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A NOVEL CONTROL METHOD FOR UNIFIED POWER QUALITY CONDITIONER USING NINE-SWITCH POWER CONDITIONER

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Abstract: The load-reactive power compensation in most of the UPQC based power quality compensation application is done by shunt APF, whereas, the series APF is generally utilized to compensate voltage related problems. In a typical distribution system the voltage sag and/or swell, flicker, unbalance, etc. are short duration power quality problems. This paper is an attempt to make the use of existing series inverter to compensate load-reactive power by introducing a power angle difference between source and load voltage, keeping both of the voltage's magnitude same. It will eventually result in better utilization of series inverter. This new reactive power sharing feature between both the inverters would help to reduce the burden on shunt inverter and ultimately results in reduction of shunt inverter rating by certain percentage. This concept is termed as the "PAC of the UPQC". The simulation results based on MATLAB/Simulink are discussed in detail to support the concept developed in the paper. The proposed approach is also validated through experimental study.

Keywords: Active powers filter (APF), power angle control, power quality, reactive power compensation, unified power quality conditioner (UPQC).

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1. Introduction

Power quality has gained significant attention in the past few years. The advancement in the semiconductor device technology has made it possible to realize most of the power electronics based devices/prototypes at commercial platform. As a rule of thumb in all areas of engineering, the proper utilization of the resources that we have in the most efficient way has lead to great development and is the major concern for most engineers in their respective fields.

Static power converter development has grown rapidly with many converter topologies now readily found in the open literature. Accompanying this development is the equally rapid identification of application areas, where power converters can contribute positively toward raising the overall system quality.

In most cases, the identified applications would require the power converters to be connected in series or shunt, depending on the operating scenarios under consideration. In addition, they need to be programmed with voltage, current, and/or power regulation schemes so that they can smoothly compensate for harmonics, reactive power flow, unbalance, and voltage variations.

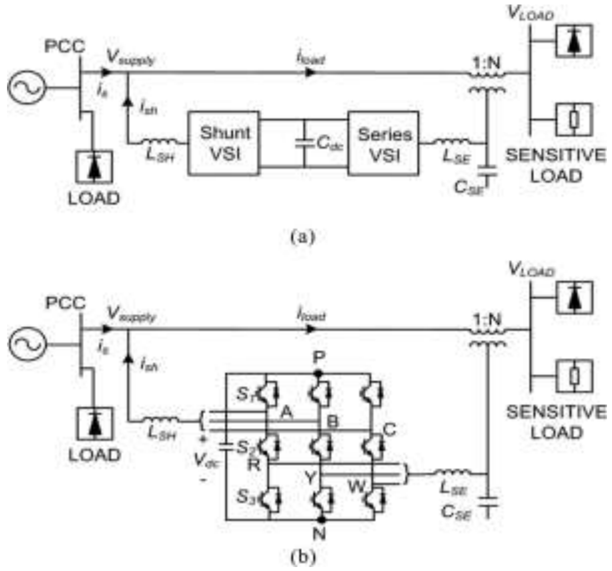

Figure 1 Representations of (a) back-to-back and (b) nine-switch power

For even more stringent regulation of supply quality, both a shunt and a series converter are added with one of them tasked to perform voltage regulation, while the other performs current regulation. Almost always, these two converters are connected in a backto- back configuration, using 12 switches in total and sharing a common dc-link capacitor, as reflected by the configuration drawn in Fig. 1(a). Where available, a micro source can also be inserted to the common dc link, if the intention is to provide for distributed generation in a micro grid, without significantly impacting on the long proven proper functioning of the back-to-back configuration.

This paper proposes a single stage integrated nine-switch power conditioner, whose circuit connection is shown in Fig. 1(b). As its name roughly inferred, the proposed conditioner uses a nine-switch converter with two sets of output terminals, instead of the usual 12 switch back-to back converter. The nine-switch converter at about the same time, and was recommended for dual motor drives, rectifier–inverter systems, and uninterruptible power supplies. Despite functioning as intended, these applications are burdened by the limited phase shift and strict amplitude sharing enforced between the two terminal sets of the nine-switch converter.

More importantly, a much larger dc-link capacitance and voltage need to be maintained, in order to produce the same ac voltage amplitudes as for the back-to-back converter. Needless to say, the larger dc-link voltage would overstress the semiconductor switches unnecessarily, and might to some extent overshadow the saving of three semiconductor switches made possible by the nine-switch topology.

