

An Approach to Load Balancing & Unity Power Factor Control in Multi-phase (Six-phase) Load Circuits Using Multi-phase DSTATCOM

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Abstract—Multi-phase loads, with phases more than three, especially in form of inverter fed induction motor drives suited to high power and specialized applications, are receiving growing attention in the literature. This multiphase source for such drive application may be derived from transformer connection (3 phase to 6 phase) or by DC link six phase inverters. These sources will face the problem of unbalance, harmonic distortion and poor power factor operation. In view of these developments, this paper deals with the supply side load balancing and power factor correction in such load circuits. The proposed compensation scheme uses the shunt current source compensation whose instantaneous values are determined by the instantaneous symmetrical component theory. An ideal compensator in place of physical realization of the compensator has been proposed in the form of a current controlled voltage source inverter. The compensation scheme developed in the paper is tested for their validity on 6-phase (6-wire & 7-wire) circuits through extensive simulations for unbalanced loading, phase outages, and non linear loading. The simulation results of the compensation theory and the ideal compensator verify the compensation method.

Index Terms— Load balancing, Power factor correction, Compensator, Six-phase DSTATCOM, Multi-phase

I. INTRODUCTION

DU E to the potential benefits resulting from the use of a phase order higher than three in transmission, multi-phase (phase order more than three) machine drives are gaining growing attention [1-3] in recent years, due to their several inherent benefits such as reduced torque pulsation, harmonic content, current per phase without increasing the voltage per phase, higher reliability and increased power in the same frame as compared to their three phase counterpart. Multi-phase inverter fed induction motor drives have been found to be quite promising for high power ratings and other specialized applications. The use of such drives and devices present multi-phase load circuits that may get subjected to phase outages, unbalanced as well as non-linear loadings similar to their three phase counterparts. Such conditions may lead to variety of undesirable effects on the supply system such as additional losses in connecting lines and interfacing devices, oscillatory torques in ac machines, increased ripple in rectifiers, malfunctioning in sensitive equipments, harmonic and excessive neutral currents etc. It is therefore desired to have the balanced

power system operation with minimum lower order harmonics even in the presence of such operations.

A current literature survey reveals that a number of methods have been evolved for the compensation of harmonics and unbalances [4-12] for the conventional three phase systems. The majority of the methods are based on the instantaneous reactive power theory [4-8], theory of symmetrical components [6-9], and reference frame theory [10-11]. Utilizing these theoretical concepts, techniques have been developed for balancing three phase load [6-7], power factor correction [7-8], voltage regulation [4-9] and meeting other objectives.

This paper addresses the problem of balancing an unbalanced multi-phase load and power factor correction on supply side. It is to be noted that active power compensation requires a source, which can supply the real power to load. Theoretically although possible, but practically a power source at load center requires distributed generation sources. This paper assumes a conventional power system with central generating station and therefore active power compensation is not considered. The reactive power compensation can be achieved by various Power conditioning devices like DSTATCOM realizing variable capacitor or inductor with the load circuit. The amount of compensation and the aim of compensation decide the control strategy of the power conditioner. The reactive power compensation requires the measurement of reactive power of the load circuit. Alternatively, an indirect method such as current equalization or phase constraint can be employed to realize the desired compensation for the load circuits. A new compensation technique has been proposed using the instantaneous symmetrical components in [12-13]. The proposed technique compensates for the reactive power without specific measurement of reactive power in an alternate way, i.e. determining the reference current of the shunt current source compensated system by instantaneous symmetrical component. This paper presents the scheme for compensation for 6-phase (6-wire & 7-wire) star connected load compensation. The proposed compensation scheme has been supported by simulation of an ideal switch based compensator.

II. MULTIPHASE COMPENSATOR

A. Compensation Principle

The basic compensation scheme for multi-phase (6-phase) load supplied from a balanced stiff multi-phase

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source is shown in Fig 1. A compensator represented as current source connected in parallel to the load at the node called Point of Common Coupling (PCC) is designed to supply the reactive power required by the load, whereas the active power is supplied from the source.

