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Comparison of Control Strategies for DSTATCOM in Power Distribution System

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Comparison of Control Strategies for DSTATCOM in Power Distribution System

Koteswara Rao Uyyuru and Mahesh Kumar Mishra

Abstract

In this paper, the perfect harmonic cancellation (PHC), unity power factor (UPF) control strategies of distribution static compensator (DSTATCOM) are compared along with a newly proposed control strategy. In the proposed strategy, to get the best power factor, the conductance factors for the compensated load are evaluated for a specified source current total harmonic distortion (THD) limit. The performance of this method along with perfect harmonic cancellation (PHC) and unity power factor (UPF) strategies is evaluated on a distribution system model developed using PSCAD 4.2.1. In the distribution system, harmonic resonance is one of the prime factors for the harmonic propagation. Hence, in damping the harmonic resonance, selection of an appropriate control strategy for the DSTATCOM is crucial and this is verified with a detailed study. The simulation results are presented to show the performance of these strategies in load compensation and damping the harmonic propagation in the distribution system.

KEYWORDS: active power filter (APF), distribution static compensator (DSTATCOM), harmonics, optimization, perfect harmonic cancellation, unity power factor

I. INTRODUCTION

The power system is a combination of generating plants, transmission and distribution system. Out of these three systems, distribution system is more prone to power quality problems. It contains loads that are either commercial type or residential type. Usually, the commercial customers are supplied power at a voltage level of 11 kV, whereas the domestic consumers get power supply at 400-440 V. The loads in a distribution system are generally categorized into linear and nonlinear. The current harmonics drawn by the nonlinear loads cause significant pollution in the system. There are two general categories of harmonic sources, one is saturable devices and another is power electronic devices. Saturable devices produce harmonics mainly due to magnetic core saturation. The examples for this type of devices are transformers and machines. For economic reasons, most transformers and motors are designed to operate slightly above knee point of the iron core saturation curve. The resulting magnetizing currents are peaked and rich in the third harmonic. The power electronic loads such as switch-mode power supplies, voltage source converters and pulse-width modulated converters draw the harmonic currents from the supply.

The impact of harmonics in the power system can be broadly classified into short term and long term effects. Short term effects are related to excessive voltage distortion, nuisance tripping of sensitive loads and transformer overheating. The long-term effects cause resistive losses or voltage stresses. The presence of voltage and current harmonics can degrade measuring instruments accuracy. Over loading of neutral wire appear to be the most common problem in the commercial buildings due to additive nature of triplen harmonics [1].

But, due to the use of sensitive loads, there is demand for good quality of power supply from the consumers. The power quality is considered as a combination of voltage and current quality. The utility is obliged to deliver a voltage at the customer's terminal that should remain within certain limits as specified in the standard. The voltage produced at the utility point is observed to be of reasonable quality, but the disturbances in the distribution network may cause poor quality of power supply at the point of delivery. The current quality is largely influenced by the customer's loads. Hence, it is becoming an increasing problem for the utility to maintain good voltage quality because of the interactions of the customers loads with the network [2]. These two characteristics i.e. voltage quality and current quality influence each other by mutual interaction that might cause distortion in the power supply at the point of common coupling. Hence, there is a need to compensate the voltage and current harmonics for pollution-free distribution system.

To alleviate the load current harmonics, conventionally passive filters have been used. They are basically combination of *L* and *C* elements tuned for a particular frequency. Although they are simple in operation, they have many limitations. One is that, they are not suitable for change in system conditions as these are rigidly placed at a particular location in the system. Neither the tuned frequency nor the size of the filter can be changed so easily. There is a problem of detuning, when operating conditions of the system are changed. In addition, aging, deterioration and temperature effects may increase the designed tolerances and bring about detuning. There is a chance for occurrence of resonance between a distribution transformer reactance and the passive filter elements. At light load conditions, when one of resonant frequencies between line inductance and shunt capacitors is close to one of dominant harmonic frequencies, there will be a harmonic propagation throughout the distribution system [3].

The problems encountered with the passive filters can be overcome by using active power filters [4]. Active power filters are basically voltage source or current source inverters operating in voltage or current control mode. These devices can be connected either in shunt or series with the load bus of a distribution system. The active power filter, which is connected in shunt with the load is called as DSTATCOM. The DSTATCOM is used to compensate the load current harmonics, unbalance and reactive power. Dynamic voltage restorer (DVR) is a series connected device, which is used to compensate the voltage related problems such as voltage harmonics, sag, swell and unbalance. Both voltage and current related problems can be compensated using a combination of shunt and series active filters, which is called unified power quality conditioner (UPQC).

