Shunt Active Filter with Optimum Reference Generation Algorithm for Power Factor and Harmonic Current Compensation

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Abstract -- This paper presents a shunt active power filter that uses an optimization algorithm for the harmonic reference current calculation. The algorithm is designed for an active filter that is initially rated for mitigation of only the harmonic currents given by non-linear industrial loads. To utilize the full power rating of the inverter and still be able to improve the power quality of a typical industrial plant, the algorithm takes into account the following power quality indices: total harmonic distortion, individual harmonic distortion and power factor. Therefore the proposed active filter control is able to compensate harmonic load currents as well as reactive load currents in an optimal way as long as the inverter output current is within the rated current. This optimization algorithm is verified by simulating several cases of practical interest.

Index Terms-- Active filters; Industrial power system harmonics; Optimization methods; Pulse width modulated inverters; Reactive power.

I. INTRODUCTION

A large variety of active power filters (APFs) has been developed in the recent decades. The main application of an APF is to improve the power quality of the electrical network in respect to the standard quality indices [1]. The power quality indices of high interest are total harmonic distortion (THD), individual harmonic distortion (IHD) and power factor (PF).

APFs can be connected either at a local point or at a global point to the considered network. The optimum connection point of the APF is usually based on the desired performance, e.g. network stability, harmonic-mitigation efficiency, and costs [2].

The connection of the shunt APF at the point of common coupling (PCC) for compensation of harmonic currents from non-linear loads is presented in Fig. 1. To achieve harmonic-free current at the PCC, the APF detects the harmonic spectrum of the load current and generates an output current which has ideally the same harmonic spectrum of the load current but the opposite phase. Thus, the APF output current leads to harmonic current compensation at the PCC, whereas the fundamental current components are provided by the power system [3].
The proposed optimization algorithm is designed in a simplified way to reduce the calculation burden and therefore create a realizable control that can be used in industrial applications.

The complex optimization problem of compensating both harmonic current and reactive current while staying within the APF power limits is analyzed, and a solution based on an optimization algorithm is presented. The Lagrange-Multiplier technique is used as a mathematical tool to design the reference current calculation. Moreover, the resultant objective and constraint functions concerning the power quality boundaries THDI and IHD1 are introduced in this paper. The implementation of the APF control structure and the inverter power rating is discussed. Finally, simulation results are shown to verify the proposed optimization algorithm.

The proposed optimal APF reference current calculation method shows good results in simulation. The goals set by the quality indices are reached and the APF rating is efficiently utilized.

This paper is structured as follows. In chapter II the general optimization problem is analyzed and a literature overview is given. In Chapter III the power rating of the APF is introduced and the implemented control structure is explained. Chapter IV presents the mathematical formulation of the proposed optimization algorithm. Simulation results are given in chapter V and a critical discussion of the designed algorithm is summarized in chapter VI. The paper will be closed by a conclusion presented in chapter VII.

II. STATE OF THE ART

Fig. 2 shows the exemplary characteristics of the physical constraints as well as of the constraints determined by standard IEEE 519 [7] or IEC 61000 [8] for the considered problem. To decrease the harmonic power at the PCC, i.e. decreasing the harmonic amplitudes of the critical harmonic orders, the shunt APF has to inject harmonic power D_{APF} into the network. As the shunt APF injects harmonic power, smaller THDI and IHD1 values at the PCC are achieved due to the fact that the fundamental line current component stays constant while the critical harmonic line current components are reduced, see Fig. 2 (a).

The relation between the THDI and the reactive power Q_{APF} injected by the shunt APF is presented in Fig. 2 (b). While injecting reactive power to the network the values of THDI and IHD1 are increasing. This is due to the fact that the fundamental current component at the PCC decreases while the harmonic current components at the PCC stay constant.

Fig. 2 (c) shows the relation between the reactive power Q_{APF} and the harmonic power D_{APF} injected into the network by the shunt APF. It is assumed that the shunt APF is working in steady state conditions and the consumed active power P_{APF} is negligible [6]. Moreover, the APF power rating can be derived via (1). Due to the fact that the APF has a maximum power rating S_{APF,max} additional compensation constraints are introduced.

\[ S_{APF} = \sqrt{\frac{P_{APF}^2}{\alpha_0} + Q_{APF}^2 + D_{APF}^2} \] (1)

The combination of the aforementioned physical realities reveals a complex optimization problem with many constraints. Satisfying these constraints while fulfilling the international standards is the heart of the typical optimization problem that can be formulated in terms of the generation of the appropriate harmonic reference current in APFs.

