DSTATCOM based Induction Generator for Power Quality Improvement using Fuzzy Controller

Velamakuru Vasantha Lakshmi[1], Kurakula Vimala Kumar[2], Thalluru Anil Kumar[3]
[1]M.Tech Student, [2]Assistant Professor, [3]Professor
[1,2]Dept. of EEE, JNTUA College of Engineering, Pulivendhula, Andhrapradesh, India
[3]Dept. of EEE, CVSR College of Engineering, Hyderabad, Telangana, India

Abstract: This paper presents an implementation of sliding mode controller (SMC) together with a fuzzy logic controller for a DSTATCOM (Distribution STATIC COMCOMPENSATOR) for improving current induced power quality issues and voltage regulation of three-phase self-excited induction generator (SEIG). The fuzzy controller is the most reasonable for the human basic leadership component, giving the operation of an electronic framework with choices of specialists. The utilization of SMC for directing the DC link voltage of DSTATCOM offers different preferences, for example, reduction in number of sensors for assessing reference currents and the steady DC link voltage during transient conditions. The utilization of fuzzy controller for terminal voltage control gives the error free voltage direction in consistent state conditions. The voltage control highlight of DSTATCOM offers the upsides of single point voltage operation at the generator terminals with the reactive power compensation which maintains a strategic distance from the saturation in the generator. The SMC calculation is effectively executed on a DSTATCOM utilized with a three-phase SEIG sustaining single phase or three phase loads. The execution of the proposed control calculation is discovered attractive for voltage direction and relief of energy quality issues like reactive power compensation, harmonics elimination, and load balancing under nonlinear/linear loads. Compare the results for SMC with PI controller and fuzzy controller.

I. INTRODUCTION

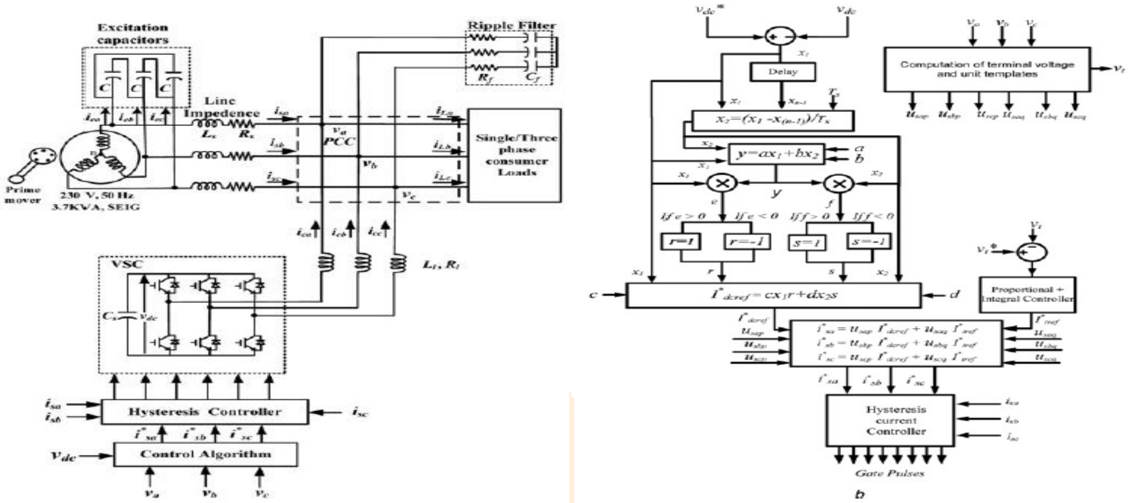
The utilization of an induction machine for the power GENERATION has expanded in recent decades because of prevalence of distributed sustainable power source assets. The utilization of an induction machine is conspicuous in remote regions, for example, smaller scale hydro power and biomass control era due to having its own particular focal points contrasted and traditional synchronous generator [1, 2]. The induction machine is prudent for little power era in the parts of low support, brush-less operation, toughness, free from field excitation and so on. Aside from these focal points, the induction machine requires driving volt ampere responsive (VAR) at its terminals for working up of the voltage. The machine requires variable capacitance crosswise over terminals for keeping up the consistent terminal voltage from no load to full load condition. In prior days, the terminal voltage of the induction machine is controlled by turning on and off of passive components, for example, inductors and capacitors [3]. The disadvantage of discrete control in the above strategy is wiped out with the development of self-commutating strong state control directing devices. The utilization of static VAR compensator with an induction generator [4, 5] has given better voltage control yet the extent of passive components, for example, capacitors and inductors has turned into the significant issue. With the current improvement of energy electronic devices and miniaturized scale controller, endeavors have been made to control the induction generator with the assistance of electronic load controller [6, 7]. Different methods [1– 9] have been accounted for voltage direction of induction generators. The utilization of single-stage induction generators for nourishing the single-stage loads is not plausible in light of low productivity and expansive size for the given yield when contrasted and a three-stage induction generator. The utilization of single-stage loads on three-stage induction generator causes the unbalance voltages and streams in the stages. A few stages with high measure of single-stage loads cause overheating of windings which brings about under-usage of appraised limit of the machine. [10] Affects other associated loads and causes warming of generator windings. Every one of these issues can be explained by utilizing custom power gadget, for example, Distribution STATic COMpensator (DSTATCOM) for the induction machine [8, 9].