The major source of the problems in the distribution system is the nonlinear and unbalanced loads. Due to the harmonic and unbalance load currents, the impedance of the system causes a harmonic and unbalance voltage drop, so that the voltages at the other buses in the system are also distorted and unbalanced. In order to alleviate the effect of nonlinear and unbalanced load, the DSTATCOM is being used. In order to get desired compensation characteristics, the selection of control strategy of the DSTATCOM plays an important role and this is very crucial in the voltage distorted grids. There are mainly three control strategies for the DSTATCOM [5]-[19]. These are perfect harmonic cancellation, unity power factor, optimal and flexible control strategies. The formulation of these strategies is given and discussed in the following section.

II. FORMULATION OF CONTROL STRATEGIES FOR DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

Perfect Harmonic Cancellation (PHC) Strategy

In order to make the source currents to be balanced and sinusoidal, the extracted fundamental positive sequence voltages from the actual supply voltages are used in the instantaneous symmetrical component theory [12]. These reference source currents are therefore fundamental positive sequence components. The phase-*a* reference source current is expressed as following.

$$i_{sa1}^{+} = \frac{v_{sa1}^{+} - v_{sa1}^{0}}{\left({v_{sa1}^{+}}^{2} + {v_{sb1}^{+}}^{2} + {v_{sc1}^{+}}^{2} - 3\left(v_{sa1}^{0}\right)^{2}\right)} P_{lavg} \tag{1}$$

In the above equation, v_{sa1}^{+}, v_{sb1}^{+}, and v_{sc1}^{+} are the positive sequence fundamental supply voltages. Here, $v_{sa1}^{0} = \frac{1}{3}\left(v_{sa1}^{+} + v_{sb1}^{+} + v_{sc1}^{+}\right)$ is zero sequence component, which is equivalent to zero, as the considered supply voltages are fundamental positive sequence voltages. P_{lavg} is the average load power. Here the feature of the term $\left({v_{sa1}^{+}}^{2} + {v_{sb1}^{+}}^{2} + {v_{sc1}^{+}}^{2}\right)$ is that, it is constant at every instant. Hence, the reference source currents resemble the fundamental positive sequence voltages with a scaling factor.

Unity Power Factor (UPF) Compensation Strategy

In this strategy, the components of (1) are replaced by the actual supply voltages. Also, the compensation for the zero sequence voltages is not provided; therefore v_{sa1}^{0} term is eliminated in the numerator and denominator. As a consequence of this, the neutral current after compensation is no longer zero. Hence, reference source currents are proportional to the actual supply voltages and this will ensure the unity power factor. For phase-*a*, source current is given below.

$$i_{sa} = \frac{v_{sa}}{\left\langle v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2} \right\rangle} P_{lavg} \tag{2}$$

Here the symbol '$\langle\ \rangle$' represents running mean of ($v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2}$) over a period and its value is constant at every instant. The period of running mean is half or one cycle depending upon the odd or even harmonics in the supply voltages. In the above expression, P_{lavg} is also constant, therefore the source currents resemble the supply voltages. This operation results unity power factor in all the three phases [19].

Optimal and Flexible Control (OFC) Strategies

In [8]-[9], authors proposed a two step optimization process as shown in Fig. 1. First the supply voltages are filtered by using a filter bank system G(s). The G(s) is designed such that the compensating voltage e^* and the reference source current i^* should provide some desired power quality features like maximizing the power factor or minimizing the total harmonic distortion (THD) of the source currents. These are considered as objective functions and the constraints can be taken as upper bound on THDs of source currents, harmonic factors of individual harmonics, unbalance factor of the source currents and lower bound on power factor.

