INTRODUCTION TO THE POWER WORLD SIMULATOR SOFTWARE.

EXPERIMENT NO: DATE:

AIM: INTRODUCTION TO THE POWER WORLD SIMULATOR SOFTWARE.

EQUIPMENT: PC system containing POWER WORLD SIMULATOR SOFTWARE

THEORY:

Introduction to PowerWorld Simulator:

After installing PowerWorld, double-click on the PW icon to start the program. Power system analysis requires, of course, that the user provide the program with a model of the power system. With PowerWorld, you can either build a new case (model) from scratch or start from an existing case. Initially, we'll start from an existing case. PowerWorld uses the common Ribbon user interface in which common commands, such as opening or saving a case, are available by clicking on the blue and white PowerWorld icon in the upper left hand corner. So to open a case click on the icon and select Open Case. This displays the Open Dialog.

Electric power systems range in size from small dc systems with peak power demands of perhaps a few milliwatts (mW) to large continent spanning interconnected ac systems with peak demands of hundreds of Gigawatts (GW) of demand (1 GW=1 x 10^9 Watt). PowerWorld are the high voltage, high power, interconnected ac systems. Almost without exception these systems operate using three-phase ac power at either 50 or 60 Hz. A full analysis of an arbitrary three-phase system requires consideration of each of the three phases. Drawing such systems in full schematic form quickly gets excessively complicated. Thankfully, during normal operation three-phase systems are usually balanced. This permits the system to be accurately modeled as an equivalent single-phase system.

Most power system analysis packages, including PowerWorld, use this approach. Then connections between devices are then drawn with a single line joining the system devices, hence the term “one-line” diagram. However, do keep in mind that the actual systems are three phase.
Fig. 1.1 illustrates how the major power system components are represented in PowerWorld. Generators are shown as a circle with a “dog-bone” rotor, large arrows represent loads, and transmission lines are simply drawn as lines. In power system terminology, the nodes at which two or more devices join are called buses. In PowerWorld thicker lines usually represent buses; the bus voltages are shown in kilovolts (kV) in the fields immediately to the right of the buses. In addition to voltages, power engineers are also concerned with how power flows through the system. In PowerWorld, power flows can be visualized with arrows superimposed on the generators, loads, and transmission lines. The size and speed of the arrows indicates the direction of flow. One of the unique aspects of PowerWorld is its ability to animate power systems. To start the animation, select the Tools tab on the Ribbon and then click on the green and black arrow button above Solve (i.e., the “Play” button). The one-line should spring to life! While the one-line is being animated you can interact with the system. Fig. 1.1 represents a simple power system in which a generator is supplying power to a load through a 16 kV distribution system feeder. The solid red blocks on the line and load represent circuit breakers. To open, a circuit breaker simply clicks on it. Since the load is series connected to the generator, clicking on any of the circuit breakers isolates the load from the generator resulting in a blackout. To restore the system click again on the circuit breaker to close it and then again select the button on
the Tools ribbon. To vary the load click on the up or down arrows between the load value and the “MW” field. Note that because of the impedance of the line, the load’s voltage drops as its value is increased.

You can view additional information about most of the elements on the one-line by right-clicking on them. For example right-clicking on the generator symbol brings up a local menu of additional information about the generator, while right-clicking on the transmission line brings up local menu of information about the line. The meaning of many of these fields will become clearer as you progress through the book.

To modify the display itself simply right-click on a blank area of the one-line. This displays the one-line local menu. Select One-line Display Options to display the One-line Display Options Dialog. From this dialog you can customize many of the display features. For example, to change the animated flow arrow color select the “Animated Flows” from the options shown on the left side of the dialog. Then click on the green colored box next to the “Actual MW” field (towards the bottom of the dialog) to change its color.

There are several techniques for panning and/or zooming on the one-line. One method to pan is to first click in an empty portion of the display and then press the keyboard arrow keys in the direction you would like to move. To zoom just hold down the Ctrl key while pressing the up arrow to zoom in, or the down arrow to zoom out. Alternatively you can drag the one-line by clicking and holding the left mouse button down and then moving the mouse—the one-line should follow. To go to a favorite view from the one-line local menu select the Go To View to view a list of saved views.

If you would like to retain your changes after you exit PowerWorld you need to save the results. To do this, select the PowerWorld icon in the upper left portion of the Ribbon and then Save Case As; enter a different file name so as to not overwrite the initial case. One important note: PowerWorld actually saves the information associated with the power system model itself in a different file from the information associated with the one-line. The power system model is stored in *.pwb files (PowerWorld binary file) while the one-line display information is stored in *.pwd files (PowerWorld display file).

**PowerWorld Simulator—Edit Mode:**

PowerWorld has two major modes of operations. The Run Mode, which was just introduced, is used for running simulations and performing analysis. The Edit Mode, which is used for modifying existing cases and building new cases, is introduced in this example. To switch to the Edit Mode click on the Edit Mode button, which is located in the upper left portion of the display immediately below the PowerWorld icon. When switching to the Edit Mode notice that the Ribbon changes slightly, with several of the existing buttons and icons disabled and others enabled. Also, the one-line now has a superimposed grid to help with alignment (the grid can be customized using the Grid/Highlight Unlinked options category on the Oneline Display Options Dialog). In the Edit Mode, we will first add a new bus to the system. This can be done graphically by first selecting the Draw tab, then clicking on the Network button and selecting Bus. Once this is done, move the mouse to the desired one-line location and click (note the Draw tab is only available in the Edit Mode). The Bus Options dialog then appears. This dialog is used to set the bus parameters. For now leave all the bus fields at their default values, except set Bus Name to “Bus 3” and set the nominal voltage to 16.0; note that the
number for this new bus was automatically set to the one greater than the highest bus number in the case. The one-line should look similar to Figure 1.2. You may wish to save your case now to avoid losing your changes.

By default, when a new bus is inserted a “bus field” is also inserted. Bus fields are used to show information about buses on the one-lines. In this case the new field shows the bus name, although initially in rather small fonts. To change the field’s font size click on the field to select it, and then select the Format button to display the Format dialog. Click on the Font tab and change the font’s size to a larger value to make it easier to see.

![Bus Power System Diagram]

You can also change the size of the bus itself using the Format dialog, Display/ Size tab. Since we would also like to see the bus voltage magnitude, we need to add an additional bus field. On the Draw ribbon select Field, Bus Field, and then click near bus 3. This displays the Bus Field Options dialog. Make sure the bus number is set to 3, and that the “Type of Field” is Bus Voltage. Again, resize with the Format, Font dialog.

Next, we'll insert some load at bus 3. This can be done graphically by selecting Network, Load, and then clicking on bus 3. The Load Options dialog appears, allowing you to set the load parameters. Note that the load was automatically assigned to bus 3. Leave all the fields at their default values, except set the orientation to “Down” and enter 10.0 in the Constant Power column MW Value field. As the name implies, a constant power load treats the load power as being independent of bus voltage; constant power load models
are commonly used in power system analysis. By default PowerWorld “anchors” each load symbol to its bus. This is a handy feature when changing a drawing since when you drag the bus the load and all associated fields move as well. Note that two fields showing the load’s real (MW) and reactive (Mvar) power were also auto-inserted with the load. Since we won’t be needing the reactive field right now, select this field and then select click Delete (located towards the right side of the Tools Ribbon) to remove it. You should also resize the MW field using the Format, Font command.

Now we need to join the bus 3 load to the rest of the system. We’ll do this by adding a line from bus 2 to bus 3. Select Network, Transmission Line and then click on bus 2. This begins the line drawing. During line drawing PowerWorld adds a new line segment for each mouse click. After adding several segments place the cursor on bus 3 and double-click. The Transmission Line/Transformer Options dialog appears allowing you to set the line parameters. Note that PowerWorld should have automatically set the “from” and “to” bus numbers based upon the starting and ending buses (buses 2 and 3). If these values have not been set automatically then you probably did not click exactly on bus 2 or bus 3; manually enter the values. Next, set the line’s Series Resistance (R) field to 0.3, the Series Reactance (X) field to 0.6, and the MVA Limits Limit (A) field to 20 (the details of transformer and transmission line modeling is covered in Chapters 3 through 5). Select OK to close the dialog. Note that Simulator also auto-inserted two circuit breakers and a round “pie chart” symbol. The pie charts are used to show the percentage loading of the line. You can change the display size for these objects by right-clicking on them to display their option dialogs.

**PowerWorld Simulator—Run Mode:**

Next, we need to switch back to Run Mode to animate the new system developed in Click on the Run Mode button (immediately below the Edit Mode button), select the Tools on the ribbon and then click the green and black button above Solve to start the simulation. You should see the arrows flow from bus 1 to bus 2 to bus 3. Note that the total generation is now about 16.2 MW, with 15 MW flowing to the two loads and 1.2 MW lost to the wire resistance. To add the load variation arrows to the bus 3 load right click on the load MW field (not the load arrow itself) to display the field’s local menu. Select Load Field Information Dialog to view the Load Field Options dialog. Set the “Delta per Mouse Click” field to “1.0,” which will change the load by one MW per click on the up/down arrows. You may also like to set the “Digits to Right of Decimal” to 2 to see more digits in the load field. Be sure to save your case. The new system now has one generator and two loads. The system is still radial, meaning that a break anywhere on the wire joining bus 1 to bus 2 would result in a blackout of all the loads. Radial power systems are quite common in the lower voltage distribution systems. At higher voltage levels, networked systems are typically used. In a networked system, each load has at least two possible sources of power. We can convert our system to a networked system simply by adding a new line from bus 1 to bus 3. To do this switch back to Edit Mode and then repeat the previous line insertion process except you should start at bus 1 and end at bus 3; use the same line parameters as for the bus 2 to 3 line. Also before returning to Run Mode, right click on the blue “Two Bus Power System” title and change it to “Three Bus Power System.” Return to Run Mode and again solve. Your final system should look similar to the system shown in Fig. 1.3
CONCLUSION:
THE VOLTAGE STABILITY USING POWERWORLD SIMULATOR FROM THE PV & QV CURVES AT GIVEN BUS

EXPERIMENT NO: DATE:

AIM: TO ANALYZE THE VOLTAGE STABILITY USING POWERWORLD SIMULATOR FROM THE PV & QV CURVES AT GIVEN BUS IN THE POWER SYSTEM.

EQUIPMENT: PC system containing POWER WORLD SIMULATOR SOFTWARE

THEORY:

MATHEMATICAL FORMULATION OF VOLTAGE STABILITY PROBLEM

The slower forms of voltage instability are normally analysed as steady state problems using power flow simulation as the primary study method. “Snapshots” in time following an outage or during load build up are simulated. Besides these post-disturbance power flows, two other power flow based methods are often used; PV curves and QV curves. These two methods give steady-state loadability limits which are related to voltage stability. Conventional load flow programs can be used for approximate analysis.

