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A Reduction of harmonics at the Interface of Distribution and Transmission Systems by using Current Source active Power Filter

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Abstract:- A current source converter (CSC) based shunt active power filter (APF) system is designed and implemented to suppress the amplification of low order harmonics at the medium voltage (MV) interface bus between the distribution and transmission systems. Four CSC based APF modules designed at 1.0 Kv are operated in parallel, and connected to the 31.5 kV MV bus via a specially designed coupling transformer. In each APF module, a specially designed LC-type input filter eliminates the switching ripples, and active damping method embedded into the control software suppresses harmonic frequencies around corner frequency of the input filter. The resulting system can operate at relatively high frequencies in the range from 2.0 to 3.0 kHz, depending upon which selected harmonics among 5th, 7th, 11th, and 13th are to be eliminated. Furthermore, in order to reduce the installed capacity of CSCs, selective harmonic amplification method (SHAM) is applied to the APF system described in the paper.

I. INTRODUCTION

Electric power quality (PQ) is being an important issue in the transmission, distribution, and utilization of electrical energy. Improvements in PQ cause a considerable reduction in electrical power and production losses, and a significant improvement in the quality of final industrial products. On this occasion, utilities and the operators have published grid codes, regulations, and recommendations in order to ensure quality of the electrical power in transmission and distribution systems.

The flow of reactive power in O/H lines and feeders should be kept under control. This work is dedicated to the temporary correction of wrong solutions applied to the problem of tight reactive power compensation requirements in distribution systems, which bring the first parallel resonance frequency of the associated distribution system typically to a value between 5th and 7^{th} harmonic frequencies. In this research and technology development work, a case study has been carried out in Denizli-2 Transformer Substation, which was subject to the 5^{th} harmonic amplification problem due to the installation of high amount of shunt capacitor banks to the system for power factor correction. To cope with this problem, until a permanent solution is brought by the system operator, a CSC based APF prototype has been developed, and then connected to the MV interface bus.

II. PROBLEM DEFINITION

In recent years, distribution companies, industrial plants and commercial customers with peak power demands higher than 50 kVA have raised their mean power factors at their input terminals to nearly unity by installing shunt compensation systems, because of the tight reactive power compensation requirements specified in the associated regulations. The most popular solution to the reactive power compensation problem at LV level is to use shunt connected contactor-switched plain capacitor banks. However, at the MV level, circuit breaker switched capacitors with either inrush current limiting reactors or de-tuned reactors are more common than plain capacitors. These installations brought the parallel resonance frequency (as viewed from the distribution system side) to unusually lower values, i.e. around 5th harmonic frequency as pointed out in. Since the dominant current harmonic component produced by the industrial plants is the 5th harmonic, the parallel resonance characteristic of the system may significantly amplify the 5th harmonic component particularly for distribution systems containing large shunt capacitor banks which are installed only for p.f. correction.

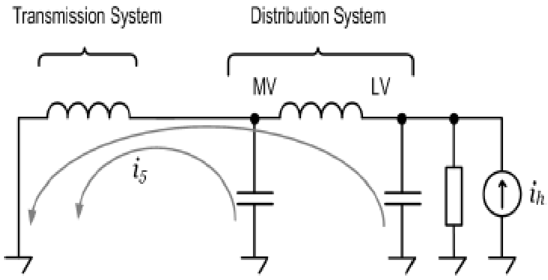

Fig.1 Illustration of parallel resonance

The amplified 5th harmonic current component penetrates into the transmission system and causes extra power dissipation in transmission system elements, and distorts HV and MV bus voltages as illustrated in Fig.1. Therefore reactive power compensation equipment should be chosen in view of the *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems* [4]. The connection point of the radially operated distribution system to the transmission system is called *MV interface bus* and marked on Fig.2.

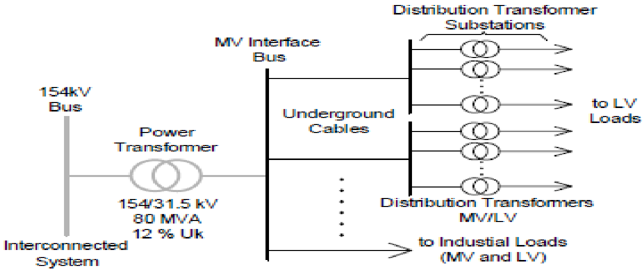

Fig.2 A typical part of radially operated distribution system (Gray color indicates the transmission system, black color indicates the distribution system)