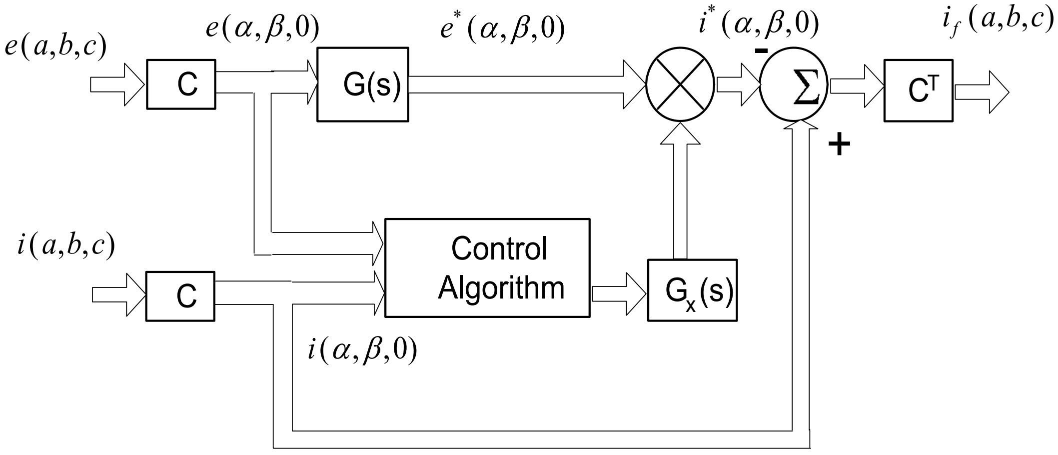

Fig. 1 Block diagram of two step OFC strategy

Once the objective function and the constraints are selected as per the compensation requirements, the optimization problem is solved using the MATLAB optimization toolbox. The filter bank gains obtained from the optimization process are used in the formulation of reference source currents. Though the desired power quality features are achieved, this method has the drawbacks like involving multiple transformations (*abc* to *α-β* and *α-β* to *abc*) and it uses filters which deteriorate the transient response of the compensator. The drawbacks with any nonlinear optimization based method are selection of proper initial conditions, convergence and its inablitity in arriving the global solution. The initial conditions can not be fixed for the entire compensation period. With the change in load, the initial conditions have to be changed. Any wrong selection of initial conditions leads to compensation failure.

In [18], authors proposed a one step approach and it is shown in Fig. 2. The desired source currents are obtained from multiplication of the RMS value of each harmonic component of the sensed supply voltage by the corresponding conductance factor (K_n). The conductance factors are obtained by the nonlinear optimization technique.

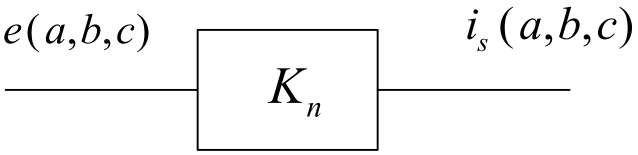

Fig. 2 Block diagram of one-step approach to calculate reference currents

Lagrange function is formulated with the objective function of minimizing the source apparent power and the constraints are: source average power must be equal to the average load power and the total harmonic distortion of the source current (THD_I) must be less than or equal to the specified limit. The formed Lagrange function is solved by using Newton Raphson method with initial values of the variables in the objective function. The general Lagrangian function is formed as shown below

$$L = f + l \quad r + m\, s. \tag{3}$$

where L is the Lagrangian function, f is the objective function, λ and μ are the Lagrangian multipliers. The terms r and s are the equality and inequality constraints respectively. In the optimization technique, the objective function is to minimize the apparent power which will directly influence power factor. The objective function is constructed as

$$S^2 = \sum_1^n V_n^2 \sum_1^n I_n^2 . \tag{4}$$

In the above equation, S is the apparent power of the source. V_n and I_n represent the RMS values of n^{th} harmonic source voltage and current respectively. By replacing the currents using relation $I_n = K_n * V_n$, the objective function is

$$f = S^2 = \sum_1^n V_n^2 \sum_1^n K_n^2 V_n^2 . \tag{5}$$

Equality constraint is $P_{dc}=\sum_{1}^{n}V_nI_n=\sum_{1}^{n}V_n^2K_n$ and inequality constraint is $s=\sum_{2}^{n}K_n^2V_n^2-THD_I^2K_1^2V_1^2\le 0$. The Lagrangian function thus can be written as following.

$$L=\sum_{1}^{n}V_n^2\sum_{1}^{n}K_n^2V_n^2+\lambda\left(P_{dc}-\sum_{1}^{n}V_n^2K_n\right)+\mu\left(\sum_{2}^{n}K_n^2V_n^2-THD_I^2K_1^2V_1^2\right) \tag{6}$$

By taking the first order derivatives of the above function with respect to the unknown (K_1, K_n, λ and μ) variables, four equations are derived, which are solved for the conductance factors. By knowing the conductance factors, the reference source currents can be formulated. Though, this algorithm is not involving multiple transformations and filters, the nonlinear optimization problem will deteriorate the transient response of the compensator and there is no guarantee for the convergence of the solution to meet the dynamic load.

From the above two optimization techniques, it is observed that, though these strategies are giving the optimal compensation characteristics between PHC and UPF, the inherent problem with them is the poor transient response and no guarantee for the convergence of the optimization problem under different conditions of supply and load. Hence, this paper proposes a new control strategy to find out the conductance factors without optimization process, yet the objectives of the compensation are preserved. This is explained in the following section.

