# SIMULATION OF THREE PHASE FOUR WIRE SYSTEM FED DSTATCOM USING SRF THEORY

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*Abstract*—With the development in power sector, switching elements gives a great impact with electrical load. These elements create distortions in lines increasing the line losses, reducing power quality and purity of sin wave. DSTATCOM has a voltage source converter (VSC) which works in back to back configuration with a DC coupling capacitor. At the point of common coupling (PCC) the power is injected by the VSC and the reference current is generated using Synchronous reference frame control algorithm. The harmonic components are separated from reference current, the reference is compared with actual current and the pulse width to control VSC is adjusted by the PI controller. The motive of proposed approach is to illustrate using simulation in MATLAB software. By using (FFT) analysis Total harmonic distortion (THD) of line current can be measured.

Keywords: Synchronous reference frame (SRF) theory, DSTATCOM, HBCC, PI controller, Power Quality.

## I. INTRODUCTION

Maintaining approx sinusoidal power distribution bus voltage at rated magnitude and frequency is called as power quality. The general power quality problems in three-phase four-wire distribution system are low power factor, voltage imbalance, load unbalance, increase in neutral current, harmonic distortion, voltage imbalance, etc [1]. For the compensation of current harmonics and compensation of neutral current also improving the characteristics of the system, voltage source converter with parallel connected capacitor is used as a DSTATCOM [2]. The different control algorithms developed for generating reference control signals for voltage source converter of DSTATCOM are: power balance theory, synchronous reference frame theory (SRF theory), instantaneous reference frame theory (p-q theory).In this paper, the control approach is based on synchronous reference frame theory which is used for generation of control signal for voltage source converter of DSTATCOM in three phase four leg four-wire (3P4W) distribution system [3-10] The advantages of DSTATCOM are-

(a) Operation of DSTATCOM supported by means of a capacitor.
(b) Neutral current compensation
(c) Load balancing
(d) Perform under non-sinusoidal supply condition.
(e) Indirect current compensation.

## II. SYSTEM DESCRIPTION

The system represents a three phase four wire system main components of system are Source followed by a VI measurement, nonlinear load for balance and unbalanced system and there is a DSTATCOM connected in parallel for which gating signals are provided by the pulse generator also including subcomponents as, Voltage source inverter, DC link capacitor, Reference current generator and Current Controller shown in Fig1.

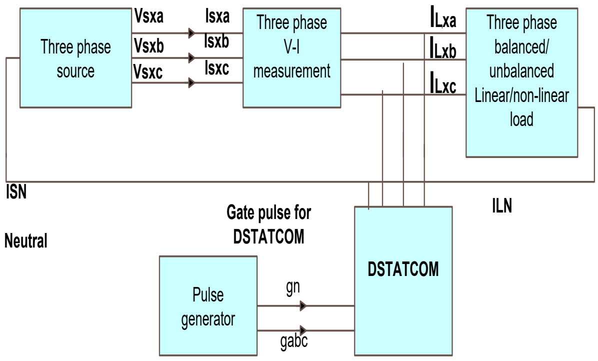


Fig.1. Block diagram of proposed system

DSTATCOM consists of a typical three-phase Insulated Gate Bipolar Transistor (IGBT) based four leg VSC bridge with the dc bus capacitor. An extra leg is added to control the current in neutral wire. DSTATCOM is used for instant monitoring of load current, improvement of power factor, regulation of voltage along with, elimination of harmonics, current compensation and maintaining the linear and nonlinear loads also generation of reference compensating current [3]. The gate pulse generator used for giving the gate pulses to the VSC of DSTATCOM as well as for the neutral. In this block all the control pulses exists and also consist Reference current generation, PI controllers, HBCC, PLL etc [4].

Algorithm of PI controller involves two separate parameters: The Proportional parameter determines equation of the current error; Integral parameter determines the equation based on the sum of recent errors [5,8].

Correct regulation of proportional controller's value plays an important role in DC voltage control system's response. Too much increase in proportional gain may leads to unsteadiness (fluctuations) in control system and too much reduction decreases the responding speed of control system. Further the Integral gain of controller modifies the steady state error. Hence the system becomes stable only at a particular regulated value of PI controller. Many techniques of generation of gating pulses but the most widely used technique is hysteresis controller because of this simplicity and quick response. In hysteresis controller the reference current which was obtained by SRF technique is compared with the filter current and provides the gate pulses for DSTATCOM [12,19].