It is worth to investigate that penetration of the 5th harmonic current component into the transmission system would be avoided if the conventional reactive power compensation systems on LV and MV side were properly designed. For this purpose, all contactor-switched plain capacitor banks are replaced by contactor-switched shunt harmonic filters tuned to 240 Hz and circuit breaker switched MV plain capacitor banks are replaced by de-tuned harmonic filters at the tuning frequency of 189 Hz. this solution does not lead to the amplification of 1.0 A rms 5th harmonic current generated by the loads in the lines of the transmission system, but attenuates it significantly, i.e. 0.09 A rms 5th harmonic current component in the lines of transmission system. Refurbishment of conventional shunt compensation systems, which were wrongly chosen and designed, needs time. Therefore, a temporary solution should be found to the penetration problem of 5th harmonic current component into the transmission system during the transition period. For this purpose, a fully mobile CSC based APF system has been designed and implemented for connection to the MV interface bus as illustrated in Fig.3.

III. PROPOSED APF AS A EMPORARY SOLUTION TO 5th HARMONIC PROBLEM

Field measurements show that at several MV interface buses of Turkish Electricity System some of the low order harmonics such as 5th, 7th, 11th, and 13th do not comply with IEEE Std. 519. Among these current harmonics, primarily the 5th harmonic component and secondarily 7th are the most common ones. To suppress the 5th or simultaneously 5th and 7th harmonic components at the MV interface bus (≤ 34.5 kV), an APF system has been developed.

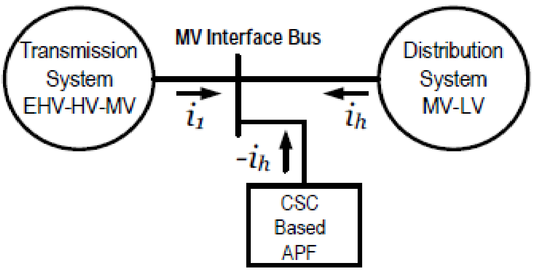

Fig.3 CSC based APF system connected to the MV interface bus

With the present power semiconductor technology, the kVA rating of an individual CSC based APF with SHAM for switching frequencies in the range from 800 Hz to 3 kHz can be around 1 MVA under the assumption that converter topologies employing series and/or parallel connected semiconductors is avoided. Therefore, the shunt APF system should be composed of more than one parallel-operated APF modules. This is because most of the problematic interface buses between the transmission and distribution systems needan APF installed capacity ranging from 2 to 5 MVA.

Operating Principles

The circuit diagram of each CSC based APF module is as given in Fig.3 DC-link current, *Idc* of each CSC is kept constant over the entire operating range. DC-link current is chopped by HV IGBTs of CSC in order to create the selected current harmonic components by PWM techniques. The selected harmonic current component is the 5th harmonic component (5x50 Hz) for the sample application. The need for the fundamental current generation is to allow sufficient amount of active power flow from
the MV interface bus in order to compensate for CSC losses, and hence to keep the DC-link current constant. The desired line current waveform of the CSC based APF on its AC side is created by the Modified Dead Band Sinusoidal PWM technique [2]. The input filter amplifies the5th harmonic current created by the CSC modules operating in parallel. The amplification property of the input filter, which reduces the kVA rating and hence the initial cost of the overall system [1], is employed in the sample application as described in this paper.

Control System

The block diagram representation of the control system for each APF module is given in Fig.4. Master controller is common to all APF modules. The overall control system is composed of three main parts: 1) current and voltage measurement circuits, 2) reference current generation circuit PWM circuit. Due to a high number of distribution system feeders, the load current, *il* is measured indirectly as the difference between supply current, *is* and the APF system current, *ip* by using summing type measurement transformers. A phase-locked loop (PLL) circuit takes the lineto- line voltage signals from the MV interface bus, and then generates a reference vector which rotates at the angular frequency of the supply voltage. The number of APF modules in operation, *K* and the associated status signals are sent to the control system of each APF module by means of a master PLC, which is also used for supervisory control and protection purposes. The inputs of the reference current generation circuit in Fig.8 are total load current waveforms (*ila, ilb, ilc*) on the MV side and the APF line current waveforms of each APF module (*iapfa, iapfb, iapfc*). Since the selected 5th harmonic current component in MV lines of the sample system is to be suppressed equally by operating K number of APF modules in parallel, load current waveform signals (*ila, ilb, ilc*) on Fig. should be divided by *K*. The selected 5th harmonic current component of the load current waveforms is then extracted by using a synchronously rotating reference frame ($\omega 5 = 2\pi x5x50$ *rad/sec*). For this purpose, first the actual line currents in *abc* axes are transformed to stationary $\alpha\beta$ axes by using 3-phase to 2-phase transformation matrix, ***C1***, and then to synchronously rotating *dq* axes by the use of transformation matrix, ***C2***, where ***C1*** and ***C2*** are given in Appendix. ***C2*** defines synchronously rotating reference frames, for the fundamental and the 5th harmonic components. Under these transformations, fundamental current component and harmonic components other than the *5th* harmonic will appear as AC signals at different frequencies. A low-pass filter (LPF) is then used to extract only the DC signal proportional to the *5th* harmonic component. The extracted DC signal is limited in order to keep modulation index, M between zero and unity. The output signals of the limiter circuit in Fig.8 are then converted to $\alpha\beta$ currents at the 5th harmonic frequency by applying the back transformation, ***C2****-1 =* ***C2****T*. These functional blocks are marked as *Selective Harmonic Extraction* sub circuit in Figs.4 and 5.