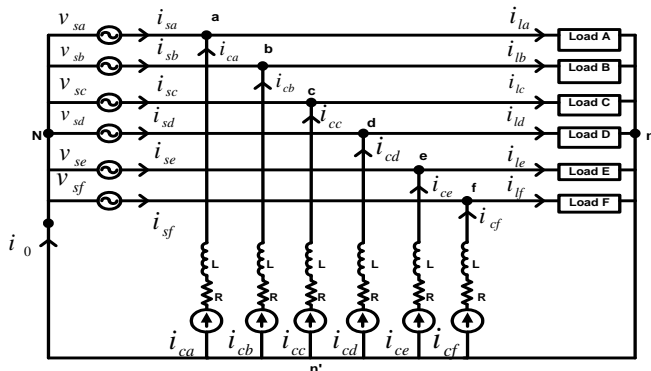


Fig. 1 A Conceptual Six-phase, 7-wire compensation scheme

Single-phase impedance loads connected in star formation can represent a general six-phase load or a multiphase load. The three nodes of the circuit represented graphically in Fig. 1 by n , N and n' represent nodes at load, source and compensating current sources respectively. The node N may be either floating or connected with load point n as per the requirement of the source and the load. Connecting n with n' forms a local loop of the compensator current sources and load circuit. This results phase wise in independent operation of compensator from the supply voltage sources. As a consequence, unbalanced operation of the compensator can be achieved, i.e. the sum of the compensator reference currents $i_{ca}^*, i_{cb}^*, \dots, i_{cf}^*$ need not be zero. Therefore, each phase of the compensator can supply current independent to other phases.

B. A Six-phase Symmetrical Component Theory

Let an unbalanced six phase instantaneous load currents be denoted by $i_a, i_b, i_c, i_d, i_e, i_f$ whereas the corresponding sets of six balanced symmetrical components are represented by $i_{a0}, i_{a1}, i_{a2}, i_{a3}, i_{a4}, i_{a5}$. The power invariant instantaneous symmetrical components of these currents are given by (1).

$$\begin{bmatrix} i_{a0} \\ i_{a1} \\ i_{a2} \\ i_{a3} \\ i_{a4} \\ i_{a5} \end{bmatrix} = \frac{1}{\sqrt{6}} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & b & b^2 & -1 & b^4 & b^5 \\ 1 & b^2 & b^4 & 1 & b^2 & b^4 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & b^4 & b^2 & 1 & b^4 & b^2 \\ 1 & b^5 & b^4 & -1 & b^2 & b \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_d \\ i_e \\ i_f \end{bmatrix} \quad (1)$$

Where $b = \exp(j2\pi/6)$. All the six components are graphically represented in Fig. 2.

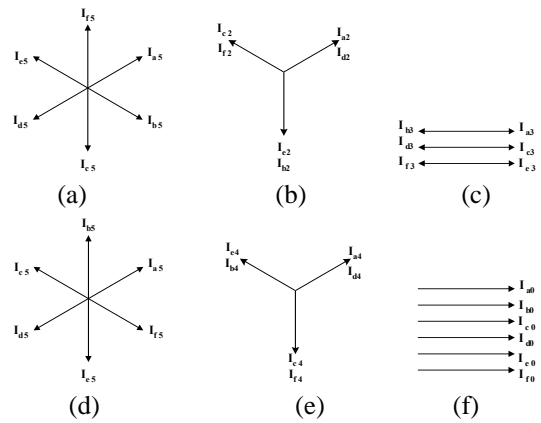


Fig. 2 Sequence components of a six-phase source (a) First-sequence (b) Second-sequence (c) Third -sequence (d) Fourth-sequence (e) Fifth-sequence (f) Sixth- sequence component.

The first-(positive) sequence component system consists of six phasors displaced 60° relative to each other whereas the second-sequence component system consists of three phasor displaced 120° relative to each other, each phasor representing two phases- constituting two three-phase superimposed positive sequences. The third-sequence component system has two phasors displaced 180° relative to each other, each representing three phases constituting two three-phase zero sequences in opposition whereas the fourth- sequence component system is a sequence in the opposite sense of rotation to that of the second-sequence system. Similarly, the fifth-(negative) sequence component system is a sequence of phasors in the opposite sense of rotation to that of the first-sequence system. The sixth sequence component also known as zero sequence components has all the six phasors placed at zero degree apart to each other. It is to be noted that the instantaneous vector pairs i_{a1}, i_{a5} and i_{a2}, i_{a6} are complex conjugate pairs whereas i_{a0} and i_{a3} are real quantities, which is zero, if mains currents are balanced.

C Derivation of Reference Currents

The aim of the compensator is to make the source current balanced and operates at desired power factor. As said earlier, the amount of the shunt current required to make the source current balanced in presence of unbalanced load, is referred as the reference current. There are six compensating current and therefore six linearly independent simultaneous equation need to be formulated and solved. As known from the symmetrical component theory, a balanced system of current, the zero sequence components will have zero summation value. Accordingly, to provide balanced source currents, the zero sequence components added together must be zero i.e.

$$i_{sa} + i_{sb} + i_{sc} + i_{sd} + i_{se} + i_{sf} = 0 \quad (2)$$

The degree of compensation required for a system is decided by share of the reactive power supplied by the load with respect to amount of reactive power supplied by the compensator. In most ideal situation, the compensator may be required to compensate completely the load reactive power. However, this requires a large size of compensating

device, wasting completely the capability of the source to supply the reactive power. Therefore, all the practice compensators are expected to partially compensate.