## III. METHODOLY

### A. Synchronous reference frame (SRF) method

The SRFT is used in this proposed work for the control of (3P4W) three-phase four wire DSTATCOM. The load currents $i_{Lxa}$, $i_{Lxb}$ and $i_{Lxc}$ the PCC voltages $V_{sxa}$, $V_{sxb}$ and $V_{sxc}$ and a dc bus voltage $V_{dcl}$, of DSTATCOM is sensed as feedback signals, the transformation of coordinates from a three-phase a-b-c stationery coordinate to 0-α-β further in 0-d-q rotating coordinate using Park's and Clark's transformation and further the inverse of the same system. This transformation is necessary for the sake of 0-d-q reference frame signal which can effectively be controlled to get the desired reference output signal [11-14].

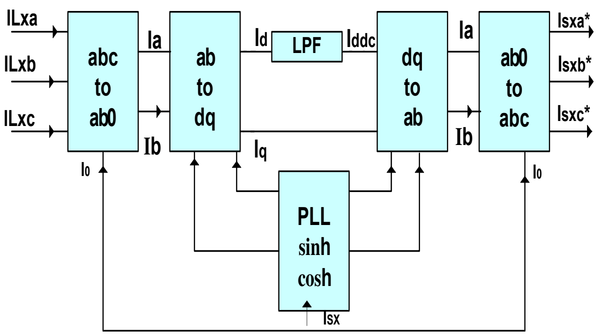


Fig.2 Block diagram of Synchronous reference frame (SRF) method

### B. CONTROL ALGORITHM

Fig. 3 shows the control algorithm consisting srf algorithm. In this work the cosθ and sinθ are determined using a three-phase phase-locked loop (PLL). A Phase loop signal is obtained from voltages at terminal for fundamental unit vectors generation for transformation of sensed currents to the d-q-0 reference frame [11].

$$\begin{bmatrix} i_{Lxq} \\ i_{Lxd} \\ i_{Lx0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} I_{Lxa} \\ I_{Lxb} \\ I_{Lxc} \end{bmatrix} \quad (1)$$

A unit vector control technique requires only two feedback sensors for source voltages ($V_{sxa}$, $V_{sxb}$ and $V_{sxc}$), one feedback sensor for dc bus voltage ($V_{dcl}$) , one feedback sensor for source currents($i_{sxa}$, $i_{sxb}$ and $ix_{sc}$), and last sensor for the third phase voltage $V_{sxc}$ [-($V_{sxa}$+$V_{sxb}$)] & current $i_{sc}$ [- ($i_{sxa}$, +$i_{sxb}$)].

The main feature of unit based template control technique is to reduce number of feedback sensors which will improve performance of DSTATCOM, It is the effective solution to mitigate harmonics, load unbalancing, power factor correction, reactive power control and neutral current compensation [7].

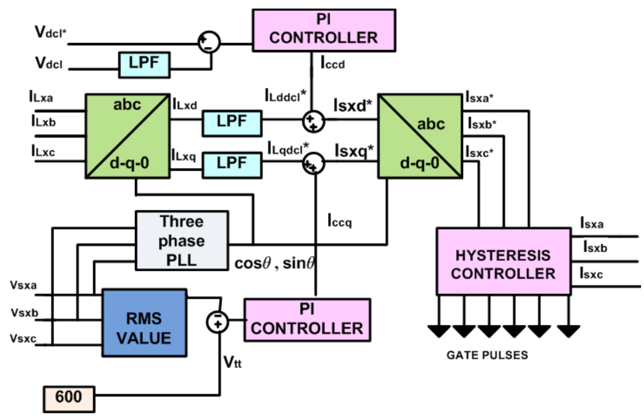


Fig 3 Synchronous Reference Frame Control Strategy

$$V_{sxa} = V_{mp} \sin(\omega t) \quad (2)$$
$$V_{sxb} = V_{mp} \sin(\omega t - 120°) \quad (3)$$
$$V_{sxc} = V_{mp} \sin(\omega t - 240\,°) \quad (4)$$

The magnitude of three phase voltages ($V_{sa}$, $V_{sb}$ and $V_{sc}$) at PCC is given by:

$$V_{tt} = \sqrt{\frac{2({V_{sxa}}^2 + {V_{sxb}}^2 + {Vx_{sc}}^2)}{3}} \quad (5)$$

