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Weakest Bus Frequency Identification of Power System via TFDI

Athraa Iessa*, Noor Izzri Abdul Wahab* and Norman Mariun

Centre for Advanced Power and Energy Research (CAPER), Department of Electrical and Electronic Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

ABSTRACT

One of the concerns in power system preventive control and security assessment is to find the point where the voltage and frequency collapse and when the system forces a severe disturbance. Identifying the weakest bus in a power system is an essential aspect of planning, optimising and post-event analysing procedures. This paper proposes an approach to identify the weakest bus from the frequency security viewpoint. The transient frequency deviation index for the individual buses is used as the weakest bus identification as well as a frequency security indicator. This approach will help to determine the bus with the worst deviation, which helps to analyse the system disturbance, takes proper control action to prevent frequency failure, and most importantly, observes consumer frequency. The approach is applied to the WSCC 9 bus test system to show the feasibility of the method.

Keywords: Power frequency stability, transient frequency, deviation index

INTRODUCTION

In recent years, the integration of various renewable resources has made power system control and protection complicated. When there is any change in the operation condition due to increased load demand, it results in generator outage or in a natural fluctuation of the generating sources. Consequently, system voltage and frequency will experience a state of instability. The detection of the weakest point of the system where the voltage or frequency collapses is a vital aspect in studies related to power system security assessment.

The are several studies on the identification of the weakest bus based on voltage security. Kuhn-Tucker's theorem has a voltage stability indicator which helps to identify the weakest voltage bus or area. This indicator is comprehensive because it covers all marginal costs (Gau, 1994). Chen (1996),describes a method to identify the weak bus using voltage collapse proximity

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E-mail addresses:
athraa_aissa_2000@yahoo.com (Athraa Iessa),
izzri@upm.edu.my (Noor Izzri Abdul Wahab)
norman@upm.edu.my (Norman Mariun)
*Corresponding Author

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indicator to install the VAR source and enhance the system security margin. A study of the power system's weak bus identification using model analysis, multivariable control, and SVD (Singular Value Decomposition) was conducted by (M. K. Jalboub, H. S. Rajamani, 1998). An easy method to locate the critical voltage bus using a basic power flow equation and KVL law was carried out by (Bhonsle, Deshpande & Renge, 2004).

The above studies are focused on voltage stability indices, effects of voltage stability control on system failure and blackouts. Despite the importance of understanding frequency behaviour for different bus systems as a result of integration of renewable energy resources, there are only a few studies that deal with identifying the weakest frequency bus. Such studies are essential for post-event analysis and for minimising the individual machine deviation when the system load is suddenly increased, or when outage occurs in the online units (Adibi & Fink, 2006).

The frequency deviation differs from one bus to another. Consequently, the frequency deviation has been used in several studies either to locate each electrical area established on both coherent generators and related non-generator buses (Khalil, Member, & Iravani, 2016) or for islanding control (Bevrani & Tikdari, n.d.).

This paper recommends the use of transient frequency deviation index (TFDI) for individual system buses. The TFDI is a good indicator for frequency stability to identify the worst deviation bus in the system. This approach will contribute effectively to the analysis of system disturbances, system partitioning into control areas, as well as observe consumer frequency. The rest of this paper is structured as follows: the concept of frequency stability is discussed in Section 2 while Section 3 presents the methodology. Section 4 discusses the simulation results while Section 5 provides the conclusions.

CONCEPT OF POWER SYSTEM FREQUENCY STABILITY

Frequency stability is the ability of a power system to withstand any credible disturbances and maintain a nominal operation frequency. Frequency stability depends on the ability of a power system to restore the balance of system generation with a minimum loss of load (Sun, H. D., Tang, Y., & M. A., n.d.). Frequency stability problems are related to insufficient reverse generation, inadequate protection and control devices, and the weakness in equipment responses.

