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Load compensation of Unbalance Non-Linear Loads using DSTATCOM

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Abstract: Power distribution network consists of mostly non-linear loads and power electronic related devices, that cause power quality issues like power interruptions, voltage sag, voltage swell, harmonic distortions. In this paper, modified instantaneous reactive power theory is used as a control technique for distribution static compensator (DSTATCOM) for reactive power compensation and voltage balancing in the distribution network. In this algorithm for the formation of reference compensator currents sequence voltages are extracted. Hysteresis controlled PWM technique is employed for the generation of switching pulses for the neutral clamped capacitor split voltage source inverter. MATLAB-Simulink Software environment is used to implement the DSTATCOM in the distribution system.

Keywords: Reactive power compensation, Load balancing, Distribution static compensator (DSTATCOM), Hysteresis controlled pulse width modifier (HCPWM).

I. INTRODUCTION

In general plenty of loads used by the customers and industrials are non-linear, asymmetrical, and power electronic devices. These loads cause distortions in current and voltage on the distribution side. The power loss generated in distribution system is much higher compared to the transmission and generation systems. Thus reactive power compensation is required to beat these losses.

The Power quality of Electrical power at the distribution level is worse affected by the voltage unbalances in the system.

The voltages presented in the transmission and generator systems are perfectly balanced. But due to unbalanced faults, bad connections to electrical connectors, uneven distribution of single-phase loads and uneven system impedances, these voltages become unbalanced at utilization level. The power quality will be significantly reduced by the excessive level of voltage Unbalance.

FACTS devices are custom devices that are used to diminish the power quality problems. These are DSTATCOM, UPQC, DVR, UPFC, etc. Out of these devices, DSTATCOM is mostly used because compensates both reactive power and voltage balancing at the lower costs. The various control techniques are given in [1].

The IRP theory is best suitable for voltage balancing and load compensation [2], but it fails to compensate for the source currents in distorted supply voltages. The modified instantaneous reactive power theory can eliminate those problems effectively by extracting sequence voltages using a sequence analyzer and Phase locked loop (PLL).

The simulation results are generated by using the perfect selection of various parameters such as hysteresis band, dc storage capacitor, interfacing inductor and dc-link voltage.

II. OPERATION OF DSTATCOM

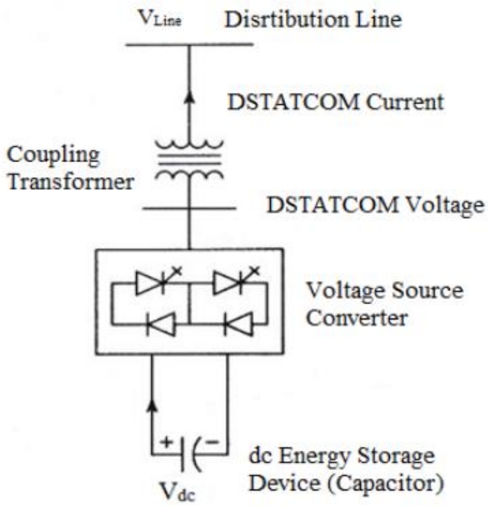

Fig. 1. Structure of DSTATCOM

DSTATCOM is a convention power device, connected in shunt manner with the load and consists of a dc-link capacitor; IGBT/diodes based VSC, and coupling inductor shown in Fig.1.

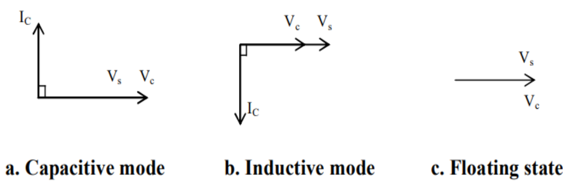

Fig. 2. Operation modes of DSTATCOM

- Capacitive mode, $V_D > V_S$, The DSTATCOM provides reactive power to the grid.
- Floating mode, $V_D = V_C$.
- Inductive mode, $V_D < V_S$, the DSTATCOM absorbs reactive power from the grid.