The in-phase component of unit templates ($u_{sa}$, $u_{sb}$, and $u_{sc}$) are calculated from ($V_{sa}$, $V_{sb}$ and $V_{sc}$) which are given by

$$u_{sxa} = \frac{V_{sxa}}{V_{tt}},\ u_{sb} = \frac{V_{sxb}}{V_{tt}},\ u_{sc} = \frac{V_{sxc}}{V_{tt}} \qquad (6)$$

A summing block separated desirable and undesirable parameters further by using low-pass filter the unwanted parameters (harmonics) which can be removed from the reference signal. The direct-axis and quadrature-axis currents consist of Fundamental component as well as harmonic components,

$$I_{Lxd} = I_{ddc} + I_{dac} \qquad (7)$$
$$I_{Lxq} = I_{qdc} + I_{qac} \qquad (8)$$

The d-q parameter of the load currents are calcuated from the following equations:

$$\begin{bmatrix} I_{Lxd} \\ I_{Lxq} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos\omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \qquad (9)$$

$$V_{dcle} = V_{dcl^*} - V_{dcl} \qquad (10)$$
$$V_{tte} = V_{tt^*} - V_{tt} \qquad (11)$$

$V_{dc^*}$ and $V_{dc}$ are the reference voltage and actual voltage of DC bus and $V_t$ and $V_{t^*}$ are amplitude of PCC voltage and the reference voltage at PCC respectively. $V_{dcle}$ is error in DC bus voltage, $V_{tte}$ is error in amplitude of the PCC voltage PI controllers output corresponds to required current for self supporting DC bus and voltage regulation at PCC as:

$$I_{ccd} = K_{pd}\, V_{dcle} + K_{id} \int V_{dcle}\, dt \qquad (12)$$
$$I_{ccq} = K_{pq}\, V_{tte} + K_{iq} \int V_{tt}\, dt \qquad (13)$$

$K_{pq}$ and $K_{iq}$ are the proportional and integral gains of the PI controller over the PCC voltage, $K_{pd}$ and $K_{id}$ are the proportional and integral gains of the PI controller over the DC bus voltage, the SRF control theory is based on the transformation of currents in synchronously rotating three to two dimensional frame d-q frame. The desired source current in d-q frame are obtain as,

$$I_{sxd^*} = I_{Lddcl} + I_{ccd} \qquad (14)$$
$$I_{sxq^*} = I_{Lqdcl} + I_{ccq} \qquad (15)$$

Where $I_{sxd^*}$ and $I_{sxq^*}$ are estimated dc components of active and reactive component of reference Source currents in d-q frame. $I_{ccq}$ and $I_{ccd}$ are the output results of the DC voltage of Proportional integral controller and AC voltage PI controller respectively. The standard value of $I_{Lxd}$ and $I_{Lxq}$ are obtain from the two alike low pass filters $I_{Lddc}$ and $I_{Lqdc}$. The reference source currents are achieved as:

$$\begin{bmatrix} I_{sxa^*} \\ I_{sxb^*} \\ I_{sxc^*} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\omega t & \cos\omega t \\ \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} I_{sxd^*} \\ I_{sxq^*} \end{bmatrix} \qquad (16)$$

Where the signals $\sin\omega t$ and $\cos\omega t$ are obtained using the phase locked loop (PLL) over point of common coupling (PCC) voltage. Three-phase source reference currents are obtained by inverse Park's transfromation. In a summing block, the source ($I_{sxa}$, $I_{sxb}$, $I_{sxc}$) and reference currents ($I_{sxa^*}$, $I_{sxb^*}$, $I_{sxc^*}$) are compared and a proportional controller is used for amplify these error currents in all the phases before compared with a source current to generate the gating pulses for six IGBT switches of VSC of DSTATCOM. The generated gating pulses control the IGBT switches to inject the current such that the sensed source currents accurately follow the reference source currents [18,19].

## IV. RESULTS AND DISCUSSION

### (a) Output waveform analysis of SRF based DSTATCOM with balance linear load for the compensation of harmonic components

Under balanced system timings of circuit breakers are identical to each other also the load must having identical load parameters.