2. PROPOSED NINE-SWITCH POWER CONDITIONER

The per-phase representation of the common back-to-back unified power quality conditioner (UPQC) as shown in Fig 1(a), where a shunt converter is connected in parallel at the point-of common- coupling (PCC), and a series converter is connected in series with the distribution feeder through an isolation transformer. The shunt converter is usually controlled to compensate for load harmonics, reactive power flow, and unbalance, so that a sinusoidal fundamental current is always drawn from the utility grid, regardless of the extent of load nonlinearity. Complementing, the series converter is controlled to block grid harmonics, so that a set of three-phase fundamental voltages always appears across the load terminals.

Being so flexible, the UPQC is indeed an excellent “isolator,” capable of promptly blocking disturbances from propagating throughout the system. Despite its popularity, the back-to-back UPQC is nonetheless still complex and quite underutilized, even though it offers independent control of two decoupled converters.

Its underutilization is mainly attributed to the series converter, whose output voltages are usually small, since only small amount of grid harmonics need to be compensated by it under normal steady-state conditions, especially for strong grids. Such a low modulation ratio gives rise to computational problems, which fortunately have already been addressed in , but not its topological underutilization aspect. Resolving the topological aspect is, however, not so easy, especially for cases where the dc-link voltage must be shared and no new component can be added. Tradeoffs would certainly surface, meaning that the more reachable goal is to aim for an appreciable reduction in component count, while yet not compromising the overall utilization level by too much.

The nine-switch converter is formed by tying three semiconductor switches per phase, giving a total of nine for all three phases (Refer Fig 1(b)). The nine switches are powered by a common dc link, which can either be a micro source or a capacitor depending on the system requirements under consideration.

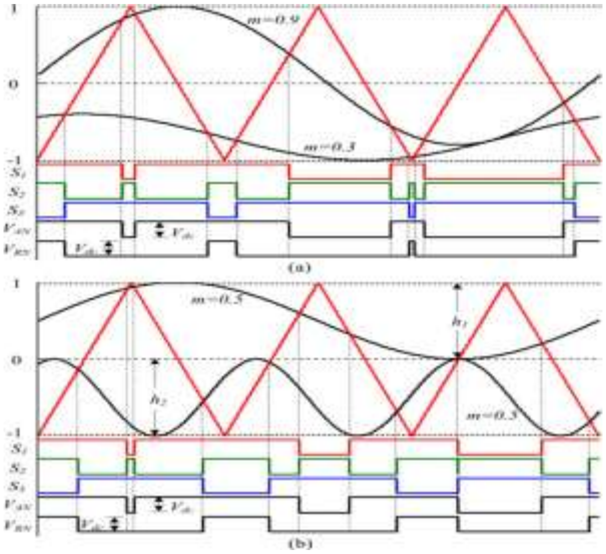

Figure 2 Arrangements of references having (a) the same frequency but different

Like most reduced component topologies, the nine-switch converter faces limitations imposed on its assumable switching states, unlike the fully decoupled back-to-back converter that uses 12 switches. Those allowable switching states can conveniently be found in Table I, from which, it is clear that the nine-switch converter can only connect its two output terminals per phase to either Vdc or 0V, or its upper terminal to the upper dc rail P and lower terminal to the lower dc rail N.

Table 1 SWITCH STATES AND OUTPUT VOLTAGES PER PHASE

S_1	S_2	S_3	V_{AN}	V_{BN}
ON	ON	OFF	V_{dc}	V_{dc}
ON	OFF	ON	V_{dc}	0
OFF	ON	ON	0	0

The last combination of connecting its upper terminal to N and lower terminal to P is not realizable, hence constituting the first limitation faced by the nine-switch converter. That limitation is nonetheless not practically detrimental, and can be resolved by coordinating the two modulating references per phase, so that the reference for the upper terminal is always placed above that of the lower terminal, as per the two diagrams drawn in Fig. 2.

Under normal operating conditions, the output voltage amplitude of the shunt converter is comparatively much larger than the voltage drop introduced by the series converter along the distribution feeder. That indirectly means the modulating reference needed by the shunt converter is much larger than that associated with the series converter, which might simply consist of only the inverse harmonic components for grid voltage compensating purposes. Drawing these details in the carrier range would then result in a much wider vertical range h1 in the left diagram of Fig. 3 for controlling the upper shunt terminal, and a narrower h2 for controlling the lower series terminal Other operating details like logical equations used for generating gating signals for the three switches per phase would remain unchanged.

