The Impact of Communications Channels Availability on Distribution State Estimator

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Abstract: *This paper describes an advanced distribution management system controller and how a distribution network state estimator is formulated. The effect of communications channel availability on the distribution network state estimator under various types of communication systems is then analysed and discussed in details. From the distribution network state estimator, the accuracy of all network node voltages estimation against different communication system availability data with and without the consideration of communication channel redundancy are calculated and evaluated.*

1.0 INTRODUCTION

By carefully co-ordinating voltage control, power flow and using new applications in an advanced Distribution Management System (DMS) controller [1, 2], 'active' distribution network operation will allow a large amount of Distributed Generations to be connected to the existing distribution networks.

In the development of the advanced DMS controller, one of major functions is to formulate a Distribution Network State Estimator (DNSE). Although transmission system state estimation algorithms that use large number of real-time measurements have been successfully applied for years [3], these cannot be directly translated into DNSE. Distribution networks are large and complete SCADA systems are seldom available at 33kV and below due to the cost associated with using communication channels for potential hundreds of distributed measurements. Hence the availability of real-time measurements is limited and the deficiency of them must be compensated using the estimation of load consumptions at the network substation transformers as pseudo measurements. In order to reduce real-time measurements, a technique to local critical points for voltage measurement placement has been developed based on a series of load flows [4]. The method locates a given number of critical measurements to minimise voltage variances on the on the unmeasured buses.

Since only a limited number of critical measurement points are considered, a newly developed DNSE must consider using the limited number of communication channels. This requires these communication channels to be available to use all the time. The use of fibre optic channels or microwave channels [5, 6] can provide the highly reliable communication channels for DNSE application, but they are expensive.

Traditionally, distribution network are radial carrying low energy to its customers. The design of SCADA system for distribution network operation and control poses a major challenge to power system utilities [7]. Putting in highly reliable fibre optics or microwave channels is expensive for DNSE applications [8]. Low cost and maintenance communication mediums, such as public switch telephone network or unlicensed low power radio or power lines, may be used for DNSE applications. But they are less reliable comparing with fibre optics or microwave channels. Hence the selection between more reliable with high cost and less reliable with low cost communication systems for DNSE applications is an important issue to many power utilities.

This paper investigates the effect of communication channel availability on the DNSE voltage estimation accuracy. The relationship between communication system availability and the DNSE voltage estimation accuracy are presented and discussed.

2.0 DISTRIBUTION MANAGEMENT SYSTEM (DMS) CONTROLLER AND STATE ESTIMATOR

2.1 DMS Controller Architecture

A possible advanced DMS controller architecture is proposed by [4] as shown in figure 1. The DMS controller estimates the state of a distribution network. If an abnormal state occurs, it will carry out the proper control actions to ensure the level of the network security. The main objective of the DMS controller is to allow for maximum generation without exceeding any voltage limit or overloading any line rating.

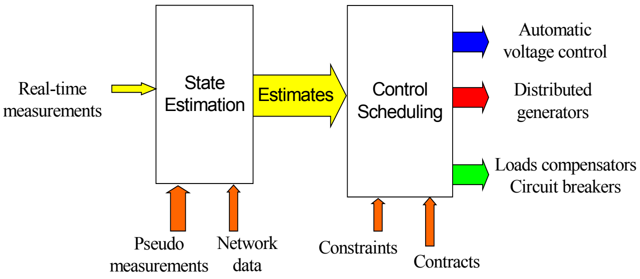

Figure 1: DMSC architecture

The DMS controller mainly consists of state estimator and control scheduling blocks. The inputs to the state estimator consist of real time network measurements, pseudo measurement injections and network data. Each measurement has an associated variance that weighs it to the state estimator. The real-time measurements are supplied from remote and local substations within the area where the DMS controller is managing the network. Pseudo-measurements are the estimation of load consumptions at the network substation transformers based on load model. The control-scheduling block requires network constraints and contracts for taking proper control actions.

2.2 Distribution Network State Estimator

Unlike transmission system state estimation algorithms that use large number of real-time measurements, the DNSE (as illustrated in Fig.1) uses both real-time measurements and pseudo-measurements. The real-time measurements are obtained from critical monitoring points via communication systems. A technique to locating critical points for voltage measurement placement has been developed based on a series of load flows [4]. Pseudo measurements are obtained from load model based on the estimation of load consumptions at the network substation transformers.

The state estimation is a mathematical procedure by which the state of an electric power system is extracted from a set of measurements. The basic measurements are P, Q and V (real power, reactive power and voltage magnitude). In general, any measurement can be expressed as a function of the system states. Let z_i denote a measured quantity:

$$z_i = f_i(\mathbf{x}) \qquad (1)$$

where **x** is the vector of the system states, $f_i(\mathbf{x})$ is a function of the system states specific to the measured quantity z_i.