Let ϕ be the desired the power factor angle between v_{sa1} and i_{sa1} (positive sequence components), then the following equation must hold true.

$$\begin{aligned} \angle(v_{sa} + bv_{sb} + b^2v_{sc} - v_{sd} + b^4v_{se} + b^5v_{sf}) = \\ \angle(i_{sa} + bi_{sb} + b^2i_{sc} - i_{sd} + b^4i_{se} + b^5i_{sf}) + \phi \end{aligned} \quad (3)$$

For a balanced operation, all sequence components except positive sequence will be zero. For a balanced circuit, the following holds true.

$$i_{sa} = -i_{sd}, \quad i_{sb} = -i_{se}, \quad i_{sc} = -i_{sf} \quad (4)$$

Let the instantaneous real power of the load be given by

$$v_{sa}i_{sa} + v_{sb}i_{sb} + v_{sc}i_{sc} + v_{se}i_{se} + v_{sf}i_{sf} = P_{lav} \quad (5)$$

Solving (3), by taking $b = e^{j\pi/3}$ we obtain

$$\phi / 2 = \angle(A - B) \quad (6)$$

where, $A = v_{sa} + b^2v_{sb} + b^4v_{sc}$ and $B = i_{sa} + b^2i_{sb} + b^4i_{sc}$

Taking tangent on both sides of (6) and solving together (2) to (6) for i_{si} ($i = a, b, \dots, f$); all the source currents, in the balanced operation of the power system, can be explicitly defined in terms of the other variables. Phase 'a' current i_{sa} is shown in (7) as an example.

$$i_{sa} = \frac{v_{sa} + (v_{sb} - v_{sc})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (7)$$

Where, $\gamma = \tan \frac{\phi}{\sqrt{3}}$ and $|\Delta| = v_{sa}^2 + v_{sb}^2 + v_{sc}^2$

It is to be noted that the calculated source currents are for balanced operation of an unbalanced load. If the compensator is designed in such a way that the unbalance component of the load currents is supplied by the compensator and balanced component from the source, KCL at node point of common coupling (PCC) will give the reference current for compensator (8) to (13)

$$i_{ca}^* = i_{la} - \frac{v_{sa} + (v_{sb} - v_{sc})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (8)$$

$$i_{cb}^* = i_{lb} - \frac{v_{sb} + (v_{sc} - v_{sa})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (9)$$

$$i_{cc}^* = i_{lc} - \frac{v_{sc} + (v_{sa} - v_{sb})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (10)$$

$$i_{cd}^* = i_{ld} + \frac{v_{sa} + (v_{sb} - v_{sc})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (11)$$

$$i_{ce}^* = i_{le} + \frac{v_{sb} + (v_{sc} - v_{sa})\gamma}{\Delta} \frac{P_{lav}}{2} \quad (12)$$

$$i_{cf}^* = i_{lf} + \frac{v_{sc} + (v_{sa} - v_{sb})\gamma}{|\Delta|} \frac{P_{lav}}{2} \quad (13)$$

For practical realization of the compensator, a current controlled voltage source inverter can be used for the current source with the reference current, derived above, tracking. In next section, an ideal switch and diode based compensator has been proposed for a six-phase load.

III. A SIX-PHASE COMPENSATION REALIZATION

Current controlled voltage source inverter can do a practical realization of the compensator. Using this principle, an ideal switch based compensator is proposed. Let it be called as a six-phase DSTATCOM as its circuit topology is an extension of a conventional three-phase DSTATCOM. The topological description of the proposed six-phase DSTATCOM, its circuit analysis and methodology of simulation for verification are briefly discussed as follows

A. Topology of Six-Phase DSTATCOM

The topology of the proposed six-phase DSTATCOM has been derived from its three-phase counterpart where an inverter circuit is employed with a self-charged capacitor as DC source and unbalanced load circuit connected at PCC as load to the inverter. The proposed six-phase compensator consists of six arms of a single-phase H- inverter circuits as shown in Fig.3 with split capacitor for providing the neutral point n' of the compensator.