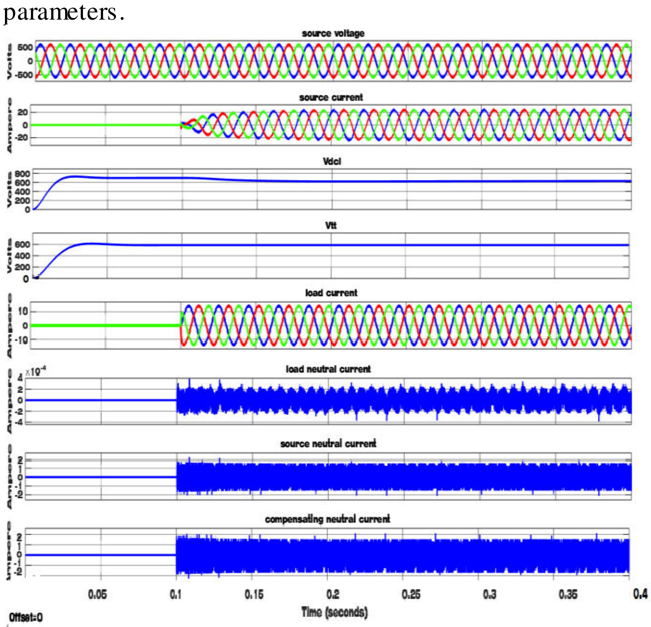


Fig.4 The performance analysis for linear balance load

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It is observed that the at time t=0 to t=0.1 sec the DSTATCOM is switched OFF the source current is out of phase with source voltage and distorted at time t=0.1sec the DSTATCOM is switched ON the source current is setting down at time t=0.3 sec and in phase with the source voltage as we desired ideally.

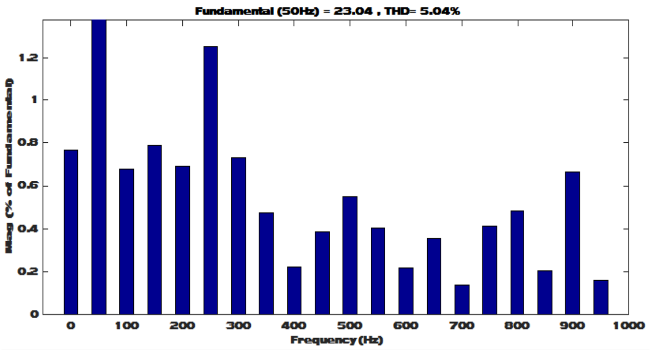


Fig.5 THD analysis

Fig.5 shows the harmonic distortion study of supply current before compensation the THD was 23.57% which is insupportable hence the harmonic distortion analysis of supply current after compensation the THD was 5.04%.

**(b) Results analysis of SRF based DSTATCOM with unbalance linear load for load balancing and neutral current compensation**

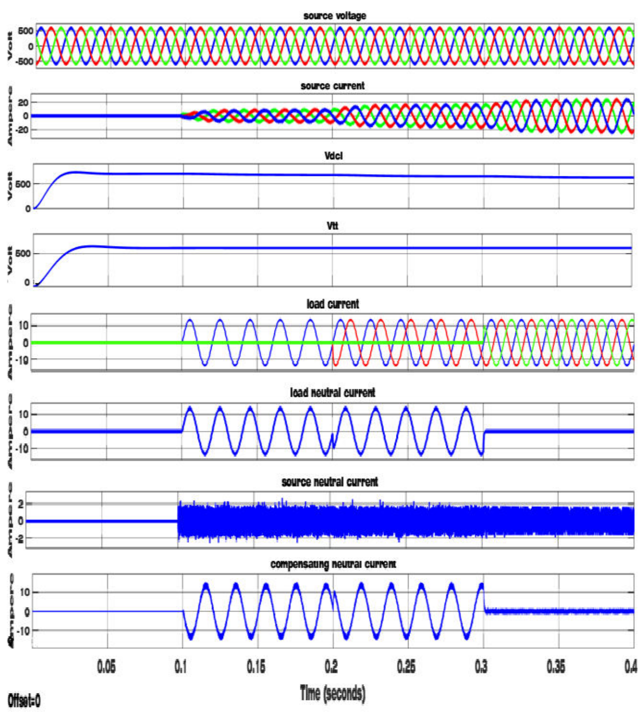


Fig.6 The performance analysis for linear unbalance load

It is found that at t=0 to t=0.1sec when the controller was off the source voltage and current are out of phase. Fig.6 shows the performance analysis for unbalanced linear load. This figure shows that at t=0.1sec when the controller was on the source current settled down in phase at t=0.3sec. Fig. 7 shows the FFT analysis for unbalanced nonlinear load, The THD was 23.57% which is intolerable hence the harmonic distortion analysis of supply current after compensation. The THD was 5.17%.