P-V curves are useful for conceptual analysis of voltage stability and for study of system.

The model that will be employed here to judge voltage stability is based on a single line performance. The voltage performance of this simple system is qualitatively similar to that of a practical system with many voltage sources, loads and the network of transmission lines.

Fig. 1 Radial two bus system
Consider the radial two bus system of Fig.1. Here $E$ is $V_s$ and $V$ is $V_R$, and $E$ and $V$ are magnitudes with $E$ leading $V$ by $\delta$. Line angle $\phi = \tan^{-1} \frac{X}{R}$ and $|z|=X$. In terms of $P$ and $Q$, the system load end voltage can be expressed as:

$$V = \left[ -\frac{2QX + E^2}{2} \pm \frac{1}{2} \sqrt{(2QX - E^2)^2 - 4X^2(P^2 + Q^2)} \right]^{1/2} \quad \text{......(1)}$$

It is seen from the Eq. (1) that $V$ is a double-valued function (i.e., it has two solutions) if $P$ for a particular $pf$ values of $pf$ are plotted in Fig. 2. For each value of $pf$, the higher voltage solution indicates a stable voltage case, while the lower voltage lies in the unstable voltage operation zone.

The changeover occurs at $V_{cri}$ and $P_{max}$. The locus of $V_{cri}$ - $P_{max}$ points for various $pf$s is drawn in dotted line in the Fig. 2.

![Fig. 2 PV curve for various power factor](image)

Any attempt to increase the load about $P_{max}$ causes a reversal of voltage and load. Reducing voltage causes an increasing current to be drawn by load. In turn the larger reactive line drop causes the voltage to dip further. This being unstable operation causes the system to suffer voltage collapse. This is also brought out by the fact that in upper part of curve $\frac{dP}{dV} < 0$ and in the lower part (unstable part) $\frac{dP}{dV} > 0$ (reducing load means reducing voltage and vice versa). It may be noted here that the type of load assumed in Fig. 2 is constant impedance. In practical systems, the type of loads are mixed or predominantly constant power type such that system voltage degradation is more and voltage instability occurs much prior to the theoretical power limit.

As in the case of single line system, in a general power system, voltage instability occurs above certain bus loading and certain $Q$ injections. This condition is indicated by the
singularity of the Jacobian of Load Flow equations and level of voltage instability is assessed by the minimum singular value.

Certain results that are of significance for voltage stability are as under:

1. Voltage stability limit is reached when
   \[ \left| \frac{S}{Y_{LL}V^2} \right| = 1 \] \(\text{...(2)}\)
   Where \( S = \) complex power at load bus,
   \( Y_{LL} = \) load bus admittance,
   \( V = \) load bus voltage.

   Nearer the magnitude in Eq. (2) to unity, lesser the stability margin.

2. The loading limit of a transmission line can be determined from
   \[ |S| = \frac{V_{cri}^2}{X_{cri}} \] \(\text{...(3)}\)
   \( X_{cri} \) is the critical system reactance beyond which voltage stability is lost. It can be expressed as
   \[ X_{cri} = \frac{E^2}{2P} \left( -\tan \delta + \sec \delta \right) \] \(\text{...(4)}\)

   We have so far considered how the PV characteristics with constant load power factor affect the voltage that follows stability of a system. A more meaningful characteristics for certain aspects of voltage stability is the QV characteristic, which brings out the sensitivity and variation of bus voltage with respect to reactive power injections (+ve or −ve).

Consider once again the simple radial system of Fig. 1. For Q flow it is sufficiently accurate to assume \( X \gg R \) i.e., \( \delta \cong 90^\circ \).

\[ Q = \frac{E}{X} \cos \delta - \frac{V^2}{X} \] \(\text{...(5)}\)

Or \[ V^2 - EV \cos \delta + QV = 0 \] \(\text{...(6)}\)

Taking derivation wrt \( V \) gives
\[ \frac{dQ}{dV} = \frac{E \cos \delta - 2V}{X} \] \(\text{...(7)}\)

The QV characteristic on normalized basis \( (Q/P_{max}, V/E) \) for various values of \( P/P_{max} \) are plotted in Fig. 3.
Fig. 3 QV characteristics for the system of Fig.1 for various value of $P/P_{\text{max}}$

The system is stable in the region where $\frac{dQ}{dV}$ is positive, while the voltage stability limit is reached at $\frac{dQ}{dV} = 0$ which may also be termed as the critical operating point.

The limiting value of the reactive power transfer at the limiting stage of voltage stability is given by

$$Q_{\text{lim}} = \frac{V^2}{X} \cos 2\delta$$ ....(8)

The inferences drawn from the simple radial system qualitatively apply to a practical size system. Other factors that contribute to system voltage collapse are: strength of transmission system, power transfer levels, load characteristics, generator reactive power limits and characteristics of reactive power compensating devices.

ATTACH SIMULATION MODEL AND WAVEFORMS SHEET:

CONCLUSION:
TO STUDY ABOUT ELECTRICAL MARKET RESTRUCTURING

EXPERIMENT NO:  

AIM: TO STUDY ABOUT ELECTRICAL MARKET RESTRUCTURING.

THEORY:

A VERTICALLY INTEGRATED UTILITY

POWER SYSTEM STRUCTURE

Power systems traditionally have been what are known as "vertically integrated utilities". In this type of structure, one utility handles the all functions of generation, transmission and distribution within a certain geographical area. The operation and coordination of such a system is somewhat simple, since all functions are controllable by a system operator. The operational objectives were to provide quality power (voltage and frequency nearly constant) to a consumer, while ensuring reliability and overall economy (low cost). The price of power was "regulated" and based on actual costs.

An alternative is to treat power as a tradeable commodity. The functions of generation and in many cases, distribution, are open to private participation. While the "technical objectives" are similar to those in a vertically integrated utility, the price is not regulated, but depends on market forces and competition between the participants. In a generation deficit scenario, price may still need to be regulated. Alternatively, the amount of loads should be price sensitive or else prices will spiral upwards. The cost of use of transmission lines (to which all players will have "open access" subject to the transmission constraints) would also be regulated. Therefore a "regulator" would still be required. However, a regulator would be an independent body. An independent system operator would perform the co-ordination functions required to operate the system reliably and ensure that voltage and frequency are within limits. The real and reactive power resources required to maintain voltage, frequency and reliability may be "purchased" and charged to all the players in a fair manner.

Structure of a traditional Vertically Integrated electric industry

The electric power industry has over the years been dominated by large utilities that had an overall authority over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have often been
referred to as vertically integrated utilities. Such utilities served as the only electricity provider in a region and were obliged to provide electricity to everyone in the region.

The typical structure of a vertically integrated electric utility is shown in figure below. In the figure, the money flow is unidirectional, i.e. from the consumer to the electric company. Similarly, the information flow exists only between the generators and the transmission systems.

In vertically integrated utilities, it was often difficult to segregate the costs involved in generation, transmission or distribution. So, the utilities often charged their customers an average tariff rate depending on their aggregated cost during a period.

The state electricity boards (SEB) in India were examples of a vertically integrated utility; they are now being re-structured.

Characteristics of a traditional Vertically Integrated electric industry

**Monopoly Franchise**

Only the local electric utility can produce, move, or sell commercial electric power within its service territory.

**Obligation to serve**

The utility must provide service to all electric consumers in its service territory, not just those that would be profitable.

**Regulatory Oversight**

The utility’s business and operating practices must confirm to guidelines and rules set down by government regulators. The utility’s rates are set in accordance with government regulatory rules and guidelines. The utility is assured a fair return on
its investment, if it confirms to the regulatory guidelines and practices.

During early days of the electric power industry, governments favoured a regulated monopoly - vertically integrated utility structure. The reasons are manifold:

This offered a risk free way to finance the creation of electric industry. Establishment of electric industry required large capital for infrastructure building. Thus for the purpose of risk minimization, a local monopoly and stable market was assured. The utility leaders could focus on building up their systems without having to worry about the competitors undercutting the prices to gain market share etc.

To prevent exploitation of consumers due to monopoly, the government brought in regulation.

This legitimized the electric utility business. Government franchises and regulation clearly implied to a possibly skeptical public that civic leaders thought electricity was a good thing.

It gave electric utilities recognition and support from the government, which was necessary to solve problems like ‘Right of Way’ (i.e. the "right" to an exclusive corridor to build a transmission line).

During the nineties, many electric utilities and power network companies worldwide have been forced to change their way of operation and business, from vertically integrated mechanisms to open market systems. This can be specifically observed in countries like UK, Sweden, Finland, Norway, US and some countries of South America. The reasons for change have been many and have differed over regions and countries. We shall study of these developments in the next lecture.

Conditions which are leading to changes in traditional power system structures

Basic motivation for changes in power industry scenario

There are many reasons that are leading to restructuring of power systems. One force was the change in generation economies of scale that occurred throughout the 1980's. Traditionally, electric utility systems evolved with the central station concept because of significant economy of scale in power generation. Very large generators produced power at less than half the cost per kilowatt of small generator units, and the bigger the generator, the more economical the power it produced. For the reasons stated below, the shift in economy of scale was observed:

Technological innovation improved the efficiency of small units for gas turbines, combined cycle, hydro and fuel cells over that of large ones.
Improvements in materials, including new high temperature metals, special lubricants, ceramics, and carbon fiber, permit vastly stronger and less expensive small machinery to be built.

Computerized control systems have been developed that often reduce the number of on-sight personnel to zero.

Data communications and off-site monitoring systems can control the units from remote operations centers, where one central operator can monitor a dozen units at various sites, as if present at each.

Thus in some instances, it is possible to build new power plants that could provide energy at a lower price than what customers were paying. It became possible for the industrial and commercial users of electricity to build and operate their own plants also sell the excess power to small customers especially in generation deficit areas.

The reasons for restructuring are:

Following are the main reasons:

1. The need for regulation changed.

More fundamental than any other reasons for change was the fact that the basic needs for regulation of electric industry had died away before the end of 20th century. First, the original need for regulation, which was to provide risk free finance to build the infrastructure, did not exist anymore. Second, most of the the major electrical infrastructure was paid for, decades ago. The revenues gained by the electric utilities was invested to renew their system, and the level of risk in doing so was less as compared to that existed in the initial era. Being a proved technology, the risk involved in investing money in such a technology was nullified. The electricity could now be thought of as an essential commodity, which can be bought and sold in the marketplace in a competitive manner, just like other commodities.

2. Ideological Reason: Privatization

Usually the motive was the government’s firm conviction that private industry could do a better job of running the power industry. This belief, of course came from better privatization experiences of the other industries. Deregulation does not necessarily have to be a part of privatization efforts.

3. Cost is expected to drop

Competition is expected to bring innovation, efficiency, and lower costs.