III. PROPOSED NEW CONTROL STRATEGY TO FIND OUT THE CONDUCTANCE FACTORS

In this section, a new control strategy to calculate the conductance factors and hence reference source currents, without optimization process, yet satisfying the objectives of the compensation is presented. The interesting point in this method is that, the conductance factors obtained through this method are similar to the conductance factors, which are obtained through the optimization process mentioned in (6). This type of direct solution is not feasible if the compensation objectives are increased. For the present strategy, the objectives of the compensation are:

1. The source should not supply any reactive power.
2. The average source power should be equal to the average load power.
3. The THD of the source currents must be within the prescribed limit.

The method is shown here for phase-*a*, the same can be applied to the other two phases to get the corresponding conductance factors. For simplicity, harmonics are considered up to 5th harmonic order. The supply voltages considered are given here below.

$$\begin{aligned} v_{sa}(t) &= \sum_{n=1}^{5}(v_{san}(t)) \\ v_{sb}(t) &= \sum_{n=1}^{5}(v_{sbn}(t)) \\ v_{sc}(t) &= \sum_{n=1}^{5}(v_{scn}(t)) \end{aligned} \tag{7}$$

The reference source currents are formulated as given in the equation below.

$$i_{sa}{}^{*}(t) = K_{1a}\left(v_{sa1}\right) + K_{na}\left(\sum_{n=2}^{5}\left(v_{san}\right)\right) \tag{8}$$

Considering the power balance condition, to get a balanced source currents after compensation irrespective of the load currents, the average source power supplied from the phase-*a* should be equal to the one third of the total average load power.

$$V_{1a}I_{1a}\cos\phi_{1a} + V_{2a}I_{2a}\cos\phi_{2a} + V_{3a}I_{3a}\cos\phi_{3a} + V_{4a}I_{4a}\cos\phi_{4a} + V_{5a}I_{5a}\cos\phi_{5a} = \frac{P_{lavg}}{3} \tag{9}$$

where, V_{1a}, V_{2a}, V_{3a}, V_{4a} and V_{5a} are RMS values of the phase-*a* fundamental, 2nd, 3rd, 4th and 5th harmonic components. The currents I_{1a}, I_{2a}, I_{3a}, I_{4a} and I_{5a} are the RMS values of phase-*a* fundamental and mentioned harmonics. The letter P_{lavg} denotes the total average load power.

The second objective of the compensation is that the source current THD after compensation must be less than or equal to the prescribed limit.

$$\frac{\sqrt{I_{2a}^2 + I_{3a}^2 + I_{4a}^2 + I_{5a}^2}}{I_{1a}} \le THD_I \tag{10}$$

In order to control the THD_I and power factor, the conductance factors of fundamental and harmonics have to be controlled. Here, in this method, the conductance factor for the fundamental is K_{1a} and for harmonics, it is same and fixed i.e. K_{na} (for $n = 2, 3, 4$ and 5) to get a nearly collinear source currents with respect to the supply voltages.

$I_{1a} = K_{1a} V_{1a}$ and $I_{na} = K_{na} V_{na}$ for $n = 2, 3, 4$ and 5 (11)

where n is the harmonic number. For the reactive power compensation, the phase angle difference between fundamentals and respective harmonics of voltages and currents are considered as zero. By substituting (11) in (9) and (10), they are modified as,

$$V_{1a}I_{1a} + V_{2a}I_{2a} + V_{3a}I_{3a} + V_{4a}I_{4a} + V_{5a}I_{5a} = \frac{P_{lavg}}{3} \tag{12}$$

$$K_{1a}V_{1a}^2 + K_{na}\left(V_{2a}{}^2 + V_{3a}{}^2 + V_{4a}{}^2 + V_{5a}{}^2\right) = \frac{P_{lavg}}{3} \tag{13}$$

$$V_{1a}^2\left(K_{1a} + K_{na}THD_V^2\right) = \frac{P_{lavg}}{3}. \tag{14}$$

In (14), THD_V is total harmonic distortion in phase-a supply voltage.

From (10), $$\frac{K_{na}\sqrt{V_{2a}^2 + V_{3a}^2 + V_{4a}^2 + V_{5a}^2}}{K_{1a}V_{1a}} = THD_I \tag{15}$$

$$K_{na} = K_{1a}\frac{THD_I}{THD_V}. \tag{16}$$

By substituting the K_{na} value from the above equation in equation (14), it is modified as,

$$V_{1a}^2\left(K_{1a} + K_{1a}THD_V THD_I\right) = \frac{P_{lavg}}{3}. \tag{17}$$

Finally, $$K_{1a} = \frac{P_{lavg}}{3\ V_{1a}^2\ \left(1+THD_V THD_I\right)} \text{ and } K_{na} = K_{1a}\frac{THD_I}{THD_V}. \tag{18}$$

The terms K_{1a} and K_{na} in the above two equations can be computed online and hence this method gives good transient response while satisfying the compensation objectives.

