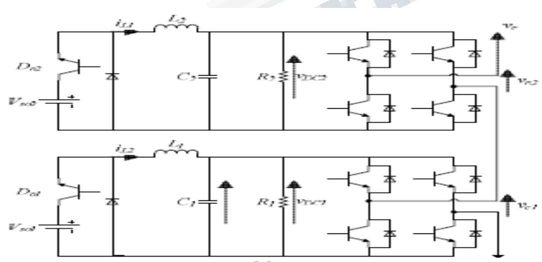
what's more, even as high as 99% with the rise of silicon carbide (SiC) exchanging gadgets and another attractive center material, legitimize the expansion of another power switch.
Whatever remains of this paper is sorted out as takes after: Section II exhibits the examination and the plan of the technique connected to five-level SHE-PWM inverter. Area III locations the STATCOM framework arrangement and the DC/DC converter controls. Chosen reenactment and tentatively approved outcomes are accounted for in Section IV. At long last, conclusions are condensed in Section V.

II. FIVE-LEVEL SHE-PWM WITH VARIABLE DC VOLTAGE LEVELS

Fig. 1 demonstrates the proposed single-stage (one-leg) five-level voltage source CHI also its related SHE-PWM yield voltage waveform. In this paper, eight exchanging edges inside a quarter-cycle with a dispersion proportion of N1/N2 = 3/5 are accepted as an case through develop the five-level SHE-PWM waveform as appeared in Fig. 1(b). The objective for this situation is to get the ideal exchanging edges and the improved levels of the DC voltage sources that wipe out nine non-triplen low request sounds (i.e. fifth, seventh, eleventh, thirteenth, seventeenth, nineteenth, 23rd, 25th, and 29th) while controlling the basic part at pre-characterized esteem. The STATCOM yield voltage waveform is depicted by Fourier arrangement (1) and the ideal exchanging edges and the DC voltage levels are acquired by comprehending the accompanying target work when it is liable to the imperatives of conditions (2) and (3).



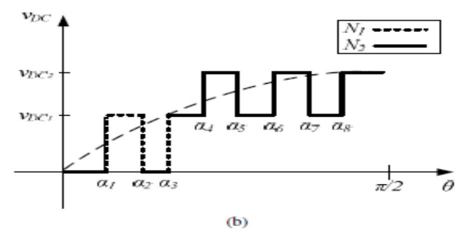


Fig.1. Single-phase five-level inverter (a) two cascaded H-bridges with the associated DC/DC buck converters and (b) SHE-PWM waveform (quarter-cycle shown).

$$\left(vDC1 \sum_{l=1}^{N1} (-1)^{l+1} \cos(\propto_l) + vDC2 \sum_{l=N1+1}^{N1+N2} (-1)^{l} \cos(\propto_l) \right) = \frac{m_i \times \pi}{4}$$

$$\left(vDC1 \sum_{l=1}^{N1} (-1)^{l+1} \cos(5 \propto_l) + vDC2 \sum_{l=N1+1}^{N1+N2} (-1)^{l} \cos(5 \propto_l) \right) = 0$$

$$\left(vDC1 \sum_{l=1}^{N1} (-1)^{l+1} \cos(n \propto_l) + vDC2 \sum_{l=N1+1}^{N1+N2} (-1)^{l} \cos(n \propto_l) \right) = 0$$

where N1= 3 is the quantity of exchanging changes in the vicinity of zero and the principal level, N2 = 5 is the quantity of exchanging advances between the primary level and the second-level, and mi is the tweak list.

$$\left(0 < \propto_1 < \propto_2 < \propto_3 < \cdots < \propto_{N1+N2} < \frac{\pi}{2} \right) \quad (2)$$

$$v_{min} \leq v_{DC_M} \leq v_{max} \quad (3)$$

where min v and max v are the base and most extreme estimations of the DC voltage source, individually and M DC v is the Mth DC voltage level (i.e. M =1, 2). The limitations are forced in the plan to guarantee that the resultant waveform is feasible and physically right. In particular (3) guarantees that the ideal DC level is inside a specific range. An enhancement strategy in view of the approach proposed in [42] and [49] is utilized to discover

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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the arrangement of (1) and numerous arrangements of answers for different multilevel waveform with various appropriation proportions and diverse scopes of adjustment file were gotten. In any case, just two arrangements of answers for the 3/5 waveform are displayed in this paper as delineated in Fig. 2, while more answers for the same multilevel waveforms can be found in [49].