Frequency stability may be short-term such as the rapid frequency deviation of the un-generated island when it is insufficient under frequency load shedding such that the island is experiencing a blackout within seconds (Kundur et al., 2004), or it may be a long-term stability with the time frame ranging from tenths of a second to few minutes. This phenomenon can be caused by controls of over speed steam turbine or boiler protection (Hatziargyriou & Karapidakis, 1998; Chow, Kundur, & Acchione, n.d.). Frequency deviations can damage the equipment, degrade load performance, overload transmission lines, and interfere with system protection schemes. Moreover, the significant frequency deviation events can ultimately lead to system collapse. Therefore, frequency stability assessment is essential for power system operation and control.

TRANSIENT FREQUENCY DEVIATION INDEX OF SYSTEM BUSES

In a power system, if any generation or part of a generation unit trips, the frequency will deviate from the nominal value. Likewise, if any load disconnects from the system, the latter will experience a high-frequency deviation. In other words, the frequency deviation can reflect system generation balance.

The frequency deviation is a good indicator of system stability. Most of the frequency security assessment studies used frequency deviation indices such as maximum frequency deviation index MDFI, total frequency deviation index FDI, and frequency security index FSI (Manuel, Alvarez, Mercado, & Member, 2007). However, although these indices can measure the rigorousness of disturbances in a particular time, they are incapable of measuring the effect of frequency deviation in a period. Additionally, they are unable to indicate the different frequency decay for various buses (consumer) (Dai, Xu, Dong, Wong, & Zhuang, 2012).

Therefore, TFDI was established by Zhang, Li and Liu (2015). The TFDI can be obtained from frequency response trajectory and two elements tables (f_{cr} ,t_{cr}). The general formula for the index is:

$$\eta = \frac{S_d}{(f_N - f_{cr})t_{cr}} \tag{1}$$

$$S_d = \min\int_{t_s}^{t_s+t_{cr}} (f - f_{cr})dt \tag{2}$$

where:

S_d = the minimum area surrounded by the frequency response curve and the critical frequency (f_{cr}) in within critical time (t_{cr}). fN =standard frequency of the system, f_{cr} =frequency deviation threshold, t_{cr} = the acceptable duration for frequency deviation for going beyond f_{cr}, t_s = starting time of statement window.

According to (Zhang et al., 2015) the determination of TFDI depends on Sd, which also depends on the relation between the frequency trajectory, the critical system frequency, critical system time, and the break time as follows:

1) If there is no intersection between the frequency response trajectory and the line of critical frequency $f=f_{cr}$, and the break time is zero t_b=0 (figure.1a), then the TFDI will be:

$$\eta = \frac{s_1}{(f_N - f_{cr})t_{cr}} \tag{1a}$$

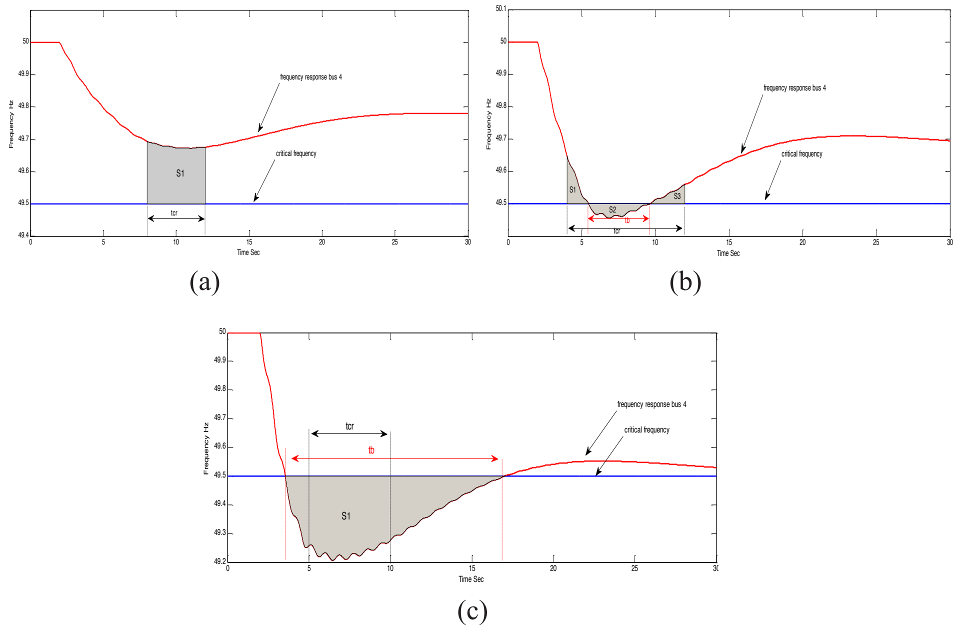

Figure 1. S_d determination (a) when t_b=0, (b) when $0<t_b<t_{cr}$, (c) when $t_b>t_{cr}$

