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Development of optimal shunt hybrid compensator based on improving the measurement of various signals

M. Torabian Esfahani, B. Vahidi *

Dept. of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

Voltage and current harmonics generated by nonlinear loads in power systems cause a reduction in electric power quality (EPQ) which has recently become a serious preoccupation in electrical networks due to the increasing number of perturbing loads such as electric arc furnaces and nonlinear loads. Various devices such as static Var compensator (SVC) and static synchronous compensator (STATCOM) can be used to improve EPQ. Due to economic issues, using a STATCOM with high-rated power is not cost-effective. So, development of hybrid compensator based on STATCOM and SVC, type of TCR-BPF, is proposed in this paper by improving the measurement of various signals in their control systems. Hence, the SVC will compensate the fundamental reactive power and balancing of nonlinear load and STATCOM can be used with lower-rated power as an active filter to eliminate the harmonics generated by set of TCR and load. Also, STATCOM compensates the reactive power, voltage flicker, and the unbalancing load which SVC has not been able to compensate them. To use all of the capabilities of TCR-BFP, its control system is improved by new TCR reactive power measurement and predicted reactive power (PRP). Also, the STATCOM control strategy is optimized by FPSO method. Then, the proposed hybrid compensator is implemented in one of the largest steel industries in Iran, Mobarakeh Steel Company (MSC).

1. Introduction

Electric power quality (EPQ) parameters have been recently caused serious problems for electric power networks due to an increase in the number of nonlinear loads such as electric arc furnaces (EAFs), dimmers, and converters. Obviously, EPQ parameters such as voltage and current harmonics, reactive power, voltage flicker, and unbalances. can have consequential economic results for utilities and customers. On the other hand, increasing development of sensitive loads such as microprocessors, private computers, and susceptible production processes has added to the importance of EPQ in power systems which have been critically crucial in recent years. Therefore, these companies attempt to enhance the EPQ by different compensators such as passive filters, capacitor banks, SVC, STATCOM, and other flexile alternative transmission systems (FACTS). When the aim of compensation is the improvement of reactive power and voltage flicker, the reactive power is the most effective parameter in a control system. In particular, large steel industries with heavily polluting loads like EAFs can raise the kind of EPQ problems such as unbalances, voltage, current harmonics and inter-harmonics, power factor, reactive power, voltage fluctuations, and intense current changes. The role of these compensators is critical. In most of these industries, SVCs is applied to EPQ for enhancement, but it is important to know that a time delay exists in SVC natural performance that affects the compensating procedure and does not allow reactive power and voltage flicker mitigation in the power system. On the other hand, the

* Corresponding author. Tel.: +98 21 6454 3330; fax: +98 21 6640 6469.
E-mail address: vahidi@aut.ac.ir (B. Vahidi).

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Nomenclature

EPQ	electric power quality
SVC	static Var compensator
STATCOM	static synchronous compensator
PRP	predicted reactive power
TCR-BFP	thyristor controlled reactor-band pass filter
TCR/FC	thyristor controlled reactor/fix capacitor
FACTS	flexile alternative transmission systems
ARMA	autoregressive moving average
MA	moving average
AR	autoregressive model
MMSE	minimum mean square error
LMS	least mean square
NRLS	normalized recursive least square
HMM	hidden Markov model
TDR	Techint digital regulator
IGBT	insulated-gate bipolar transistors
PCC	point of common coupling
Direct Current Capacitor	DC capacitor
PSO	particle swarm optimization
FPSO	fuzzy particle swarm optimization
EEBO	evaluation of existing best operation
NEEBO	normalization evaluation of existing best operation
PI controller	proportional-integral controller
MSC	Mobarakeh steel company
RC filters	resistor–capacitor filter
T_d	number of samples per half-cycle
T	time period
s	sample number
t	time series components.
r and o	ARMA coefficients
$a(t)$	white Gaussian noise or error
d_k	desired response
R_k	autocorrelation of input
P_k	correlation of the input and desired response
C_{dc} and v_{dc}	the capacitor and the voltage
T_a	delay time in STATCOM control system
P_{best}	a particle of the group
G_{best}	a group of particles
c_1 and c_2	acceleration constants coefficients
$x_j^{(k')}$	the jth particle speed at iteration k
$v_j^{(k')}$	the jth particle position at iteration k

harmonic compensation cannot be done within a wide range by this compensator due to the existence of band-pass filters in certain orders. So far, limited methods such as estimation of reactive power in future time [1–3] are proposed to predict this parameter. In [3] a method for reactive power predicting based on the least mean square (LMS) algorithm employed for EAF power system is suggestive of the fact that this method cannot predict the reactive current in multi-EAF due to intense changes. Investigating the static compensators and their dynamic analysis are among the important issues in EAFs [3–8]. In [4,5], the SVC and STATCOM design is proposed, but nothing is indicated about their control system. A particular example of a power system with an EAF along with SVC and their applications are investigated in [6,7]. In addition, a comparison is made between TCR/FC operation and static compensators for mitigating the flicker due to the EAF in [3,9]. Inasmuch as the EAF loads have time variant with nonlinear nature causing harmonics, flicker, unbalances, and power factor destruction in the power system, several researchers have proposed the EAF operational analysis by different models and provided a great number of routines to compensate the PQ problems of these loads [10,11].

In this paper, a new shunt hybrid compensator based on optimal TCR-STATCOM is proposed for power quality enhancement in actual power systems of steel industries. At first, the SVC is improved by presenting the prediction of reactive power based on time series; a type of autoregressive moving average (ARMA) to generate reactive power time series; and normalized recursive least square (NRLS) for coefficient updating of ARMA. Then, a method is proposed for the reactive power measuring SVC. Now, the power system deals with upgraded TCR-BPF although it can desirably enhance the flicker mitigation and reactive power compensation with the rise of the number of EAF. First, the main bus may be saturated where the EAFs is connected to it and second, the SVC cannot follow the current intense changes. Therefore, flicker reduction is not adequately done in the point of common coupling bus (PCC Bus). In such a case, usually the advanced static compensators as STATCOM which impose heavy costs on the factory are proposed. To overcome the above mentioned problems, the shunt hybrid compensators based on a combination of SVC and STATCOM are proposed in this paper. Through this method, SVC has the duty of improving the fundamental reactive power and STATCOM with low-rated power and economical for customers can improve the voltage flicker and harmonics and partly compensate the reactive power and solve saturation problems of EAFs bus. The proposed control strategy of STATCOM is based on a combination of p–q theory and synchronous method. Also for the development of the STATCOM control system, an optimization method based on fuzzy particle swarm optimization (FPSO) to obtain PI controller is presented and a comparison is made between other existing methods. In fact, measuring three signals of TCR and STATCOM control system including TCR reactive power, predicting system reactive power and optimizing the DC voltage link of STATCOM are improved. Finally, all designs are implemented in one of the largest steel industries, i.e. Mobarakeh steel company (MSC) in Iran.

2. Proposed hybrid compensator structure

The proposed structure of the hybrid compensator is shown in Fig. 1. Also, this figure illustrates the single-line diagram of the MSC power system with its four EAFs per