4. Customer focus will improve
Although monopoly franchise utilities have an obligation to serve all customers, that does not promote the pro-active attention to customer needs. A monopoly franchise utility listens to its customers when they explain their needs, and then responds. A competitive electric service company anticipates customer’s needs and responds in advance. The technological advances that will be applied under deregulation, address customer service. More important gain of competition in the electricity market is the customer value rather than lowering the cost.

5. Encouragement for innovation

The regulatory process and the lack of competition gave electric utilities no incentive to improve on yesterday’s performance or to take risks on new ideas that might increase customer value. If a new idea succeeded in cutting costs, the utility still made only its regulated rate of return on investment; if it didn’t work, the utility would usually have to ‘eat’ a good deal of the failed attempt, as imprudent expenses. Furthermore, why would a regulated utility want to use new ideas to lower its costs under a regulated rate of return framework?

Under deregulated environment, it was felt that the electric utility will try to innovate something for the betterment of service and in turn save its costs and maximize the profit. By means of this, the utility will try to ensure that it will maintain its customer base in spite of competition.

**Structure of a Deregulated Industry**

**Overview of A Deregulated Industry**

Unbundling of traditionally vertically integrated utility.

One of the principal characteristics of a competitive structure is the identification and separation of the various tasks which are normally carried out within the traditional organization so that these tasks can be open to competition whenever practical and profitable.

This process is called **unbundling**.

An unbundled structure contrasts with the so-called vertically integrated utility of today where all tasks are coordinated jointly under one umbrella with one common goal, that is, to minimize the total costs of operating the utility.

One of the first steps in the restructuring process of the power industry has been the separation of the transmission activities from the electricity generation activities.

The subsequent step was to introduce competition in generation activities, either through the creation of power pools, provision for direct bilateral transactions or bidding in the spot markets.
On the other hand, the transmission system has significant economics of scale (i.e., it is economical to have a common bulk transmission system of a large capacity rather than individual small capacity transmission links). Consequently it was suited to be a natural monopoly and a separate entity. It was felt necessary to introduce regulation in transmission so as to prevent it from overcharging for its services. The transmission system thus became a neutral, natural monopoly subject to regulation by public authorities. And to overcome the monopolistic characteristic, the trend has been to establish new legal and regulatory frameworks offering third parties "open access" to the transmission network subject to technical constraints.

An important point to note is that the restructuring process was however not uniform in all countries. While in many instances, it started with the breaking up of a large vertically integrated utility, in certain other instances restructuring was characterized by the opening up of small municipal monopolies to competition.

In brief, Electric utilities are expected to split apart into unbundled companies, with each utility re-aligning itself into several other companies that respectively focus on each part of the new industry, i.e., power delivery and retailing. This is known as Disaggregation.

Under deregulation, the vertically integrated utility, one giant company that generates, transmits, distributes and sells electricity in coordinated manner will become thing of the past. To function in an open access system, such utilities will have to rearrange their operational organization to match the unbundled functions they must perform. Each part of the company will need to work in its new form. Generation will have to compete in the competitive power generation market place. T & D will have to operate as an open provider of delivery services. Competition will be present in retailing.

Generally, the governments advocating deregulation want competition in energy production, and they want to see significant levels of customer choice in the retail market for electricity. At the same time, it recognizes that it is best to have only one transmission and one distribution system in any one area.

Therefore, the purpose of deregulation is to restructure the electric industry so that power production and retail sales are competitive, while delivery is still a regulated, monopoly franchise business.

**Structure of deregulated industry**

The figure below shows the typical structure of a deregulated electricity system with links of information and money flow between various players.

The configuration shown in the figure is not a universal one. There exist variations across countries and systems.
Different power sellers will deliver their product to their customers (via retailers), over a common set of T & D wires. These operations are supervised by an independent system operator (ISO). The generators, T & D utility and retailers communicate with the ISO. Mostly, customers communicate with a retailer, demanding energy. The retailer contacts the generating company and purchases the power from it and makes it transferred to its customer’s place via regulated T & D lines. The ISO is the one responsible for keeping track of various transactions taking place between various entities. A customer can also enter into a bi-lateral contract with a generator directly for supply of the required energy.

In the vertically integrated environment, the electricity bill consisted of a single amount to be paid towards the generation, transmission and all other costs. But, in the restructured environment, the electricity price gets segregated into the following:
Different entities in deregulated environment:

The introduction of deregulation has brought several new entities in the electricity market place, while on the other hand redefining the scope of activities of many of the existing players. Variations exist across market structures over how each entity is particularly defined and over what role it plays in the system. However, on a broad level, the following entities can be identified as shown in the figure below.

Genco (Generating Company)  Genco is an owner-operator of one or more generators that runs them and bids the power
into the competitive marketplace. Genco sells energy at its sites in the same manner that a coal mining company might sell coal in bulk at its mine.

Transco (Transmission Company) Transco moves power in bulk quantities from where it is produced to where it is delivered. The Transco owns and maintains the transmission facilities, and may perform many of the management and engineering functions required to ensure the system can continue to do its job. In most deregulated industry structures, the Transco owns and maintains the transmission lines under monopoly franchise, but does not necessarily operate them. That is done by Independent System Operator (ISO). The Transco is paid for the use of its lines. In some countries, Transco itself act as a system operator.

Disco (Distribution Company) It is the monopoly franchise owner-operator of the local power delivery system, which delivers power to individual businesses and homeowners. In some places, the local distribution function is combined with retail function, i.e. to buy wholesale electricity either through the spot market or through direct contracts with gencos and supply electricity to the end use customers. In many other cases, however, the disco does not sell power. It only owns and operates the local distribution system, and obtains its revenues by ‘renting’ space on it, or by billing for delivery of electric power.

Resco (Retail Energy Service Company) It is the retailer of electric power. Many of these will be the retail departments of the former vertically integrated utilities. Others will be companies new to the electric industry that believe they are good at selling services. Either way, a resco buys power from gencos and sells it directly to the consumers.

ISO (Independent System Operator) The ISO is an entity entrusted with the responsibility of ensuring the reliability and
security of the entire system. It is an independent authority and does not participate in the electricity market trades. It usually does not own generating resources, except for some reserve capacity in certain cases. In order to maintain the system security and reliability, the ISO procures various services such as supply of emergency reserves, or reactive power from other entities in the system.

Customers

A customer is an entity, consuming electricity. In deregulated markets, a customer has several options for buying electricity. It may choose to buy electricity from the spot market by bidding for purchase, or may buy directly from a genco or even from the local distribution company.

The competition:

In a deregulated environment, two levels of competition exist or are encouraged. At what can be termed as wholesale level, gencos produce and sell bulk quantities of electric power. Power is typically sold in bulk quantities to other companies or very large industrial customers, through some deregulated power market mechanism. The gencos bid their power at the marketplace so as to maximize their profits.

Locally, retail delivery is accomplished by retailers, who compete for the business of the consumers in the area by offering low price, good service and additional service features.

Thus, a restructured, completely competitive electric industry is a sandwich of competition above and below a power delivery system. This structure can be conveniently divided into wholesale and retail levels. The important thing to note is that the power delivery i.e. transmission and distribution remains a monopoly. This is shown in the figure below.
Ancillary Service Management

Ancillary services are defined as all those activities on the interconnected grid that are necessary to support the transmission of power while maintaining reliable operation and ensuring the required degree of quality and safety. This requires that a independent system operator should have adequate leverage to implement "normal" functions like frequency and voltage regulation, but also carry out actions of preventive, emergency and restorative control actions as discussed in module 6.

In deregulated power systems, transmission networks are available for third-party access to allow power wheeling, and spot markets for electricity have been developed in many countries. In such an environment, ancillary services are no longer treated as an integral part of the electric supply. They are unbundled and priced separately and system operators have to purchase ancillary services from ancillary service providers. The following are some examples of ancillary services which are procured and managed by an ISO.
| Regulation | The use of generation or load to maintain minute-to-minute generation/load balance within control area (like AGC). |
| Load Following | This service also refers to instant-to-instant balance between generation and load (governor action). |
| Operating Reserve Spinning | The provision of unloaded generating capacity that is synchronized to the grid and can immediately respond to correct for generation/load imbalances, caused by generation and/or transmission outages and that is fully available within several minutes. |
| System Control | The control area operator functions that schedule generation and transactions and control generation in real time to maintain generation/load balance. |
| Reactive Power and Voltage Control from Generator Sources | The injection or absorption of reactive power from generators or capacitors to maintain system voltages within required ranges. |
| Real power transmission losses | Any power flow in the network will cause losses which have to be supplied by purchasing some additional power. |
| Network Stability Services from Generation sources | Maintenance and use of special equipment (e.g. for emergency control) to maintain a secure transmission system. |
| System Black-Start Capability | The ability of a generating unit to proceed from a shutdown condition to an operating condition without assistance from the grid and then to energize the grid to help other units start after a blackout occurs. |

CONCLUSION:

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TO STUDY ABOUT INDIAN SCENARIO OF POWER SYSTEM AND ELECTRICITY ACT 2003

AIM: TO STUDY ABOUT INDIAN SCENARIO OF POWER SYSTEM AND ELECTRICITY ACT 2003.

THEORY:

Indian Scenario: Ownership Issues

In India, the power sector was mainly under the government ownership (>95% distribution & ~98% generation) under various states and central government utilities, till 1991. The remarkable growth of physical infrastructure was facilitated by four main policies:

- centralized supply and grid expansion
  - large support from government budgets
  - development of sector based on indigenous resources
  - cross subsidy

Cross-Subsidization means that a certain class of customers are charged higher prices for energy usage, while another class is charged less. This is done with a social objective in mind.

In mid 1990s, Orissa began a process of fundamental restructuring of the state power sector. This consisted of a three pronged strategy of:

1) Unbundling the integrated utility in three separate sectors of generation, transmission and distribution,
2) Privatization of generation and distribution companies and, Establishment of independent regulatory commissions to regulate these utilities. Meanwhile,
3) some moderate steps were taken towards reforms until the Electricity Bill 2003 was approved by Parliament in May 2003.

The Electricity Act 2003:

The conceptual framework underlying this new legislation is that the electricity sector must be opened for competition. The Act moves towards creating a market
based regime in the power sector. The Act also seeks to consolidate, update and rationalize laws related to generation, transmission, distribution, trading and use of power. It focuses on:

- Creative competition in the industry
- Protecting consumer interest
- Ensuring supply of electricity in all areas
- Rationalizing tariff
- Lowering the cross-subsidization levels.

**Some of the major provisions of the Electricity Act are:**

- Elimination of licensing for setting up a generating station, subject to compliance with technical standards. This excludes Hydro-Electric power station
- Removal of captive power plants from the ambit of licensing and other permissions
- Provision for issuing more than one license for transmission and distribution in the same geographical area.
- Provision of ‘Open Access’ with respect to transmission for all generators (subject to technical constraints)
- Introduction of a spot market for bulk electricity
- Unbundling of the SEBs on the basis of functions (Generation, Transmission and Distribution)
- Compulsory metering of all consumers in order to improve accountability
- State Governments will have the freedom to decide the sequence and phases of restructuring, and also retain the integrated structure of the SEB for a limited period.