2) If there is an intersection between the frequency response and the critical frequency line, and, the break time t_b is less than t_{cr} (figure 1b) , the TFDI will be:

$$\eta = \frac{S_1 + S_3 - S_2}{(f_N - f_{cr})t_{cr}} \tag{1b}$$

3) If there is an intersection between the frequency response and the critical frequency line, and, the break time tb is greater than t_{cr} (figure 1c), the TFDI will be:

$$\eta = \frac{-S_2}{(f_N - f_{cr})t_{cr}} \tag{1c}$$

The TFDI has the ability to evaluate the frequency security of individual buses (consumers), especially when the system withstands large disturbances such as 3-phase fault at any system buses or lines. Therefore, TFDI can be used to find the weakest or unstable bus from the frequency security viewpoint. The bus with the smallest TFDI is the worst deviation bus.

PROPOSED METHODOLOGY

The methodology to locate the TFDI for individual buses, and then to decide the wind turbine location is shown in Figure 3.

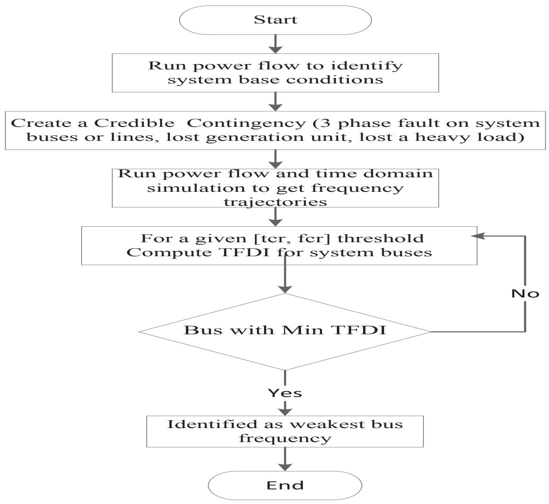

Figure 2. Flowchart of identifying weak bus frequency

SIMULATION RESULTS AND DISCUSSION:

The test system to be used for this simulation is the IEEE 9-bus, 3-machine test system shown in Figure 4. System data are given in (Ahmadi & Ghasemi, 2012). After running a power flow in order to identify the base operation conditions of the system, full-time domain simulations are applied with different contingencies. The results show that the frequencies of various buses are not the same. Therefore, the TFDI of buses is also different. Figure 5 below shows the frequency response of system buses for a 3-phase fault at bus 2. It is obvious from this plot that the responses are not similar. Consequently, the TFDI of system buses will be different.

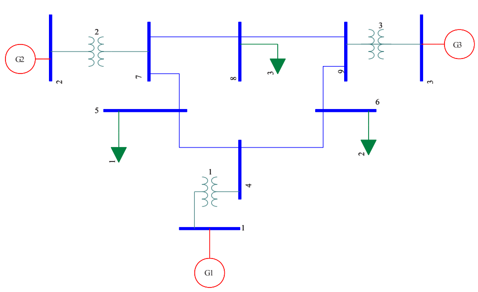

Figure 3. IEEE 9-bus test system

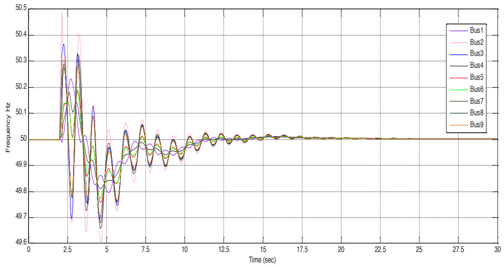

Figure 4. Frequency response of system buses for 3-phase fault at bus 2_r

The TFDI of each bus is calculated. Figures 6, 7 and 8 show the TFDI of each bus with bus numbers for different cases. It can be seen clearly from the results that we get approximately the same pattern for all cases. It can be observed that bus 2, 5 and bus 7 are the lowest TFDI buses. Thus, these buses can be mentioned as the weakest buses frequency of the system. Since bus 5 is the lowest TFDI among all load buses it can be selected as wind power integration bus to assess perfectly the maximum wind power penetration level. These results seem to be consistent with other studies which chose bus 5 as wind farm integration bus (Ahmadi & Ghasemi, 2012).