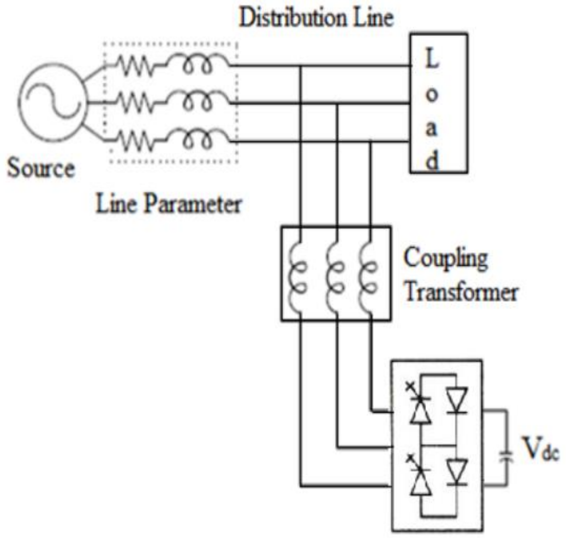

Fig. 3. Three-phase distribution line with DSTATCOM

In DSTATCOM the capacitor of 2200 microfarads is connected at the inverter input side.

The Energy stored in the capacitor is directly proportional to the capacitors voltage. This voltage is used to control inverter voltage [3].

III. ALGORITHM FOR REFERENCE CURRENT GENERATION

The desired quantity of reactive power is supplied by DSTATCOM such that reactive power compensation is achieved. The unity power factor was achieved by the supplying the average active power to the load from the Source supply. Fig. 4 shows the 3phase four-wire distribution system with DSTATCOM.

A. Extraction of Sequence Components

Due to distorted supply voltages and currents, the IRP algorithm fails to compensate for the supply currents. Hence to overcome this problem the sequence components are extracted, by using a sequence analyzer block the magnitude and phase angle are determined as shown in Fig.5.

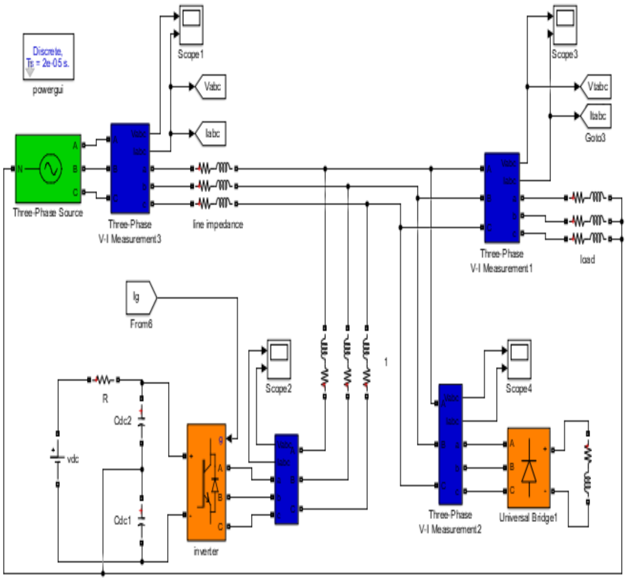

Fig. 4. Simulink model of the Distribution system

By using these magnitude and phase angles, various mathematical equations will be generated respectively. Equation (1) indicates the positive sequence voltages with three-phase instantaneous. Here, for synchronizing, only one phase is used.

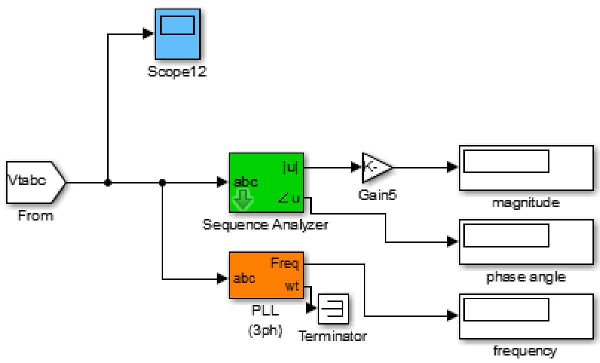

Fig. 5. Extraction of positive sequence component

$$V_{ta1}^{pos}(t)=|V_{ta1}^{pos}|\sqrt{2}\sin\left(\omega t+\angle V_{ta1}^{pos}\right) \quad (1)$$

$$V_{tb1}^{pos}(t)=|V_{ta1}^{pos}|\sqrt{2}\sin\left(\omega t-\frac{2\pi}{3}+\angle V_{ta1}^{pos}\right) \quad (2)$$

$$V_{tc1}^{pos}(t)=|V_{ta1}^{pos}|\sqrt{2}\sin\left(\omega t+\frac{2\pi}{3}+\angle V_{ta1}^{pos}\right) \quad (3)$$

B. Voltage control of DC-link capacitor

The losses generated in the inverter are optimized by reducing the DC link capacitor voltages with respect to its periodical manner of steady-state operation. The PI controller is results the switching loss and by maintaining the proper capacitors voltage, all the losses will be optimized with perfect power balance.

$$V_{error}=2V_{dcr}-(V_{dc1+}V_{dc2}) \quad (4)$$

$$P_l=K_pV_{error}+K_i\int V_{error}dt \quad (5)$$

Let P_l is a total power loss, which is obtained by using a PI controller as shown in Fig.6.