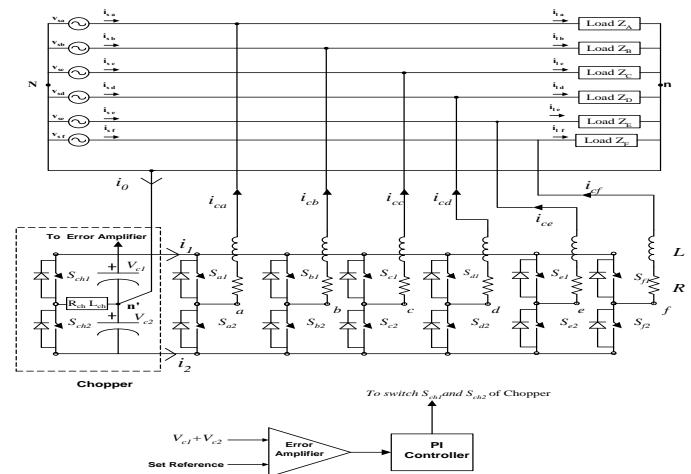


Fig. 3. Six-phase 7-wire distribution System with DSTATCOM

B. Analysis of six-phase DSTATCOM

To illustrate the working of the converter, phase -a of the six-phase compensator shown in Fig.3 has been analyzed. The equivalent circuit of phase 'a' with switch S_{a1} closed is shown in Fig.4. The current through the switch S_{a1} is the series current i_{ca} , which can be determined by applying KVL for the circuit.

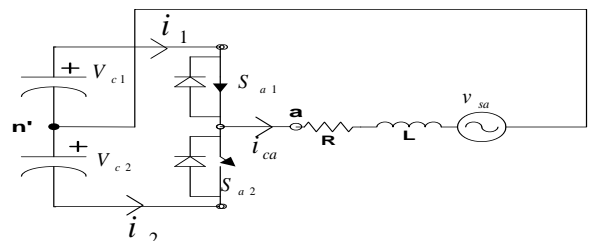


Fig. 4 Equivalent Circuit for Phase 'a' operation of the converter with switch S_{a1} closed

The resulting equation is given by (14)

$$\frac{di_{ca}}{dt} = -\frac{R}{L}i_{cb} + S_a V_{c1} - \bar{S}_a \frac{V_{c2}}{L} - \frac{v_{sa}}{L} \quad (14)$$

Where S_a is switching function defined by (15) and \bar{S}_a is complement of the switching function S_a .

$$S_a = \begin{cases} 1 & \text{if switch is on} \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

The sources are assumed to be ideal and the impedance blocks shown in Fig. 1 express loads for each phase. For a physical realization of the converter circuit, the loss occurring in all the elements of the compensator and connecting inductor or transformer must be compensated by exchange of real power from source to DC side capacitor of the DSTATCOM. Therefore the reference currents expressed in (8-13) are replaced by additional loss term (P_{loss}) in the power. The modified version for compensator current for phase-a is given by (16).

$$i_{ca}^* = i_{la} - \frac{\{v_{sa} + \xi(v_{sb} - v_{sc})\}}{|\Delta|} (P_{lavg} + P_{loss}) \quad (16)$$

B. Mathematical Modeling and Simulation for Six-phase DSTATCOM

Simulations have been carried out for the proposed six-phase DSTATCOM to validate the proposed compensation scheme. The state space equations has been written in terms of the switching functions (S_a, S_b, \dots) of the converter and (S_u & S_l) of chopper of the DSTATCOM and solved by Runge-kutta method in MATLAB by ode45 function. The state space equations of the six-phase compensator system are given in (17-22).

$$\frac{di_{ca}}{dt} = -\frac{R}{L}i_{ca} + S_a \frac{V_{c1}}{L} - \bar{S}_a \frac{V_{c2}}{L} - \frac{v_{sa}}{L} \quad (17)$$

$$\frac{di_{cb}}{dt} = -\frac{R}{L}i_{cb} + S_b \frac{V_{c1}}{L} - \bar{S}_b \frac{V_{c2}}{L} - \frac{v_{sb}}{L} \quad (18)$$

$$\frac{di_{cc}}{dt} = -\frac{R}{L}i_{cc} + S_c \frac{V_{c1}}{L} - \bar{S}_c \frac{V_{c2}}{L} - \frac{v_{sc}}{L} \quad (19)$$

$$\frac{di_{cd}}{dt} = -\frac{R}{L}i_{cd} + S_d \frac{V_{c1}}{L} - \bar{S}_d \frac{V_{c2}}{L} - \frac{v_{sd}}{L} \quad (20)$$

$$\frac{di_{ce}}{dt} = -\frac{R}{L}i_{ce} + S_e \frac{V_{c1}}{L} - \bar{S}_e \frac{V_{c2}}{L} - \frac{v_{se}}{L} \quad (21)$$

$$\frac{di_{cf}}{dt} = -\frac{R}{L}i_{cf} + S_f \frac{V_{c1}}{L} - \bar{S}_f \frac{V_{c2}}{L} - \frac{v_{sf}}{L} \quad (22)$$