For h2 , a comment raised here is that it can be set to zero, if an ideal grid with no distortion and rated sinusoidal voltage is considered. In that case, the lowest three switches, labeled as S3 for each phase in Fig. 1(b), should always be kept ON to short out the series coupling transformer, and to avoid unnecessary switching losses. If desired, the series transformer can also be bypassed at the grid side to remove unwanted leakage voltage drop without affecting the compensating ability of the shunt converter.

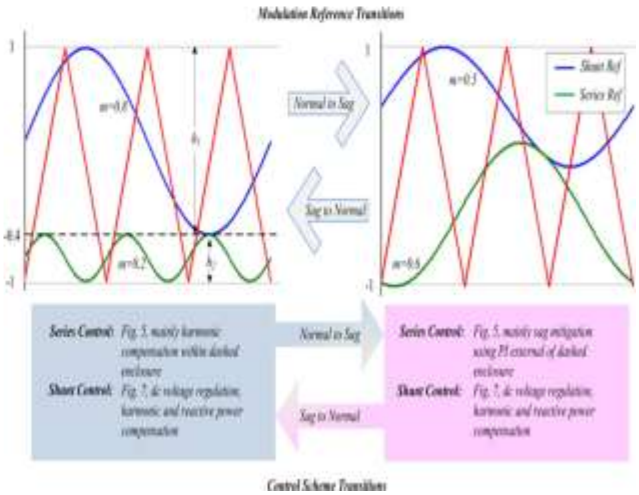

Figure 3 Transitions of modulating references and control schemes between normal (left) and sag mitigation (right) modes.

Back-to-back UPQC allows independent control of its shunt and series converters, and hence does not need to divide its carrier band into two, like in Fig. 3. That means h2 is zero, and its dc-link voltage can be set to the minimum of Vdc−BB = 2√2/1.15 p.u. (subscript BB stands for "back-to-back"), if the nominal RMS grid voltage is chosen as the base. Voltage ratings of the dc-link capacitor, series and shunt switches would thus have to be higher than this value, after adding some safety margin. Current rating of the series switches also has to be higher than (1 + k) p.u., after adding some safety margin, and treating the nominal sinusoidal RMS load current as the base. The term k then represents the amount of load current "polluted" by low order harmonic and reactive components, whose negation −k represents the current flowing through the shunt switches, while performing load current compensation. Rating of the shunt switches must however be larger than k p.u., so as to allow the shunt converter to channel enough energy to the series converter for onward transferring to the load during period of sag compensation, as would also be shown later through experimental testing. For that, the raised shunt value can be set equal to the series value of (1 + k) p.u. for uniformity, or any other higher value that is deemed appropriate.

As shown in Fig. 3, the proposed nine-switch UPQC operates with its carrier band divided into h1 and h2 . The latter, being much narrower, is for blocking small grid harmonic voltages from propagating to the load, which from the example described in , is only about 5% of the full carrier band. The minimum dc-link voltage, and hence voltage ratings of components, must then be chosen based on Vdc-NS = 1.05 Vdc-BB, where subscript NS is used to represent "nine-switch." Current rating wise, analysis of the nine-switch UPQC is slightly different, because of its merging of functionalities to gain a reduction of three switches. Focusing first at the upper S1 switch, maximum current flowing through it would be the sum of shunt (−k) and series (1 + k) currents per phase when S1 and S2 are turned ON, and hence giving a final value of 1 p.u. Being slightly higher, the common maximum current flowing through S2 and S3 is (1 + k) p.u., which flows when S1 and S2 are turned ON for the former, and S1 and S3 are turned ON for the latter. Note, however that these maximum currents are only for sizing the switches, and should not be exclusively used for computing losses. The reason would be clear after considering S1 as an example, where it is noted that the maximum current of 1 p.u. does not always flow. In fact, when S1 and S3 are turned ON, the current flowing through S1 is smaller at –k p.u., whose duration depends on a number of operating parameters like modulation ratio, phase displacement, and others. Analytical computation of losses is therefore nontrivial, as also mentioned in [1], whose simulation approach is now practiced here for computing the UPQC losses. Obtained results for both normal and sag operating modes are subsequently summarized in Table II for easier referencing.

