Electric Power Systems Research 143 (2017) 451–461

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Optimal design of RC snubber circuit for mitigating transient overvoltage on VCB via hybrid FFT/Wavelet Genetic approach

Mohamed A. Ebrahim [a], Tamer Elyan [a], Fady Wadie [b,*], Mousa A. Abd-Allah [a]

[a] Faculty of Engineering at Shoubra, Benha University, Shoubra, Cairo, Egypt
[b] Faculty of Engineering, Egyptian Russian University, Badr, Egypt

ARTICLE INFO

Article history:
Received 15 August 2015
Received in revised form 21 July 2016
Accepted 13 September 2016
Available online 15 November 2016

Keywords:
Switching overvoltage
Vacuum circuit breaker
Induction motor
Fast Fourier Transform
Wavelet Transform

ABSTRACT

This paper presents a new approach to the analysis of the transient overvoltage (TOV) generated during switching of vacuum circuit breaker (VCB). The new technique overlaps the merits of both Fast Fourier Transform (FFT) and Wavelet Transform (WT). The new approach was applied on a real case study of a pumping station of a wastewater treatment plant located at Abu Rawash, Egypt. The pumping station is driven by induction motors. Alternative transients program (ATP) is used to simulate the selected case study. The Referential Integrity between FFT and WT analyses (RI-FFT/WT) is employed to choose the RC snubber circuit parameters (R and C). The optimal snubber circuit parameters design was determined from the hybridization between genetic algorithm (GA) and RI-FFT/WT. It is evident from the simulation results that the new hybrid GA-FFT/WT approach succeeded in the selection of the most optimal RC-snubber circuits required for the mitigation of the TOV.

1. Introduction

Vacuum circuit breakers (VCBs) are vital elements in the medium voltage interconnected power systems. Switching of VCBs causes transient overvoltages across circuit breakers' contacts. Switching of VCBs and the accompanied transient overvoltages has been under study by many researchers [1,2]. These studies are focused primarily on the voltage escalation caused by successive reignitions of the arc during the switching process. Such oscillation could cause severe damage to the connected loads. Additional protection measures including surge arresters and RC snubber circuits were proposed by researchers [2–4]. Selection of the most suitable protection and the optimal snubber circuit parameters "R" and "C" is the target of this paper.

To define an adequate protection for the VCB, a simulation of the electrical network understudy should be done. Modeling of VCB and other electrical components would be required. The VCB model depends on defining the events related to switching transient overvoltages including current chopping, multiple reignitions and virtual current chopping [5]. Current chopping refers to the extinction of the arc before reaching its zero crossing leading to the transient recovery voltage appears across the contacts of VCB [2–4]. If the TRV exceeds the dielectric strength of vacuum gap, a reignition of the vacuum arc occurs and a high-frequency current will be superimposed on the power frequency current. If the high-frequency current due to phase (A) forces the power frequency currents of the two phases (B and C) to reach zero, multiple reignitions will occur in the two phases (B and C), this phenomenon is known as virtual current chopping [4].

Section 2 describes the system components modeling using ATP. Section 3 presents the simulation of the selected case study and its results. Section 4 gives detailed FFT analysis for the simulation results. Section 5 performs WT analysis and its integration to FFT. The RC snubber circuit connection at motor terminal mitigates the transient overvoltages. In Section 6, the values of R and C were calculated by three different approaches: trial and error, FFT/Wavelet analysis and hybridization of FFT/WT and an optimization technique. Finally, the conclusion was drawn.

The main contribution of this research work is the presentation of a novel approach that determines the optimal sizing of snubber circuit parameters (R and C values) based on the hybridization between FFT/Wavelet analysis and genetic algorithm. The novel approach is more accurate, quicker than the conventional ones applied in literature for sizing the snubber circuit parameters.

* Corresponding author.
E-mail address: engfadywadie@hotmail.com (F. Wadie).

http://dx.doi.org/10.1016/j.epsr.2016.09.035

Nomenclature

A	Manufacturer's parameter for rate of rise of dielectric strength
ATP	Alternative transients program
B	Breaker's TRV just before current zero
D	HFQC of the VCB just before contact separation
E	Rate of rise of the HFQC of the VCB
FFT	Fast Fourier Transform
HFQC	High-frequency current quenching capability
RRDS	Rate of rise of dielectric strength
TRV	Transient recovery voltage
TOV	Transient overvoltage
VCB	Vacuum circuit breaker
WT	Wavelet Transform

2. Modeling of case study

The main problem under study is the voltage escalation phenomenon which is caused by the multiple reignitions of the arc during the switching of the VCB. Approaching such problem requires modeling of the VCB. Also, other elements are modeled such as induction motors (IM), transformers, cables, and busbars. Since the VCB is the key element in this study, a special attention was given for modeling it accurately.