**Indian Scenario: Power Transmission System**

The Indian Power System is made of 3 synchronous grids, the Northern Region, Western-Eastern-North Eastern Region (W-E-NE R), and the Southern Grid. The installed capacity is greater than 110 GW and a demand of 70 GW is met (2005). The synchronous regions are interconnected by asynchronous (HVDC) ties. Therefore, it is possible to operate the three grids independently since the power through the HVDC links can be independently controlled.
All DC links as shown in the figure are back to back, except for the one at Talcher-Kolar, which is a long HVDC line.

Most of the power generation is likely to come up in the coal rich central-eastern region and the hydro-potential rich north eastern region. Therefore adequate capacity transmission is necessary to transmit this power to the load centres.

**Plan for a National Grid**

The plan for formation of national grid includes synchronous interconnection of the Northern Region with the W-E-NE-Region around 2006. Synchronous operation will allow for subsequent interconnection at several other locations using AC lines, thereby increasing the power exchanges between regions. Of course, one may increase the number and capacity of asynchronous links and
achieve the same thing. Eventually, it is a tradeoff between the technical considerations and costs.

Challenges of Synchronous Operation: A practical example of emergency control

The Talcher - Kolar HVDC link is a high capacity link which transfers power from Talcher in the Eastern Region to Kolar in the Southern Region. In case the link trips, the W-E-NE Region is left with surplus power. Most of the surplus power rushes towards the western region (which has a large load) through relatively weak AC tie lines. The ensuing power swings (relative motion between generators) are not stable and the system separates into two regions due to loss of synchronism.

Therefore, in order to prevent ER-WR system separation, the following emergency scheme was conceived:

In case due to an unexpected contingency, the heavily loaded HVDC link trips, then a few generators at Talcher are also tripped immediately. This ensures that the W-E-NER system is not left with too much surplus power.

The other asynchronous links to the Southern Region (e.g. the one at Gazuwaka) are of limited capacity and cannot suddenly push the excess power to the Southern Region unless they are lightly loaded. Moreover, power flow through these links is regulated. Therefore, power can be ramped slowly by manual intervention. However, a strategy specifically suited to deal with this situation can be conceived.

**CONCLUSION:**
TO STUDY ABOUT OPERATING STATES AND CONTROL ACTIONS OF A POWER SYSTEM

EXPERIMENT NO: 

DATE:

AIM: TO STUDY ABOUT OPERATING STATES AND CONTROL ACTIONS OF A POWER SYSTEM.

THEORY:

INTRODUCTION

We have been primarily concerned with the economical operation of a power system. An equally important factor in the operation of the power system is the desire to maintain system security. System security involves practices suitably designed to keep the system operating when components fail. Besides economizing on fuel cost and minimizing emission of gases (CO₂, CO, NOₓ, CO₂), the power system should be operationally ‘secure’. An operationally ‘secure’ power system is one with low probability of system back out (collapse) or equipment damage.

If the process of cascading failure continuous, the system as a whole or its major part may completely collapse. This is normally referred to as system blackout. All this aspects require security constrained power system optimization (SCO).

An important part of security study moves around the power system’s ability to withstand the effects of contingencies. A particular system state is said to be secure only with reference to one or more specific contingency cases, and a given set of quantities monitored for violation. Most power systems are operated in such a way that any single contingency will not leave other components heavily overloaded, so that cascading failures are avoided.

System security can be said to comprise of three major functions that are carried out in an energy control central:

1) system monitoring, 

2) contingency analysis, and 

3) corrective action analysis

System monitoring supplies the power system operators or dispatchers with pertinent up-to-date information on the condition of the power system on real time basis as load
and generation change. Telemetry systems measure, monitor and transmit the data, voltage, currents, current flows and the status of circuit breakers and switches in every substation in transmission network. Further, other critical and important information such as frequency, generator outputs and transformer tap positions can also be telemetered. Digital computers in a control centre then process the telemetered data and place them in a data base from and inform the operators in case of an overload or out of limits voltage. Important data are also displayed on large size monitors. Alarms or warnings may be given if required.

State estimation is normally use in such system to combine telemetered data to give the best estimate (in statistical sense) of the current system condition or 'state'. Such system often work with supervisory control system to help operators control circuit breakers and operate switches and taps remotely. This system together are called SCADA (supervisory control and data acquisition) system.

The second major security function is contingency analysis. Modern operation computer have contingency analysis programs stored in them. this for see possible system troubles (outages) before they occur. They study outage events and alert the operators to any potential overloads or serious voltage violations. For example, the simplest form of contingency analysis can be put together with a standard LI' program along with procedures to set up the load flow data for each outage to be studied by the LF program. This allows the system operators to locate defensive operating states where no single contingency event will generate overloads and/or voltage violations. This analysis thus evolves operating constraints which may be employed in the ED (economic dispatch) and UC (unit commitment) program. Thus contingency analysis carries out emergency identification and 'what if' simulations.

The third major security function, corrective action analysis, permits the operator to change the operation of the power system if a contingency analysis program predicts a serious problem in the event of the occurrence of a certain outage. Thus this provides preventive and post-contingency control. A simple example of corrective action is the shifting of generation from one station to another. This may result in change in power flows and causing a change in loading on overloaded lines.

These three functions together consist of a very complex set of tools that help in the secure operation of a power system.

**SYSTEM STATE CLASSIFICATION**

In Fig.1, arrowed lines represent involuntary transitions between Levels 1 to 5 due to contingencies. The removal of violations from Level 4 normally requires EMS directed 'corrective rescheduling' or 'remedial action' bringing the system to Level 3, from where it can return to either Level 1 or 2 by further EMS, directed 'preventive rescheduling' depending upon the desired operational security objectives.
Levels 1 and 2 represent normal power system operation. Level 1, has the ideal security but is too conservative and costly. The power system survives any of the credible contingencies without relying on any post-contingency corrective action. Level 2 is more economical, but depends on post-contingency corrective rescheduling to alleviate violations without loss of load, within a specified period of time. Post-contingency operating limits might be different from their pre-contingency values.

**POWER SYSTEM OPERATING STATES**

A classification of operating states was first proposed by Fink and Carlsen in 1978. The system is said to be normal if (i) all the loads are met, (ii) the frequency and bus voltage magnitudes are within the prescribed limits and (iii) no components of power system are overloaded. For more than 99 percent of the time, a typical power system is found in its normal state. In this state, the frequency and the bus voltages are kept at prescribed values.

The 'equality' between generation and demand is a fundamental prerequisite for system 'normalcy' and is indicated by the symbol 'E' which refers to Equality constraints i.e., the power balance and flow equations are satisfied and frequency and voltage constancy observed. The second symbol 'I' indicate that certain 'inequality' must also be observed in the normal state. The symbol 'I' refer to Inequality constraints and imply that the system is operating within rated limits of the component i.e., generator and
transformer, loads must not exceed the rated values and transmission lines must not be loaded above their thermal or static stability limit. The subscript ‘v’ refers to the constraint violation.

If a system suffers from any event i.e., reduction in the security level (e.g., sudden increase of load), then the system would switch to 'insecure normal' state. The 'E' and 'I' would still be satisfied. However, with preventive control strategy, the operator would seek to return the system to its 'normal' state. In the 'insecure normal' state, if some additional disturbance occurs or in 'normal' state a serious disturbance is encountered (e.g., tripping of tie line or loss of an additional generator), then the system will enter to 'emergency' state. In this state the system remains intact, i.e., 'E' is still satisfied but 'I' change to 'I_v' (e.g., overloads of system components). By means of corrective control (i.e., generator rescheduling) the operator would try to relieve the overload situations. If corrective control is not possible, then emergency control (i.e., generator rescheduling/ load shedding) is restored to.

Fig. 2 Operating states and control action of a power system

If the emergency control fails, then a series of cascading events may lead to the 'cascade (extremis)' state. Typically, the system would breakup into 'islands', each of which would be operating at their own frequencies. Both 'E' and 'I' would then changes to 'E: and respectively and the system will result in a blackout. A series of resynchronization controls are required to restart generators and gradually pickup loads. This is a long process and at this stage the system is in the 'restorative' state. The various transitions due to disturbances, as V' ell as various control actions are shown in Fig.2. In practice, the power system never remains in the normal state due to disturbances, as a result preventive/ corrective control actions are required to bring back the System to the normal state.
EXPERIMENT NO:          DATE:

AIM: APPLY WLSI METHOD TO THE RAW MEASUREMENT TO DETERMINE STATE VARIABLE FROM RESULTANT VALUE

APPARATUS:

THEORY:

Voltage magnitudes and phase angles are the two state variables of an electrical power system. Unlike the voltage magnitudes, which can be directly measured, the relative voltage angles cannot be measured directly. However, the online system data.

The real time input to the state estimator is constituted of online data (bus voltages, real and reactive powers, and line flows) and status information associated with the system switching devices, such as circuit breakers and transformer taps. The state estimator operates on data which is akin to the conventional power flow data. However, the volume of data used by the state estimator (in terms of the number of actual measurement performed in practical state estimation) exceeds by far the data required for a system power flow study for the purpose of planning and design. Redundancy in data is a necessary and desirable feature in state estimation to take care of malfunctioning in data acquisition equipment and erroneous measurements. Thus, in state estimation the number of equations, whose solution is sought, is invariably in excess of the number of unknown state variables.

Raw measurement data is never used directly in state estimation. The state estimator first processes the raw data to identify gross bad measurements, filters such measurements, and then performs the computations to obtain average estimates of the state variables.

Simulation of the State Estimation given the following solution

\[
\begin{align*}
\text{xilT+1} - \text{xilT} = & (HxITt \cdot R^{-1} \cdot HxITt) \cdot \text{R-1} \\
& HxITt R-1
\end{align*}
\]

In equation (1), the Jacobian HxIT at iteration count IT is written as follows
\[
Hx_{IT} = \begin{bmatrix}
\frac{\partial h_1}{\partial x_1} |_{IT} & \frac{\partial h_1}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_1}{\partial x_n} |_{IT} \\
\frac{\partial h_2}{\partial x_1} |_{IT} & \frac{\partial h_2}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_2}{\partial x_n} |_{IT} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{\partial h_n}{\partial x_1} |_{IT} & \frac{\partial h_n}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_n}{\partial x_n} |_{IT}
\end{bmatrix}
\]  

(2)

It is noted from the foregoing that equation (1) provides the iterative formula for estimating the values of the \( n \) state variables.

The following step-wise procedure outlines the method of obtaining a solution of eq. (2) iteratively and verifying the accuracy of the estimated state variables by applying the chi-square test.