In this paper, the sliding mode control with fuzzy logic controller calculation is utilized for control of the dynamic operation of the DSTATCOM in conveyed generation which enhances the power quality at the terminals of the induction machine with lessened number of sensors. Broad research has been done on the investigation of self-energized induction generator (SEIG) sustaining adjusted/uneven loads. The control calculations for the operation of DSTATCOM, for example, synchronous reference outline hypothesis, prompt responsive power hypothesis, Icos Ø calculation, Adaline calculation and step channel based calculation utilize detected load streams for evaluating the reference supply ebbs and flows [10– 13]. The principle preferred standpoint of utilizing sliding mode controller (SMC) is that the reference supply streams are evaluated from the DC-link voltage of voltage source converter (VSC) which gives the strong control amid transient conditions [14]. The fuzzy logic controller helps in terminal voltage direction of the induction generator. The power quality at the SEIG terminal is enhanced inside the points of confinement of an Institute of Electrical and Electronics Engineers (IEEE)- 519 standard [15].

In the present paper, the DC-connect voltage of VSC utilized as DSTATCOM is controlled by the SMC which stifles undershoots and overshoots in the DC-interface voltage. A lessened rating of DC-connect capacitor might be utilized inferable from this component. The terminal voltage of the SEIG is likewise controlled at value which lies far from the immersion purpose of the SEIG (even beneath the knee voltage). The operation must be single point voltage operation; in this way, a fuzzy controller is utilized to accomplish the reference voltage with no unfaltering state mistake. The operation beneath the knee voltage decreases the charging current drawn by the generator and henceforth expands its ability and lessens the symphonious twisting caused by the polarizing current. In addition, the power quality issues are likewise moderated. The generator streams are constantly adjusted and free from sounds; consequently, the usage of the generator is additionally expanded and the operation is watched quiet.

II. CONFIGURATION OF DSTATCOM SUPPORTED INDUCTION GENERATOR

Fig. 1a shows the schematic diagram of an induction generator supported by VSC-based DSTATCOM in the distributed generating system. DSTATCOM is linked in parallel with the load and an induction generator at the point of common coupling (PCC) for improving the power quality. The system is developed in such a way that an induction generator can feed the single- or three-phase linear/non-linear loads of the consumers simultaneously. The rated voltage of the induction generator is 230 V line–line voltages. Excitation capacitors are linked at the terminal of the induction generator for initial voltage buildup. Once the voltage is built and it is feeding the load, DSTATCOM starts its operation. It regulates the voltage by supplying the total reactive power required by the load and the extra reactive power required for maintaining the terminal voltage of an induction generator. The DSTATCOM operation is achieved by a control algorithm which is implemented in digital signal processor (DSP) as shown in Fig. 1a. Its details are discussed in the next section. The control algorithm gives the reference currents and the current tracking is carried out by hysteresis controller which generates gate pulses for VSC of DSTATCOM. The DC-link voltage and its capacitor of DSTATCOM are selected depending on the PCC voltage and rating of the load which is to be adjusted for enhancing the power quality.



(a) (b)

Fig. 1 design of DSTATCOM supported induction generator (a) diagram of induction generator supported by VSC-based DSTATCOM (b) Control algorithm of DSTATCOM for estimation of reference currents using SMC with PI controller

The estimation of DC-link voltage should to be chosen in such a way, to the point that the DSTATCOM should to have the capacity to inject the currents into the system during the overvoltage condition and most exceedingly terrible load progression. The DC-link voltage should to manage during the transient conditions and its value should to be chosen no less than double the peak estimation of the system phase voltage [9]. The DC-link voltage is evaluated as

$$v_{dc}=\frac{(2\sqrt{s}(\frac{VL}{\sqrt{3}})}{ma}=\frac{(2\sqrt{s}(\frac{220}{\sqrt{3}})}{1}=360\text{V}$$

where V_L is the line voltage at PCC, ma is the modulation index and its maximum value is 1. The minimum value estimated as 360 V for 220 V AC system where as the reference DC-link voltage is chosen as 400 V. The estimation of the capacitor should to be chosen such that it should to permit the energy exchange during transient conditions and computational deferral of the control activity. From the name plate points of interest of the induction generator, the estimation of full load responsive power required at the terminals can be processed as dynamic part of current,

$$I_{active}=\frac{P_{gen}}{\sqrt{3}*V_L}=\frac{3700}{\sqrt{3}*230}=9.28A \quad (2)$$