Table 2 P.U. COMPONENT RATINGS AND LOSSES NORMALIZED TO NOMINAL GRID VOLTAGE AND LOAD CURRENT

UPQC Type	Capacitor Voltage Rating	Semiconductor Voltage Rating	Semiconductor Current Rating	Total Semiconductor Lo (Conduction & Switchi
		*** With Series Compensation ***		
Back-to-Back UPQC	$2\sqrt{2}/1.15$	$2\sqrt{2}/1.15$	$1+k$	4.62% Normal; 5.40% S
Proposed Nine-Switch UPQC	$1.05\times2\sqrt{2}/1.15$	$1.05\times2\sqrt{2}/1.15$	$1+k$	3.24% Normal; 5.19% S
Nine-Switch UPQC with Equally Divided Carrier	$2\times2\sqrt{2}/1.15$	$2\times2\sqrt{2}/1.15$	$1+k$	9.26% Normal; 11.27% S
		*** Without Series Compensation ***		
Back-to-Back UPQC	$2\sqrt{2}/1.15$	$2\sqrt{2}/1.15$	$1+k$	0.62% Normal; 5.40% S
Nine-Switch UPQC with CF Control	$2\sqrt{2}/1.15$	$2\sqrt{2}/1.15$	$1+k$	0.71% Normal; 4.94% S

Evaluated with a 40% in-phase sag

3. SIMULATION RESULTS

The series terminals of the nine-switch UPQC are given two control functions that can raise the quality of power supplied to the load under normal and sag operating conditions. For the former, the series terminals of the conditioner are tasked to compensate for any harmonic distortions that might have originated at the PCC. Where necessary, they should also help to regulate the load voltage to compensate for any slight fundamental voltage variation. This second functionality is, however, more relevant under voltage sag condition, where a sizable series voltage (VSERIES = $V^*_{LOAD} - V_{SUPPLY}$) needs to be injected to keep the load voltage nearly constant.

As per previous power conditioners, the shunt terminals of the nine-switch power conditioner are programmed to compensate for downstream load current harmonics, reactive power, and to balance its shared dc-link capacitive voltage. To realize these control objectives, an appropriate control scheme is drawn.

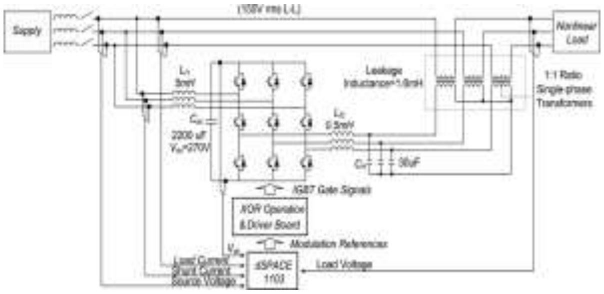

Figure 4 Experimental Set up

To validate its performance, a nine-switch power conditioner was implemented in the laboratory, and controlled using a dSPACE DS1103 controller card. The dSPACE card was also used for the final acquisition of data from multiple channels simultaneously, while a 4-channel Lecoy digital scope was simply used for the initial debugging and verification of the dSPACE recorded data, but only four channels at a time. The final hardware setup is shown in Fig. 4, where parametric values used are also indicated.

