Module 6 : Preventive, Emergency and Restorative Control

Lecture 26 : Power System State Estimation

Objectives

In this lecture you will learn the following

- The fundamentals of Power System State Estimation
- Handling errors and bad data in static state estimation
- Dynamic Measurements

Power System State Estimation

Power System State Estimation is a process whereby telemetered data from network measuring points to a central computer, can be formed into a set of reliable data for control and recording purposes.

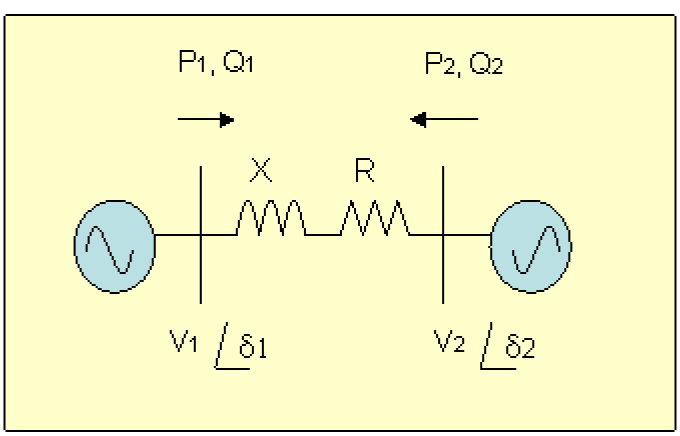
A *static* state estimate is obtained from measurements taken within a time interval of about 0-5 s. This is the commonly used state estimator. Obviously, a state estimator of this type essentially gives a steady state snapshot of the system.

A *dynamic* state estimate is obtained from measurements in a relatively shorter time (say 0.01 s). Moreover, all such measurements are synchronised or "time stamped" using a common clock and communicated from geographically distant locations to a load dispatch centre. These measurements could be used for advanced control schemes which we shall see later.

The main concern in state estimation is the reliability of the measured data. Usually to minimize the errors, the data is crosschecked using more measurements than necessary (redundant measurements). This is done in a systematic fashion as discussed in the following slides.

Static State Estimation Procedure

We will try to understand the procedure in an informal fashion. Consider the simple system shown below:



In the above system we have obtained the following measurements: P1, Q1, P2, Q2, V1 , V2 : i.e, the real and reactive flows on both ends of the line and the voltage magnitudes at the two ends. If d1-d2 is known then, the system is fully "estimated" (i.e., nothing more is left to be known). We assume here that the parameters of the line are known fairly accurately.

If all measurements are accurate, then it should be possible to obtain d1-d2 quite easily by the following formula:

$P1 = V1*V1*\cos f / Z - V1*V2*\cos(f + d1-d2) /Z$

where, $Z =| R+jX |$, and $f = \arctan(X/R)$

However if there is a measurement error in P1, V1 or V2, then d1-d2 will be inaccurate. So it is best to cross-check the results with other formulae:

$Q1 = V1*V1*\sin f /Z- V1*V2* \sin(f + d1-d2) / Z$

$P2 = V2* V2*\cos f /Z - V1*V2 * \cos(f + d2-d1) /Z$

$Q2 = V2*V2*\sin f /Z- V1*V2* \sin(f + d2-d1) / Z$

If $R+jX= 0.01 + j0.1$, then check that the following set of measurements will give consistent values of d1-d2.

P1 = 5.1; P2 = -4.82; Q1 = 0.83; Q2 = 1.82; V1 =1.0; V2 = 1.0 ;

Verify that d1-d2 = 30

If d1-d2 obtained using different expressions are inconsistent, it means that error exists in one or more of the measurements. Thus, using redundant measurements Q1, P2 and Q2 we can check for presence of errors (which will invariably exist).

For example, one or more of the following set of measurements have some error.

P1 = 4.8; Q1 = 0.789; V1 = 1.0 ; V2 = 1.0;

d1-d2 = 28.19 when substituted in P1 but -17.96 when used in Q1.

Now the question arises: how do we get a correct estimate of d1-d2 ?

Handling Errors and Bad Data in Static State Estimation

One possibility is to take the average value of d1-d2 obtained from formulae for P1 and P2. This way, one does not place too much faith on one measurement.

Alternatively one could try to obtain a value of d1-d2 such that plugging that value will minimize the following error:

$$J = k1 * (P1 - V1*V1*\cos f / Z + V1*V2*\cos(f + d1-d2) /Z)^2 + k2 * (Q1 - V1*V1*\sin f /Z + V1*V2* \sin(f + d1-d2) / Z)^2$$

$$+ k3 * (P2 - V2* V2*\cos f /Z + V1*V2 * \cos(f + d2-d1) /Z)^2 + k4 * (Q2 - V2*V2*\sin f /Z + V1*V2* \sin(f + d2-d1) / Z)^2$$

where, k1,k2,k3 and k4 are positive weights. Note that J is always greater than or equal to zero. Minimization of J, results in the "least square" deviation from the measured values.The main problem, however, is to chose the weights k1, k2, k3 and k4 appropriately. For similar quantities (power, reactive power) one can choose weights to be equal. Minimizing J requires us to use an optimisation procedure as outlined in the previous module.