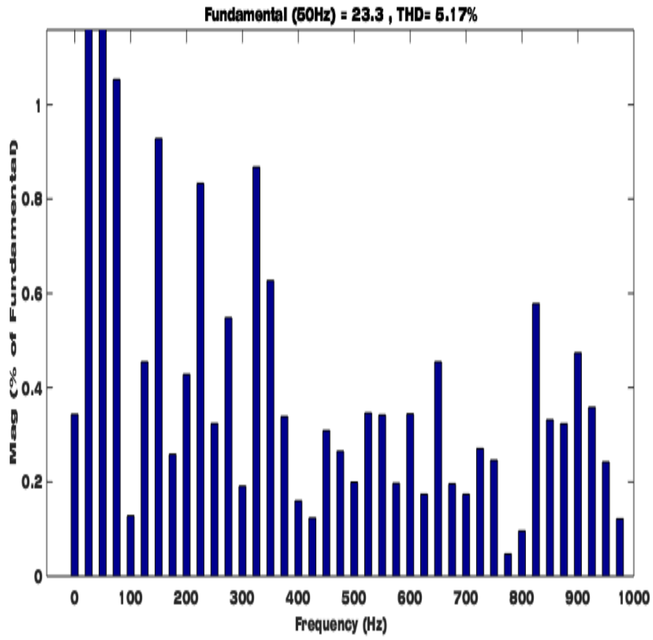


Fig.7 THD analysis

## V. CONCLUSION

A innovative control scheme based on synchronous reference frame (SRF) theory had been used for the four-leg DSTATCOM for three-phase four-wire distribution system to improve the performance under Balanced/ unbalanced linear load condition. The model was developed using Simulink and Sim Power System toolbox. The simulation was performed for balanced unbalance linear loads. It was seen that before the compensation for current was provided, the current and the voltage waveforms were out of phase not a pure sine wave . The SRF based DSTATCOM was connected in the system, the compensation for current was provided, and making the current and voltage waveforms in phase and make approximate sinusoidal waveform. The following objectives have been successfully achieved.

- Harmonics Current Compensation.
- Voltage Regulation
- Load balancing

APPENDIX

Table I-: Simulink performance parameters

| parameter | Unit | lanced linear load | balanced linear load |
|---|---|---|---|
| $V_s$ | Volts | 600 | 600 |
| $I_s$ | Ampere | 25 | 25 |
| $V_{dc1}$ | Volts | 630 | 630 |
| $V_{tt}$ | Volts | 585 | 585 |
| $I_{LX}$ | Ampere | 14 | 14 |
| $I_{LN}$ | Ampere | 4 | 4 |
| $I_{SN}$ | Ampere | 2 | 2 |
| $I_{CN}$ | Ampere | 4 | 4 |
| $I_{CC}$ | Ampere | 25 | 25 |
| Thd | % | 4.97 | 5.17 |

Three phase supply voltage=415V, 50Hz.
Supply Impedance: Rs=0.01Ω, Ls=1mH
Unbalanced/ Balanced Non-Linear loads: Three single phase diode bridge rectifier R=25Ω and L=8mH
DC bus Capacitor Cdc=4000 µF
DC bus PI Controller: $K_p = 0.10, K_i = 0.1$
Low pass filter :25Khz pf:0.707

REFERENCES

[1] Bhim Singh, Yash Pal, A. Swarup, "A Review of Compensating Type Custom Power Devices for Power Quality Improvement" 978-1-4244-1762-9/08/C 2008.

[2] Bhim Singh and Vishal Verma, "Selective Compensation of Power-Quality Problems Through Active Power Filter by Current Decomposition" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 23, NO. 2, APRIL 2008, 0885-8977/ 2008

[3] Sabha Raj Arya, Bhim Singh, "Desigin and control of a DSTATCOM for power quality imporvement used cross corrilation function approach" International Journal of Engineering, Scieince and Technology Vol. 4, No. 1, pp. 74-86, 2012.