The chopper dynamics has been realized by writing the state space equations for the circuit shown in Fig. 3. Let i_1 and i_2 be the currents in circuit of the chopper (Fig. 3), then (23) and (24) represents the relation of these in terms of switching function and the converter currents.

$$i_1 = S_a i_{ca} + S_b i_{cb} + S_c i_{cc} + S_d i_{cd} + S_e i_{ce} + S_f i_{cf} \quad (23)$$

$$i_2 = \bar{S}_a i_{ca} + \bar{S}_b i_{cb} + \bar{S}_c i_{cc} + \bar{S}_d i_{cd} + \bar{S}_e i_{ce} + \bar{S}_f i_{cf} \quad (24)$$

The final expressions (25) - (27) can be obtained by applying the principle of KCL and KVL.

$$\frac{V_{c1}}{dt} = -S_a \frac{i_{ca}}{C} - S_b \frac{i_{cb}}{C} - S_c \frac{i_{cc}}{C} - S_d \frac{i_{cd}}{C} - S_e \frac{i_{ce}}{C} - S_f \frac{i_{cf}}{C} - S_u \frac{i_{ch}}{C} \quad (25)$$

$$\frac{V_{c2}}{dt} = \bar{S}_a \frac{i_{ca}}{C} + \bar{S}_b \frac{i_{cb}}{C} + \bar{S}_c \frac{i_{cc}}{C} + \bar{S}_d \frac{i_{cd}}{C} + \bar{S}_e \frac{i_{ce}}{C} + \bar{S}_f \frac{i_{cf}}{C} + S_l \frac{i_{ch}}{C} \quad (26)$$

$$\frac{di_{ch}}{dt} = \frac{R_{ch}}{L_{ch}} + S_u \frac{V_{c1}}{L_{ch}} - S_l \frac{V_{c2}}{L_{ch}} \quad (27)$$

The variables used in the expressions (25)-(27) are indicated in the circuit diagrams. The capacitor voltages reduce if not compensated for the losses in the connecting transformer/ inductor, which can be accounted by changing the duty cycle of the chopper. The change in duty of the chopper is based on the change in the capacitor voltage from the set reference voltage. The difference in the capacitor voltage and set voltage (i.e. the error voltage) is put forward to a proportional-integral (PI) controller. The PI controller estimates the P_{loss} component as stated in (16) and determines the duty cycle of the chopper to maintain the capacitor voltage at a pre specified set reference voltage. The set values are taken approximately 1.3 times the peak AC voltage of the source voltage for compensator to work satisfactorily.

IV. SIMULATION STUDIES

The simulation study has been carried out to validate the proposed six-phase DSTACOM for various cases of unbalanced loadings, and phase outages. The results and analyses for each case are discussed in the sections to follow.

A. Compensation of unbalanced Loads

The simulation of the converter and compensator has been carried with the following parameters. The voltages v_{sp} ($p = a, b, c, d, e, f$) and the impedances Z_p ($p = a, b, c, d, e, f$) all in ohm for the six-phase system are employed as follows.

$$v_{si} = 325.26 \sin(100\pi t - i^* \pi / 3), \text{ where } i = 0, 1, 2, 3, 4, 5 \text{ corresponding to phase a, b, c, d, e, f respectively.} \\ Z_a = 25 + j25, Z_b = 15 + j20, Z_c = 10 + j20, \\ Z_d = 20 + j25, Z_e = 20 + j5, Z_f = 30 + j30 \quad (28)$$

The isolation transformer parameters are as follows:

$$R = 1 \Omega \text{ and } L = 200 \text{ mH.}$$

The control parameters for regulating the capacitor voltage of the chopper are adjusted heuristically and are given in (29).

$$K_p = 1 \quad K_i = 10 \quad (29)$$

The inverter current and capacitor have voltage hysteresis band of 100 Ma and 40V respectively. It is desired that the source current be balanced and the source operates at unity power factor under this condition. The system is run, with unbalanced load for one cycle (0.02 sec) which follows turning **on** of the DSTATCOM. The system is run with compensator for another three cycles (0.08 sec). It can be

seen from Fig. 5 (b) and Fig. 5(c) that the load currents are highly unbalanced and equal when compensator is not turned **on**. After 0.02 sec. when the compensator is turned **on** source currents are perfectly balanced as shown in Fig. 5 (c). In order to compensate the unbalanced load currents, the compensator currents become unbalanced accordingly as shown in Fig. 5(d).