Both the approaches (1. averaging and 2. minimizing J) are likely to work well if errors are small in magnitude. If there exist gross errors in the data (which occur, say, due to failure of communication), then the above approaches may fail.

For example, if the measured values are P1 = 5.1; P2 =0 ; Q1 = 0.83; Q2 = 1.82; V1 = 1.0 ; V2 = 1.0; then it is obvious that some major flaw exists in the data.

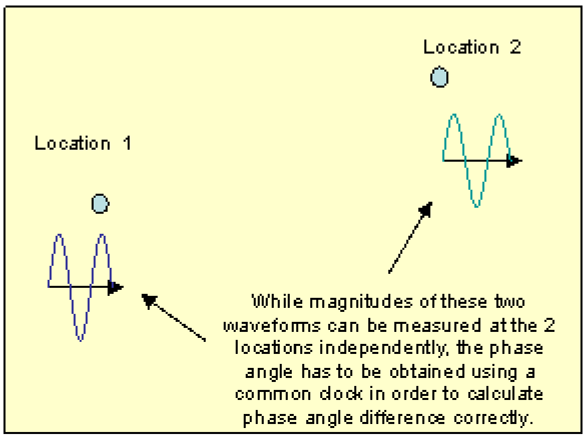
Can you find a reasonable way to identify grossly erroneous measurements ("bad data detection") ?

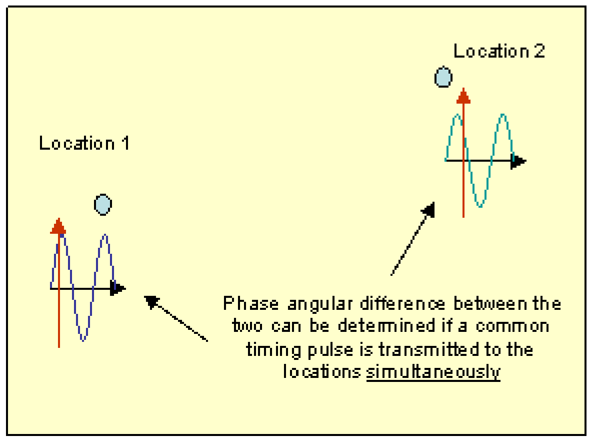
Question: Can d1 and d2 be estimated individually ? Why?

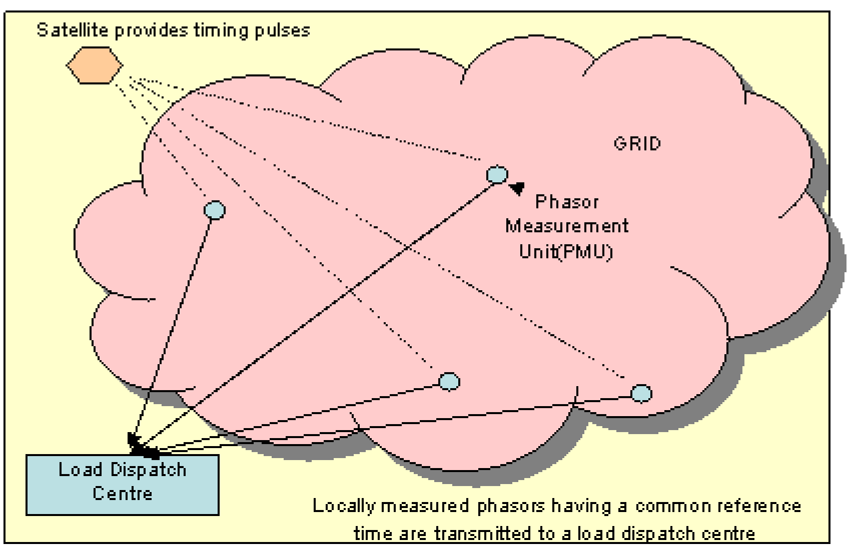
Dynamic Measurements : Wide Area Measurements

Dynamic state estimation allows data acquisition at a faster rate (say several samples within a cycle of 20 ms). This data can be obtained from various locations which may be geographically far apart. Since data is measured and transmitted at a fast rate, it is possible to capture changes as they evolve in time e.g., transients like angular oscillations (see Module 2).

These measurements are also *synchronised*. Synchronisation is made possible by common timing signals provided to the various measuring units at different locations by a satellite. Therefore the voltage/current phasors at different locations can be measured with respect to a common reference and communicated to a load dispatch centre, facilitating the direct calculation of angular differences. In *Static State Estimation,* measurements are usually not synchronised and phase angular differences are obtained not by direct measurement, but estimated from real and reactive power measurements.







Use of these phasors for line and equipment protection is conceivable. Moreover, these measurements may be used to detect or predict angular instability when a system is actually undergoing a transient. This can allow for quick control actions to avoid complete failure of the grid (blackout). At present, these systems are not widely deployed, but in future they are likely to find greater use in real time control and protection of power systems.

Recap

In this lecture you have learnt the following

- Power System State Estimation is a process whereby data from network measuring points to a central computer, can be formed into a set of reliable data for control and recording purposes.

- Dynamic state estimation allows time synchronised data acquisition at a faster rate.

Congratulations, you have finished Lecture 26. To view the next lecture select it from the left hand side menu of the page.