The DNSE is then presented as a minimisation problem, where the least square objective function minimises the sum of the squares of all measurements, $\sum z_i^{meas}$, of residuals, i.e. $\sum [z_i^{meas} - f_i(x)]^2$. A number of iterations are carried out to reduce these residuals. The equation for all measurements, including real-time measurements and pseudo measurements, is described by:

$$\min_{\mathrm{x}} J(\mathrm{x}) = \sum_{i=1}^{m} \frac{[z_i^{real} - f_i(\mathrm{x})]^2}{\sigma_i^2} + \sum_{j=m+1}^{n-m} \frac{[z_j^{pseu} - f_j(\mathrm{x})]^2}{\sigma_j^2} \qquad (2)$$

where **x** is the vector of the system states; n is the total numbers of measurements; m is the number of real-time measurements; n-m is the number of pseudo measurements; z_i^{real} is a the i^{th} real-time measurement value, $i = 1,.., m$, $f_i(\mathbf{x})$ is a function of the system states specific to the real-time measured quantity z_i^{real}; σ_i^2 is the variance of the i^{th} real-time measurement; z_j^{pseu} is the j^{th} pseudo measurement, j = m+1, .., n-m; $f_j(\mathbf{x})$ is a function of the system states specific to the pseudo measured quantity z_j^{pseu} and σ_j^2 is the variance of the j^{th} pseudo measurement.

3.0 EVALUATION OF DISTRIBUTION NETWORK STATE ESTIMATION

3.1 Distribution Network

An evaluation of a wind farm project at a predetermined location in a rural 11kV network as shown in figure 2 was carried out. The main source of the network is the 33/11kV transformer on bus 1 at the 33kV substation. The network includes two locations of wind farms connected at 11kV system on bus 11 and 51. The rest of the buses are connected in a radial network to supply distribution feeders at 11kV. To ensure the estimation voltage uncertainty below 0.71% for all buses, the DNSE needs a minimum four critical voltage measurement placement points at buses 1, 11, 51 and 81, which were identified based on a series of load flows [4].

The DNSE algorithm calculates the voltages for all buses based on the minimum four real-time monitoring points and pseudo-measurement placement on wherever the real-time monitoring points are not used at the load buses in the network.

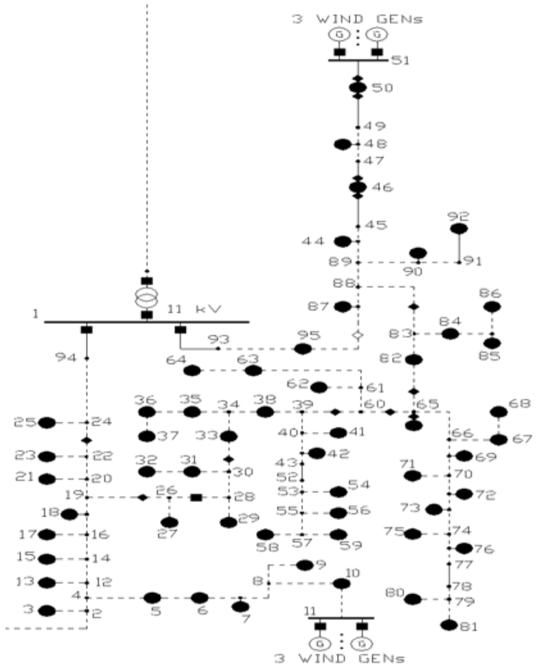

Figure 2: 11kV distribution network

Although pseudo measurements are subject to errors from load model calculation, they are always available to use. The concern for the DNSE algorithm is the availability of these communication channels used for real-time monitoring points. Thus the study focused on the evaluation of the DNSE algorithm performance against the availability of these four real-time measurement inputs.

3.2 Cases Studies

The work assessed the level of estimated voltage uncertainty of the DNSE if there's any unavailable real-time measurement from these four real-time measurement locations. The DNSE was run considering the real-time voltage measurements accuracy of ±1% and a fixed pseudo measurement accuracy of ±25% at all load buses. The estimated voltage accuracy and uncertainties based on the availability of real-time measurements were evaluated.

Case 1: Fig.3 shows that four curves are the estimated voltage uncertainty in percentage based on one real-time voltage measurement, V_m, either from bus1 or 11 or 51 or 81 at any time. The standard deviation of the estimated voltage uncertainty for these four curves was in the range of 3.2% to 4.0%. Fig.3 also shows that the mean curve plotted as a dot line is calculated based on the four estimated voltage uncertainty curves. The calculated mean voltage estimation uncertainty is in the range of 1.1% to 1.3%. The maximum standard deviation of the mean voltage estimation uncertainty was of 0.3%.