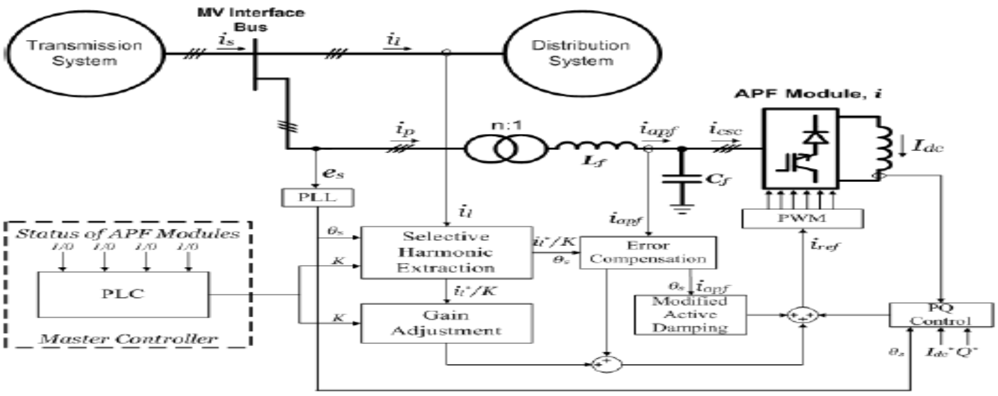

Fig4. Block diagram representation of the control system for each APF module

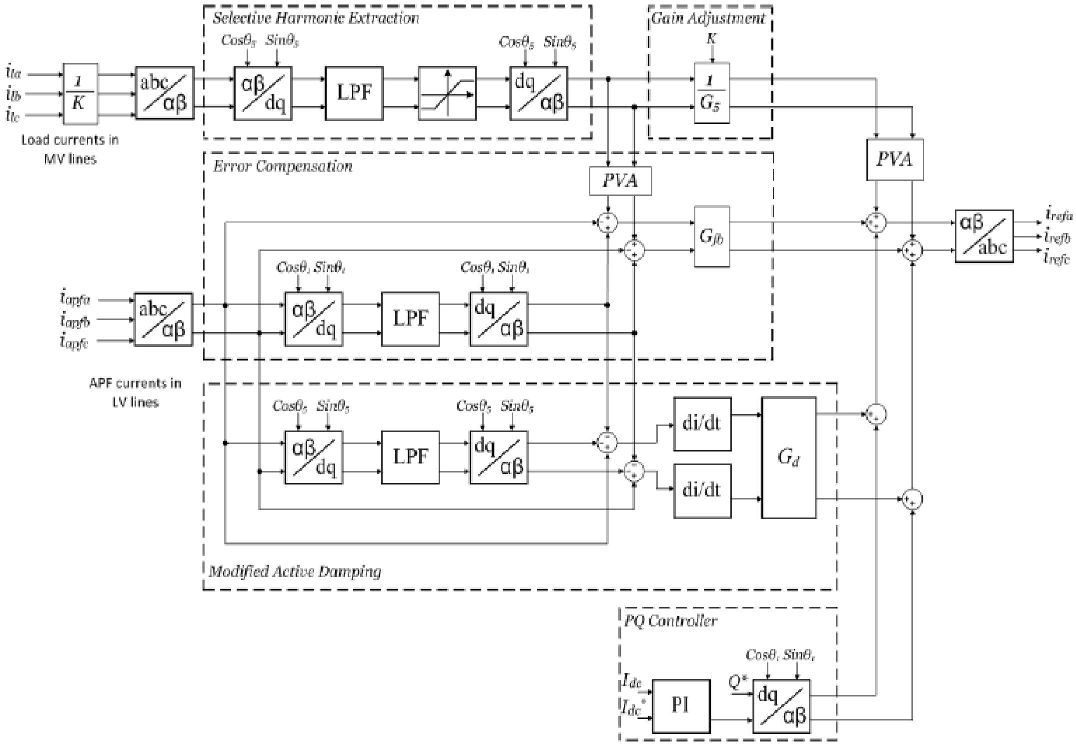

Fig.5 Block diagram representation of the reference current generation circuit

The AC signals corresponding to pre-determined 5th harmonic current component in *αβ* coordinates are then multiplied by the associated constant *1/G5* of the *Gain Adjustment* block in Figs.4 and 5. Gain coefficient *G5* is directly determined by the design of the ac side filter and the number of parallel-operating APF modules, *K*. *G5* would have constant values greater than unity according to SHAM and differ in a narrow range as a function of *K*. The reference currents in *αβ* coordinates are then multiplied by transformer's line-to-line voltage ratio, *n* and shifted by θ*n* in order to refer these currents to the secondary side of the coupling transformer, where θ*n* is the phase shift between primary and secondary currents, which arises from the transformer connection. This operation is represented by *PVA (Phase and Voltage Ratio Adjustment)* block in Fig.5. In the *Error Compensation* block line current signals of each APF module are transformed to *dq* coordinates rotating at the fundamental frequency (*ω5 = 2πx50 rad/sec*). The LPF in *Error Compensation* block extracts only the fundamental component. This signal is then back transformed, and subtracted from the APF line current signals in *αβ* coordinates.

This operation yields the sum of all characteristic harmonic current components generated by the APF excluding the fundamental and including the 5th harmonic and also the carrier and its side band harmonics. Error signal is generated by subtracting input current signals of the APF module as described above from the harmonic reference currents of the oad obtained by the *Selective Harmonic Extraction* block. The proportional type closed-loop controller part, where proportional gain is *Gfb,* in Fig.5 tends to make the error signal zero. Unfortunately, this part of the controller is not as effective as it should be in eliminating characteristic and uncharacteristic harmonics around the corner frequency of the input filter because large values of *Gfb* are not applicable. This makes necessary the use of a proper damping technique. The active damping technique causes much lower power dissipation in APF modules than that of the passive damping [3]. Therefore, the active damping technique is employed in the sample application. The active damping technique is applied in a modified manner to suppress all characteristic and uncharacteristic harmonics around the corner frequency excluding the fundamental and the selected 5th harmonic current component as illustrated by the *Modified Active Damping Block* in Figs.4 and 5.