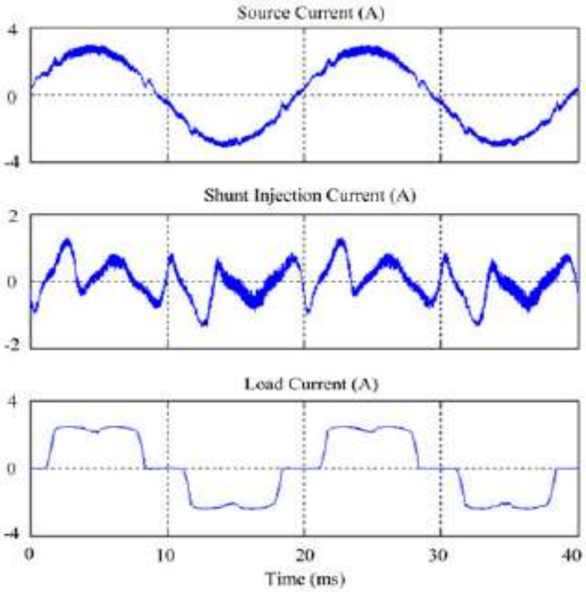

Figure 5 Experimental source, shunt injection, and load currents captured

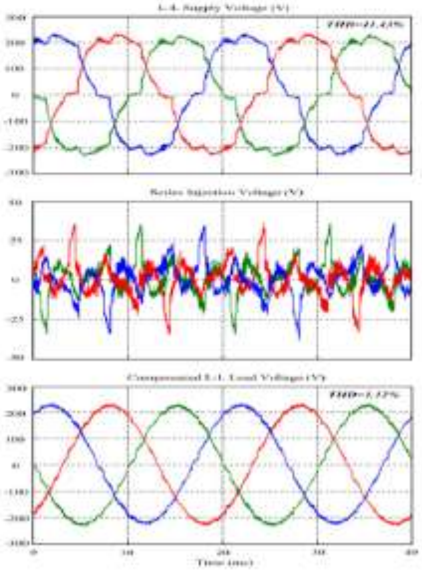

Figure 6 Experimental supply, series injection, and load voltages captured during

Other features noted from the figure include the shunt connection of the upper UPQC terminals to the supply side, and the series connection of the lower terminals to the load side through three single-phase transformers.

Reversal of terminal connections for the setup, like upper→series and lower→shunt, was also affected, but was observed to produce no significant differences, as anticipated. For flexible testing purposes, the setup was also not directly connected to the grid, but was directed to a programmable ac source, whose purpose was to emulate a controllable grid, where harmonics and sags were conveniently added.

4. Conclusions

In this paper, This paper proposes a new functionality of UPQC in which both the shunt and series APFs share the load-reactive power demand, termed as PAC of UPQC. The complete mathematical analysis is presented in this paper. The proposed approach is validated through extensive simulation and experimental studies.

Based on the given system, load and UPQC constraints, the maximum series APF VAR compensation can be estimated. This helps to fix the maximum shunt APF compensation limit. Thus, results in the reduced shunt APF rating, without affecting the existing series APF rating and, hence, the overall cost of UPQC. The simulation results for full load of 15 kW show that the shunt APF kVA rating can be reduced up to 25.6%, by utilizing proposed PAC approach.

This paper evaluates shortcomings experienced by previous applications of the newly proposed nine-switch converter. With a better understanding developed, the conclusion drawn is that the nine-switch converter is not an attractive alternative for replacing back-to-back converter with two shunt bridges. Instead, the nine-switch converter is more suitable for replacing back to- back converter in “series–shunt” systems, where one good example is the UPQC. As a further performance booster, a modified 120◦-discontinuous modulation scheme is presented for reducing the overall commutation count by 33%.

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References:

[1] H. Akagi, “New trends in active filters for power conditioning,” IEEE Trans. Ind. Appl., vol. 32, no. 6, pp. 1312–1322, Nov.-Dec. 1996.

[2] B. Singh, K. Al-Haddad, and A. Chandra, “A review of active power filters for power quality improvement,” IEEE Trans Ind. Electron., vol. 45, no. 5, pp. 960–971, Oct. 1999.

[3] L. Gyugyi, “Unified power-flow control concept for flexible AC transmission systems,” Proc. Inst. Elect. Eng. C, Gen., Transm., Distrib., vol. 139, no. 4, pp. 323–331, Jul. 1992.

[4] H. Fujita and H. Akagi, “The unified power quality conditioner: The integration of series and shunt-active filters,” IEEE Trans. Power Electron., vol. 13, no. 1, pp. 315–322, Mar. 1998.

[5] D. L. Ashcroft, “The static power converter committee—Some perspectives,” IEEE Trans. Ind. Applicat., vol. IA-21, no. 5, pp. 1097–1098, Sep. 1985.

[6] B. Han, B. Bae, H. Kim, and S. Baek, “Combined operation of unified power-quality conditioner with distributed generation,” IEEE Trans. Power Delivery, vol. 21, no. 1, pp. 330–338, Jan. 2006.

[7] H. Johal and D. Divan, “Design considerations for series-connected distributed FACTS converters,” IEEE Trans. Ind. Applicat., vol. 43, no. 6, pp. 1609–1618, Nov./Dec. 2007.

[8] T. L. Lee, J. C. Li, and P. T. Cheng, “Discrete frequency tuning active filter for power system harmonics,” IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1209–1217, May 2009.

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