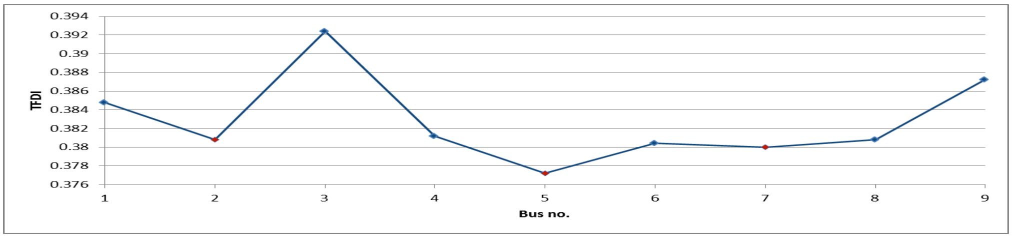

Figure 5. TFDI with bus no. for 3-phase fault at bus 7

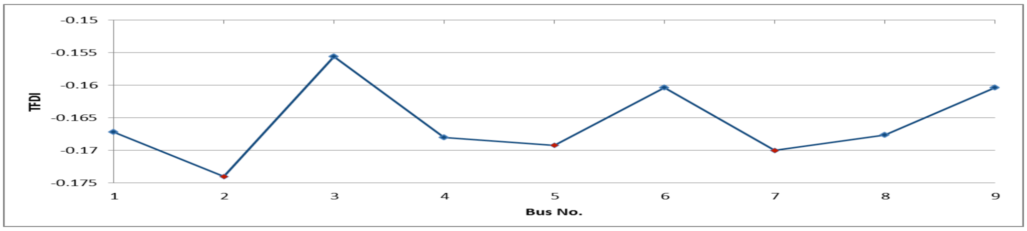

Figure 6. TFDI with bus 3-phase fault on line 4

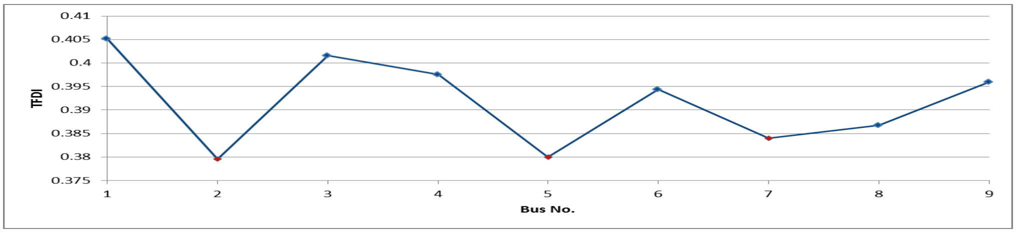

Figure 7. TFDI with bus 3phase fault at bus 2

CONCLUSION

For economic load shedding protection design, it is necessary to evaluate the frequency instability. The first step to evaluate this instability is to find the severity of frequency deviation. Another important aspect of power system frequency stability is to observe the frequency decay for different buses (consumers). There is a need to find the weak frequency points of the network to select the wind turbine integration bus to estimate the maximum allowable wind power level accurately according to the impact of this turbine on system frequency.

The main aim of this study is to show the ability of TFDI to evaluate the frequency stability for different system buses. The study also suggests an approach to find the most suitable bus for locating the load shedding schemes and for observing the frequency of customers. The feasibility of the proposed approach has been achieved on IEEE 9- bus test system.

Determining the critical level of variable renewable resources penetration while considering the system's frequency limits can be explored in future research.

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