In order to create an APF controller that is able to compensate harmonic currents as well as reactive currents an optimization algorithm must be introduced in the control system. Most of these optimization algorithms calculate the best achievable line-side current at the PCC for specified constraints. Once this current is derived the optimal APF reference current can be obtained by Kirchhoff’s Current Law by taking the actual load current into account [9].

Lately, such optimization approaches became of high interest for industrial applications because of increased demands on network stability, and a desire to reduce the overall system losses. In addition to this, utilization of the full APF power rating increased the value proposition for APFs.

In [10] and [11] the APF reference current calculation is...
formulated as an optimization problem, either in natural a-b-c reference frame or in stationary α−β−0 reference frame. The approach used was to consider the Matlab® Optimization Toolbox™ as an effective optimization tool. Due to the fact that there is a deep physical understanding and an easier implementation of the given constraints in the natural a-b-c frame it is concluded to have the optimization method in the stationary frame.

In [12] an optimal current reference calculation algorithm in natural a-b-c frame is also introduced. The Lagrange-Multiplier technique as a mathematical tool for optimization is studied. The concept used here is to derive the optimal achievable line-side current by introducing a load current compensator into the APF control system.

In [13] a source voltage compensator in natural a-b-c frame is recommended for generating the optimal APF reference current. Further, a hysteresis current controller is presented to control the harmonic currents.

In [14] a load current compensator is described. With the knowledge of the actual load current and the actual line-side voltage this algorithm derives the optimal achievable line-side current within specified constraints. The proposed optimization problem leads to the derivation of transfer function coefficients for every harmonic current taken into account.

All the presented optimization methods for calculating the optimal achievable line-side current have a two fold challenge. First, it is difficult to introduce the APF power rating limits into these optimization algorithms. Second, the optimization method is computationally intensive if one takes the line voltage distortion into account. This paper attempts to produce a better solution to these two challenges. The proposed optimization algorithm provides the possibility of implementing constraints given by power quality indices as well as constraints given by the APF power rating in a simplified way. Furthermore the line voltage distortions and current harmonics that can not be controlled by the APF’s current controller will not be taken into account by the optimization algorithm. This simplification greatly reduces the overall calculation burden and creates a realizable control that could be used in industrial applications.

### III. CONTROL STRUCTURE OF SHUNT APF

#### A. Power Rating

The design of a shunt APF for harmonic compensation for an industrial power plant is dependent on the expected non-linear load currents. In this paper it is assumed that these non-linear loads are only D-ASDs; where the apparent power of a D-ASD is described in (2).

\[
S_{D-ASD} = \sqrt{P_{D-ASD}^2 + Q_{D-ASD}^2 + D_{D-ASD}^2}
\]  

(2)

Initially the shunt APF is rated for compensation of only the harmonic power D_{D-ASD} that is produced by the load. Considering sinusoidal supply voltages the desired APF power rating can be calculated via (3) [6].

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**Fig. 3.** Detailed block diagram of proposed shunt APF control structure (reference current calculation highlighted)
In (3) the apparent power $S_{D, ASD}$ and the total harmonic load current distortion $THD_{IL}$ describe the D-ASD related power.

### B. General Block Diagram

Fig. 3 presents the detailed block diagram of the proposed shunt APF control. The control structure is implemented in synchronous dq-reference frame. The fundamental inner current control is shown with the outer DC-voltage control loop. The inner current controller is composed of a typical proportional-integral (PI) regulator for controlling the fundamental components and resonant current control structure (emphasized for the d-component and for the q-component) for filtering the critical D-ASD harmonic currents (5th, 7th, 11th, 13th, 17th, 19th, 23th and 25th current harmonics).

The measured load currents and the measured supply voltages of each phase are defined as input values to the reference current calculation. Moreover the supply voltage phases are also used as inputs for the Phase Locked Loop (PLL) algorithm to calculate the actual transformation angle $\gamma$ needed for the coordinate transformation into the synchronous reference frame.

The APF harmonic reference current is calculated with the proposed optimization algorithm. Once the harmonic reference current is calculated, it is given as a command value to the inner current control. Moreover the d-component takes the actual voltage control output into account. 

In Fig. 3 it is emphasized that the resultant reference current signal is split into its harmonic and its fundamental component. The harmonic reference currents are given to the resonant control structure and the fundamental reference is given to the fundamental PI controller separately. By splitting the reference current signal, better overall APF control performance is achieved by preventing the fundamental regulator from acting on the harmonics. The cross coupling terms between the d- and q-component of the current control are neglected in the proposed APF control structure to simplify the control design.