It merits nothing that the eight exchanging edges inside a quarter-cycle with a circulation proportion of N1/N2 = 3/5 make the successful exchanging recurrence of the inverter equivalents to 1.6 kHz (i.e. 32*50 Hz). In this way, when contrasted with the CB-PWM based STATCOM with a regular exchanging recurrence goes between 5 kHz and 10 kHz, the proposed strategy offers less misfortunes and less cooling and influence dispersal prerequisite, which could impressively lessen the volume and weight of the generally speaking framework and thus increment its unwavering quality and execution.

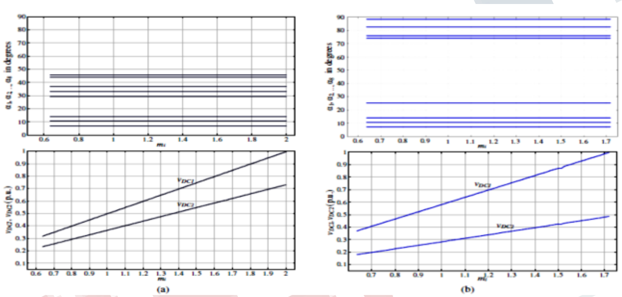

Fig.2. Switching angle and DC voltage levels solution for five-level waveform with (a) N = 3/5 and 0.64 < mi <2.0 and (b) N = 3/5 and 0.64 < mi <1.72).

III. THE STATCOM: KEY OPERATION

Fig. 3 demonstrates the single-line piece chart of the STATCOM framework in light of the five-level SHE-PWM inverter alongside the related control plans. The STATCOM is shunted to the power framework through coupling inductor Zf at the Point of Normal Coupling (PCC).The dq current vector controller of the STATCOM framework by the creators in [8] is utilized in this work, where the resultant dq-voltage reference esteems are delineated as takes after:

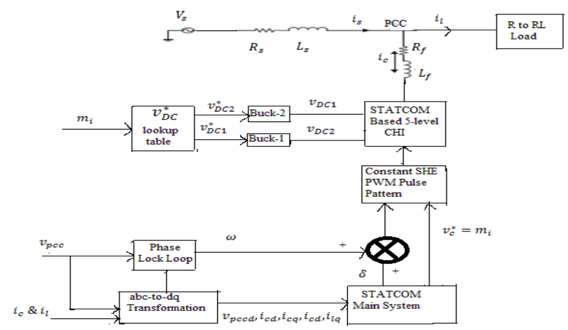

Fig.3. Block diagram of the STATCOM system with the associated control scheme.

$$v_{cd}(k) = v_{pccd}(k) - R_f i_{cd}(k) + \omega L_f\left[\tfrac{1}{2}i_{cq}(k) + \tfrac{1}{2}i_{lq}(k)\right] - k_{p_{id}}[-i_{cd}(k)] \quad (4)$$

$$v_{cq}(k) = -R_f i_{cq}(k) - \omega L_f\left[\tfrac{1}{2}i_{cd}(k)\right] - k_{p\_iq}\left[i_{lq}(k) - i_{cq}(k)\right] \quad (5)$$

Where, Vpccd characterizes the d-hub framework voltage, Rf and Lf, are the coupling resistance and inductance, individually, ù characterizes the key framework voltage recurrence, icd and icq, are the STATCOM dynamic and receptive current, separately, icd is the STATCOM current, and ilq is the reference receptive current removed at the heap side. From (4) and (5), the particular corresponding increase Kp_i(d,q) of the P-controller is given by:

$$k_{p\_i(d,q)} = \frac{L_f}{T_{i(d,q)}} + \frac{R_f}{2} \quad (6)$$

where Ti characterizes the chose controller working rate. The coveted STATCOM yield voltage greatness vc * and its stage point ä as for vpcc is given as takes after:

$$v_c = \sqrt{(v_{cd})^2 + (v_{cq})^2} \quad (7)$$

$$\delta = \tan^{-1}\left[\frac{v_{cq}}{v_{cd}}\right] \quad (8)$$

The technique depends on the accessibility of the variable DC voltage levels which can be effortlessly acquired by cutting edge DC/DC converters. With the quick development in semiconductor gadgets industry and propelled materials, for example, nano crystalline delicate attractive center that offers high immersion flux thickness (more than 1.2 T) and high relative porous ness (more than 10 000 at 100 kHz), prompting a to a great degree low center misfortune. The mix of the attractive center with the most recent trench-entryway IGBTs and super-intersection MOSFETs has made it conceivable to enhance the framework proficiency of the DC/DC converters up to 97% or higher [55]. In the close future, the rise of silicon carbide (SiC) exchanging gadgets and another attractive center material will permit the framework effectiveness to achieve higher than 99%. This transformation prompts create moderately medium-to high-voltage DC/DC converters with high changing frequencies ranges from 5 kHz [56] and as high as 50 kHz which proposed for various applications counting matrix associated converters, PV incorporation with the network. To outline the attainability of the strategy and for straightforwardness, DC/DC buck converter working at just 2kHz and with a little size of yield LC channel and straightforward control configuration is considered in this work (as appeared in Fig. 3) to give the variable DC voltage levels for every cell of the CHI as indicated by the working point (i.e. adjustment record mi). With the suspicion of perfect parts i.e. switches, capacitor C, and inductor L, the voltage shut circle controller for the DC/DC buck converter is composed in constant conduction mode (CCM) by utilizing the state space averaging displaying method with Venable approach. The non-direct, time invariant state space arrived at the midpoint of condition which depicts the lower recurrence conduct of the buck converter in view of two methods of operation (i.e. on and off) is given by:

$$\frac{dX}{dt} = [A_1]X + [B_1 D]U \qquad (9)$$

Where $X = \begin{bmatrix} I_L \\ v_{DC} \end{bmatrix}$ defines the vector of state variables, $A_1 \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{c} & -\frac{1}{R_B c} \end{bmatrix}$ and

$B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$ Characterizes the buck converter framework elements, D is the obligation cycle, SO U = V displays the vector of DC input source, and RB is the buck converter's heap resistor. From (9), the conduct for little deviations of D, U, and X from a working point is considered as given by:

$$X \Rightarrow X_o + X, D \Rightarrow D_o + d, U \Rightarrow U_o + u \qquad (10)$$

where the XO, DO, and UO characterize the relentless state working point while x, d, and u are the little bothers from the working point.

By substituting (10) into (9), one can acquire:

$$\frac{dX_o + dx}{dt} = [A_1](X_o + x) + [B_1](D_o U_o + D_o u + dU_o + du) \qquad (11)$$

To linearize (11), $\frac{dX_o}{dt}$ is overlooked since XO is characterized to be the unfaltering state point. A similar approach is considered for the irritation terms as the result of du is little. This yields the last straight, time invariant state space arrived at the midpoint of condition as takes after:

$$\frac{di_L}{dt} = -\frac{v_{DC}}{L} + \frac{D_o v_{so} + d v_{so}}{L} \qquad (12)$$

$$\frac{dv_{DC}}{dt} = \frac{i_L}{c} - \frac{v_{DC}}{R_b C} \qquad (13)$$

By taking Laplace change, a direct DC yield voltage vDC(s) condition in (13) is framed by comparing (7) and (8).

$$v_{DC}(s) = \left(\frac{v_{so} D_o(s)}{s^2 LC + s\frac{L}{R_B} + 1}\right) + \left(\frac{v_{so} d(s)}{s^2 LC + s\frac{L}{R_B} + 1}\right) \qquad (14)$$

where the principal section characterizes the buck converter's information voltage deviation at the working point and the second section characterizes the buck converter's exchange work Gconv(s) for outlining the voltage shut circle controller GV(s). Thus, the control arrangement of the DC/DC buck converter can be essentially represented by the single line square outline of Fig. 4 underneath.