Step -1 : Initialize the relative process by setting iteration count \( IT=0 \) and guesstimating \( h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT}) \).

Step -2 : From the weighting factors compute the diagonal variance matrix \( R \).

Step -3 : Compute the elements of the jacobian \( Hx_{IT} \) and the vector elements \( z_i = h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT}) \).

Step -4 : Solve Eq. (2) and the compute the corrections to be made to the state variables and therefore calculate the new estimates of the state variables as follows \( x_{IIT+1} = x_{IIT} + \Delta x_{IIT} \).

Step -5 : Check for convergence by using the expression \( x_{IIT+1} - x_{IIT} < \epsilon \).

Step -6 : If the tolerance \( \epsilon \) is within the specified limit go to step 7; if not, set \( IT=IT+1 \), replace \( h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT}) \) by the latest estimates of the state variables and go to step 3.

Step -7 : Compute the measurements error vector \( \zeta = z - h(x_1, x_2, \ldots, x_n) \) and use the relation \( \hat{f} = \sum (\zeta_i^2 / \sigma_i^2) \) to compute the sum of the squares of the performance function \( \hat{f} \). Apply the chi-square test to determine bad measurements if any.

After step 6, if convergence is obtained, the estimated values of the state variables are obtained by WLSE and may be represented by \( x_{IIT+1} = \hat{x} = [\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n]^T \).
Theory of case study:

In the power system network shown in fig (1), a generator is feeding a load over a transmission line whose reactance is jX12. The system is being monitored for (i) voltage magnitudes at two buses, (ii) reactive power at bus 2, (iii) real power flow bus 1 to 2, and (iv) reactive power flow bus 1 to 2. Formulate the Jacobian matrix H and develop the linearized mathematical model for computing the state variables. Assume the voltage at bus 1 as the reference and the shunt reacance at bus 2 equal to jX20.

The state variables required to be estimated are:

\[
\begin{align*}
  x_1 &= \delta_2 \\
  x_2 &= V_2 \\
  x_3 &= V_1
\end{align*}
\]

The measurement variables are:

\[
\begin{align*}
  z_1 &= V_2 \\
  z_2 &= V_1 \\
  z_3 &= Q_2 \\
  z_4 &= P_{12} \\
  z_5 &= Q_{12}
\end{align*}
\]

Q2 = \((\frac{1}{X_{12}} + \frac{1}{X_{20}})V_2^2 - \frac{V_1V_2}{X_{12}}\cos(\delta_2 - \delta_1) = \left(\frac{1}{X_{12}} + \frac{1}{X_{20}}\right)x_3^2 - x_3x_2\cos x_1\)

P12 = \(-\frac{V_1V_2}{X_{12}}\sin(\delta_2 - \delta_1) = -\frac{V_1V_2}{X_{12}}\sin x_2 = -x_3x_2\sin x_1\)

Q12 = \(-\frac{V_1V_2}{X_{12}}\cos(\delta_1 - \delta_2) = \frac{1}{X_{12}}\{x_3^2 - x_3x_2\cos x_1\}\)

The non-linear functions h1, h2, h3, h4, and h5 may be written as

h1 (x1, x2, x3, x4, x5) = x2

h2 (x1, x2, x3, x4, x5) = x3

h3 (x1, x2, x3, x4, x5) = \((\frac{1}{X_{12}} + \frac{1}{X_{20}}) x_3^2 - \frac{X_3X_2}{X_{12}}\cos x_1\)

h4 (x1, x2, x3, x4, x5) = -\frac{X_3X_2}{X_{12}}\sin x_1

Fig(1): Power system network
Thus the element of the Jacobean H , for an iteration count IT , are derived from eq.() as follows:

\[
H^{IT} = \begin{bmatrix}
0 & \frac{x_3x_2}{x_{12}} \sin x_1 |^{IT} & -\frac{x_3}{x_{12}} \cos x_1 |^{IT} & 0 & 0 \\
0 & -\frac{x_3x_2}{x_{12}} \cos x_1 |^{IT} & -\frac{x_3}{x_{12}} \sin x_1 |^{IT} & 0 & 1 \\
\frac{x_3x_2}{x_{12}} \sin x_1 |^{IT} & -\frac{x_3}{x_{12}} \cos x_1 |^{IT} & 1 & \frac{1}{x_{12}}(X_3^2 - X_3X_2 \cos x_1) |^{IT}
\end{bmatrix}
\]

Similarly, the vector is written as

\[
\begin{bmatrix}
\zeta_1 \\
\zeta_2 \\
\zeta_3 \\
\zeta_4 \\
\zeta_5
\end{bmatrix} = \begin{bmatrix}
z_1 - x_2 |^{IT} \\
z_2 - x_3 |^{IT} \\
\left(\frac{x_3x_2}{x_{12}} \sin x_1 |^{IT}\right) \\
\left(\frac{x_3x_2}{x_{12}} \cos x_1 |^{IT}\right) \\
\left(\frac{1}{x_{12}}(x_3^2 - x_3x_2 \cos x_1) |^{IT}\right)
\end{bmatrix}
\]

The linearized equation , similar to eq. () is now written as

\[
X_{i+1} - x_i = (Hx^{IT}t R^{-1} Hx^{IT}t) - 1 \ Hx^{IT}t R - 1
\]

From the presending equation , WLSE of the state variables can be obtained.

**Example of case study:**

For the power system in above example, the measured variables, in per unit are as follows:

\[
\begin{align*}
z_1 &= V_2 = 0.95; \\
z_2 &= V_1 = 1.05; \\
z_3 &= Q_2 = 0.55; \\
z_4 &= P_{12} = 0.93; \\
z_5 &= Q_{12} = 0.34;
\end{align*}
\]

With WLSE technique, determine the values of the state variables and the confidence level of the accuracy of the results. Assume the values of the variance of the measurement errors as follows: \(\sigma_{12} = \sigma_{22} = \sigma_{32} = 0.0001, \sigma_{42} = 0.0002, \) and \(\sigma_{52} = 0.0004.\) Also , assume a tolerance value of 0.0001 for convergence.

- ATTACH PROGRAMME WITH RESULTS
CONCLUSION:

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A GIVEN FOUR BUS SYSTEM TO DETERMINE THE INJECTED CURRENT AT EACH BUS

EXPERIMENT NO: ___________________________ DATE: ___________________________

AIM: EXECUTE THE PROGRAM FOR A GIVEN FOUR BUS SYSTEM TO DETERMINE THE INJECTED CURRENT AT EACH BUS

APPARATUS:

THEORY:

Morden day tradition is to interconnected system operated by different power companies through tie-lines and this increases the reliability of electrical energy supply. It is, therefore, important to introduce the concepts for modelling interconnected networks for addition or removal of tie lines for contingency analysis.

The modelling of power networks, interconnected through tie-lines, adopts the piecewise methods for their solutions. the piecewise methods are based on the assumption that each network is simulated by a linear model for its analysis by the individual operating authority.

Figure 1 shows a four-bus power system A interconnected through two tie-lines, of impedances Za and Zb, with another three-bus power network B. Both the power systems are independent except for the interconnection are earthed, thereby providing a common reference point.

Fig.1 Two power system networks connected through tie-lines
Initially it is assumed that both the systems operate in the stand alone mode, and use
the Zbus of their own networks for analysing their systems. These results can be later
modified, by each system, to take advantage of the interconnections between the two
networks.

From fig.1, it may be noted that buses 3 and 4 of system A are connected to buses 5 and
6 of system B. The current injections and the voltages at each bus, shown in the figure,
are assumed known and represent the networks in the stand alone mode. Mathematically, the relationship between the bus voltages and injected currents with
the tie-lines open may be written as

\[
V = \begin{bmatrix}
V_1 \\
\vdots \\
V_4 \\
V_5 \\
\vdots \\
V_7 \\
\end{bmatrix} = \begin{bmatrix}
Z_{bus}^A & 0 \\
0 & Z_{bus}^B \\
\end{bmatrix}\begin{bmatrix}
I_1 \\
\vdots \\
I_4 \\
I_5 \\
\vdots \\
I_7 \\
\end{bmatrix} \quad \ldots \ldots \ldots \quad (1)
\]

Where \(Z_{bus}^A\) is the 4 x 4 bus impedance matrix of system A. Similarly \(Z_{bus}^B\) is the 3 x 3
bus impedance matrix of system B.

The task is to determine the new injected bus currents and the resulting changed bus
voltages, in the two power systems, when they are interconnected via two tie-lines.
Assume that the impedances of the tie-lines connected between buses 3-5 and 4-6 are
\(Z_a\) and \(Z_b\) respectively, while the currents flowing through them are respectively, \(I_a\) and
\(I_b\). Also assume that the changed voltages are represented by \(V'_1\), \(V'_2\), \(V'_3\) and \(V'_4\) in
system A by \(V'_5\), \(V'_6\) and \(V'_7\) in power system B due to the injected currents \(I_a\) and \(I_b\).
The effect of the tie-line currents can be simulated by tearing the interconnected
network shown in fig.1 into two pieces at the tie-lines and applying Eq (a final equation
of loop impedance \(Z\)). Figure 2 shows the two equivalent power systems along with
the injected currents.
Fig 2  Equivalent system networks along with the injected currents $I_a$ and $I_b$

The impedance matrix $Z$ can be substituting $i = 3, j = 5, p = 4,$ and $q = 6$ in Eq(a final equation of loop impedance $Z$). Thus,

$$Z = a \begin{bmatrix} Z_{33}^A + Z_{55}^B + Z_a & Z_{34}^A + Z_{56}^A \\ Z_{43}^A + Z_{65}^A & Z_{44}^A + Z_{66}^A + Z_b \end{bmatrix}$$ \hspace{1cm} (2)

For the individual system $A$, the bus voltages $V_3$ and $V_4$ are known. Similarly for the system $B$, the bus voltages $V_5$ and $V_6$ are also known. By using eq , the tie-line currents are computed as follows

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = Z^{-1} \begin{bmatrix} V_3 - V_5 \\ V_4 - V_6 \end{bmatrix} = a \begin{bmatrix} Z_{33}^A + Z_{55}^B + Z_a & Z_{34}^A + Z_{56}^A \\ Z_{43}^A + Z_{65}^A & Z_{44}^A + Z_{66}^A + Z_b \end{bmatrix}^{-1} \begin{bmatrix} V_3 - V_5 \\ V_4 - V_6 \end{bmatrix} \hspace{1cm} (3)$$

From eq (3), the Thevenin’s equivalent circuits for the power systems $A$ and $B$ can be perceived directly. Fig 3 shows the Thevenin’s equivalent circuits for the two power systems. The paths traced by the tie-line currents $I_a$ and $I_b$ through the reference bus, are also shown. The tie-line to bus impedance matrix $A$ is given by

$$A = a \begin{bmatrix} 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & -1 & 0 \end{bmatrix}$$
It may be observed that matrix A shows the incidence of tie-lines on the bus of system A and B.