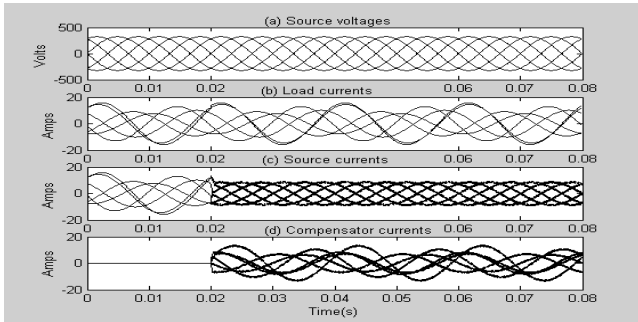


Fig. 5 Variation of source voltages and load current, source and compensator currents for 6-phase 7-wire supply system.

The three instantaneous powers namely source; load and compensator powers are shown in Fig. 6 (a) & (c), while two neutral currents (source & load neutral currents) are plotted in Fig. 6 (b). It can be seen that before compensation, that is, when compensator is switched **off**, source power and load power have the same magnitude and are of oscillating nature as shown in Fig. 6 (a). This is due to unbalance in load currents. But after compensation (when compensator is turned **on**) the source power attains a steady state value as can be seen from Fig. 6 (a) while load power is oscillating Fig. 6(a). Moreover, the source neutral current attains zero value as shown in Fig. 6(b) when the compensator is turned **on** as it balances the source currents. This also implies that the sum of the instantaneous compensator currents is equal to load neutral current

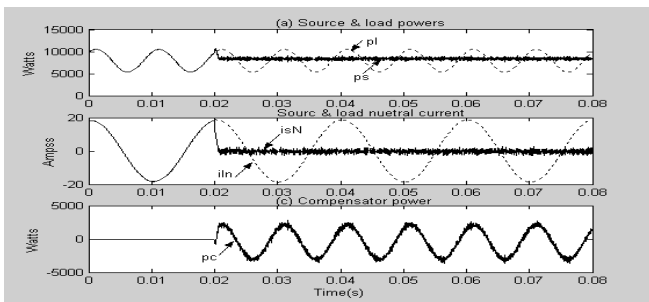


Fig. 6 Variation of power and neutral current for a 6-phase 7-wire supply system

The variation of cophasors-voltage and currents shows unity power factor operation with compensator as it is evident from Fig.7 It can be seen from (28) that impedances are unbalanced and have all reactive elements except one, but the currents are not only balanced but also operate at unity power factor with compensator

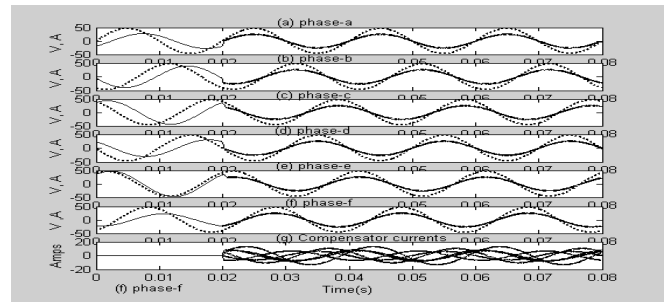


Fig. 7 (a)-(d) (1:7) scaled source voltages (dashed line), source currents (solid line) (e) variation of compensator currents portraying unity power factor operation for a 6-phase 7-wire supply system

The D.C. link capacitor maintains the constant voltage through the PI controller. The voltage variation of individual capacitor is shown in Fig. 8. Please note that the capacitor voltage is assumed to be initially charged or pre-charged

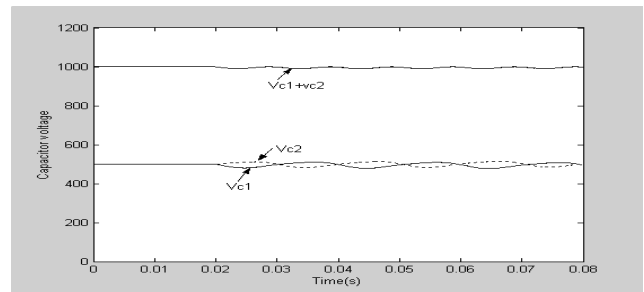


Fig 8 Capacitor voltage variation

B. Load Compensation for phase outages

The advantages of loads like motor in its capacity to operate The advantage of multiphase loads like motor is in its capability to operate with phase outage. The motor operates with degraded performance and source sees an unbalanced operation and therefore other loads connected to such a source get affected. The proposed compensator has been tested with various combination of phase outages and it has been found that it works satisfactorily even with three phases open (with phase outage (a, b, c)) in a six phase source. The result is shown in Fig. 9 & 12 where the entire source currents are balanced with compensator **on**.