Reactive component of current,

$$I_{re}=\sqrt{{I_{rated}}^2-{I_{active}}^2}=\sqrt{14.5^2-9.28^2}=11.1A \quad (3)$$

The kilo volt ampere receptive (kVAR) required by an induction generator for keeping up terminal voltage at full load condition is processed as kVAR rating of induction generator,

$$Q_{IG}=\sqrt{3}*V_L*I_{re}=\sqrt{3}*230*11.1=4.48\,kVAR \quad (4)$$

For having self-excitation, 1.7 kVAR (QCap), 230 V, three-phase delta associated capacitor bank is connected over the terminals of the Induction generator.

The load reactive power is considered as 2 kVAR (Q_{load}) and the total receptive power provided by the DSTATCOM is figured as

$$Q_{DSTAT}=Q_{load}+(Q_{IG}-Q_{Cap})$$
$$\text{kVAR}=2+(4.48-1.7)=4.78\text{ kVAR} \quad (5)$$

The reactive component of compensating current is calculated as

$$I_{com}= \frac{QDSTAT}{\sqrt{3}*VL}=\frac{4780}{\sqrt{3}*220} = 12.54A \qquad (6)$$

Generally, 10% of the total available energy is sufficient to make the energy exchange during transient conditions

$$\Delta edc= 0.1 \times 3 \times V_{ph}\times (a \times I_{com}) \times t = \frac{1}{2} Cdc({v^2}_{dcsteady} - {v^2}_{dc}) \qquad (7)$$

where V_{ph} is the phase voltage of the system, a is the overloading factor, I is the phase current, t is the time allowed for DC-link voltage to recover during transient conditions, Cdc is the capacitance estimation of the capacitor in Farads, $v_{dcsteady}$ and vdc are the enduring state voltages of DC-link on and undershoot of DC voltage, separately. the DC-link consistent state voltage is considered as 385 V. Substituting the system parameters in (7) gives

$$\Delta edc= 0.1 \times 3 \times (220/\surd 3) \times (1.2 \times 12.5) \times 30 \times 10{-}3 = \frac{1}{2} Cdc(385^2 - 375^2) \qquad (8)$$

From the above expression, the estimated capacitor value is 1508 μF, whereas selected value in hardware implementation is considered as 1650 μF. The interfacing inductors help to mitigate the ripples in the compensating currents. The selection of link inductor depends on the switching frequency of the pulse-width modulation and the allowable percentage ripple current through it. Its value is selected as 10%. The value of inductor can be computed as

$$L_f = \frac{(\sqrt{3}/2)m_a v_{dc}}{6af_s I_{cr,pp}} = \frac{\left(\frac{\sqrt{3}}{2}\right)1*385}{6*1.2*8*10^3*(0.1*12.54)} = 4.63mH \qquad (9)$$

where v_{dc} is the DC bus voltage, ma is the modulation index, fs is switching frequency, $I_{cr,pp}$ is the allowable ripple current through inductor, 'a' is a overloading factor. From the calculation the estimated inductor value is 4.63 mH, whereas its selected value is 5 mH. A ripple filter is made with the resistors and capacitors for separating the exchanging clamor at PCC because of exchanging of protected door bipolar transistors (IGBTs) of VSC. A three-phase three-wire VSC comprises of six IGBTs alongside the counter parallel diodes. In the proposed control calculation, the dynamic operation of DSTATCOM relies upon the little variety in DC-link voltage and terminal voltage under sudden change in load conditions.

III. CONTROL OF DSTATCOM

This SMC with PI controller-based calculation utilized for control of three-stage VSC-based DSTATCOM is clarified in the accompanying segment. The focal points offered by the SMC with PI controller are as per the following:

1. For equipment execution, the utilization of SMC in the control of DC-interface voltage can take out the load current sensors which make the DSTATCOM practical.
2. SMC gives the robust control amid transient conditions and the quick powerful reaction as far as overshoot and undershoot of DC-connect voltage of VSC during load variety/transient condition.
3. The utilization of PI controller in terminal voltage direction gives the zero-voltage control during consistent state condition.