The output signal created by the current control (i.e. the reference voltage) is given to the PWM block where the gate signals for the IGBT modules are generated. This leads to an APF output current that is able to compensate reactive fundamental load currents as well as harmonic load currents. The overall controller design is chosen to achieve a high transient performance for the fundamental current control and for harmonic control.

### C. Load Current Analysis

In order to provide the understanding of the physical problem that stands behind the proposed optimization algorithm a load current analysis is shown here. This analysis introduces the general idea for designing the optimization algorithm that calculates the optimal APF harmonic reference current.

In this paper, it is assumed that the shunt APF is connected to a three-wire three-phase system. Moreover an ideal voltage supply system is assumed, without voltage harmonics, frequency variations, unbalances or DC-offsets.

For the load current analysis the first 50 harmonics are taken into account to be aligned with the standard IEEE 519, cf. Table II. The load current can be divided into its fundamental active and reactive current component and the respective harmonic components. The harmonic components are separated in two: harmonics that can be controlled and harmonics that can not be controlled by the APF resonant current controller. The classification of the measured load current for one phase is summarized in Fig. 4. The introduced notation is explained in (4).

$D_{APF} = S_{D, ASD} \cdot THD_{IL}$

In (4) $X_{\nu}$ is the $\nu$th harmonic of $X$ referred to phase $\zeta$ (a, b or c)
IV. OPTIMUM SHUNT APF REFERENCE CURRENT CALCULATION

In [15] and [16] the underlying mathematical principle of the optimization problem is introduced and described in detail. Due to the fact that there are several boundaries given by international standards and physical power ratings of the shunt APF, the controller design optimization problem in this work is a constrained optimization problem. Several solutions exist in literature to solve this constrained optimization problem. The desired optimization technique for this work is the Lagrange-Multiplier method.

The Lagrange-Multiplier technique uses the gradient method, i.e. a set of mathematical equations that principally declare that the gradient of the objective function and the gradients of the constraint functions must be linearly dependent. The optimization problem turns into a minimization problem by using the Lagrange-Multiplier formalism.

To use the Lagrange-Multiplier Method for the proposed constrained optimization problem a load current compensator is introduced, i.e. the reference current calculation as shown in Fig. 5. This load current compensator calculates the optimal achievable line-side current at the PCC. The compensation gains for the load compensator are derived by the proposed optimization algorithm. Moreover this optimization algorithm has the actual load current and the actual supply voltage of the considered phase as inputs. It is important to mention that the load current compensator and the associated optimization algorithm block are introduced for each phase separately, i.e. the proposed optimization technique can be used in single-phase as well as in three-phase (three-wire or in four-wire) systems. By knowing the actual optimal achievable line-side current the optimal APF reference current can be derived by Kirchhoff’s Current Law for each phase separately. To create an efficient and realizable optimal reference calculation the following assumptions are made:

(i) Ideal voltage supply.
(ii) Load conditions are stationary and repetitive, which allows a cycle by cycle updating of the reference currents.
(iii) The active power that is consumed by the APF is neglected.

In the next paragraphs the objective function and the constraint functions for the proposed optimization algorithm are introduced. These functions are designed for the use of Lagrange-Multiplier technique as the desired optimization method.

A. Lagrange Multiplier Technique

Lagrange-Multiplier technique is used to solve the proposed optimization problem. The objective and constraint functions relating the optimal APF reference current calculation have to be defined. Generally, a Lagrange-Function relating an optimization problem is defined as shown in (5); whereas \( f_{\text{obj}} \) describes the objective function, \( h_j \) is the equality constrained function and \( g_i \) is the inequality constrained function relating to the optimization problem. All functions must be at least first order differentiable.

\[
L(x, \lambda_i, \mu_i) = f_{\text{obj}}(x) + \sum_j \lambda_j [h_j(x) - k_j] + \sum_i \mu_i [g_i(x) - c_i] \tag{5}
\]

The variables \( \lambda_j \) and \( \mu_i \) are called Lagrange-Multipliers. A Lagrange-Multiplier can be interpreted as the rate of change of the optimum if the constraints are changing.

