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Neutral Current Problem and Mitigation Techniques: An Overview

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Abstract: *In this paper, an attempt to overview a various number of mitigation techniques and power quality problems associated with neutral current for commercial loads are discussed. The load connected to three phase four wire system are generally single-phase loads and generate triplen harmonic currents due to unbalancing in phases at neutral. There are various neutral current mitigation techniques including active and passive has been discussed. The existing approach and a framework of references for researchers in this field are provided.*

I. 'Introduction

The ample use of electronic devices in all types of loads i.e. residential, commercial and industrial is adversely affecting the power quality (PQ) of the system[1]-[10]. When three-phase four-wire distribution (3P4W) systems are used to supply single-phase low voltage loads such as lighting ballasts (electronic type), light emitting diodes (LED), compact fluorescent lighting (CFL), personal computers, monitors, laser printers, variable speed drives, adjustable speeds drives (ASD) in air conditioner, UPS systems and other electronic equipment. These loads produces harmonics especially 3rd harmonics in the neutral. In general, the distribution systems designed for linear load type and no longer suitable for delivering large number of non-linear and harmonic generating loads [11]-[15]. The concern PQ issues are high reactive power requirement, harmonic current, low power factor and increased losses[16], [17]. The common problems due to 3rd harmonics are overloading of neutral conductor, overheating distribution transformer, high neutral-to-ground voltage, deteriorate power factor, distortion in supply voltage[18]-[22].

A zero sequence current includes multiple of 3rd harmonic current which is carried by neutral. It is mainly consists of third harmonics currents. The unbalanced single-phase loads result in high neutral current [22]-[26]. The excessive neutral current consisting of both fundamental and harmonic frequency creates over loading of the neutral conductor leading to bursting of it [27]-[31]. The power quality problems rise due to different types of non-linear loads and expansion of the distribution system without much planning [32], [37]. The voltage regulation is also poor due to the unplanned expansion and the putting in different types of loads in the standing distribution system [38]-[42]. The algebraic sum of all three phases current is zero in neutral with balanced and linear loads in 3P4W system. However, for nonlinear loads the neutral carries non-sinusoidal and non-zero current and the algebraic sum of three balanced and non-sinusoidal phase currents does not sum to zero[43][44]. Here i_L represents the load current and i_n is neutral current.

$$i_{La}=I_1\sin\omega t+I_3\sin 3\omega t+I_5\sin 5\omega t+... \quad (1)$$

$$i_{Lb}=I_1\sin(\omega t-120)+I_3\sin 3(\omega t-120)+I_5\sin 5(\omega t-120)+..... \quad (2)$$

$$i_{Lc}=I_1\sin(\omega t+120)+I_3\sin 3(\omega t+120)+I_5\sin 5(\omega t+120)+... \quad (3)$$

$$i_{nL}=3\times I_3\sin 3\omega t+3\times I_9\sin 9\omega t+3\times I_{15}\sin 15\omega t+... \quad (4)$$

All triplen odd harmonics are additive in nature, thus resulting in excessive current in neutral. So the neutral current is blend of harmonics zero sequence and fundamental zero sequence current which is to be mitigate from the system[45], [46].

The power quality aspects governed by the standards such as the IEEE-519 [47], [48]. It estimated that 70 to 85 percent of all power quality problem generated within commercial and industrial facilities. Usually this type of load includes electric appliances used in restaurants, shops, offices, hospitals, education buildings etc [49], [50]. If harmonic voltages excess due to harmonic current from the recommended limits can results replacement of transformers, switchgear and lines at extortionate cost. The voltage quality is depend on current quality and they affect each other by mutual interaction. Usually, the size of neutral conductor is similar as phase conductors but in new commercial installation, larger cross section area of neutral conductor has preferred to take account of extra triplen harmonics current [51]. But use of larger size neutral conductor increase cost, size and significant increase in copper and aluminum requirement [52]. Previously K-rated distribution transformers, L-C tuned filters and phase shifting transformer are employed to deal with harmonics [53]. Unfortunately, these solutions have some limitations, in actual the K-rated transformer designed to bear higher harmonics than non K-rated one. To bear this extra harmonic current in K-rated transformer require bigger size, which ultimately increase the cost than normal transformer. The primary of K rated transformer will force the all triplen harmonics to circulate at its primary winding and eliminated all [54]. But this "circulating" action will creates losses in terms of heat in the transformer and reduces its working efficiency. The use of shunt L-C tuned filters can cause undesirable effect like system resonance that leads to failure [55]. The effectiveness of passive filters will also changes as loads are changes. Phase-shifting transformer or Zigzag transformer is also a very attractive solution to such harmonic problems[56]. In such type of arrangement a small zigzag transformer is connected to isolate and reduce triplen harmonics current. This solution is having advantage of low cost, easy installation and ability to reduce most harmonics current thus eliminating the necessity for larger neutral wires[57].