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ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 3, Issue 9, September 2017

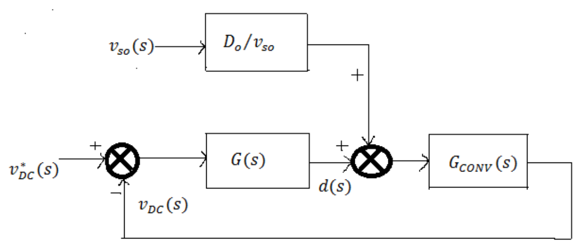


Fig.4. Block diagram of the buck converter with voltage loop feedback control.

With respect to P, PI, and PID controllers, the Gv(s) appeared in Fig. 4 is essentially a blunder speaker for the voltage mode shut circle controller to produce the obligation cycles request d for the exchanging gadget of the buck converter. From [54], the exchange capacity of Gv(s) is characterized as:

$$G_v(s) = \frac{A}{s}\left[\frac{1+\frac{s}{\omega_z}}{1+\frac{s}{\omega_p}}\right] \qquad (15)$$

Table: 1 System Parameters Used In The Simulation Study

Buck Converter Steady State Parameters
DC voltage source: V_{so}=240v
Switching frequency: f_{sw}=2KHZ
Filter Inductance: L=500μH
Filter Capacitance: C=250μF
Load Resistance: R_B=0.25Ω
Crossover frequency: ω_{cross}=5657rad/sec
Single-Phase Power System Parameters
S_{base}=1.44KVA, V_{base}=240Vrms, I_{base}=6Arms, Z_{base}=40 Ω
Single Phase power rating=1 per unit(P.U)
Single phase source voltage: Vs=1p.u
Source resistance: R_s=0.398 Ω=0.00995p.u
Coupling resistance: R_f=3.98 Ω=0.0995p.u
Source inductance: L_s=12.669mH=0.00025p.u
Coupling Inductance: L_f=126.69mH=0.0025p.u
R Load: P=1008W=0.7p.u
RL Load: P=1008W=0.7p.u,Q=1008VAR=0.7p.u
d-axis proportional gain: K_{pid}=0.21
q-axis proportional gain: K_{piq}=1.63

where An is the pick up of the mistake speaker, z (i.e. cross/K) and p (i.e. cross*K), separately, are the zero recurrence and post recurrence in view of the chose hybrid recurrence and K factor peak.

IV. FUZZY LOGIC CONTROLLER:

A) Introduction

Fuzzy Logic is about the relative significance of accuracy: How essential is it to be precisely right when an unpleasant answer will do?

You can utilize Fuzzy Logic Toolbox programming with MATLAB specialized figuring programming as an instrument for taking care of issues with fluffy rationale. Fluffy rationale is an interesting region of examination in light of the fact that it benefits an occupation of exchanging off in the middle of criticalness and accuracy something that people have been overseeing for quite a while.

In this sense, fluffy rationale is both old and new on the grounds that, in spite of the fact that the present day and efficient art of fluffy rationale is still youthful, the idea of fluffy rationale depends on age-old aptitudes of human think in.

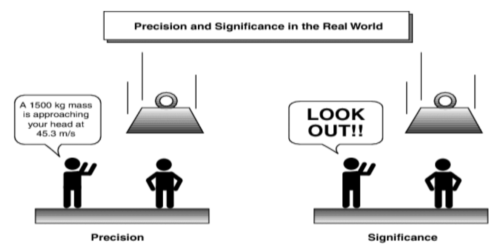
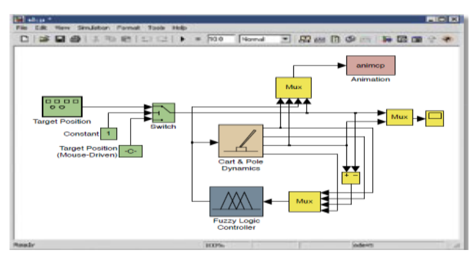


Fig5: Fuzzy Description.