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Hence, this method is free from the non-convergence setback of the optimization process. Therefore, there is no interruption in the compensation. By knowing the conductance factors, the reference source currents can be formulated in phase with the supply voltages using (8). When the set current THD limit (THD_I) is equal to voltage THD (THD_V), then $K_{na}=K_{1a}$, leading to unity power factor operation. For $THD_I = 0$, the conductance factor K_{na} becomes zero. This gives the perfect harmonic cancellation (PHC) operation. If the set current THD limit is in between THD_V and 0, then the corresponding conductance factors will give the optimum power factor, which is in between unity and the power factor corresponds to PHC strategy. The same method can be applied to other two phases (b and c) to get K_{1b}, K_{nb} and K_{1c}, $K_{nc.}$ If the supply voltages are balanced distorted then conductance factors will satisfy the relation $K_{1a}= K_{1b} = K_{1c}$ and $K_{na}= K_{nb}= K_{nc}$ and the source currents after compensation will be balanced and distorted. For the unbalanced distorted supply voltages, considering the actual voltages in the calculation of conductance factors leads to unbalanced compensated source currents i.e. $K_{1a}\neq K_{1b}\neq K_{1c}$ and $K_{na}\neq K_{nb}\neq K_{nc}$. In order to get the source currents balanced, instead of taking actual supply voltages, the extracted balanced distorted supply voltages can be considered [19]. Then, this unbalance problem can be overcome along with the power balance criterion.

IV. EVALUATION OF CONTROL STRATEGIES PERFORMANCE USING A PSCAD DISTRIBUTION SYSTEM MODEL

The performance of the three strategies i.e. PHC, UPF and proposed method are evaluated in a distribution system. The system is simulated using PSCAD 4.2.1. The system comprises of three unbalanced linear and nonlinear loads at the three nodes supplied by an ideal voltage source through a transformer as shown in the Fig 3. The three loads are departed by an impedance equivalent to the distance between them. The compensation was performed at the Node 3. The results of the strategies are tabulated in Table I, II, III, IV and V. The RMS and THD values at the four nodes in the distribution system are measured for the strategies.

Table I represents the status of the distribution system before compensation in terms of the RMS and THD values. The RMS and THD values of voltages are measured at four nodes and the same values are measured for source currents at the Node 3, where the compensation is done by using ideal current sources. The compensation results for the PHC strategy are given in Table II. From the results, it is clear that the voltage THDs at different nodes in the system along with the compensating node, are reducing more in proposed and the UPF strategies compared to the PHC strategy. In this strategy, the voltage distortions at the compensating node are not much reduced from before compensation. The reason for this is that the currents drawn from the source under this strategy are fundamental and hence there is a voltage drop at the fundamental level in the distribution system. This will reduce the magnitude of the fundamental voltage at the point of common coupling (Node 3). But the harmonic part of the voltages is unaltered as the harmonic part of the current is zero. Therefore, the total harmonic distortions (THDs) of the PCC voltages are not decreased much and moreover there is a chance in this strategy that it may increase to the values more than the before compensation. The advantage of this strategy is that the source currents are balanced and sinusoidal.

In the UPF strategy, the source currents are linear to the supply voltages respectively. Therefore, the source currents will draw similar harmonics from the supply voltages. These source current harmonics result in voltage drops at the harmonic level, which will reduce the magnitude of the harmonic part in the supply voltages. The RMS and THD values for this strategy are given in Table III. The distortion at the compensated node found to be below 5%, as per *IEEE 519-1992* standards [20]. Though, the supply voltage THDs at the PCC reduced below 5% for the taken distribution system, however this reduction is not always guaranteed. There is a chance to get the same UPF at the distortion more than 5%. But this strategy has the potential to bring down the distortions at the different nodes in the distribution system. The improvement of the power factor in this strategy over the PHC strategy is less, because the increase in the power factor depends on the voltage distortion. If the distortion in the supply voltages is more, power factor in the PHC strategy will be less, and then the improvement of the power factor in this strategy is more compared to the PHC strategy [21].