In order to keep the DC-link current constant at the design value, converter and reactor losses should be supplied from the utility grid by equipping the control system with a closed loop active power controller. However, in some applications, controlled reactive power generation may also be needed, thus allocating part of the kVA rating for operation in DSTATCOM mode. That is why the active power controller has been designed as a closed-loop *PQ Controller* as shown in Fig. 5 with two reference inputs, *Idc** and *Q**. The outputs of the *Gain Adjustment Block, Error Compensation Block, Modified Active Damping Block* and *PQ Controller Block* in *αβ* coordinates are summed up, and transformed back to *abc* coordinates by ***C1**-1 =* ***C1****T*, thus generating final reference vectors of CSC.

IV. CONCLUSIONS

In this work, CSC based APFs operated in parallel and connected at the interface bus between the distribution and transmission systems, has been proposed as a temporary solution to the harmonic resonance problem in the associated network, owing to the presence of large shunt capacitor banks installed for reactive power compensation. Thus mitigating the amplification of load current harmonics in the neighbourhood of the associated power system resonance frequency. Relatively low installed kVA capacity can be used by choosing a CSC based APF rather than a VSC based APF, owing to the Selective Harmonic Amplification Method proposed in the paper. The mobility of the implemented MV APF system makes it applicable as a temporary solution to the harmonic amplification problem at any point of the MV interface bus, until the distribution system operator takes a permanent countermeasure.

REFERENCES

[1]. A. Terciyanli, M. Ermis, I. Cadirci, "A Selective Harmonic Amplification Method for Reduction of kVA Rating of Current Source Converters in Shunt Active Power Filters", *IEEE Trans. on Power Delivery*, vol.26, no.1, pp. 65-78, Jan. 2011.

[2]. J. R. Espinoza, G. Joos, "Current Source Converter On-Line Pattern Generator Switching Frequency Minimization," *IEEE Trans. On Industrial Electronics*, vol.44, pp. 198- 206, Apr. 1997.

[3]. Y. Sato, T. Kataoka, "A Current-Type PWM Rectifier with Active Damping Function" *IEEE Trans. On Ind. Appl.*, vol.32, no.3, pp. 533-541, 1996

[4]. IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Standard 519-1992.