[4] Bhim Singh, A.Adya, A.P.mittal and J.R.P Gupta, "Modeling and Control of DSTATCOM for Three-Phase, Four-Wire Distribution Networks" IAS 2005 2428 0-7803-9208-6/05/$20.00 © 2005

[5] Asad Ullah, Inam Ul Hasan Sheikh, Shahzad Arshad, Faisal Saleem, " Digital Active Power Filter Controller Design for Current Harmonics in Power Network, Proceedings of 2019 16th International Bhurban Conference on Applied Sciences & Technology (IBCAST), 978-1-5386-7729-2/19/$31.00©2019 IEEE

[6] Najiya C K1, Krishnakumari T 2 , Sijo George3, "Shunt Active Power Filter based on SRF theory and Hysteresis Band Current Controller under different Load conditions" IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, PP 20-26, National Conference on "Emerging Research Trends in Electrical, Electronics & Instrumentation" 20 | Page (ERTEEI-2017)

[7] J.Bangarraju1 V.Rajagopal2 A.Jayalaxmi3, "Mitigation of PQ Disturbances using Unit-Template Control Algorithm based DSTATCOM" Asian Power Electronics Journal, and Digital Ref: APEJ-2015-02-0461 Vol. 11, No. 1, July 2017

[8] Monika Jain and Sushma Gupta, "Soft Computing Technique-Based Voltage/Frequency Controller for a Self-Excited Induction Generator-Based Microgrid" Journal of Circuits, Systems, and Computers #.c World Scienti¯c Publishing Company DOI: 10.1142/S0218126616500122, Vol. 25, No. 2 - 1650012 (2016).

[9] Bhim Singh, P. Jayaprakash, D P Kothari, "Three Single-Phase Voltage Source Converter Based Three-phase four wire DSTATCOM" 2009 Third International Conference on Power Networks, Kharagpur, INDIA December 27-29, 978-1-4244-4331-4/09/$25.00 ©2009

[10] Akash V. Barva1, and Priyank R. Bhavsar2, "Design and Simulation of Four-Leg Based Three- Phase Four-Wire Shunt Active Power Filter" 978-1-5386-2051-9/18/$31.00 ©2018 IEEE, International Conference on Communication, Information & Computing Technology (ICCICT), Feb. 2-3, 2018.

[11] Bhim Singh, IEEE and Jitendra Solanki, "A Comparative Study of Control Algorithms for DSTATCOM for Load Compensation"1-4244-0726-5/06/$20.OO '2006 IEEE.

[12] Prasad Miskal *, Ashok Kumar Akella2 "Modeling and Simulation of SRF and PI Controlled Dstatcom for Power Quality Enhancement" International Journal of Techno-Chem Research ISSN:2395-4248 Vol.02, No.02, pp 141-150, 2016 IJOTR

[13] Monika Jain, Sushma Gupta, Deepika Masand & Gayatri Agnihotri "Isolated Operation of Micro Grid Under Transient Conditions Using AI-Based VF Controller" IETE Journal of Research, DOI: 10.1080/03772063.2019.1644970, (2019)

[14] J. Bangarraju & V. Rajagopal "Mitigation of Load Current Harmonics Using DSTATCOM based on SRF Theory" https://www.researchgate.net/publication/286451696 Research gate January, 2013.

[15] Kakooli Bharjee "using Adaptive Hysteresis Control Harmonic Mitigation by SRF Theory Based Active Power Filter" Power and Energy Networks: Towards Sustainable Energy (PESTSE 2014)

[16] Monika Jain,1 Sushma Gupta,1 DeepikaMasand,2 Gayatri Agnihotri,1 and Shailendra JaiN " Real-Time Implementation of Islanded microgrid for Remote Areas" Journal of Control Science and Engineering, Article ID 5710950, 9 pages http://dx.doi.org/10.1155/2016/5710950 Volume 2016

[17] C. Vivekanandant, Chennai and Dr.MGR University, "Modelling and Power Quality Enhancement of Induction Motor with Soft Starter using Synchronous Reference Frame Theory"Second International Conference on Sustainable Energy and Intelligent Network (SEISCON 2011) Charles. S IEEE*.July 20-22, 2011.

[18] Ambrish Chandra, Vinod Khadkikar, Mukhtiar Singh, and Bhim Singh, "Implementation of Single-phase Synchronous dq Reference Frame Controller for Shunt Active Filter under Distorted Voltage Condition" 2015.

[19] Monika JAIN Sushma GUPTA Deepika MASAND Shailendra JAIN Gayatri AGNIHOTRI, " VOLTAGE AND FREQUENCY REGULATION WITH SYNCHRONIZATION OF MICRO GRID UNDER ISLANDING OPERATION" Journal of Electrical Engineering : Volume 15 - Edition : 2/ 2015.

[20] Riya B. vasava "SRF BASED CONTROL FOR POWER QUALITY IMPROVEMENT USING D-STATCOM" International Journal of Innovative and Emerging Research in Engineering
e-ISSN: 2394 - 3343 p-ISSN: 2394 - 5494 .

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