B) Building a Fuzzy Inference System:

Fuzzy surmising is a strategy that deciphers the qualities in the data vector and, taking into account client characterized principles, allocates qualities to the yield vector. Utilizing the GUI editors and viewers in the Fuzzy Logic Toolbox, you can fabricate the guidelines set, characterize the participation capacities, and investigate the conduct of a fluffy derivation framework (FIS). The accompanying editors and viewers



ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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Fig.6 Fuzzy Interference System

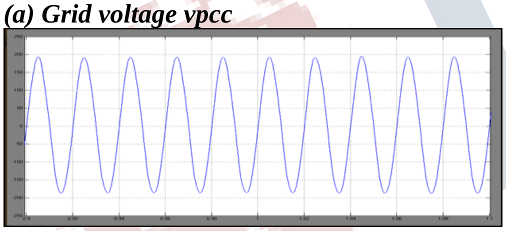
C) Key features:

■ Specialized GUIs for building fuzzy inference systems and viewing and analyzing results
■ Membership functions for creating fuzzy inference systems
■ Support for AND, OR, and NOT logic in user-defined rules
■ Standard Mamdani and Sugeno-type fuzzy inference systems
■ Automated membership function shaping through neuro adaptive and fuzzy clustering learning techniques
■ Ability to embed a fuzzy inference system in a Simulink model
■Ability to generate embeddable C code or stand-alone executable fuzzy inference engines.

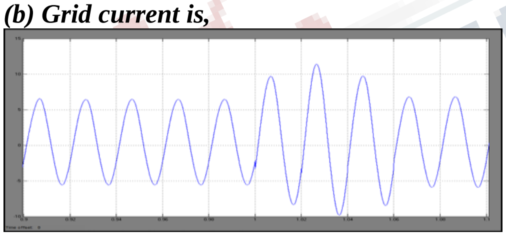
V.SIMULATION RESULTS:

Fig.7. Simulation results of AC single-phase line-to-neutral and DC quantities:

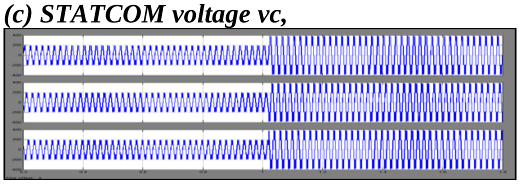
(a) Grid voltage vpcc



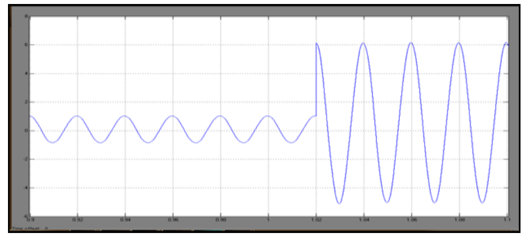
(b) Grid current is,



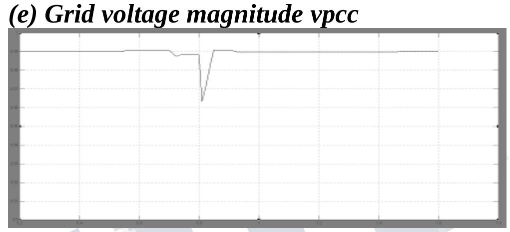
(c) STATCOM voltage vc,



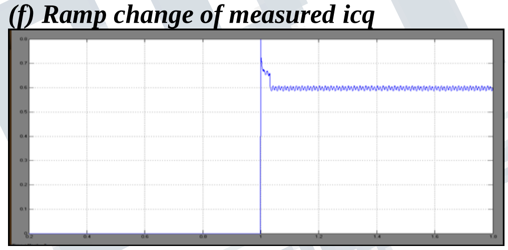
(d) STATCOM current ic,



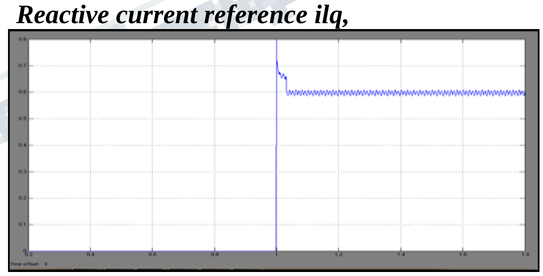
(e) Grid voltage magnitude vpcc



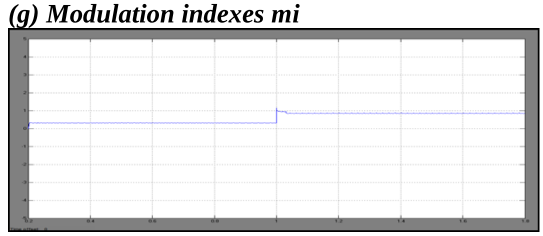
(f) Ramp change of measured icq



Reactive current reference ilq,



(g) Modulation indexes mi



(h) Buck converters output voltages vDC1 and vDC2 at different loading conditions.

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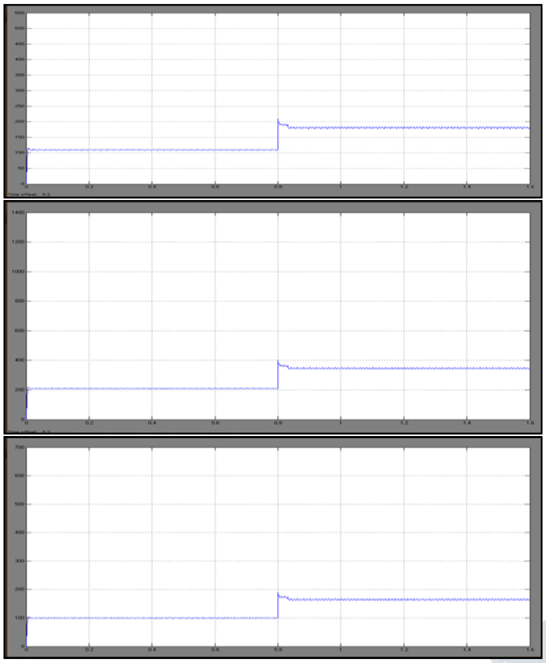
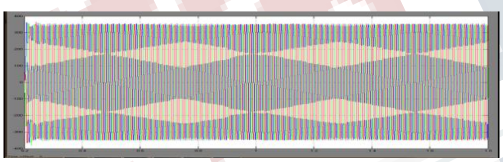


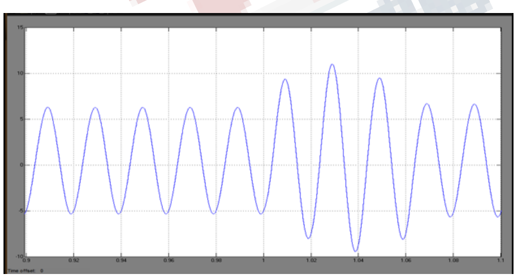
VI. BY USING FUZZY LOGIC CONTROLLER:

Fig.8. Simulation results of AC single-phase line-to-neutral

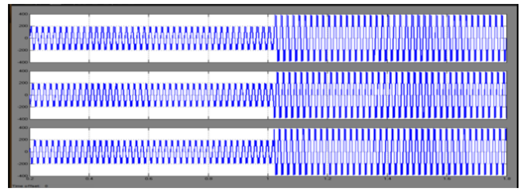
(a) Grid voltage vpcc,



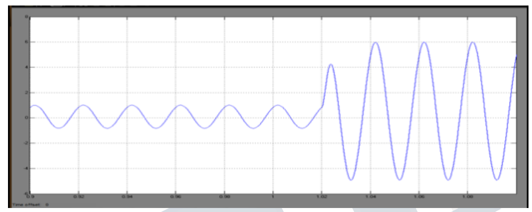
(b) Grid current is,



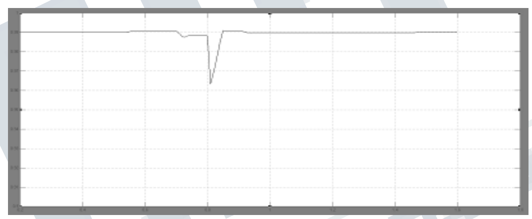
(c) STATCOM voltage vc,



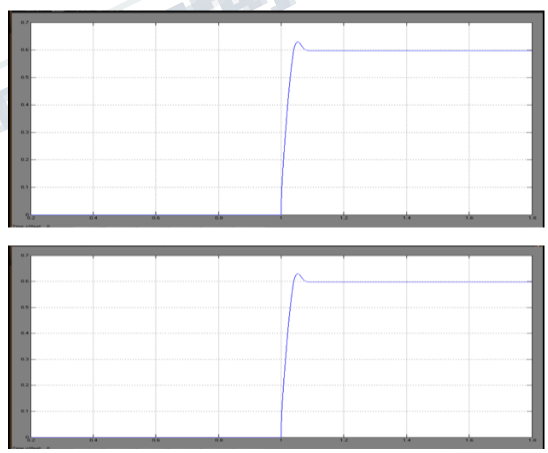
(d) STATCOM current ic, and DC quantities



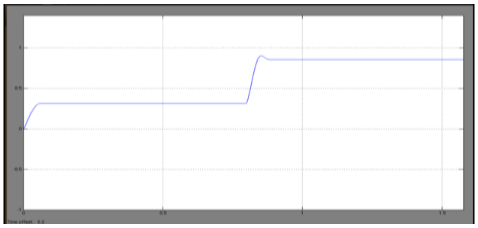
(e) Grid voltage magnitude vpcc,



(f) Ramp change of measured icq and reactive current reference ilq,



(g) Modulation indexes mi, and



(h) Buck converters output voltages vDC1 and vDC2 at different loading conditions.

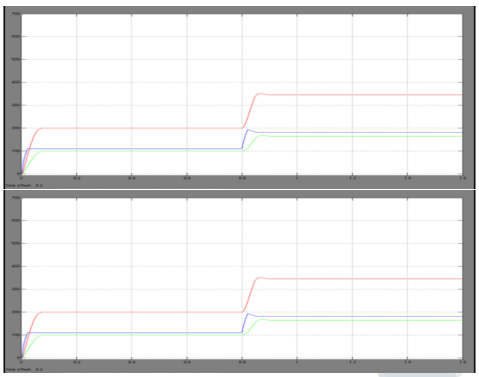


Table: 2 Results comparison

S.No.	Parameter Name	Total Harmonic Distortion	
		Without Fuzzy Logic Controller THD (%)	With Fuzzy Logic Controller THD (%)
1.	Vp	2.20	1.16
2.	Ip	1.99	1.10
3.	Ish	1.90	1.20
4.	Vsh	2.20	1.16

VII. CONCLUSIONS

A novel transformer less STATCOM controller in view of another variant of MSHE-PWM control system implementable with the fell H-connect topology was researched in this paper. The detailing of the MSHE-PWM furnishes a yield with a more extensive scope of balance record by making the DC voltage levels variation without influencing the number of sounds being dispensed with. It additionally gives consistent exchanging edges and direct example of DC voltage levels over the full scope of the balance list, which in turns takes out the monotonous strides of the disconnected estimations of exchanging points and facilitates the usage of the MSHE-PWM for dynamic frameworks, for example, STATCOM. The strategy is additionally contrasted and the ordinary CB-PWM procedure connected through the same STATCOM framework and worked with a similar exchanging recurrence (i.e. 1.6 kHz). Diverse stacking conditions were considered in both reproduction and exploratory investigations and it was discovered that the strategy beats the last in numerous angles, for example, yield voltage symphonious profile (THD), reaction time and consistent state exhibitions. Variable DC voltage sources were acquired through a basic DC/DC converter, where the progression and the fast improvement in control semiconductors gadgets and propelled materials guaranteed high productivity DC-DC change frameworks. Albeit just buck converter was considered and also Fuzzy Logic Controller is used in this paper, then the MSHE-PWM technique and Fuzzy Logic Controller technique these two comparing the outputs of Total Harmonic Distortion (THD) will reduces the THD values of voltages and currents and that as it may, different topologies can be similarly connected and this will be explored in future works for potential boost of the framework proficiency and execution
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VIII. REFERENCES

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