Fig 3  Thevenin's equivalent circuits of the interconnected system showing the paths of the tie-line currents Ia and Ib through the reference bus

Assume that due to the injected tie-line currents Ia and Ib, the changed bus voltage in system A are designated by V'1, V'2, V'3, V'3 and similarly the new bus voltages in system B are represented by V'5, V'6, and V'7. By using eq the new bus voltages are computed as follows

\[
\begin{bmatrix}
V'_1 \\
\vdots \\
V'_4 \\
V'_5 \\
\vdots \\
V'_7
\end{bmatrix} =
\begin{bmatrix}
V_1 \\
\vdots \\
V_4 \\
V_5 \\
\vdots \\
V_7
\end{bmatrix} - Z_{bus} A\begin{bmatrix}
0 & 0 & 1 & 0 & -1 & 0 \\
0 & 0 & 0 & -1 & 0 & 0
\end{bmatrix}^T\begin{bmatrix}
I_a \\
I_b
\end{bmatrix}
\]

Alternatively, the piece-wise method may also be applied to obtain the new system voltages as follows

\[
\begin{bmatrix}
V'_1 \\
V'_2 \\
V'_3 \\
V'_4
\end{bmatrix} =
\begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4
\end{bmatrix} - Z_{bus} A\begin{bmatrix}
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}^T\begin{bmatrix}
-I_a \\
-I_b
\end{bmatrix}
\]

And
\[
\begin{bmatrix}
V'_5 \\
V'_6 \\
V'_7
\end{bmatrix} = \begin{bmatrix}
V_5 \\
V_{56} \\
V_7
\end{bmatrix} - Z_{bus}^{A} a b \begin{bmatrix}
-1 \\
0 \\
-1
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b
\end{bmatrix} ... ... ...
\] (5)

In computing the new bus voltages, when the two networks are interconnected through tie-lines, the major task is the formation of the loop impedance matrix \(Z\). The computation of the inverse of the loop impedance matrix \(Z\), however is simple since its order is dependent on the number of tie-lines and is small.

**FORMULATION OF THE LOOP IMPEDANCE MATRIX:**

Mathematically, the loop impedance matrix \(Z\) may be formed by using the piece-wise method and applying Eq. (a final equation of \( AZ_{bus} A^t \)) in the following manner:

Equation (2) shows the loop impedance matrix \(Z\) is made of the tie-line impedance and the respectively sub-matrices from the bus impedance matrices \(Z_{bus}^A\) and \(Z_{bus}^B\). Hence, for the interconnected network shown in fig. 1, the sub-matrices of interest would be

\[
\begin{bmatrix}
Z_{33} & Z_{34} \\
Z_{43} & Z_{44}
\end{bmatrix}
\] from \(Z_{bus}^A\) and

\[
\begin{bmatrix}
Z_{55} & Z_{56} \\
Z_{65} & Z_{66}
\end{bmatrix}
\] from \(Z_{bus}^B\)

The branch to bus incidence matrix \(AA\) showing the incidence of the tie-lines on the boundary buses of system A is given by

\[
A^A = \begin{bmatrix}
a & 1 \\
b & 0
\end{bmatrix}
\]

\[
Z^A = A^A \begin{bmatrix}
Z_{33} & Z_{34} \\
Z_{43} & Z_{44}
\end{bmatrix} A^{A^t} ... ... ...
\] (6)

Similarly, for system B

\[
A^B = \begin{bmatrix}
a & -1 \\
b & 0
\end{bmatrix}
\]

\[
Z^B = A^B \begin{bmatrix}
Z_{33} & Z_{34} \\
Z_{43} & Z_{44}
\end{bmatrix} A^{B^t}
\]
The loop incidence matrix $Z$, therefore, is computed as

In a generalised form from the sub matrices, removed from the original $Z^A_{bus}$ and $Z^B_{bus}$ system impedance matrices may be expressed as

$$
\begin{bmatrix}
Z_{ii} & Z_{ij} & Z_{ik} \\
Z_{ji} & Z_{jj} & Z_{jk} \\
Z_{ki} & Z_{kj} & Z_{kk}
\end{bmatrix}
$$
taken out from $Z^A_{bus}$ matrix of system A and

$$
\begin{bmatrix}
Z_{pp} & Z_{pq} & Z_{pr} & Z_{ps} \\
Z_{qp} & Z_{qq} & Z_{qr} & Z_{qs} \\
Z_{rp} & Z_{rq} & Z_{rr} & Z_{rs} \\
Z_{ki} & Z_{sq} & Z_{sr} & Z_{ss}
\end{bmatrix}
$$
taken out from $Z^B_{bus}$ matrix of system B

In the two matrices, i, j, and k are the boundary buses of system A and p, q, r and s are the boundary buses of system B. The two system are interconnected via tie-lines at the boundary buses.

Inverse of the above sub matrices leads to the bus admittance matrices. These bus admittance matrices symbolize the systems A and B connected via tie-lines at the boundary buses. The equivalent admittance sub-matrices are called ward equivalents. The mathematical computation of the loop impedance matrix $Z$ may physically be interpreted in the following manner.

From the thevenin’s equivalent circuit of the interconnected power system in fig xxx and a perusal of eq (2), the following conclusions can be drawn:

The diagonal element of the loop impedance matrix $Z$ are the sum of the impedance in the loop or the path traversed by the tie-line currents starting from the references bus of system A to reference bus of the system B. For example in fig (3) the sum of the impedances of the path traversed by tie-lines current $I_b$ (starting from the reference bus of system A) is $(Z_{43}+(Z_{44}-Z_{43})+Z_b+(Z_{66}-Z_{65})+Z_{65}) = Z_{44}+Z_{66}+Z_b$, which as per eq (2) is diagonal element of $Z$.

The off-diagonal element of $Z$ are represented by those impedances through which tie-line currents are flowing and are the cause for producing new system voltages when systems are interconnected. Referring to fig(3) is observed that tie-line currents $I_a$ and
Ib are following through $Z_{34} = Z_{43}$ and $Z_{56} = Z_{65}$. Hence, the off-diagonal elements in $Z$ are equal to $Z_{34} + Z_{56}$ or $Z_{43} + Z_{65}$.

- **ATTACH PROGRAMME WITH RESULTS**

**CONCLUSION:**

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A GIVEN FOUR BUS SYSTEM TO DETERMINE THE BUS ADMITTANCE MATRIX FOR A REDUCED NETWORK.

EXPERIMENT NO: DATE:

AIM: EXECUTE THE PROGRAM FOR A GIVEN FOUR BUS SYSTEM TO DETERMINE THE BUS ADMITTANCE MATRIX FOR A REDUCED NETWORK.

APPARATUS:

THEORY:

Network reduction

At time, computation of voltage at all nodes (or buses) is of no immediate interest. In stability studies of power system, non generator buses or buses which are neither to be faulted not required for metering purposes can be eliminated from the network. In such cases, variables associated with these buses are not required and, therefore these can be eliminated from the node equations.

Equation (1) expresses the node equation for a hypothetical power system consisting of five buses.

\[
\begin{bmatrix}
Y_{11} & Y_{12} & 0 & Y_{14} & 0 \\
Y_{21} & Y_{22} & Y_{23} & 0 & Y_{25} \\
0 & Y_{32} & Y_{23} & 0 & Y_{35} \\
Y_{41} & 0 & 0 & Y_{44} & Y_{45} \\
0 & Y_{52} & Y_{53} & Y_{54} & Y_{55}
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4 \\
V_5
\end{bmatrix}
=
\begin{bmatrix}
I_1 \\
I_2 \\
I_3 \\
I_4 \\
I_5
\end{bmatrix}
\] … … … \( (1) \)

Assume that buses 4 and 5 are required to be eliminated. The Ybus matrix and the voltage and current vectors in eq. (1) are partitioned such that they are conformable to matrix multiplication.

Let
\[
\begin{bmatrix}
Y'_{11} & Y'_{12} & 0 \\
Y'_{21} & Y'_{22} & Y'_{23} \\
0 & Y'_{32} & Y'_{23}
\end{bmatrix}
= \begin{bmatrix}
Y_{11} & Y_{12} & 0 \\
Y_{21} & Y_{22} & Y_{23} \\
0 & Y_{32} & Y_{23}
\end{bmatrix}
Y'_{12} = \begin{bmatrix}
Y_{14} & 0 \\
0 & Y_{25} \\
0 & 0
\end{bmatrix}
\]

\[
Y'_{21} = \begin{bmatrix}
Y_{11} & Y_{12} & 0 \\
Y_{21} & Y_{22} & Y_{23} \\
0 & Y_{32} & Y_{23}
\end{bmatrix}
Y'_{22} = \begin{bmatrix}
Y_{44} & Y_{45} \\
Y_{54} & Y_{55}
\end{bmatrix}
\]

\[
V'_{1} = \begin{bmatrix}
V_{1} \\
V_{2} \\
V_{3}
\end{bmatrix}
V'_{2} = \begin{bmatrix}
V_{4} \\
V_{5}
\end{bmatrix}
I'_{1} = \begin{bmatrix}
I_{1} \\
I_{2} \\
I_{3}
\end{bmatrix}
I'_{2} = \begin{bmatrix}
I_{2} \\
I_{3}
\end{bmatrix}
\]

After Making The Above Substitutions, Eq. (1) takes the following form

\[
\begin{bmatrix}
Y'_{11} & Y'_{12} \\
Y'_{21} & Y'_{22}
\end{bmatrix}
\begin{bmatrix}
V'_{1} \\
V'_{2}
\end{bmatrix}
= \begin{bmatrix}
I'_{1} \\
I'_{2}
\end{bmatrix}
\] \hspace{1cm} (2)

From the compound matrix form of Eq. (2), the following equation are obtain

\[
Y'_{11}V'_{1} + Y'_{12}V'_{2} = I'_{1} \hspace{1cm} (3)
\]

\[
Y'_{21}V'_{1} + Y'_{22}V'_{2} = I'_{2} \hspace{1cm} (4)
\]

Equation (6.57) is used to obtain the expression for \( V'_{2} \) as

\[
V'_{2} = Y'_{22} - 1(I'_{2} - V'_{21}V'_{1}) \hspace{1cm} (5)
\]

And substituting for \( V'_{2} \) in Eq. (6.56) gives

\[
Y'_{11}V'_{1} + Y'_{12}(Y'_{22} - 1(I'_{2} - V'_{21}V'_{1})) = I'_{1}
\]

Simplification of the above expression results in the following

\[
(Y'_{11} - Y'_{12}Y'_{22} - 1Y'_{21})V'_{1} = I'_{1} - Y'_{12}Y'_{22} - 1I'_{2}
\] \hspace{1cm} (6)

Substituting

\[
Y''_{11} = (Y'_{11} - Y'_{12}Y'_{22} - 1Y'_{21})
\] \hspace{1cm} (7)

And

\[
I''_{1} = I'_{1} - Y'_{12}Y'_{22} - 1I'_{2}
\] \hspace{1cm} (8)

In Eq. (8) gives
\[ Y''11V'1 = I''1 \]  \[ \ldots \ldots (9) \]

Or

\[ V'1 = Y''11 - 1 I'1 \]  \[ \ldots \ldots (10) \]

It may be observed from Eq.(10) that \( y''11 \) represent the reduced admittance matrix (also called Kron reduction). Buses 4 &5 have also been eliminated and the order of the equation is equal to the number of buses retained in the system further, the second term in Eq.(10) gives the distributed currents from the eliminated buses into the retained buses. If, however, the loads at the eliminated buses are disregarded, the load matrix \( L'1 \) is set to zero.