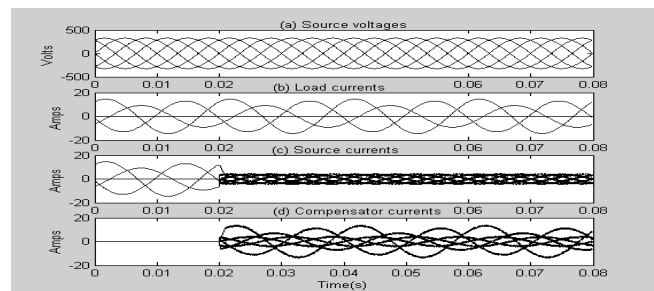


Fig. 9 Variation of source voltage & various currents for the phase outage (a, b, c) of the load for a 6-phase supply system.

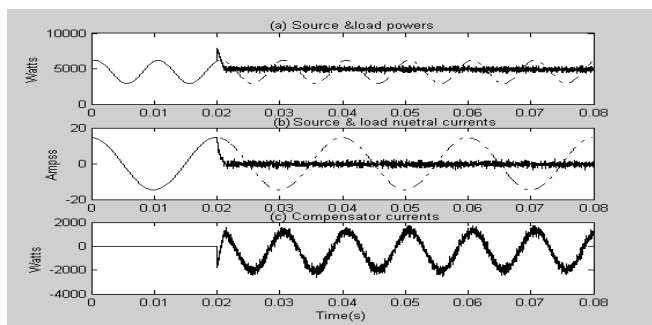


Fig. 10 Variation of powers and neutral currents for phase phase outage (a, b, c) of load for a 6-phase supply system

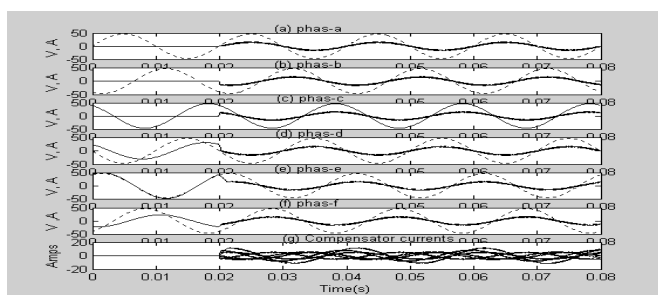


Fig. 11 (a)-(d) (1:7) Scaled source voltages (dash line), source currents (solid line) & (e) variation of compensator currents portraying unity power factor operation for phase outage (a, b, c) of the load for a 6-phase supply system.

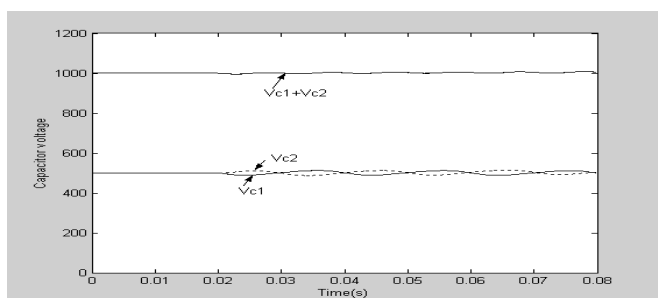


Fig. 12 Capacitor voltage variation for phase outage (a, b, c) of the load for a 6-phase supply system.

C. Load Compensation for non-linear load

The proposed compensation scheme has also been tested with nonlinear loadings by simulating a rectifier load for each phase drawing a constant d.c. current from each phase. The simulation results are presented in Figs. 13-16. A brief summary of observation is as follows:

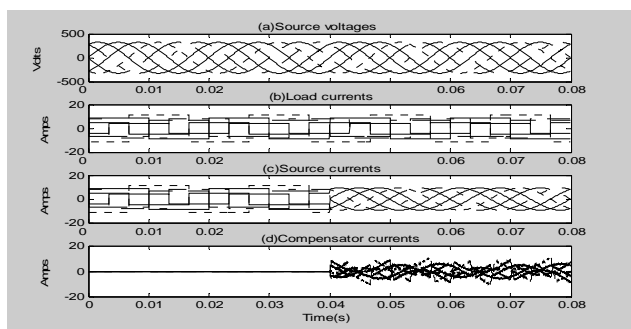


Fig. 14 Variation of source voltage & various currents for a 6-phase supply system

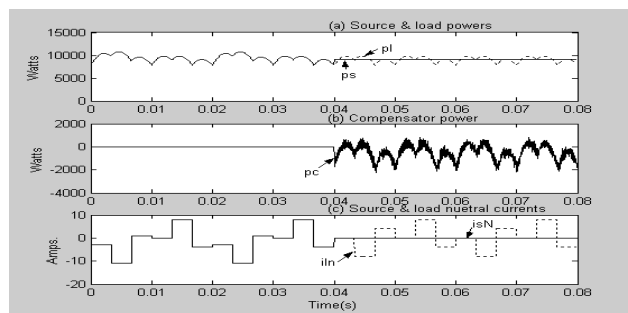


Fig. 15 Variation of powers and neutral currents with non linear loading for a 6-phase supply system