There are various possible topologies for a 3P4W system and some mitigation techniques are reported in the literature. The 3P4W shunt compensators are reported in the literature for neutral current compensation along with harmonic elimination and load balancing. The DSTATCOM for the mitigation of neutral current harmonics along with power quality improvement are four-leg voltage source converter (VSC), three single phase VSC, three-leg VSC with split capacitors three-leg VSC with zig-zag transformer and three-leg VSC with neutral terminal at the positive or negative terminal of DC bus. The Four-leg VSC requires more number of switches when compared to a three leg VSC with split capacitor whereas three leg VSC with split capacitor uses minimum number of switches due to which losses are reduced and is a lesser complex topology. The performance of three-leg VSC with integrated zig-zag transformer is dependent on the location close to the load and is also affected during the conditions of distorted and unbalanced voltages [57]. The application of a zig-zag transformer for reduction of the neutral current is advantageous due to passive compensation, rugged and less complex over the active compensation techniques [58]-[60]. A new topology of DSTATCOM is proposed in which a two-leg VSC along with a star/delta transformer. It is also reported in literature to use of split capacitors with 2-leg VSC for compensation. The DSTATCOM can be controlled for voltage regulation on a power distribution system and the star/delta transformers are employed for isolation of VSC from the distribution voltage. Also, the single phase active power filter (APF) or inverter are used with star-delta transformer for neutral current compensation [61]. The H-bridge VSC is controlled suitably to enhance power quality. A new topology of a DSTATCOM, which an integrated three-phase three-leg VSC with a T-connected transformer to perform all the compensations required for a 3P4W system. In case of a T-connected transformer, rating of transformer depends on the amount of the imbalance in the load and harmonic content. Its performance also depends on the imbalance of the transformer location and source voltage [62].

II. Neutral Current Compensation

The neutral current compensation techniques includes zig-zag transformer, a star/delta transformer, T-connected transformer, Scott-transformer, star-hexagon transformer and star-polygon transformer [63],[64]. The different topologies divided into two part:

III. isolated

IV. non-isolated

The further division of isolated and non-isolated are three leg and two VSC with all type of transformers as mentioned above [65]. All different types of combinations are shown in Fig. (1) - (3).

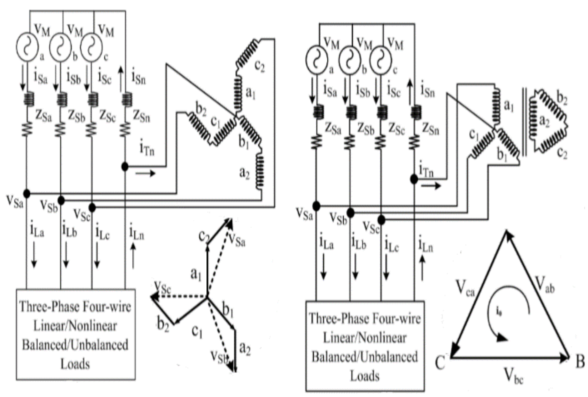


Fig1(a). Zig- Zag Transformer (b) Star/Delta transformer

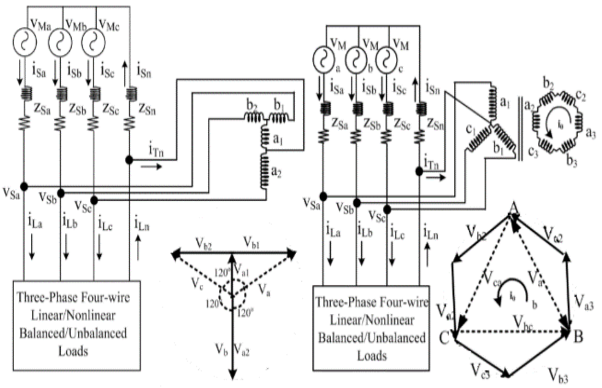


Fig. 2(a). T connected transformer (b) Star/ hexagon transformer

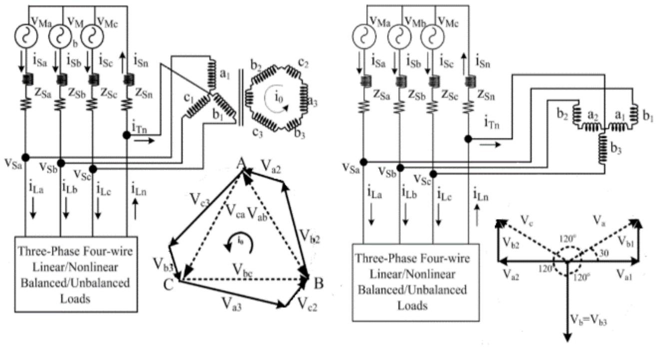


Fig 3(a). Star/Polygon transformer (b) Scott transformer

The zig-zag and Star-Delta Transformer with their phasor diagram are shown in Fig. 1(a) and (b).