For a few cases, the SMC offers a drawback additionally, which is the consistent state error. SMC tracks the reference vigorously however with a little steady state mistake. This is not an issue in the present case as the DC connect must be kept up at a specific least level and stays inside a predefined run, not at a given level. Fig. 1b demonstrates the well ordered strategy to assess the reference supply streams utilizing SMC and PI controller-based calculation. The SMC gives in-stage segment current for meeting the load dynamic power, misfortunes in the DSTATCOM, and PI controller gives the quadrature part current for managing the terminal voltage. In sliding mode control, the DSTATCOM compensating currents are controlled to track or slide along the reference or direction. The SMC control calculation [16– 21] distinguishes the deviation from the reference direction and expeditiously changes the changing control procedure to take after the reference direction. The SMC control gives the vigorous execution under parameter varieties. The in-stage parts of unit vectors are evaluated from the PCC voltages (va, vb, and vc).

The instantaneous amplitude of PCC is estimated as

$$V_t = \sqrt{2({v^2}_a + {v^2}_b + {v^2}_c)} \qquad (10)$$

The in-phase components of unit templates are computed as

$$u_{sap}= va/Vt\ ;\ u_{sbp}= vb/Vt\ ;\ u_{scp}= vc/Vt \qquad (11)$$

The quadrature components of unit templates are computed as

$$\begin{aligned} u_{saq} &= (-u_{sbp}+ u_{scp})/ \sqrt{3} \\ u_{sbq} &= (u_{sap}\sqrt{3}+ u_{sbp}- u_{scp}) /2 \qquad (12) \\ u_{scq} &= (-u_{sap}\sqrt{3}+ u_{sbp}- u_{scp})/2 \end{aligned}$$

In SMC algorithm, the amplitudes of in-phase reference currents are estimated from DC-link voltage. The sensed DC voltage (vdc) is filtered using a low-pass filter and it is compared with the reference voltage (${v^*}_{dc}$) to generate the error signal, x1 as

$$x_1= {v^*}_{dc} - vdc \qquad (13)$$

Moreover, the derivative of above equation gives

$$x_2= \dot{x}_1= \frac{1}{T}\{x_1 - x_{(n-1)}\} \qquad (14)$$

where x1, x2 are the state variables, x(n−1) is the previous sample value, and T is the sampling time. According to the slope of the DC-link voltage error, the switching parameters r and s are selected.

The values of r and s are found from the logic decisions as follows

$$\begin{aligned} r &= +1 \text{ if } yx_1 > 0 = -1 \text{ if } yx_1 < 0 \\ s &= +1 \text{ if } yx_2 > 0 = -1 \text{ if } yx_2 < 0 \qquad (15) \end{aligned}$$

where 'y' is the switching hyper plane function, $y = ax_1 + bx_2$.

The amplitudes of reference active source currents are found as

$$I^*_{dref} = cx_1r + dx_2s \qquad (16)$$

where a, b, c, and d are the constants of the SMC.

The estimated amplitude of the reference source current is multiplied with the in-phase unit templates to generate the active power component of reference source currents as

$$i*_{sap} = I^{*}_{dref}\ usap; \quad i*_{sbp} = I^{*}_{dref}\ usbp; \ i*_{scp} = I^{*}_{dref}\ uscp \qquad (17)$$

The amplitude of quadrature component (I^{*}_{acref}) is computed using PI controller, taking the difference of reference AC voltage (V^{*}_{t}) and the calculated amplitude of PCC voltage (Vt) as

$$vace = V^{*}_{t} - Vt \qquad (18)$$

The output of PI controller for maintaining terminal voltage at reference value is given as

$$I^{*}_{acref}\ (k) = I^{*}_{acref}\ (k-1) + K_{pa}\{v_{ace}(k) + v_{ace}(k-1)\} + K_{ia}v_{ace}(k) \qquad (19)$$

where K_{pa}, K_{ia} are the PI gains of the PI controller, respectively $v_{ace}(k)$ and $v_{ace}\ (k-1)$ are the voltage errors at the kth and (k − 1)th instants, respectively.

The output of PI controller (I^{*}_{acref}) is multiplied with the quadrature unit templates to generate the reference quadrature source currents for regulating terminal voltage

$$i^{*}_{saq} = i^{*}_{acref}\ u_{saq}; \quad i*_{sbq} = I^{*}_{acref}\ u_{sbq}; \ i*_{scq} = I^{*}_{acref}\ u_{scq} \qquad (20)$$

The total reference source currents can be calculated by adding both quadrature reference currents ($i^{*}_{saq}, i^{*}_{sbq}, i^{*}_{scq}$) and the in-phase reference currents ($i^{*}_{spa}, i^{*}_{spb}, i^{*}_{spc}$)

$$i^{*}_{sa} = i^{*}_{sap} + i^{*}_{saq}\ ; \ I^{*}_{sb} = i^{*}_{sbp} + i^{*}_{sbq}\ ; \ I^{*}_{sc} = i^{*}_{scp} + i^{*}_{scq} \qquad (21)$$

The sensed source currents (i_{sa}, i_{sb}, i_{sc}) are compared with these estimated reference source currents ($I^{*}_{sa}, I^{*}_{sb}, I^{*}_{sc}$) and the current error signals are given to the hysteresis current controller and the gating pulses are generated for the three legs of VSC used as DSTATCOM.