The Algorithm for elimination of the buses, for a power system having \( n \) buses is mathematically written as,

\[ Y_{ij}^{\text{new}} = Y_{ij} - \left( \frac{Y_{ik} Y_{kj}}{Y_{kk}} \right) \quad i, j = 1, 2, 3, \ldots, n \text{ where; } j \neq k \]  \[ \ldots \ldots \ldots (11) \]

**Example:** In Fig., the four-bus power system A is interconnected via three tie-lines to another four-bus power system B. The bus voltages, in per unit, of the individual power systems in the stand alone mode, in the steady state, are shown in the figure. Use the piece-wise method to determine the bus voltages of the entire interconnected network when the three tie-lines are simultaneously closed. The line and tie-line reactances shown in the figure are in per unit.

![Figure: Two Four-Bus System](image)
ATTACH PROGRAMME WITH RESULTS

CONCLUSION:

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CONTINGENCY ANALYSIS (PIECEWISE LINEAR METHOD) USING MATLAB.

AIM: EXECUTE THE PROGRAM OF CONTINGENCY (PIECEWISE LINEAR METHOD) USING MATLAB.

APPARATUS:

THEORY:

Morden day tradition is to interconnected system operated by different power companies through tie-lines and this increases the reliability of electrical energy supply. It is, therefore, important to introduce the concepts for modelling interconnected networks for addition or removal of tie lines for contingency analysis.

The modelling of power networks, interconnected through tie-lines, adopts the piecewise methods for their solutions. The piecewise methods are based on the assumption that each network is simulated by a linear model for its analysis by the individual operating authority.

Figure 1 shows a four-bus power system A interconnected through two tie-lines, of impedances Za and Zb, with another three-bus power network B. Both the power systems are independent except for the interconnection are earthed, thereby providing a common reference point.

![Diagram of two power system networks connected through tie-lines](image.png)
Initially it is assumed that both the systems operate in the stand alone mode, and use the Zbus of their own networks for analysing their systems. These results can be later modified, by each system, to take advantage of the interconnections between the two networks.

From fig.1, it may be noted that buses 3 and 4 of system A are connected to buses 5 and 6 of system B. The current injections and the voltages at each bus, shown in the figure, are assumed known and represent the networks in the stand alone mode. Mathematically, the relationship between the bus voltages and injected currents with the tie-lines open may be written as

\[
V = \begin{bmatrix}
V_1 \\
\vdots \\
V_4 \\
V_5 \\
\vdots \\
V_7 \\
\end{bmatrix} = \begin{bmatrix}
Z_{bus}^A & 0 \\
0 & Z_{bus}^B \\
\end{bmatrix} \begin{bmatrix}
I_1 \\
\vdots \\
I_4 \\
I_5 \\
\vdots \\
I_7 \\
\end{bmatrix} 
\]  

(1)

Where Z\textsubscript{Abus} is the 4 x 4 bus impedance matrix of system A. Similarly Z\textsubscript{Bbus} is the 3 x 3 bus impedance matrix of system B.

The task is to determine the new injected bus currents and the resulting changed bus voltages, in the two power systems, when they are interconnected via two tie-lines. Assume that the impedances of the tie-lines connected between buses 3-5 and 4-6 are Za and Zb respectively, while the currents flowing through them are respectively I\textsubscript{a} and I\textsubscript{b}. Also assume that the changed voltages are represented by \(V'\text{A}1, V'\text{A}2, V'\text{A}3\) and \(V'\text{A}4\) in system A by \(V'\text{B}5, V'\text{B}6\) and \(V'\text{B}7\) in power system B due to the injected currents I\textsubscript{a} and I\textsubscript{b}. The effect of the tie-line currents can be simulated by tearing the interconnected network shown in fig.1 into two pieces at the tie-lines and applying Eq (a final equation of loop impedance Z). Figure 2 shows the two equivalent power systems along with the injected currents.

![Fig 2](image.png)

Fig 2  Equivalent system networks along with the injected currents I\textsubscript{a} and I\textsubscript{b}
The impedance matrix $Z$ can be substituting $i = 3, j = 5, p = 4, \text{ and } q = 6$ in Eq(a final equation of loop impedance $Z$). Thus,

$$Z = \frac{a}{b} \left[ \begin{array}{c} Z_{33}^A + Z_{55}^B + Z_a \frac{Z_{34}^A + Z_{56}^A}{Z_{43}^A + Z_{65}^B} \end{array} \right]$$

(2)

For the individual system A, the bus voltages $V_3$ and $V_4$ are known. Similarly for the system B, the bus voltages $V_5$ and $V_6$ are also known. By using eq , the tie-line currents are computed as follows

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = \begin{bmatrix} V_3 \\ V_4 \\ -V_5 \\ -V_6 \end{bmatrix} = \frac{a}{b} \left[ \begin{array}{c} Z_{33}^A + Z_{55}^B + Z_a \frac{Z_{34}^A + Z_{56}^A}{Z_{43}^A + Z_{65}^B} \end{array} \right]^{-1} \begin{bmatrix} V_3 \\ V_4 \\ -V_5 \\ -V_6 \end{bmatrix}$$

(3)

Form eq (3), the Thevenin's equivalent circuits for the power systems A and B can be perceived directly. Fig 3 shows the Thevenin's equivalent circuits for the two power systems. The paths traced by the tie-line currents $I_a$ and $I_b$ through the reference bus, are also shown. The tie-line to bus impedance matrix $A$ is given by

$$A = \frac{a}{b} \begin{bmatrix} 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & -1 & 0 \end{bmatrix}$$

It may be observed that matrix $A$ shows the incidence of tie-lines on the busus of system A and B.

Fig 3 Thevenin's equivalent circuits of the interconnected system showing the paths of the tie-line currents $I_a$ and $I_b$ through the reference bus

![Diagram showing Thevenin's equivalent circuits](image)
Assume that due to the injected tie-line currents $I_a$ and $I_b$, the changed bus voltage in system $A$ are designated by $V'_1, V'_2, V'_3, V'_4$ and similarly the new bus voltages in system $B$ are represented by $V'_5, V'_6, V'_7$. By using eq. the new bus voltages are computed as follows

$$
\begin{bmatrix}
V'_1 \\
V'_2 \\
V'_3 \\
V'_4 \\
V'_5 \\
V'_6 \\
V'_7
\end{bmatrix} = \begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4 \\
V_5 \\
V_6 \\
V_7
\end{bmatrix} - \begin{bmatrix}
Z^A_{bus} & 0 \\
0 & Z^B_{bus}
\end{bmatrix} \begin{bmatrix}
a & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\
b & 0 & 0 & 0 & -1 & 0 & -1 & 0
\end{bmatrix}^t \begin{bmatrix}
I_a \\
I_b
\end{bmatrix}
$$

Alternatively, the piece-wise method may also be applied to obtain the new system voltages as follows

$$
\begin{bmatrix}
V'_1 \\
V'_2 \\
V'_3 \\
V'_4 \\
V'_5 \\
V'_6 \\
V'_7
\end{bmatrix} = \begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4 \\
V_5 \\
V_6 \\
V_7
\end{bmatrix} - Z^A_{bus} \begin{bmatrix}
a & 0 & 0 & 1 & 0 \\
b & 0 & 0 & 0 & 1
\end{bmatrix}^t \begin{bmatrix}
-I_a \\
-I_b
\end{bmatrix} \ldots \ldots \ldots (4)
$$

And

$$
\begin{bmatrix}
V'_5 \\
V'_6 \\
V'_7
\end{bmatrix} = \begin{bmatrix}
V_5 \\
V_6 \\
V_7
\end{bmatrix} - Z^B_{bus} \begin{bmatrix}
a & -1 & 0 & 0 \\
b & 0 & -1 & 0
\end{bmatrix}^t \begin{bmatrix}
I_a \\
I_b
\end{bmatrix} \ldots \ldots \ldots (5)
$$

In computing the new bus voltages, when the two networks are interconnected through tie-lines, the major task is the formation of the loop impedance matrix $Z$. The computation of the inverse of the loop impedance matrix $Z$, however is simple since its order is dependent on the number of tie-lines and is small.

**FORMULATION OF THE LOOP IMPEDANCE MATRIX** :

Mathematically, the loop impedance matrix $Z$ may be formed by using the piece-wise method and applying Eq. (a final equation of $AZ_{bus}At$) in the following manner:

Equation (2) shows the loop impedance matrix $Z$ is made of the tie-line impedance and the respectively sub-matrices from the bus impedance matrices $Z^A_{bus}$ and $Z^B_{bus}$. Hence, for the interconnected network shown in fig. 1, the sub-matrices of interest would be

$$
\begin{bmatrix}
Z_{33} & Z_{34} \\
Z_{43} & Z_{44}
\end{bmatrix} \text{ from } Z^A_{bus} \text{ and } \begin{bmatrix}
Z_{55} & Z_{56} \\
Z_{65} & Z_{66}
\end{bmatrix} \text{ from } Z^B_{bus}
$$
The branch to bus incidence matrix $A^A$ showing the incidence of the tie-lines on the boundary buses of system A is given by

$$A^A = \begin{bmatrix} a & 1 \\ b & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$Z^A = A^A \begin{bmatrix} Z_{33} & Z_{34} \\ Z_{43} & Z_{44} \end{bmatrix} A^{A^t} \quad \ldots \quad (6)$$

Similarly, for system B

$$A^B = \begin{bmatrix} a & -1 \\ b & 0 \end{bmatrix} \begin{bmatrix} 0 \\ -1 \end{bmatrix}$$

$$Z^B = A^B \begin{bmatrix} Z_{33} & Z_{34} \\ Z_{43} & Z_{44} \end{bmatrix} A^{B^t}$$

The loop incidence matrix $Z$, therefore, is computed as

In a generalised from the sub matrices, removed from the original $Z_{bus}^A$ and $Z_{bus}^B$ system impedance matrices may be expressed as

$$\begin{bmatrix} I & j & k \\ i & Z_{ii} & Z_{ij} & Z_{ik} \\ j & Z_{ji} & Z_{jj} & Z_{jk} & \text{taken out from } Z_{bus}^A \text{ matrix of system A and } \\ k & Z_{ki} & Z_{kj} & Z_{kk} \end{bmatrix}$$

$$\begin{bmatrix} p & q & r & s \\ Z_{pp} & Z_{pq} & Z_{pr} & Z_{ps} \\ Z_{qp} & Z_{qq} & Z_{qr} & Z_{qs} \end{bmatrix} \quad \text{taken out from } Z_{bus}^B \text{ matrix of system B}$$
In the two matrices, i, j, and k are the boundary buses of system A and p, q, r and s are the boundary buses of system B. The two system are interconnected via tie-lines at the boundary buses.