2.1. Modeling of VCB

Although VCB has been under investigation by many researchers, but still there is no universal model. This can be attributed to the limitation in the information received from manufacturers due to its confidentiality. The stochastic model of VCB has been adopted by many researchers [5–8]. The VCB model incorporates different properties including the ability of the VCB to chop the current before its natural zero, the RRDS between contacts of VCB, The ability of the VCB to quench high-frequency currents at zero crossing or the HFQC and arcing time.

In this study, the VCB was modeled on ATP as an ideal switch. This assumption is justified as the voltage drop across the arc is small compared to the voltage transient [7,9]. MODELS tool available on ATP was used to control the state of the switch (shown in Fig. 1). The switch operation sequence is [4,5]:

- The switch remains closed after the mechanical opening of the VCB due to the presence of the arc.
- Once the arc value falls below the current chopping value, the MODELS tool opens the switch. The actual chopping current is non-deterministic. However, earlier research had established different mean chopping levels for different load currents and contact materials. The average chopping current is [1].

$$\bar{I}_{ch} = (\omega\,\hat{\imath}\,\alpha\,\beta)^{q} \quad (1)$$

where $\omega = 2\pi(50\,\text{Hz})$,

$\hat{\imath}$ = amplitudeofthe 50 Hz current,

$$\alpha = 6.2\times10^{-16}\ \text{s},\quad \beta = 14.3 q = (1-\beta)^{-1}.$$

The value of the chopping current used in this study was calculated to be 5.2 A.

- TRV appears across the contacts of the VCB. When the TRV exceeds the withstand voltage of the VCB (Eq. (2)) of the VCB, the switch recloses simulating the reignition of the arc.

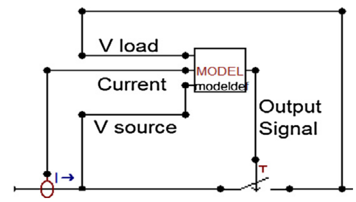

Fig. 1. VCB model on ATP/EMTP using MODELS tool.

$$U = A\left(t - t_{open}\right) + B \quad (2)$$

where U: the with stand voltage, t_{open}: the moment of contact separation.

A: Manufacturer's parameter for rate of rise of dielectric strength.

B: Breaker's TRV just before current zero.

- At this moment, a high-frequency current is superimposed on the power frequency current. When the HFQC (Eq. (3)) becomes higher than the rate of change of the current at zero crossing, the switch is reopened.

$$HFQC = E\left(t - t_{open}\right) + D \quad (3)$$

where E: Rate of rise of the HFQC of the VCB;

D: HFQC of the VCB just before contact separation.

- By repeating this sequence, a simulation of the multiple reignitions of the arc could be achieved.

The authors validated the model by comparing the results with Xue and Popov results [2].

2.2. Modeling of induction motor

The model of the IM depends on its state of operation. During the starting period, the rotor speed is very low; therefore, the generated back electromotive force is considerably small in comparison to the source voltage. The low back EMF cannot keep the TRV at a low level after opening the contacts of VCB. Therefore, the IM under starting condition is modeled as doing switching operation under locked rotor condition [2,6,10]. The T-equivalent circuit of the IM is proposed to represent the electrical characteristics of the motor under starting condition. However, T-equivalent does not consider the grounding capacitance for each phase. The modified equivalent network shown in Fig. 2(a) provides a solution for this problem [2].

The values of R_{phase}, X_{phase}, R'_{phase} and X'_{phase} are 0.85 Ω, 2 Ω, 0.2 and 2 Ω respectively. The trend of change of the grounding capacitance versus the rated power of the motor is [11].

$$C_g = 0.0086 + 0.529\ \ln(P_r) \quad (4)$$

where C_g is the grounding capacitance in nF (taken as 90 nF), P_r is the rated power in kW and R_d is the damping resistance given by [12]

$$R_d = \left(C_g\left(\frac{2}{\tau} - \frac{R_m}{L_m}\right)\right)^{-1} \quad (5)$$

where R_m: the total resistance of each phase;

L_m: the total inductance of each phase;

τ: the attenuation time constant of natural oscillation of load itself.

ATP's Universal Machine Type 3 (UM3) was used to represent the IM during full load operation condition as shown in Fig. 2(b).