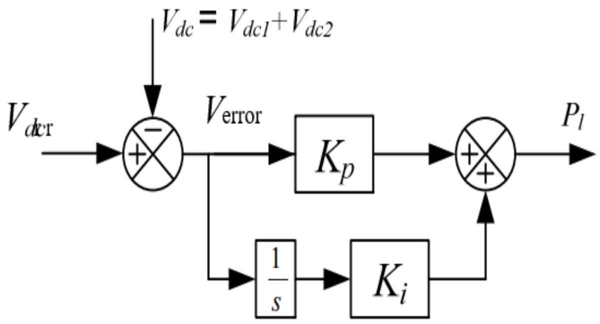

Fig. 6. Computation P_l using a PI controller

C. Extraction of reference compensator currents

The three-phase instantaneous positive sequence components are extracted and converted into two (α, β) stationary frames of reference quantities by using Clark's transformations as shown below (3).

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{ta1}^{pos}(t) \\ V_{tb1}^{pos}(t) \\ V_{tc1}^{pos}(t) \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (7)$$

The voltage and currents, which are obtained after the (α, β) transformation, the instantaneous powers are calculated as follows

$$P=v_\alpha i_\alpha+v_\beta i_\beta \quad (8) \qquad q = v_\alpha i_\beta-v_\beta i_\alpha \quad (9)$$

Where q and p are represented as the instantaneous reactive and real power in the system.

The matrix sort of instantaneous real and reactive power follows as

$$\begin{bmatrix} P \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (10)$$

The instantaneous reactive and real power components consisting of both double and average frequencies indicated as follows

$$p=\bar{p}+\tilde{p} \qquad (11)$$

$$q=\bar{q}+\tilde{q} \qquad (12)$$

The average real power is supplied by source and the compensator should supply the oscillating DC and reactive power. The losses taking place in the inverter are supplied by the source. The reference source currents are computed by the following equations

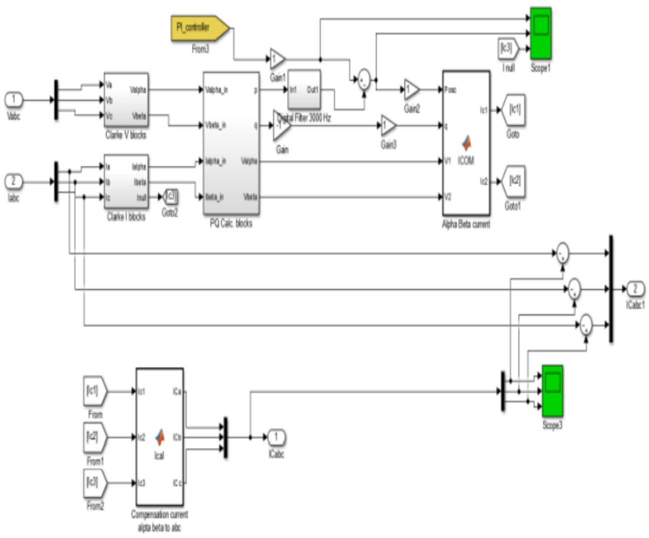

Fig. 7. Controller for DSTATCOM

$$\begin{bmatrix} i_{s\alpha}^{*} \\ i_{s\beta}^{*} \end{bmatrix} = \frac{1}{\delta}\begin{bmatrix} v_{\alpha} & -v_{\beta} \\ v_{\beta} & v_{\alpha} \end{bmatrix}\begin{bmatrix} \bar{p}+p_{l} \\ q \end{bmatrix} \qquad (13)$$

$$\delta = v_{\alpha}^{2} + v_{\beta}^{2} \qquad (14)$$

By using inverse Clark's transformation, three-phase source currents are generated from the two-phase currents respectively.

$$\begin{bmatrix} i_{sa}^{*} \\ i_{sb}^{*} \\ i_{sc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_{s\alpha}^{*} \\ i_{s\beta}^{*} \end{bmatrix} \qquad (15)$$

The injected currents are obtained by subtracting of reference source currents from load currents and the currents remaining other than reference source currents are supplied by DSTATCOM to achieve load compensation and reduction unbalance in voltages.

$$i_{fk}^{*}=i_{lk}-i_{sk}^{*} \qquad (16)$$

$$k = a, b, c.$$

The injecting currents from VSI should be an equal amount of calculated reference injection currents i_{fk}^{*}. Hysteresis controlled PWM technique was utilized to generate the required switching pulses for VSI. The Generation of reference compensating currents is extracted by using the MIRP algorithm as shown in Fig.7.

