Harmonic Resonance Assessment and Severity Estimation of Shunt Capacitor Applications in Electric Power Distribution Systems

By

Shamel Hassan Mahmoud Hamouda

A Thesis submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
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Keywords:

Harmonic distortion, power quality, power factor correction, resonance severity, shunt capacitors

Summary:

The technological development in the semiconductor field facilitates the increase of nonlinear loads, that may affect the power quality of distribution power system network and harmonic may occur. Accordingly, shunt capacitors are widely used for harmonic mitigation, but harmonic resonance may occur between the system and the connected capacitors and may have severe consequences.

In this thesis, a procedure to estimate the severity of harmonic resonance is formulated in electrical power distributed system, and a harmonic resonance index is proposed for shunt power capacitor application used to improve power factor. A simple equation to express harmonic resonance severity under different background harmonic voltage levels is formulated. Different case studies are employed to analyze the possibility and severity of harmonic resonance using the proposed formulations with various utility side's background voltage distortions. The results show that the proposed resonance index formulation can facilitate quick use by industry to estimate the severity of resonance.

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LIST OF ABBREVIATIONS

AEB	Annual electricity bill
ASDs	Adjustable Speed Drives
CSI	Current Source Inverter
DG	Distributed Generation
DPF	Displacement Power Factor
HMT	Harmonic Mitigating Transformer
HRI	Harmonic resonance index
HVDC	High voltage direct current
ITHD	Current total harmonic distortion
NB	New annual electricity Bill
OB	Old annual electricity Bill
PCC	Point of Common Coupling
PFC	Power Factor Correction
PLC	Programmable Logic Controllers
PQ	Power Quality
rms	root-mean-square
SCL	Short-Circuit Level
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
UPSs	Uninterruptible Power Supplies
VFDs	Variable Frequency Drives
VIHD	Voltage Individual Harmonic Distortion
VSI	Voltage Source Inverter
VTHD	Voltage total harmonic distortion

LIST OF SYMBOLS

$E(HRI_{Limit})$	Expected HRI_{Limit} value
$E_{consumed}$	Total annual energy consumed in kilowatt hour
$f(\alpha_i, n)$	Nonlinear data-fitting function
f_t	Parallel-resonant frequency in hertz
h	Harmonic order
HRI_{limit}	Minimum threshold value of harmonic resonance index
HR_{Sev}	Severity of harmonic resonance
I_1	Fundamental harmonic current component
I_C	Rated rms value of the capacitor current
I_{C1}	Capacitor current
I_{Ch}	The hth components of the capacitor current
I_h	The hth harmonic current component
I_L	Load current maximum demand
I_{rated}	Rated values of the current
I_{SC}/I_L	Short-circuit current to the load current
I_{Sh}	Supply current
k_h	Percentage of distortion
$KVAr_{cap}$	Nominal reactive power of the capacitor in kVA
kVA_{tr}	Transformer rating in kVA
kV_{cap}	Capacitor rated voltage in kilovolts
kV_{LL}	System voltage (line-to-line) in kilovolts
M_h	The rms value of the harmonic component at harmonic order h of the quantity M
MVA_{SC}	The short-circuit capacity of the system in MVA
n	Total number of harmonic orders
P_{demand}	Contracted demand power in kilowatts
ΔPloss	Transmission power loss
Q_C	Reactive power of capacitor
Q_{rated}	Capacitor's rated values of reactive power
R_{Sh}	The hth Thevenin resistance of the source
R_{sys}	System equivalent resistance in ohms

R_{tot}	Total resistance in ohms
R_{tr}	Transformer equivalent resistance in ohms
U_C	Unit cost of the capacitor in Egyptian pounds per kilovar (L.E./KVAr)
V_1	Fundamental harmonic voltage component
V_C	Rated rms value of the capacitor voltage
V_{C1}	Capacitor voltage
V_{Ch}	The *h*th components of the capacitor voltage
V_{CP}	Capacitor's peak voltage
V_h	The *h*th harmonic voltage component
V_{Lh}	The *h*th harmonic load voltage
$V_{peak,\ rated}$	Peak value of the rated capacitor voltage
V_{rated}	Capacitor's rated values of voltage
V_{Sh}	Thevenin open-circuit voltage
ω	Angular frequency at any frequency (radian per seconds)
ω_t	Parallel-resonant angular frequency at the tuning frequency (radian per seconds)
X/R	Reactance to resistance ratio
X_C	Capacitive reactance in ohms
X_{Sh}	The *h*th Thevenin reactance of the source
X_{sys}	System equivalent reactance in ohms
X_{tot}	Total reactance in ohms
X_{tr}	Transformer equivalent reactance in ohms
Y_{th}	The *h*th harmonic admittance
Z_{Ch}	Capacitor impedance
Z_p	Parallel resonance impedance in ohms
Z_{Sh}	The *h*th impedance of the Thevenin source
Z_{th}	Total harmonic impedance
$\emptyset_1$	Fundamental angle value between V_{Lh} and I_{Sh}
$\emptyset_h$	The *h*th harmonic phase angle between V_{Lh} and I_{Sh}
α	Turns ratio of the transformer at the PCC
α_i	Coefficients that best fit , *i* counter that has a starting value of 1

LIST OF PUBLICATIONS

Shamel H. Hamouda, Shady H. E. A. Aleem and Ahmed M. Ibrahim, "Harmonic Resonance Index and Resonance Severity Estimation for Shunt Capacitor Applications in Industrial Power Systems," 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Menoufia University, Egypt, December 19-21, 2017, Cairo, Egypt.