The T-connection of transformer has two single phase transformers for interfacing with 3P4W systems shown in fig. 2(a). The winding of the transformer provides a path to zero sequence fundamental current and harmonic currents. The current rating of the windings is based on neutral current compensation required [66].

The Scott connection has two single-phase transformers to get the neutral terminal. The voltages across windings of one transformer, Va1 and Va2 are equal. The required current rating depends on the neutral current compensated. This combination give path to zero sequence harmonics and fundamental neutral currents [67]. The connection diagram and its phasor connection as shown in fig 2(b).

In Star-Hexagon connections, three numbers of single-phase transformers are connected. Its connection and phasor diagram shown in fig. 3(a).

The star/polygon transformer has three numbers of single-phase transformers. its connection and phasor diagram are shown in Fig. 3(b).

III. Different Connection of DSTATCOM

The DSTATCOM having VSC, DC capacitor on DC side, interfacing inductor on AC side and normally connected in shunt across the consumer load or across PCC. It also requires small ripple filters to mitigate switching ripples. For sensing current and voltage Hall sensors are used to give feedback and normally a digital signal Processor (DSP) to implement the required control algorithm to generate gating signals for the switches of VSC. It also need injection and isolation transformer, with small passive filters as per application[68]-[75].The combination and different types of connections are shown in Fig (4) – (11).