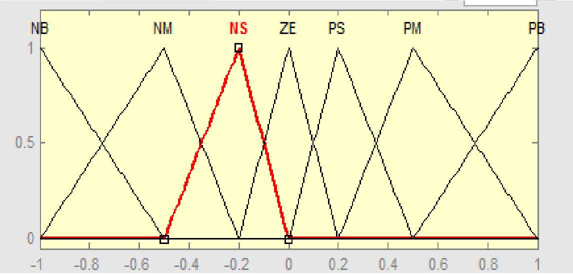
IV. FUZZY LOGIC CONTROLLER

A Fuzzy controller changes over a semantic control system into an programmed control procedure, and Fuzzy guidelines are developed by master involvement or learning database. To change over these numerical factors into phonetic factors, the following seven Fuzzy levels or sets are picked as: NB (negative enormous), NM (negative medium), NS (negative little), ZE (zero), PS (positive little), PM (positive medium), and PB (positive huge) as appeared in Figure.2.

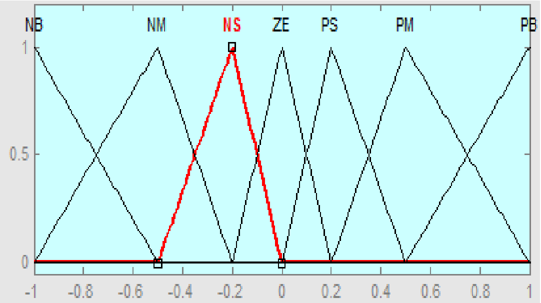
The Fuzzy controller is portrayed as takes after:

1. Seven Fuzzy sets for each info and output;
2. Fuzzification utilizing ceaseless universe of talk;
3. Suggestion utilizing Mamdani's "min" administrator;
4. De-fuzzification utilizing the "centroid" technique.

The three variables of the FLC, the error, the change in error and the output, have seven triangle membership functions for each. The basic fuzzy sets of membership functions for the variables are as shown in the Figs. 1 and 2. The fuzzy variables are expressed by linguistic variables „positive big (PB)‟, „positive medium (PM)‟, „positive small (PS)‟, „zero (Z)‟, „negative small (NS)‟, „negative medium (NM)‟, „negative big (NB)‟, for all three variables. A rule in the rule base can be expressed in the form: If (e is NL) and (de is NL), then (cd is NL). The rules are set based upon the knowledge of the system and the working of the system. The rule base adjusts the duty cycle for the PWM of the inverter according to the changes in the input of the FLC. The number of rules can be set as desired. The numbers of rules are 49 for the seven membership functions of the error and the change in error (inputs of the FLC).



Membership functions for error and change in error



Membership functions for output

Fig. 2 membership functions

Table I: Rule base of FLC

e/Δe	NB	NM	NS	z	PS	PM	PB
NB	NB	NB	NB	NM	NS	Z	PS
BM	NB	NB	NB	NM	NS	Z	PM
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

V. SIMULATION RESULTS

5.1. Simulation Results Using PI Controller

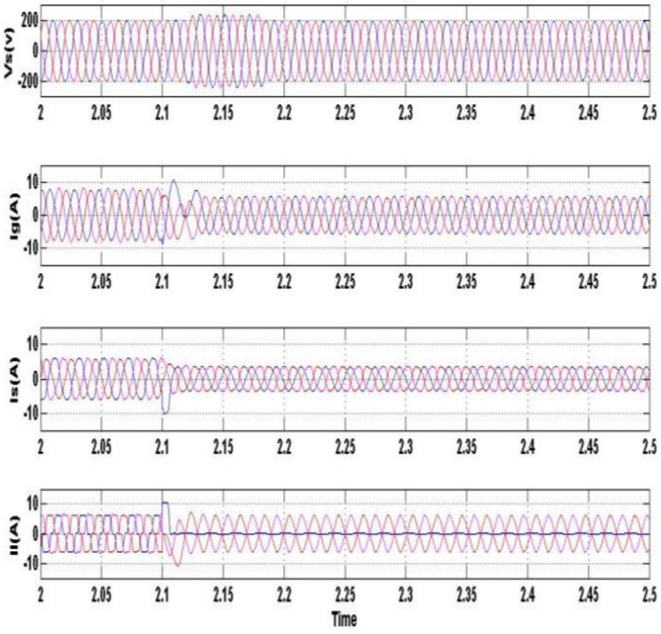


Fig. 3 Performance of DSTATCOM under three-phase and single-phase non-linear load