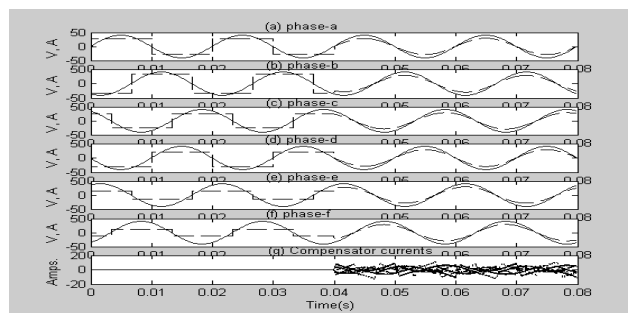


Fig. 16 (a)-(d) (1:8) scaled source voltages (solid line), source currents (dash line) (e) variation of compensator currents portraying unity power factor operation for a 6-phase supply system

V. CONCLUSION

In this paper, the problem of load balancing and power factor correction at the source side for multi-phase load circuits in the event of linear unbalance loading, phase outages and non-linear loadings have been addressed. For the purpose, a multi-phase compensator (6-phase) have been realized as a multi-phase DSTACOM extending the approach developed for three phase system in the literature. The dynamic behavior of the compensator is also simulated during the load compensation process. An elaborate study has also been made on source voltages, load currents, source currents, and compensator currents during non-compensating and compensating period. The capacitor voltage variations and the variation of the load and source powers are also analyzed. The variation of the compensator power at the time of its rise has been explained. The analysis has confirmed unity power factor operation of the source in all cases as evidenced by the voltage and current waveforms.

An interesting aspect of the simulation study has been to observe that multi-phase systems equipped with multi-phase compensator can work with phase outages as high as 3 in 6-phase system respectively without any degradation in supply system quality - a feature most valuable for multi-phase sources and multiphase induction motor drives. The findings of the present study are based on the consideration of only star connected, R-L loads, however, other combination and more realistic model of multi-phase loads may be analyzed employing these development.

REFERENCES

- [1] E. Levi, R. Bojoi, F. Profumo, H. A. Toliyat, S Williamson, "Multi-phase induction motor drives-a technology status review", *Electr. Power Applications, IET*, Vol.1, Issue 4, 2007
- [2] D. Yazdani, A. Khajehoddin, G. Joos, "Full utilization of inverter of split phase derives by mean of a dual three phase space vector", *IEEE Trans. on Industrial Electronics*, Vol. 56, No. 1, 2009
- [3] N. Gule. & M.J. Kamper. "Multiphase cage rotor induction machines derive with direct implementation of brush dc operation" *IEEE Int. Conf. on Electric Machine and Derive*, 2011
- [4] H. Akagi, Y. Kanazawa, K. Fugita and A. Nabe, "Generalized theory of instantaneous reactive power and its application," *Electrical Engg. in Japan*, Vol. 103, No.4, 1983
- [5] H. Akagi, Y. Kanazawa and A. Nabe, "Instantaneous reactive power compensators comparing switching devices without energy storage components", *Trans. on Ind.App.*, vol.1A-20, No.3, 1984.
- [6] H. Akagi, A. Nabe and S. Atosh, "Control strategy of active power filters using multi voltage-source PWM converter", *Trans. on Ind.App.*, vol.1A-22, No.3, 1986
- [7] M. Z. Elsadek, "Balancing of unbalanced loads using static var compensator," *Electr. Powr .Syst. Res.*, Vol. 12, 1987.
- [8] H. Watanabe, R.M. Stephan and M. Aredes, "New concepts of instantaneous active and reactive powers in electrical systems with generic loads," *IEEE Trans. On power Delivery*, Vol. 8, No.2, 1993
- [9] A. Kern and G. Schroder, "A novel approach to power factor control and balancing problems" *Proc., IECON*, 1994
- [10] P. Verdelho, and G.D. Marques, "An active power filter and unbalanced current compensator," *IEEE Trans. On Industrial Electronics*, Vol. 44, No. 3, 1997
- [11] F. Z. Peng, G.W. Ott, Jr., and D.J. Adams, "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire systems," *IEEE Trans. on Power Electroics*, Vol. 13, No. 6, 1998.
- [12] A.Ghosh, A.Joshi, A new approach to load balancing and power factor correction in power distribution system," *IEEE Trans.on power delivery* vol. 15, No.1, 2000.
- [13] Zakir Husain, R.K. Singh, S. N. Tiwari, Balancing of Unbalanced Load Power Factor Correction in Multi-phase (4-phase) Load Circuits using DSTATCOM, WCE, 2010, London, U.K