To derive a local minimum of the Lagrange-Function the Karush-Kuhn-Tucker (KKT) condition has to be satisfied. The requirements to reach a local minimum of the Lagrange-Function at a point \( x^* = (x_1^*, x_2^*, \ldots, x_n^*) \) are listed below:

(KKT 1) Condition for minimization:
\[
\frac{\partial L}{\partial x_i} = \frac{\partial L}{\partial x_1} = \ldots = \frac{\partial L}{\partial x_n} = 0 \tag{6}
\]

(KKT 2) Conditions for equality constraints:
\[
\frac{\partial L}{\partial \lambda_i} = \frac{\partial L}{\partial \lambda_1} = \ldots = \frac{\partial L}{\partial \lambda_j} = 0
\lambda_1, \lambda_2, \ldots, \lambda_j \in \mathbb{R} \tag{7}
\]

(KKT 3) Conditions for inequality constraints:
\[
\mu_i \frac{\partial L}{\partial \mu_i} = \mu_1 \frac{\partial L}{\partial \mu_1} = \ldots = \mu_i \frac{\partial L}{\partial \mu_i} = 0
\mu_1, \mu_2, \ldots, \mu_i \geq 0 \tag{8}
\]

In general, the KKT conditions lead to a system of equations with \( i + j + n \) unknowns; whereas \( i \) is the number of inequality constraint functions, \( j \) is the number of equality constraint functions and \( n \) is the number of unknowns in the objective function.

B. Objective Function

To achieve the desired quality indices the objective function should be chosen to minimize the harmonic distortions and to maximize the PF of the line-side current after compensation [14]. The load current compensator gains are introduced as a possibility to derive the optimal achievable line-side current at the PCC and thus the optimal achievable APF reference current for each phase. It is emphasized that the load current is analyzed and is separated into the active and reactive fundamental components as well as the controlled and uncontrolled harmonic components relating to the typical D-ASD output current spectrum (up to a maximum considered harmonic order).

The active load current component is provided by the power supply and therefore this component should be left unaffected by the objective function. To realize the capability
of reactive current compensation with the proposed APF control, the reactive current component of the load current is manipulated. The resultant optimal achievable fundamental line-side current for one phase only is shown in (9). Eq. (10) describes the consequent relation of the fundamental load current RMS value to the fundamental load current RMS value and the load current compensator gain.

\[
I_{s', \text{opt}} = \sqrt{\frac{\cos^2(\omega \delta - \delta') + G_z^2 \sin^2(\omega \delta - \delta')}{I_{L, \text{z}}} + \sum_{n=1,2,3,4} \sqrt{\frac{u_I_{L, \text{z}}}{n}} \left( \frac{\sin(\epsilon n \omega - \epsilon n \delta') \sin(\epsilon n \omega + \epsilon n \delta')}{\epsilon n \omega} \right)}
\]

Once a relation between the fundamental load- and line-side currents is introduced, a relation between the harmonic current components must also be defined. It is necessary to distinguish between the load current harmonics that can be controlled and those that can not be controlled by the proposed APF current controller. There are only load current compensator gains established for those current harmonics that can be controlled by the chosen resonant current control structure, as in (12). Therefore the harmonic components of the optimal achievable line-side current for one phase can be expressed via (11). Moreover it is assumed that the phase of each harmonic of the line-side current is equal to the phase of the same harmonic order of the load current [10], as in (12).

\[
u_{i_{s', \text{opt}}} = \sum_{n=1,2,3,4} \sqrt{2} u_{I_{L, \text{z}}} \sin(\nu \omega + \nu \delta')
\]

\[
u_{i_{s', \text{opt}}} = \sum_{n=1,2,3,4} \sqrt{2} u_{I_{L, \text{z}}} \sin(\nu \omega + \nu \delta')
\]
Therefore it is necessary to define a constraint function that limits the THD \( I \) of the line-side current at the PCC to a maximum value \( \text{THD}_{\text{max}, \zeta} \) given by the standards, e.g. IEEE 519 or IEC 61000. The required constraint function is defined (16). This constraint function is formulated as an inequality constraint function to avoid overcompensation problems and to achieve better control performance.

\[
\text{THD}_{\text{SG}}^\zeta = \sum_{\nu=0}^{1,2,3,4} G_{\nu} \left| \frac{I_Z^\nu}{I_Z^\nu} \left( \cos \left( \delta_{\nu} - \nu \right) + G_{\nu}^\zeta \sin \left( \delta_{\nu} - \nu \right) \right) \right| \leq \text{THD}_{\text{SG}, \text{max}}^\zeta
\]