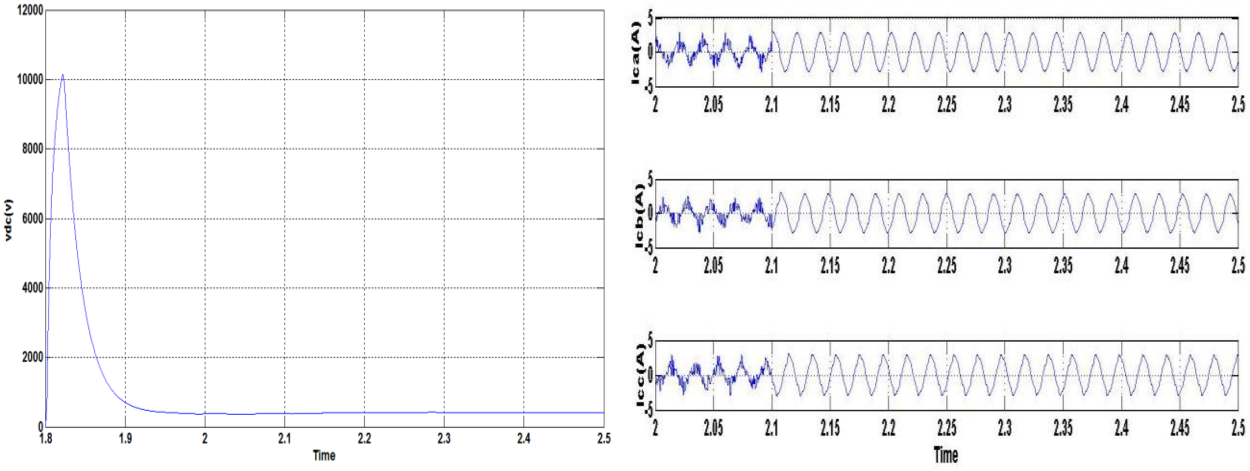


Fig. 4 DC link voltage and DSTATCOM currents

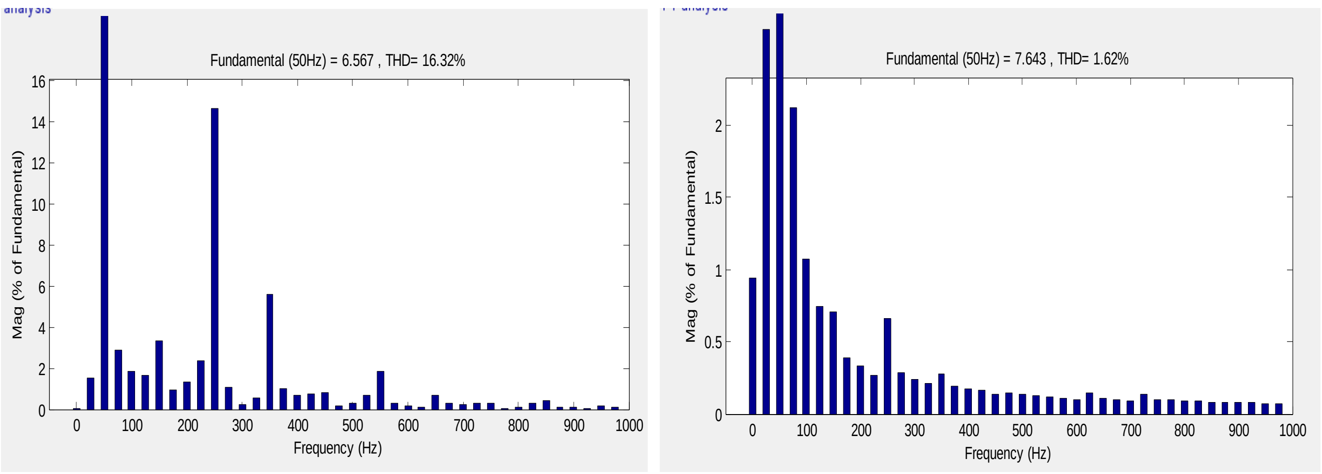


Fig. 5 Load current THD and Generator current THD

5.2 Simulation Results Fuzzy Controller

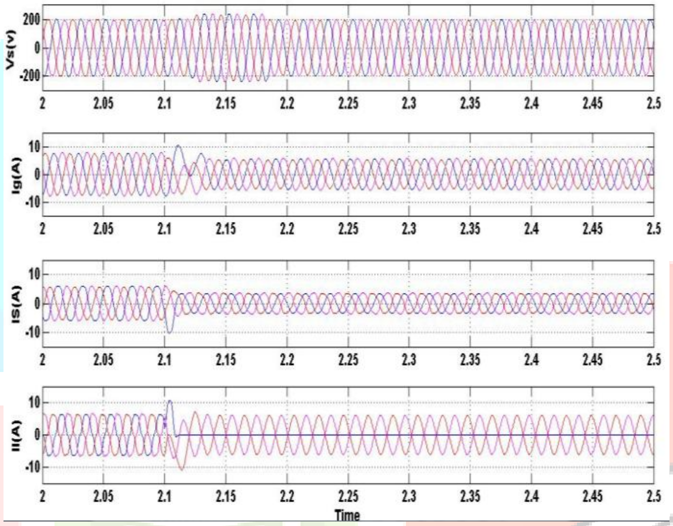


Fig. 6 Performance of DSTATCOM under three-phase and single-phase non-linear load with fuzzy logic controller