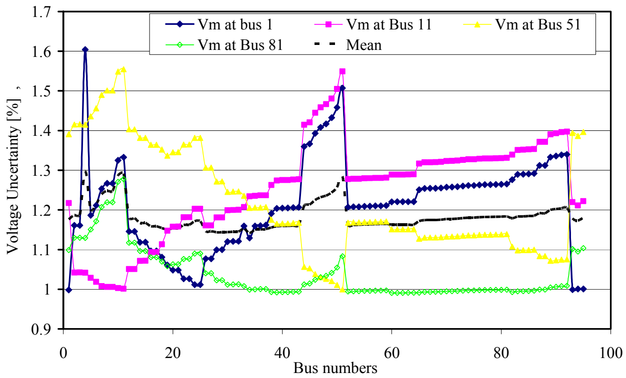

Figure 3: Voltage uncertainty when only one measurement available

Case 2: Fig.4 shows that six curves are the estimated voltage uncertainty in percentage based on two real-time measurements, either from bus1, 11 or 1, 51 or 1, 81, or 11, 51 or 11, 81 or 51, 81, at any time. The calculated mean voltage estimation uncertainty for the six curves was found in the range of 0.8% to 0.95%. The maximum deviation of the mean voltage estimation uncertainty was 0.35%.

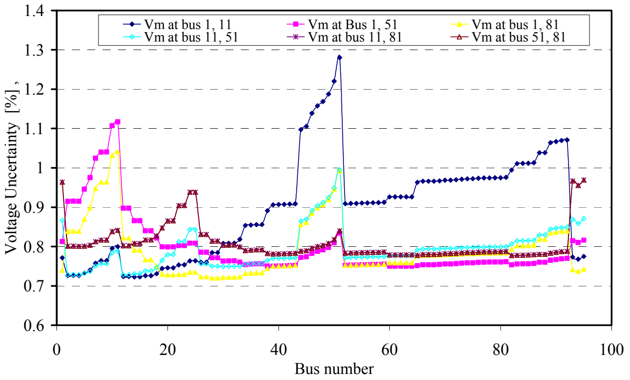

Figure 4: Voltage uncertainty when two measurements available

Case 3: Fig.5 shows that the estimated voltage uncertainty in percentage is from 0.53% to 0.73% when all four measurements were available at any time. The standard deviations of the estimated voltage uncertainty values are in the range of 0.16% up to 0.22%.

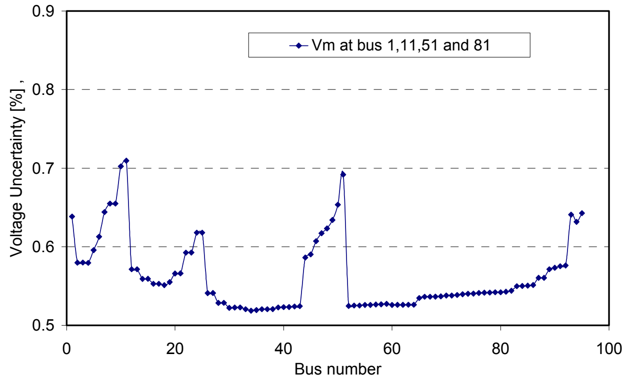

Figure 5: Voltage uncertainty when all four measurements available

3.3 Effect of Measurements On State Estimator

Based on the case studies, the estimated voltage uncertainty curves at all buses were calculated against either one, two, three or 4 measurements available at any time. Fig.6 shows four curves are the estimated voltage uncertainty on bus 1, 11, 51 and 81 against either one, two, three or four measurements available at any time. Fig.6 also shows that the mean curve plotted as a dot line are calculated based on the four estimated voltage uncertainty curves of bus 1, 11, 51 and 81.

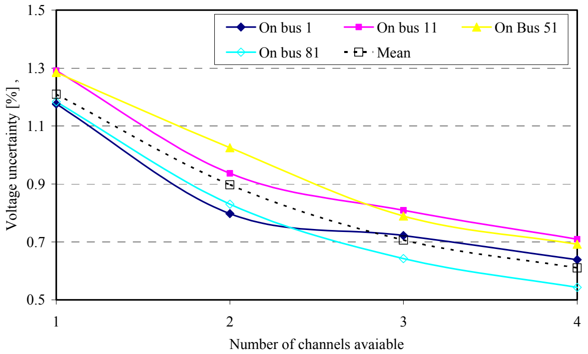

Figure 6: Voltage uncertainty against the number of channel available.

The mean curve in Fig.6 shows that the estimated voltage uncertainty is 1.2% when only one channel is available. However, the voltage uncertainty is reduced to 0.62% when all four channels are available.