E. \( \text{IHDI} \) Constraint Function

To obtain the \( \text{IHDI} \) limits given in the IEEE 519, the inequality constraint functions are formulated for the power quality indices \( \text{IHDI}_\zeta \). These inequality functions limit the critical \( \text{IHDI}_\zeta \) of the controlled harmonic at the PCC to a maximum value \( \nu\text{IHDI}_{\text{SG}, \text{max}}^\zeta \) for the \( \nu \)th harmonic order for each phase \( \zeta \) separately. The designed inequality constraint functions are presented in (17).

\[
\nu\text{IHDI}_{\text{SG}}^\zeta = \sum_{\nu=0}^{\zeta, 0, 1, 2, 3, 4} G_{\nu}^\zeta \left| \frac{I_Z^\nu}{I_Z^\nu} \left( \cos \left( \delta_{\nu} - \nu \right) + G_{\nu}^\zeta \sin \left( \delta_{\nu} - \nu \right) \right) \right| \leq \nu\text{IHDI}_{\text{SG}, \text{max}}^\zeta
\]

F. Boundaries for Solution

To minimize the calculation power of the proposed optimization algorithm and to avoid overcompensation problems introduced by the optimization algorithm it makes sense to discuss the achievable solutions of the proposed optimization method.

Once a solution of the listed objective and constraint functions is calculated, i.e. the values of the load current compensator gains are derived by Lagrange-Multiplier techniques; the optimal achievable line-side current can be reconstructed as shown in (18). The relating fundamental and harmonic components of this optimal achievable line-side current are defined in (9) and (11).

\[
i_{\nu, \zeta, \text{opt}}(t) = i_{\nu, \zeta}(t) + \nu i_{\nu, \zeta}(t)
\]

These relations show the load current compensator gains have to be limited. In order to avoid overcompensation problems in the network through the shunt APF the load current compensator gains have to be chosen between zero and one, according to (19).

\[
0 \leq G_{\nu}^\zeta \leq 1, \quad \nu = 1, 6n \pm 1; \quad n = 1, 2, 3, 4
\]

Once the derived solution is obtained by the Lagrange-Multiplier technique, the best case for most situations is that the reactive power at the PCC is zero. The worst case for this solution would result in an actual reactive power generated by the loads. It is important to mention that only those harmonics are considered by the optimization algorithm that can be affected by the APF’s current controller. Further, only the controlled harmonics can be minimized ideally to zero. Therefore, the minimum THD \( I \) that can occur at the PCC is limited by the amount of the uncontrolled harmonics and their amplitudes at the considered OP. As mentioned above, the proposed optimization algorithm assumes an ideal voltage supply. Once the supply voltage is disturbed the resultant line-side current will not satisfy the specified constraints.

G. Optimization Tool

Due to the fact that no equality constraints are formulated for the proposed optimization problem, no Lagrange-Multiplier for equality constraint function is required. Additionally the defined inequality functions are highly nonlinear which leads to a nonlinear system of equations with 19 unknowns. These unknowns are listed in (20).

\[
\{G_{\nu}^1, G_{\nu}^2, G_{\nu}^3, G_{\nu}^4, G_{\nu}^5, G_{\nu}^6, G_{\nu}^7, G_{\nu}^8, G_{\nu}^9, G_{\nu}^{10}\}
\]

- Load current compensator gains

\[
\{\mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}, \mu_{\nu}\}
\]

- Lagrange-Multiplier for inequality constraints

The Matlab® Optimization Toolbox™ is chosen to solve the formulated optimization problem. This toolbox supplies several functions to solve optimization problems and their resultant system of equations. One advantage of the Matlab® Optimization Toolbox™ is the possibility of easy implementation of the optimization algorithm in the chosen simulator Simulink®.

V. VERIFICATION OF OPTIMAL REFERENCE GENERATION ALGORITHM IN SIMULATION

This section summarizes the simulation results of the shunt APF control with the proposed optimal reference current calculation. The performance of the considered APF control is studied for different operation points. These OPs are chosen around several assumed load conditions. In the introduction it was pointed out that a D-ASD usually does not work at full power rating continuously. Therefore different D-ASD load conditions are taken under consideration. Furthermore, to demonstrate the applicability of the proposed APF control of reactive power compensation in addition to the harmonic current compensation an inductor bank (IB) is also simulated for each ASD load condition. The inductor bank, which represents a linear load, consists of a resistor and an inductor; therefore the current of the IB includes both active and reactive current components. The block diagram of this assumed network is presented in Fig. 6. The power rating of the inductor bank is chosen regarding (21).