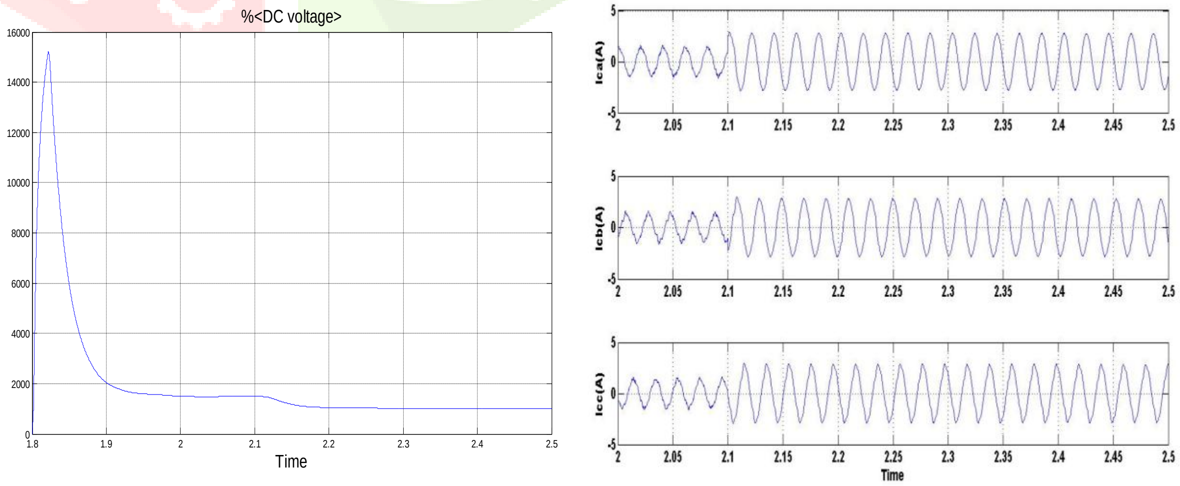


Fig. 7 DC link voltage and Currents

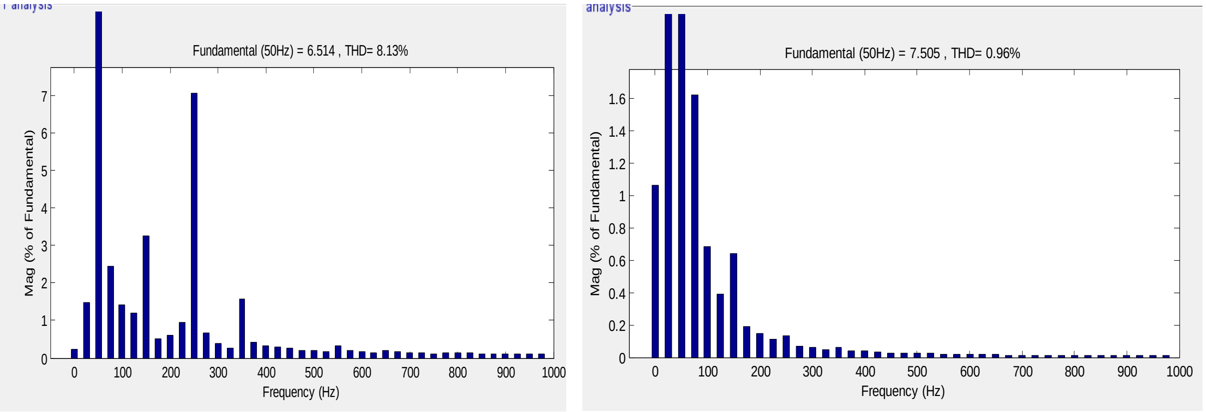


Fig. 8 Load current THD and Generator current THD

VI. CONCLUSION

A DSTATCOM supported induction generator has been implemented with the SMC with fuzzy control calculation for relieving the power quality issues and it has upgraded the dynamic power capacity of the generator. The SMC has been checked for the elements in the DC-link voltage and discovered powerful and acceptably quick to keep away from expansive varieties in DC-link voltage. Also, from the trial comes about it has been deduced that the sliding mode control with fuzzy controller calculation has been discovered equipped for meeting different functionalities of DSTATCOM.SMC with fuzzy controller gives the better performance as compared with PI controller because of lower harmonics in fuzzy controller.