Results from the case studies show that with increasing number of real-time measurements, the estimated voltage uncertainty at all bus locations can be decreased. To ensure the estimated voltage uncertainty level below 0.62%, the DNSE must use all four real-time measurements. If any real-time measurement is unavailable, the performance of the DNSE will be affected.

4.0 COMMUNICATIONS AVAILABILITY ANALYSIS

Various communication mediums, such as fibre optics, microwaves, public switch telephone network or GSM mobile network or unlicensed low power radio or power lines, can be considered for DNSE application. Since a limited number of real-time measurements at the critical monitoring points are considered by DNSE, the communication reliability for these critical measurements nodes becomes an important issue.

One of the communication system reliability components is the communication channel availability. Availability is defined [10] as the probability that an item will be available when required, or as the proportion of total time that the item is available for use. The proportion of total time that the item is available is the steady state availability (A), given by:

$$A = \frac{\mu}{\lambda + \mu} = \frac{MTBF}{MTBF + MTTR} \qquad (3)$$

where: A is the steady state availability; μ the constant mean repair rate; λ the constant failure rate; $MTBF$ the Mean Time Between Failure; $MTTR$ the Mean Time To Repair.

Different types of communication medium have different availability performance due to its inherence design, its susceptibility to noise and ageing of its components. Based on equation (3), last two and a half-year (from September 2001 to February 2004) historical data of communication networks within Tenaga Nasional Berhad (TNB), Malaysia national grid company, was used to calculate each type of communication medium availability. Three type of communication media; fibre optics, analogue power line carrier, and leased line circuit were selected. The calculated fibre optic system availability per channel was 99.99%, analogue PLC per channel was 99.97% and the leased line circuit per channel was 99.90%. However, the communication systems installed and used by TNB is more than 10 years. It is expected that the true communication channel availability figures for TNB communication systems would be lower than that based on 2.5 years data. By extending two and a half year historical data linearly to 12.5 years, it estimated that the availability for fibre optic per channel was 99.70%, for analogue PLC per channel 98.50% and for Leased Line per channel 97%. The estimated communication system availability per channel for 12.5 years is shown in Table 1.

Table 1: Availability figures of three types of communication mediums

Type of medium	Fibre Optic	Analogue PLC	Leased Line
Estimated availability per channel	99.70%	98.50%	97.00%

Based on each channel availability figure, the availability of a multiple channel system can be calculated using the formula of equation (4) below:

$$P\{m\} = \frac{n!}{m!(n-m)!} \times p^m \times q^{n-m} \qquad (4)$$

Where: n is total number of channels, m is the number of available channels, (n-m) is number of unavailable channel, p is the availability of each channel, q (=1-p) is the unavailability of each channel.

Refer to case studies, the DNSE needs 4 critical real-time measurements. Consider to select either optical fibre channels or leased channels. For 4 optic channels with 99.70% per channel, the availability of 4 optic channels is calculated as P of 98.8% (=0.997×0.997×0.997×0.997). For 4 leased channel with 97% per channel, the availability of 4 leased channels is calculated as P of 88.53% (=0.97×0.97×0.97×0.97). As the leased channel offers lower cost than optic channels, one must prefer to use the leased channels.

To achieve the same availability as 4 optic channels for leased channels, we can add one redundancy channel. It is assumed that 5 leased channels are installed, but only 4 must be used for the DNSE application and one channel is used as a redundancy channel for standard by, so that n = 5 and m=4. Based on equation (4), the availability of 4 leased channels plus one redundancy channel is calculated by:

$$P = \frac{5!}{5!(5-5)!} p^5 q^0 + \frac{5!}{4!(5-4)!} p^4 q^{5-4} = p^5 + 5p^4(1-p)$$

As p = 0.97 for leased line circuit per channel, we obtain P of 99.15%, which is greater than 98.8% of four optic fibre channels. The result shows that the use of lower cost leased channels with the consideration of redundancy channels could achieve a similar or higher communication system availability than that of using fibre optic channels. As more channels cost more, but more reliable channels also cost more. This will lead to a further work for optimal selection of communication systems and cost for DNSE application.

5.0 CONCLUSION

This paper evaluated the impact of real-time measurement availability on a distribution network state estimator. Results show that with increasing number of real-time measurements, the estimated voltage uncertainty from the DNSE at all bus locations can be decreased. However a limited number of real-time measurements for critical monitoring points are considered by DNSE, the communication channel availability for these critical measurements becomes an important issue.

The analysis of communication channel availability for three types of communication channels has been presented. Results show that the use of an adequate number of communication channel redundancy, the DNSE is able to use low cost leased line circuits to maintain or even improve all busbar voltage estimation accuracy. By carefully choosing communication systems availability associated costs, this work will lead to an optimal design of a low cost of distribution state estimator for DMS application.

6.0 REFERENCES

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