D. Hysteresis controlled PWM

Hysteresis current-controlled PWM method has more advantages than other current-controlled PWM methods. This method provides ease of implementation, fast response, and simple in approach [6].

$$u=-hys(K|z-z_r|)=hys(w) \quad (17)$$

If $w < -h$ then $u=+1$ $\{S=1, \overline{S}=0\}$

If $w > -h$ then $u=-1$ $\{S=0, \overline{S}=1\}$

Where ‘S’ is the status of the switch and ‘h’ is the small limit around the origin.

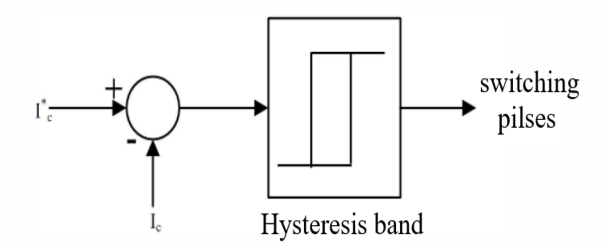

Fig. 8. Hysteresis band current controller

The switching pulses for VSI are generated by using the Hysteresis band as shown in Fig.7.

IV. SIMULATION AND RESULTS

The three-phase four-wire distribution system with the DSTATCOM model has been implemented in MATLAB/ SIMULINK environment.

A. Simulation Modelling

The distribution system is simulated using three- phase unbalanced and non-linear loads with DSTATCOM connected across PCC. Non-linear load consists of an uncontrolled three-phase diode rectifier with RL load. The DSTATCOM is implemented with three leg VSI with IGBT has a split DC capacitor configuration and semiconductor switch. The detailed DSTATCOM model is described in Fig.4. The simulation parameters are specified below.

TABLE I. System configuration

Simulation parameters	**values**
Feeder impedance per phase	Z_s=2+3.14 Ω /ph
Hysteresis band	h=±0.2 A

Unbalanced load	R_{la}=30 Ω, X_{la}=40 mH R_{lb}=41 Ω, X_{lb}=75 mH R_{lc}=24 Ω, X_{lc}=60 mH
Non-linear load	Uncontrolled three-phase rectifier with RL load of 200 Ω, 10mH Respectively.
VSI parameters	V_{dc}=500 V(each) C_{dc}=2000 μf(each)
LC filter parameters	L_f= 2 mH, R_f=0.1 Ω.
Source voltage(L-L)	400Vrms, 50Hz

B. Simulation and Results

Detailed simulation results for the above implemented system are shown in Fig.9 and Fig.10.