References

[1] Bansal, R.C.: ‘Three phase self-excited induction generators: an overview’, IEEE Trans. Energy Convers., 2005, 20, (2), pp. 292–299
[2] Murthy, S.S., Singh, B., Gupta, S., et al.: ‘General steady-state analysis of three-phase self-excited induction generator feeding three-phase unbalanced load/ single-phase load for stand-alone applications’, IEE Proc. Gener. Transm. Distrib., 2003, 150, (1), pp. 49–55
[3] Rai, H., Tandan, A., Murthy, S.S., et al.: ‘Voltage regulation of self-excited induction generator using passive elements’. Proc. IEEE Int. Conf. Electric Machines and Drives, September 1993, pp. 240–245
[4] Singh, B., Shilpakar, L.: ‘Analysis of a novel solid state voltage regulator for a self-excited induction generator’, IEE Proc. Gener. Transm. Distrib., 1998, 145,(6), pp. 647–655
[5] Singh, B., Murthy, S.S., Gupta, S.: ‘A solid state controller for self-excited induction generator for voltage regulation, harmonic compensation and load balancing’, J. Power Electron., 2005, 5, (2), pp. 109–119
[6] Rao, S., Murthy, S.S., Bhuvaneswari, G., et al.: ‘Design of a microcontroller based electronic load controller for self-excited induction generator supplying single phase loads’, J. Power Electron., 2010, 10, (4), pp. 444–449
[7] Singh, B., Murthy, S.S., Gupta, S.: ‘An improved electronic load controller for self-excited induction generator in micro-hydel applications’. Proc. IEEE Annual Conf., November 2003, vol. 3, pp. 2741–2746
[8] Rao, S., Abhishek, K.: ‘Mitigation of unbalanced currents in three-phase asynchronous generator supplying single-phase nonlinear load’. Proc. IEEE ICSET, 2012, pp. 246–251
[9] Singh, B., Murthy, S.S., Chilipi, R.S.R.: ‘STATCOM-based controller for a three phase SEIG feeding single phase loads’, IEEE Trans. Energy Convers., 2014, 29, (2), pp. 320–331
[10] Ghosh, A., Ledwich, G.: ‘Power quality enhancement using custom power devices’ (Springer International Edition, Delhi, 2009)
[11] Singh, B., Solanki, J.: ‘A comparison of control algorithms for DSTATCOM’, IEEE Trans. Ind. Electron., 2009, 56, (7), pp. 2738–2745
[12] Singh, B., Kant, K., Arya, S.: ‘Notch filter based fundamental frequency component extraction to control DSTATCOM for mitigating current related power quality problems’, IET Power Electron. 2015, Early Access
[13] Arya, S., Niwas, R., Kant, K., et al.: ‘Power quality improvement in isolated distributed generating system using DSTATCOM’, IEEE Trans. on Industry Applications, Early Access, 2015
[14] Saetio, S., Devaraj, R., Torrey, D.A.: ‘The design and implementation of a three-phase active power filter based on sliding mode control’, IEEE Trans. Ind. Appl., 1995, 31, (5), pp. 993–1000
[15] IEEE Recommended Practices and requirement for Harmonic Control on electric power System, IEEE Std.519, 1992
[16] Eldery, M.A., El-Saadany, E.F., Salama, M.M.A.: ‘Sliding mode controller for pulse width modulation based DSTATCOM’. Proc. of CCECE, 2006, pp. 2216–2219
[17] Bandal, V.S., Madurwar, P.N.: ‘Performance analysis of shunt active power filter using sliding mode control strategies’. 12th Int. Workshop Variable Structure Systems (VSS), 2012, pp. 214–219
[18] Singh, B., Al-Haddad, K., Chandra, A.: ‘Active power filter with sliding mode control’, IEE Proc. Gener. Transm. Distrib., 1997, 144, (6), pp. 564–568
[19] Errabelli, R.R., Kolhatkar, Y.Y., Das, S.P.: ‘Experimental investigation of sliding mode control of inverter for custom power applications’. IEEE Power Engineering Society General Meeting, 2006, pp. 8–16
[20] Teodorescu, M., Stanciu, D., Radoi, C., et al.: ‘Implementation of a three-phase active power filter with sliding mode control’. Proc. of IEEE Int. Conf. on Automation Quality and Testing Robotics (AQTR), 2012, pp. 9–13
[21] Mendalek, N., Al-Haddad, K., Kanaan, H.Y., et al.: ‘Sliding mode control of three-phase four-leg shunt active power filter’. Proc. of IEEE Power Electronics Specialists Conf., PESC, 2008, pp. 4362–4367.