Table I

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	204.22	17.06	47.73	5.54	189.00	29.35	196.21	18.83	158.02	29.73	32.92	8.52	0.8854
b	199.52	19.97	50.00	5.58	188.50	30.14	191.40	22.12	161.50	25.70	35.38	8.03	0.8000
c	217.77	18.63	40.23	6.65	203.16	26.60	211.32	20.40	182.94	21.50	25.27	10.37	0.9521

Table II

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	217.20	10.42	44.40	4.30	204.83	25.45	209.53	11.34	172.25	25.07	30.16	0.67	0.9935
b	217.8	12.53	44.84	4.56	205.67	25.51	210.15	14.02	178.22	19.20	30.20	0.68	0.9901
c	216.45	13.24	44.56	4.46	204.37	26.12	208.83	14.48	181.97	18.40	30.13	0.70	0.9895

Table III

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	216.05	4.00	44.75	2.85	204.30	23.04	208.16	4.17	171.32	22.07	30.40	4.40	1.0000
b	216.05	4.09	45.13	2.96	205.30	23.31	208.10	4.27	176.90	14.40	30.42	4.52	1.0000
c	214.90	3.95	44.71	2.76	204.14	23.56	207.00	4.12	181.00	12.86	30.20	4.40	1.0000

Table IV

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	216.20	4.01	44.57	2.86	204.45	23.03	208.34	4.18	171.48	22.06	30.22	4.40	1.0000
b	216.14	4.09	45.00	2.97	205.35	23.30	208.22	4.28	177.00	14.38	30.27	4.54	1.0000
c	214.77	3.95	44.90	2.75	204.00	23.58	206.80	4.12	180.80	12.85	30.40	4.39	1.0000

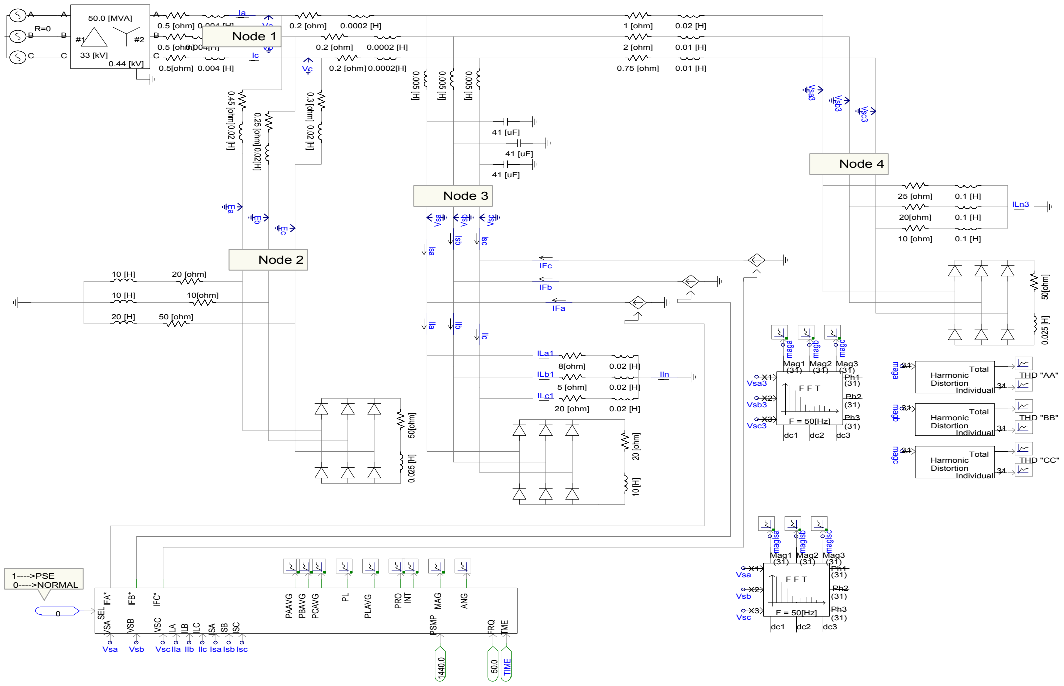

Fig. 3 Power distribution system model using PSCAD 4.2.1.

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In order to bring down the current THDs below 5%, it is required to keep a limit, so that the source currents will have only limited distortion as set by the limits. There is a need to exploit the advantages of both PHC and UPF strategies in one strategy such that it has to satisfy the set current THD limits and it should have the scope to converge at both UPF and PHC. Hence the proposed method is put forth to gain the merits of both the strategies. In some situation there is a chance that the voltage THDs at the node will reduce below 5%, and then there is no advantage in keeping the source currents THD limits still at the 5%. Hence the logic implemented here is that, if the voltage THD in any phase comes down below 5%, then the current limit will be same as the voltage THD for that phase. The same is true for the other two phases. This condition will lead the compensation to unity power factor as both the voltage and current THDs are similar. The results for this case can be seen in the Table IV. From the results, it is clear that by keeping the current THD limits in the beginning of the compensation will help in drawing the source currents at the specified THD. As the compensation proceeds, this strategy will bring the current and voltage THDs to be nearly same and hence gives the UPF at a THD of below 5% or at 0% THD (PHC).