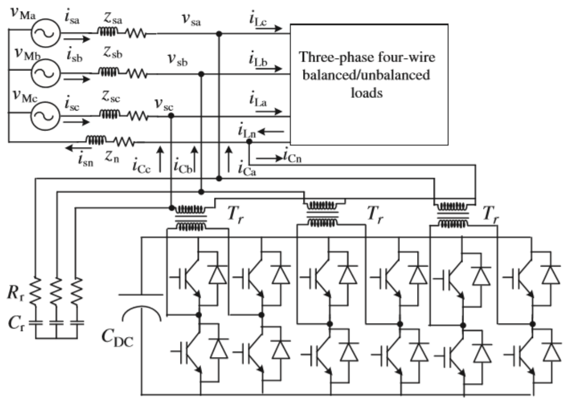


Fig 4. A three single phase VSC based 3P4W DSTATCOM

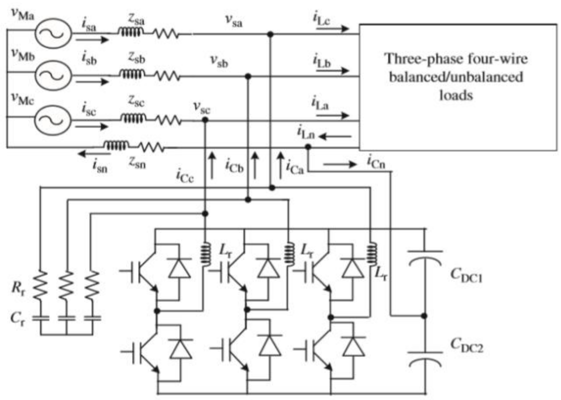


Fig 5. Three leg VSC with split capacitor

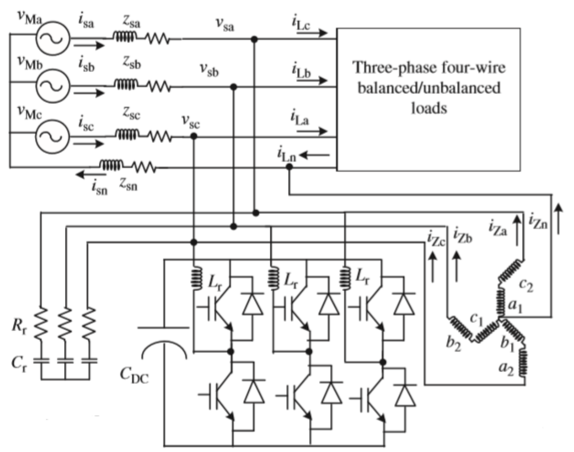


Fig 6. Three leg VSC and Zig-Zag transformer

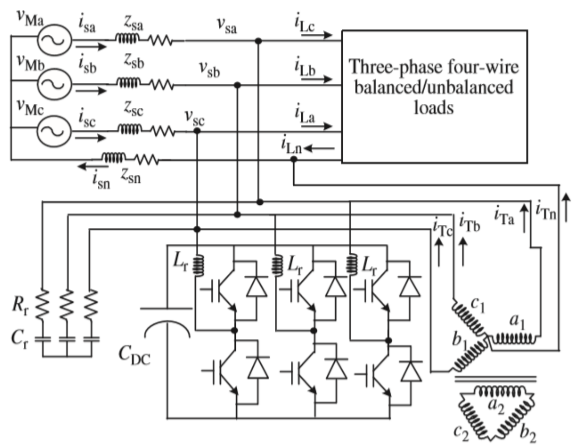


Fig 7. Three leg VSC and star/delta transformer

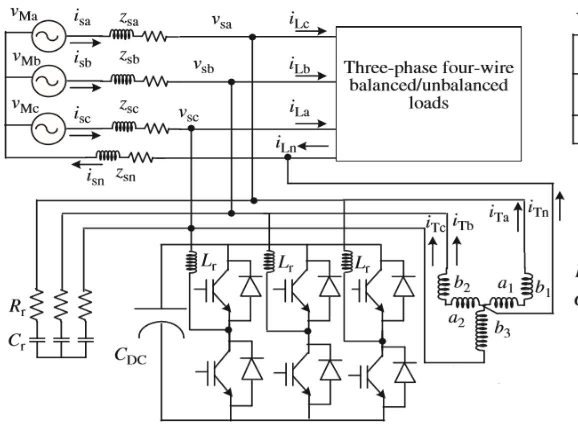


Fig 8. Three leg VSC and T connected transformer

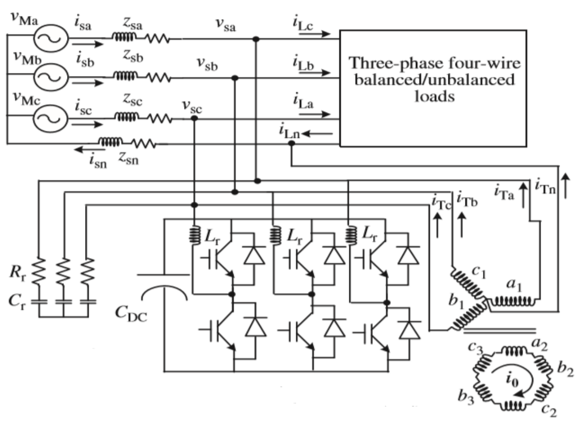
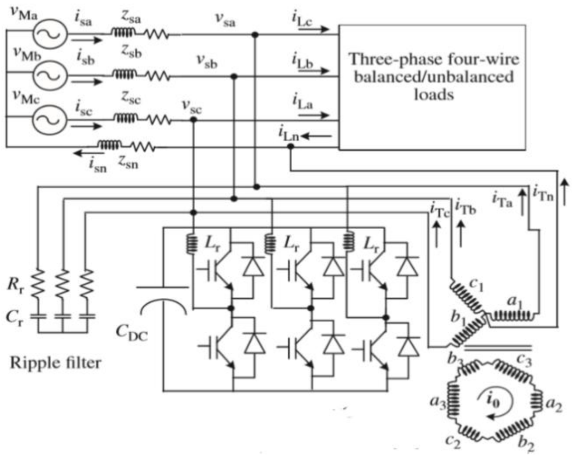


Fig 9. Three leg VSC and star/Hexagon transformer



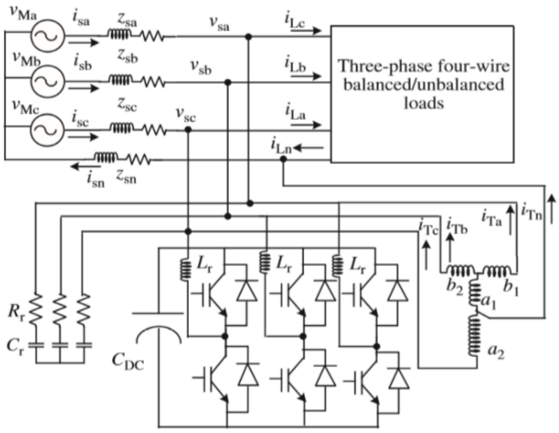


Fig 10. Three leg VSC and Star/Polygon transformer **Fig 11.** Three leg VSC and Scott Transformer

IV. Conclusion

The issue of triplen harmonics are come with commercial and domestic type of load. It is very necessary to remove triplen harmonics from the neutral otherwise neutral is overheated or burst. The neutral current mitigation techniques for a three-phase four-wire distribution system using have been reviewed. There are total six combination of transformers and eight combination with DSTATCOM are present. The neutral current mitigation transformer connections include a Scott-transformer, T-connected transformer, star-hexagon transformer and star-polygon transformer. These transformer configurations along with DSTATCOM is beneficial. All type of combinations are used according to particular requirement and application.

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