Inverse of the above sub matrices leads to the bus admittance matrices. These bus admittance matrices symbolize the systems A and B connected via tie-lines at the boundary buses. The equivalent admittance sub-matrices are called ward equivalents. The mathematical computation of the loop impedance matrix \( Z \) may physically be interpreted in the following manner.

From the thevenin's equivalent circuit of the interconnected power system in fig xxx and a perusal of eq (2), the following conclusions can be drawn:

The diagonal element of the loop impedance matrix \( Z \) are the sum of the impedance in the loop or the path traversed by the tie-line currents starting from the references bus of system A to reference bus of the system B. For example in fig (3) the sum of the impedances of the path traversed by tie-lines current \( I_b \) (starting from the reference bus of system A) is \( \{Z_{43}+(Z_{44}-Z_{43})+Z_b+(Z_{66}-Z_{65})+Z_{65}\} = Z_{44}+Z_{66}+Z_b \), which as per eq (2) is diagonal element of \( Z \).

The off-diagonal elements of \( Z \) are represented by those impedance through which tie-line currents are flowing and are the cause for producing new system voltages when systems are interconnected. Referring to fig (3) is observed that tie-line currents \( I_a \) and \( I_b \) are following through \( Z_{34} = Z_{43} \) and \( Z_{56} = Z_{65} \). Hence, the off-diagonal elements in \( Z \) are equal to \( Z_{34}+Z_{56} \) or \( Z_{43}+Z_{65} \).

- ATTACH PROGRAMME WITH RESULTS

CONCLUSION:
APPLY WLSI METHOD TO THE RAW MEASUREMENT TO DETERMINE THE BAD DATA FROM RESULTANT VALUE.

EXPERIMENT NO: DATE:

AIM: APPLY WLSI METHOD TO THE RAW MEASUREMENT TO DETERMINE THE BAD DATA FROM RESULTANT VALUE.

APPARATUS:

THEORY:

Voltage magnitudes and phase angles are the two state variables of an electrical power system. Unlike the voltage magnitudes, which can be directly measured, the relative voltage angles cannot be measured directly. However, the online system data.

The real-time input to the state estimator is constituted of online data (bus voltages, real and reactive powers, and line flows) and status information associated with the system switching devices, such as circuit breakers and transformer taps. The state estimator operates on data which is akin to the conventional power flow data. However, the volume of data used by the state estimator (in terms of the number of actual measurement performed in practical state estimation) exceeds by far the data required for a system power flow study for the purpose of planning and design. Redundancy in data is a necessary and desirable feature in state estimation to take care of malfunctioning in data acquisition equipment and erroneous measurements. Thus, in state estimation the number of equations, whose solution is sought, is invariably in excess of the number of unknown state variables.

Raw measurement data is never used directly in state estimation. The state estimator first processes the raw data to identify gross bad measurements, filters such measurements, and then performs the computations to obtain average estimates of the state variables.

Simulation of the State Estimation given the following solution

\[
\begin{align*}
\text{xiIT+1 - xiIT} &= (HxITt \cdot R-1 \cdot HxITt) -1 \cdot HxITt \cdot R-1 \\
\end{align*}
\]

In equation (1), the Jacobian HxIT at iteration count IT is written as follows
HxIT = \begin{bmatrix}
\frac{\partial h_1}{\partial x_1} |_{IT} & \frac{\partial h_1}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_1}{\partial x_n} |_{IT} \\
\frac{\partial h_2}{\partial x_1} |_{IT} & \frac{\partial h_2}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_2}{\partial x_n} |_{IT} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{\partial h_n}{\partial x_1} |_{IT} & \frac{\partial h_n}{\partial x_2} |_{IT} & \cdots & \frac{\partial h_n}{\partial x_n} |_{IT}
\end{bmatrix}

(2)

It is noted from the foregoing that equation (1) provides the iterative formula for estimating the values of the \(n\) state variables.

The following step-wise procedure outlines the method of obtaining a solution of eq. (2) iteratively and verifying the accuracy of the estimated state variables by applying the chi-square test.

**Step -1** : Initialize the relative process by setting iteration count \(IT=0\) and guesstimating \(h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT})\).

**Step -2** : From the weighting factors compute the diagonal variance matrix \(R\).

**Step -3** : Compute the elements of the jacobian \(HX_{IT}\) and the vector elements \(z_i - h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT})\).

**Step – 4** : Solve Eq. (2) and the compute the corrections to be made to the state variables and therefore calculate the new estimates of the state variables as follows \(x_{iIT+1} = x_{iIT} + \Delta x_{IT}\).

**Step -5** : check for convergence by using the expression \(x_{iIT+1} - x_{iIT} < \varepsilon\).

**Step – 6** : If the tolerance \(\varepsilon\) is within the specified limit go to step 7; if not, set \(IT=IT+1\), replace \(h_i(x_{1IT}, x_{2IT}, \ldots, x_{nIT})\) by the latest estimates of the state variables and go to step 3.

**Step – 7** : Compute the measurements error vector \(\xi = z - h(x_1, x_2, \ldots, x_n)\) and use the relation \(\hat{f} = \sum (\xi_i^2 / \sigma_i^2)\) to compute the sum of the squares of the performance function \(\hat{f}\). Apply the chi-squares test to determine bad measurements if any.

After step 6, if convergence is obtained, the estimated values of the state variables are obtained by WLSE and may be represented by \(x_{iIT+1} = \hat{x} = [\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n]^t\)

**Theory of case study:**

In the power system network shown in fig (1), a generator is feeding a load over a transmission line whose reactance is \(jX_{12}\). The system is being monitored for (i) voltage magnitudes at two buses, (ii) reactive power at bus 2, (iii) real power flow bus 1 to 2, and (iv) reactive power flow bus 1 to 2. Formulate the Jacobian matrix \(H\) and develop the
linearized mathematical model for computing the state variables. Assume the voltage at bus 1 as the reference and the shunt reactance at bus 2 equal to jX20.

The state variables required to be estimated are:

\[
\begin{bmatrix}
  x_1 &= \delta_2 \\
  x_2 &= V_2 \\
  x_3 &= V_1
\end{bmatrix}
\]

The measurement variables are:

\[
\begin{bmatrix}
  z_1 &= V_2 \\
  z_2 &= V_1 \\
  z_3 &= Q_2 \\
  z_4 &= P_{12} \\
  z_5 &= Q_{12}
\end{bmatrix}
\]

\[Q_2 = \left( \frac{1}{X_{12}} + \frac{1}{X_{20}} \right) V_1 V_2 - \frac{V_1 V_2}{X_{12}} \cos(\delta_2 - \delta_1) = \left( \frac{1}{X_{12}} + \frac{1}{X_{20}} \right) x_3 - \frac{x_3 x_2}{X_{12}} \cos x_1\]

\[P_{12} = \frac{V_1 V_2}{X_{12}} \sin (\delta_2 - \delta_1) = -\frac{V_1 V_2}{X_{12}} \sin \delta_2 = -\frac{x_3 x_2}{X_{12}} \sin x_1\]

\[Q_{12} = \frac{V_1^2}{X_{12}} - \frac{V_1 V_2}{X_{12}} \cos(\delta_1 - \delta_2) = \frac{1}{X_{12}} \{ x_3 - x_3 x_2 \cos x_1 \}\]

The non-linear functions h1, h2, h3, h4, and h5 may be written as

h1 \( (x_1, x_2, x_3, x_4, x_5) = x_2 \)

h2 \( (x_1, x_2, x_3, x_4, x_5) = x_3 \)

h3 \( (x_1, x_2, x_3, x_4, x_5) = \left( \frac{1}{X_{12}} + \frac{1}{X_{20}} \right) x_3 - \frac{x_3 x_2}{X_{12}} \cos x_1 \)

h4 \( (x_1, x_2, x_3, x_4, x_5) = -\frac{x_3 x_2}{X_{12}} \sin x_1 \)

h5 \( (x_1, x_2, x_3, x_4, x_5) = \frac{1}{X_{12}} \{ x_3 - x_3 x_2 \cos x_1 \} \)

Thus the element of the Jacobean H, for an iteration count IT, are derived from eq.(1) as follows:
Similarly, the vector is written as

\[
\begin{bmatrix}
\zeta_1 \\
\zeta_2 \\
\zeta_3 \\
\zeta_4 \\
\zeta_5
\end{bmatrix} =
\begin{bmatrix}
z_1 - x_{12}^T \\
z_2 - x_{12}^T \\
z_3 - \left(\left(\frac{1}{x_{12}} + \frac{1}{x_{20}}\right) * x_{33} - x_{12}^T \cos x_1\right) \times 1^T \\
z_4 - \left(- \frac{x_{3}x_{2}}{x_{12}} \sin x_1\right) \times 1^T \\
z_5 - \left(\frac{1}{x_{12}} \{x_{3}^2 - x_{3}x_{2} \cos x_1\}\right) \times 1^T
\end{bmatrix}
\]

The linearized equation, similar to eq. (1) is now written as

\[X_i \times 1^T + 1 - x_i = (H \times 1^T \cdot R - 1) H \times 1^T R - 1\]

From the preseding equation, WLSE of the state variables can be obtained.

**Example of case study:**

For the power system in above example, the measured variables, in per unit are as follows:

- \(z_1 = V_2 = 0.95\);
- \(z_2 = V_1 = 1.05\);
- \(z_3 = Q_2 = 0.55\);
- \(z_4 = P_{12} = 0.93\);
- \(z_5 = Q_{12} = 0.34\);

With WLSE technique, determine the values of the state variables and the confidence level of the accuracy of the accuracy of the results. Assume the values of the variance of the measurement errors as follows: \(\sigma_{12} = \sigma_{22} = \sigma_{32} = 0.0001\), \(\sigma_{42} = 0.0002\), and \(\sigma_{52} = 0.0004\). Also, assume a tolerance value of 0.0001 for convergence.

- **ATTACH PROGRAMME WITH RESULTS**
CONCLUSION:

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