\[
S_{\text{IB}} = 3 \cdot S_{\text{ASD}}
\]
The power quality indices PF and THD\textsubscript{i} for the considered OPs are summarized in Table I. Simulation results for the OP of nominal D-ASD load with the IB are shown in Fig. 7. This table and figure show the superior ability of the proposed APF reference current calculation method. The achieved line-side current spectrum relating this OP shows that all IHDI values and the resultant THD\textsubscript{i} (4.8\%, cf. Table I) value conform to the IEEE 519 harmonic specifications, as in Table II. It is evident that these values are close to the maximum allowable values of IEEE 519. This is intentional, and can be traced back to two design considerations. First, the proposed optimization algorithm minimizes the combination of both the harmonic current content and the reactive current content. Second, the APF is initially sized to provide very good compensation for the harmonic currents for only the nominal OP of the D-ASD alone. Comparing the two OPs of the D-ASD at 100\% (with IB on and IB off), it is clear that the optimization algorithm allows the THD\textsubscript{i} to increase (from 2.9\% to 4.9\%) and uses this additional APF power capacity to inject reactive currents into the network and thus achieve a better level of reactive current compensation.

To further emphasize the reactive current compensation ability of the proposed APF reference current calculation method, an OP on half nominal D-ASD load (enabled IB) is shown in Fig. 8. It is evident that less current harmonics accrue in the network when the D-ASD runs at half nominal load. Therefore more APF power can be used for PF compensation while staying in the IEEE 519 harmonic current limits. The load-side PF for this OP is 0.81 and it is increased to a line-side PF of 0.91.

In summary, these simulation results emphasize the ability of the proposed optimal APF reference current calculation for harmonic compensation and for reactive power compensation. Furthermore the achieved power quality indices at the PCC are conforming to IEEE 519 harmonic recommendations in all cases.
VI. DISCUSSION

The proposed optimization algorithm is designed in a simplified way to realize a control structure which can be implemented in industrial DSP based applications. However, there are some limitations of the proposed optimum reference current calculation, which are mentioned and discussed in this section.

One limitation is the fact that the optimization problem is quite complex in its formulation. Even with a simplified approach, there is a need for high computation power to solve the resultant derivations online. An efficient mathematical solver for the optimization problem is required to create high resolution.

The implementation selected here is for each of the three phases separately, even though there is a three-phase three-wire system. Due to the fact that each phase’s optimal APF reference current calculation is implemented individually and acts independent of the other two phases, the independent calculations can result in situations of asymmetric outputs. Further investigations of unbalanced networks and voltage disturbances need to be conducted to determine the
limitations or benefits of these asymmetric outputs.

The APF power rating limitation is implemented in the proposed optimization algorithm as an output RMS current limitation. It is evident that with this way of limiting the APF output current high transient currents can accrue; therefore an APF Peak output current limitation is required. It is possible to implement such a limitation as an additional constraint function to the proposed optimization algorithm. This additional constraint function would increase the calculation power of the proposed optimization algorithm. Typically, adequate protection is provided by a proper hardware design of the power inverter, and it is therefore only important that the resultant crest factor is in line with the APF application.

VII. CONCLUSION

This paper presents a shunt APF controller that uses a reference current calculation method based on an optimization algorithm. The proposed optimization algorithm is developed to reach important power quality indices at the PCC of an industrial plant. The proposed optimal reference current calculation method gives the possibility to compensate reactive and harmonic currents for an APF hardware initially rated for migration of only harmonic currents. The proposed optimization method uses the Lagrange-Multiplier technique to derive the optimal achievable line-side currents relative to the actual measured load currents; the following constraints are taken into account:

- Maximum allowed line-side current Total Harmonic Distortion THD, defined in IEEE 519.
- Maximum allowed line-side current individual harmonic current limits IHDIs defined in IEEE 519.
- The APF inverter power rating.

The proposed algorithm is implemented into the APF control as an optimal reference harmonic current calculation in the natural stationary a-b-c frame. The stationary frame is chosen because it provides an easier formulation of the optimization problem; therefore the implementation of the proposed objective and constraint functions is simplified.

The proposed optimal APF reference current calculation method shows good results in simulations. The goals set by the power quality indices are reached and the APF rating is efficiently utilized. This allows that the same hardware of the shunt APF can be used in the field. The proposed control is designed to reduce the computation power needed for the optimization method.

It has to be emphasized that the proposed algorithm is designed in a simplified way to reduce the complexity for the desired solution but it is still a complex problem that requires high computation power, especially in fixed-point DSP based systems.

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