V. EFFECT OF CONTROL STRATEGY SELECTION IN DAMPING THE HARMONIC RESONANCE

One of the main reason for increase of THDs is the harmonic propagation occurred due to the harmonic resonance [22]-[23]. The series or parallel resonance will occur between the distribution line inductance and the shunt capacitors installed for the power factor correction. In order to damp the resonance, the resistive part of the load plays a crucial role. This phenomenon is investigated at the Node 3 and the supply voltages at this node are given for before compensation in Fig. 4. In PHC strategy, the compensated load acts as an open circuit or in other words provides infinite impedance to the harmonics. Hence the resistive part of the compensated load is not preserved. Thus, the voltage distortion at the PCC (Node 3) becomes worse, which is shown in Fig. 5 and the values of the THDs are 31.07%, 33.68%, and 27.53% in phase *a*, *b* and *c* respectively. This drawback is alleviated using UPF strategy or the proposed method. In the UPF and proposed method, the compensated load provides some resistance to the harmonic currents. Therefore, the total resistive part of the compensated load will increase compared to the resistance offered by the fundamental alone. Hence, the resistive part helps in damping the harmonic resonance and thus the harmonic propagation. As a result, in UPF strategy, the voltage THDs at the Node 3 are reduced to 2.5%, 2.65% and 2.47% for phases *a*, *b* and *c* respectively and the bus voltages for this case are given in Fig. 6. For the proposed strategy, the THDs in phase-*a*, *b* and *c* reduced to 2.5%, 2.66% and 2.47% respectively and the bus voltages for this case are shown in Fig. 7. The compensation results for the investigation of harmonic resonance are given in Table V, VI and VII for the PHC, UPF and proposed strategies respectively.

