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Progress on power swing blocking schemes and the impact of renewable energy on power swing characteristics: A review

M.K. Gunasegaran [a,*], ChiaKwang Tan [a], A.H.A. Bakar [a], H. Mokhlis [b], H.A. Illias [b]

[a] UM Power Energy Dedicated Advanced Center (UMPEDAC), Level 4, Wisma R&D, University of Malaya, Jalan Pantai Baharu, 59990 Kuala Lumpur, Malaysia
[b] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

The occurrence of power swing had been reported to threaten the seamless operation of power system. Several cascaded outages and major blackouts in the world have been traced to mal-operation of distance relays due to power swing occurrences. As such, this paper will present a consolidated review on the power swing phenomenon, covering the causes of power swing, its impact to consumers and generators, as well as its detection and relay blocking schemes to prevent the mal-operation of distance relay. Given the wide arrays of power swing detection techniques and blocking schemes available up to date, particular attention is concentrated at the various power swing detection techniques on high voltage power system. In addition, the effect of modern renewable energy generations to the power swing characteristics is also presented in this paper.

Contents

* Corresponding author.
E-mail address: mu2kumaran@hotmail.com (M.K. Gunasegaran).

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1. Introduction

Power system stability plays a vital role in ensuring the systems reliability. In steady state, a balance power flow is maintained between the generation and load. However, unpredicted events or large disturbances such as fault, line switching, generator disconnection, and the loss or application of large blocks of loads may interrupt this balance and cause oscillation of power known as power swing [1,2] in the system. In severe circumstances, the power swing may lead to loss of synchronism between the generator and load, resulting in generator tripping and subsequently risking cascaded power outages and major power blackouts. However, not all power swings are unstable for some of the power swings are stable swing, where the generators can recover from the temporary transient instability. During these stable swing events, the distance relays are very likely to detect a temporary decrement in impedance, which can be wrongly interpreted as a fault by the relay. As oppose to a fault, it is undesirable to trip the line under these stable swing conditions given that the network has the ability to return to stability. Consequently, the undesirable operation of distance relay under a stable swing scenario is termed as mal-operation of distance relay or nuisance tripping.

The North American Electric Reliability Corporation (NERC) reported an alarming statistics where 75% of the major disturbances leading to cascaded outages and major blackouts involved the mal-operation of distance relays [3]. Table 1 lists the countries that experienced major blackout due to nuisance tripping of distance relay [1,4–7].

Acknowledging the problem of power swing causes nuisance tripping of distance relay, various power swing blocking schemes have been developed. Given the availability of various blocking schemes over the years, this paper aims to present a consolidated review of the various power swing blocking schemes up to date.

On the other hand, the increasing demand for energy and the pressure on environmental issues over the years gave rise to the penetration of renewable energy into the power system. However, the impact of large penetration of inverter interfaced renewable energy generation has yet to be clearly established. Besides benefiting the environment and generating renewable energies, there are looming concerns that the renewable generations may also significantly impact the power swing characteristics and affect the distance relay operation. Consequently, the impact of modern renewable energy generations to the power swing characteristics will also presented in this paper.

The organization of this paper is as follows. Section 2 presents the background of power swing phenomenon. The various power swing blocking schemes which forms the main contribution of this paper will be presented in Section 3. In the section, the widely used schemes, its working principle, advantages, and disadvantages will be presented. In addition, the section will also discuss the latest methods and findings in detecting power swing by means of signal analysis. Section 4 will present the potential impact to power swing characteristics due to the integration of renewable energy generations. New and significant information generated from this review that require further analysis and understanding are presented in Section 5. Finally, the conclusion is drawn in Section 6.

2. Background studies: power swing phenomenon

Power swing is defined as "*large oscillation of power between two areas of a power system*" [8]. It can be categorized into two types, stable and unstable swing. If the swing is stable, the fluctuation settles in a short period of time. On the contrary, unstable swing leads to advancement of rotor angle causing instability to the system.

2.1. Causes of power swing

Power system faults, line switching, generator disconnection, and the loss or application of large blocks of load causes fluctuations in electrical power although the mechanical power remains relatively constant in a generator [1,9–13]. When one of these disturbances occurs, it will cause changes in the electrical power parameters as in following equation.

$$P_g = [(E_g E_1)/X] sin\ \delta \quad (1)$$

Where:

P_g = Electrical power
E_g = Internal voltage
E_1 = Load voltage
X = Reactance between the generator and the load.
δ = Angle that the internal voltage leads the load voltage

Table 2
Condition and impacts due to power swing occurrence [25].

Condition	Impact
Loss of load	Loss of synchronism between voltages
Generator disconnection	Loss of synchronism between phase angles
Addition of load	Loss of synchronism between phase sequence
Line switching	Loss of synchronism between frequencies

Table 1
Record of blackouts due to zone 3 nuisance tripping [1,4–7].

Year	Affected countries
September 2003	Malaysia – Blackout for five (5) hours including capital Kuala Lumpur
September 2003	Italy major power failure
January 2005	Malaysia – Major blackout in northern region of the country
November 2009	Blackout in eight states of Brazil
July 2012	India – Blackout in the western grid.