a) With Out DSTATCOM

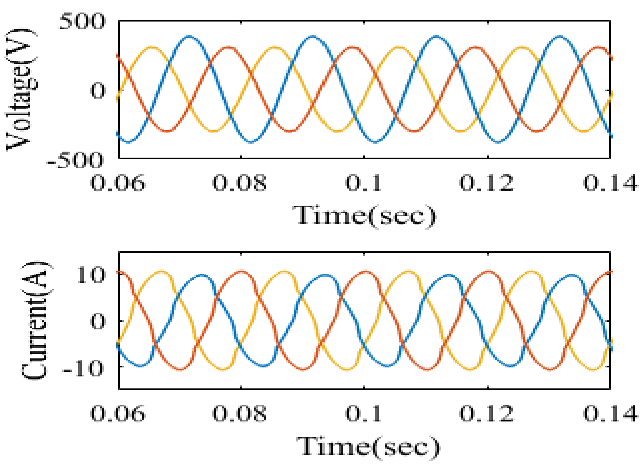

Fig.9(a). Distorted source voltages and currents

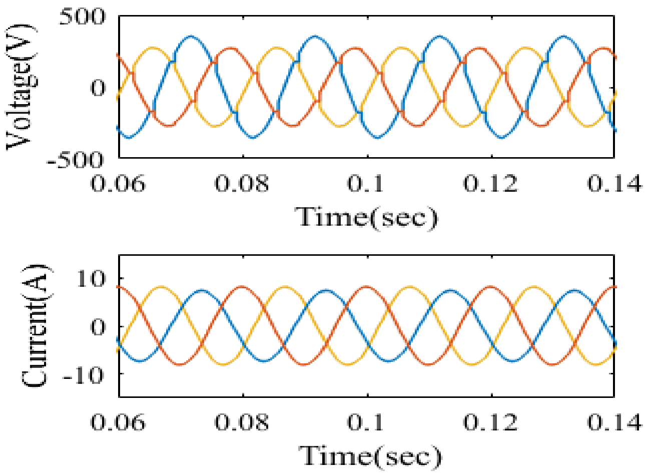

Fig.9(b). Unbalance load voltages and currents

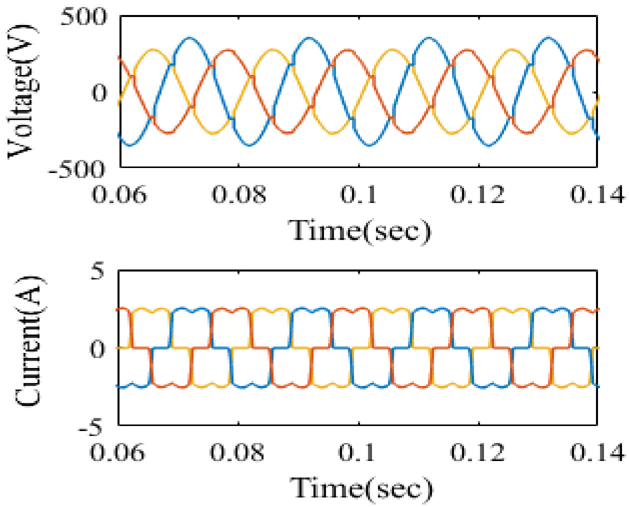

Fig.9(c). Non-linear load voltages and currents

The above simulation results are obtained when DSTATCOM is not placed in the distribution system. We observed that there is an unbalance in source voltages and currents as shown in Fig 8(a). The load side also due to unbalanced and non-linear loads the voltage and currents contain harmonics and distortions.

b) With DSTATCOM compensation

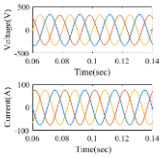

Fig.10(a). compensated source currents and voltages

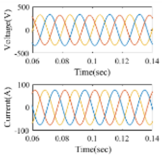

Fig.10(b). Compensated load currents and voltages

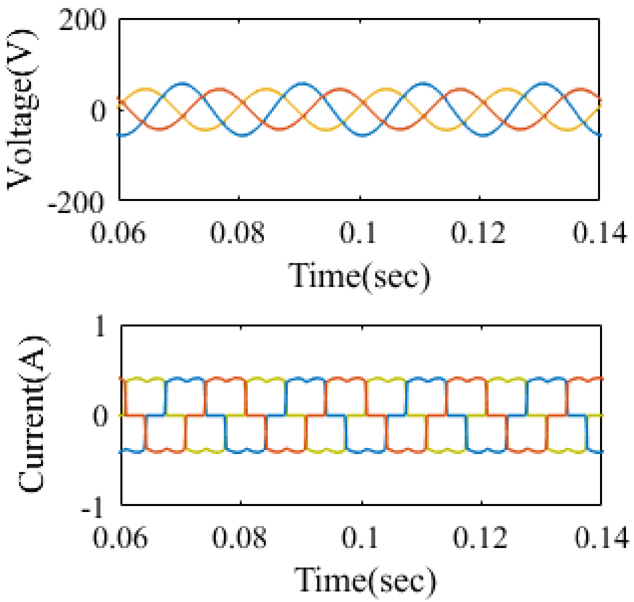

Fig.10(c). compensated Non-linear load side currents and voltages

The DSTATCOM is connected to the distribution system and the simulation results are obtained as shown in Fig.9. It is observed that the source voltages and currents were compensated satisfactorily. And the source power factor was maintained at unity power factor.

It is also observed that in the source voltages and currents each phase was approximately equal in magnitudes and phase and same peak values so that the unbalance in source voltages and currents is reduced. So that the current in the neutral wire is reduced to an approximately zero and the power loss in the distribution system is also effectively reduced.

Hence the Modified instantaneous reactive power theory (MIRP theory) algorithm satisfactorily compensates the source currents even under influence of harmonics and distortions. And the load is also effectively balanced by using of MIRP theory.

V. CONCLUSION

A MIRP control algorithm of DSTATCOM has been used for compensation and balancing of three-phase non-linear and unbalanced loads. From the experimental results of MATLAB/SIMULINK simulations, it is concluded that the proposed MIRP -algorithm perfectly compensates the reactive power and reduces the unbalance in source currents and voltages so that the unity power factor was obtained for all undesirable voltage conditions presented across the source side. The introduced positive sequence extraction in the MIRP algorithm is an effective method for neutralizing the current related power quality problems existed in a modern distribution system involving non-linear and power electronic devices.

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