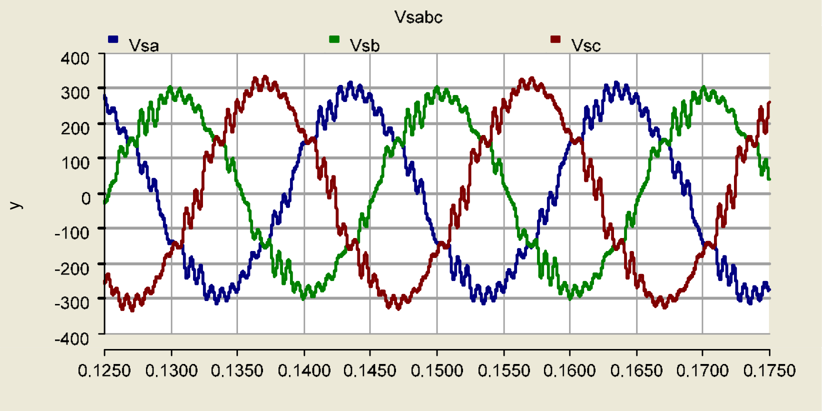

Fig. 4 Node 3 voltages before compensation

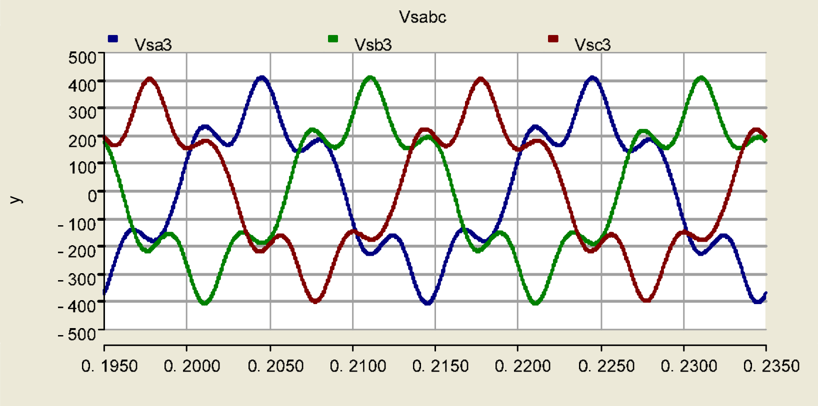

Fig. 5 Node 3 voltages using PHC compensation strategy

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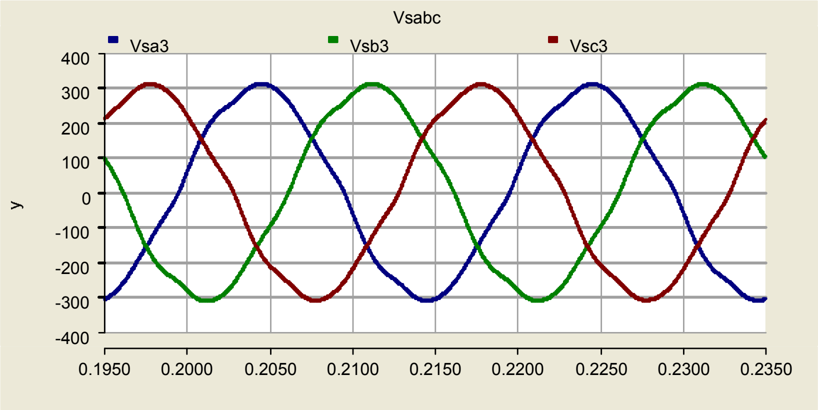

Fig. 6 Node 3 voltages using UPF compensation strategy

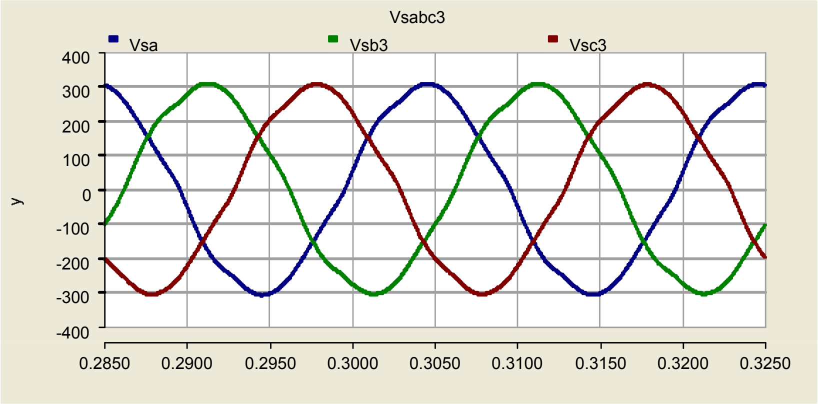

Fig. 7 Node 3 voltages using Proposed strategy of compensation

Table V

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	215.32	13.80	44.03	10.63	204.957	25.94	214.25	31.07	171.72	24.78	28.88	1.14	0.9558
b	215.68	14.94	44.52	11.40	206.01	27.50	216.03	33.68	178.10	21.78	28.92	1.12	0.9474
c	213.40	12.44	44.26	9.45	204.13	27.17	210.21	27.53	180.47	18.26	28.85	0.72	0.9640

Table VI

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	211.85	3.60	44.63	2.47	200.16	23.66	202.51	2.50	167.80	23.28	29.70	2.78	1.0000
b	211.86	3.70	44.98	2.58	201.17	23.73	202.43	2.65	173.39	15.23	29.72	2.93	1.0000
c	210.74	3.60	44.72	2.42	200.00	24.08	201.32	2.47	177.28	13.94	29.50	2.77	1.0000

Table VII

Phase	Node 1 Voltages		Node 1 Currents		Node 2 Voltages		Node 3 Voltages		Node 4 Voltages		Node 3 Currents		Power factor
	RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (V)	THD (%)	RMS (A)	THD (%)	
a	212.13	3.59	44.43	2.49	200.48	23.64	202.93	2.50	168.12	23.25	29.50	2.80	0.99998
b	212.00	3.69	44.84	2.58	201.20	23.76	202.66	2.66	173.48	15.22	29.57	2.95	1.0000
c	210.41	3.60	45.00	2.40	199.66	24.15	200.81	2.47	176.96	13.96	29.77	2.75	0.99995

VI. CONCLUSIONS

In this paper, to get optimum load compensation characteristics, a new control strategy is proposed. It does not involve the optimization process and hence this strategy can be implemented online without any interruption. Along with this control strategy, the performance of PHC and UPF strategies evaluated in the distribution system load compensation. From the results, it is understood that the UPF strategy has the ability to reduce the voltage harmonic propagation in the system. But, it will not guarantee that the compensated source currents will be within the limits of harmonic distortion. In this situation, it is found that the proposed method has the ability to keep the source currents within the specified distortion limits and give the optimum power factor. Further, it is observed that in the case of harmonic resonance, PHC strategy will not be helpful in damping the harmonic propagation. The proposed method and the UPF strategy ensure the damping of harmonic resonance and prevents the harmonic propagation. Finally, the choice of UPF or proposed method depends upon the supply voltage distortion. The UPF strategy works well in the case of low distorted voltage grids. However, in case of the highly distorted supply voltages, the proposed method is a good choice.

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