



Análisis de Flujo de Potencia Equilibrado

Análisis de Flujo de Potencia equilibrado

- ❑ Introducción al Flujo de Potencia equilibrado (FPE).
- ❑ Matriz Admitancia de barras.
- ❑ Formulación del Problema del FPE.
- ❑ Métodos numéricos.
- ❑ Algoritmos para la solución del FPE
- ❑ Ejemplos de aplicación utilizando ETAP®12.5

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- **IEEE Std 1036™ – 1.992:** *IEEE Guide for Application of Shunt Power Capacitors*
- **IEEE Std 824™ - 2.004:** *IEEE Standard for Series Capacitor Banks in Power Systems.*
- **IEEE Std C57.12.00™ – 2.006:** *IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*
- **IEEE Std C57.12.01™ – 2.005:** *IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings.*

Bibliografía

- **IEEE Std C57.12.90™ – 2.006:** *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*
- **IEEE Std C57.12.91™ – 2.001:** *IEEE Standard Test Code for Dry-Type Distribution and Power Transformers*
- **IEEE Std C57.12.80™ – 2.002:** *IEEE Standard Terminology for Power and Distribution Transformers*
- **IEEE Std C50.12™ – 2.005:** *IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.*
- **IEEE Std C50.13™ – 2.005:** *IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.*

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- **IEC 60831-2** Ed. 2.0 1995-12. *Shunt Power Capacitors of the self-healing type for AC Systems having a rated voltage up to and including 1.000 V – Part 2: Ageing test, self-healing test and destruction test.*
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- **ETAP®12.5 User Guide.**

Análisis de Sistemas Eléctricos de Potencia

Régimen permanente

Red en condiciones de operación normal

Red en condiciones de operación bajo falla

Equilibrada Desquilibrada

Equilibrada Desquilibrada

1. Sistema lineal o no lineal
2. Parámetros concentrados
3. "Foto" de un instante en el tiempo

Sistema de ecuaciones algebraicas

Régimen dinámico

Red en condiciones de operación normal

Red en condiciones de operación bajo falla

Equilibrada Desquilibrada

Equilibrada Desquilibrada

1. Sistema lineal o no lineal
2. Parámetros concentrados o distribuidos
3. Solución en el dominio del tiempo

Sistema de ecuaciones diferenciales

Introducción al FPE

❑ Objetivos para la operación de un SEP

- ✓ Producir energía eléctrica al menor costo posible.
- ✓ Transportarla hacia los centros de consumo con mínimas pérdidas.
- ✓ Distribuir la al usuario final.
- ✓ Mantener en todo momento la calidad y seguridad.



Introducción al FPE

❑ Dificultades Tecnológicas

- ✓ La energía eléctrica no puede ser almacenada como tal.
- ✓ En todo momento la producción debe igualar al consumo de energía eléctrica.



Introducción al FPE

❑ Cómo logramos estos objetivos?

- ✓ A través de un exhaustivo análisis donde se evalúe el comportamiento del sistema en el corto, mediano y largo plazo.

❑ Que actividades desarrollamos para ello?

- ✓ Planificación de la expansión
- ✓ Programación de la operación
- ✓ Operación/control en tiempo real

Introducción al FPE

- ❑ Estamos interesados en determinar el estado del sistema al operar en régimen permanente y equilibrado calculando:
 - ✓ Tensiones en barras (modulo y fase).
 - ✓ Potencia (activa y reactiva) en las líneas de transmisión y cables.
 - ✓ Pérdidas de potencia asociadas al sistema.
 - ✓ Condición de operación (carga/sobrecarga) del equipamiento.

Introducción al FPE

Propiedades requeridas a los algoritmos para solución de FPE

<i>Alta velocidad de computo</i>	Grandes sistemas Aplicaciones en tiempo real Casos múltiples Aplicaciones interactivas
<i>Bajo requerimiento de almacenamiento</i>	Grandes sistemas Restricciones de hardware
<i>Robustos</i>	Problemas mal condicionados Análisis de Contingencias Aplicaciones en tiempo real

Introducción al FPE

Propiedades requeridas a los algoritmos para solución de FPE	
<i>Versatilidad</i>	Habilidad para manejar tanto las características convencionales como las especiales (representación y controles del equipamiento)
<i>Adecuabilidad</i>	Posibilidad de incorporarlo en procesos de cómputos mas complicados
<i>Simplicidad</i>	Facilidad para codificar, mantener y mejorar el software

Breve Historia de los algoritmos para FPE

~ 1915 hasta 1955 - Analizadores de Redes en CA y CC

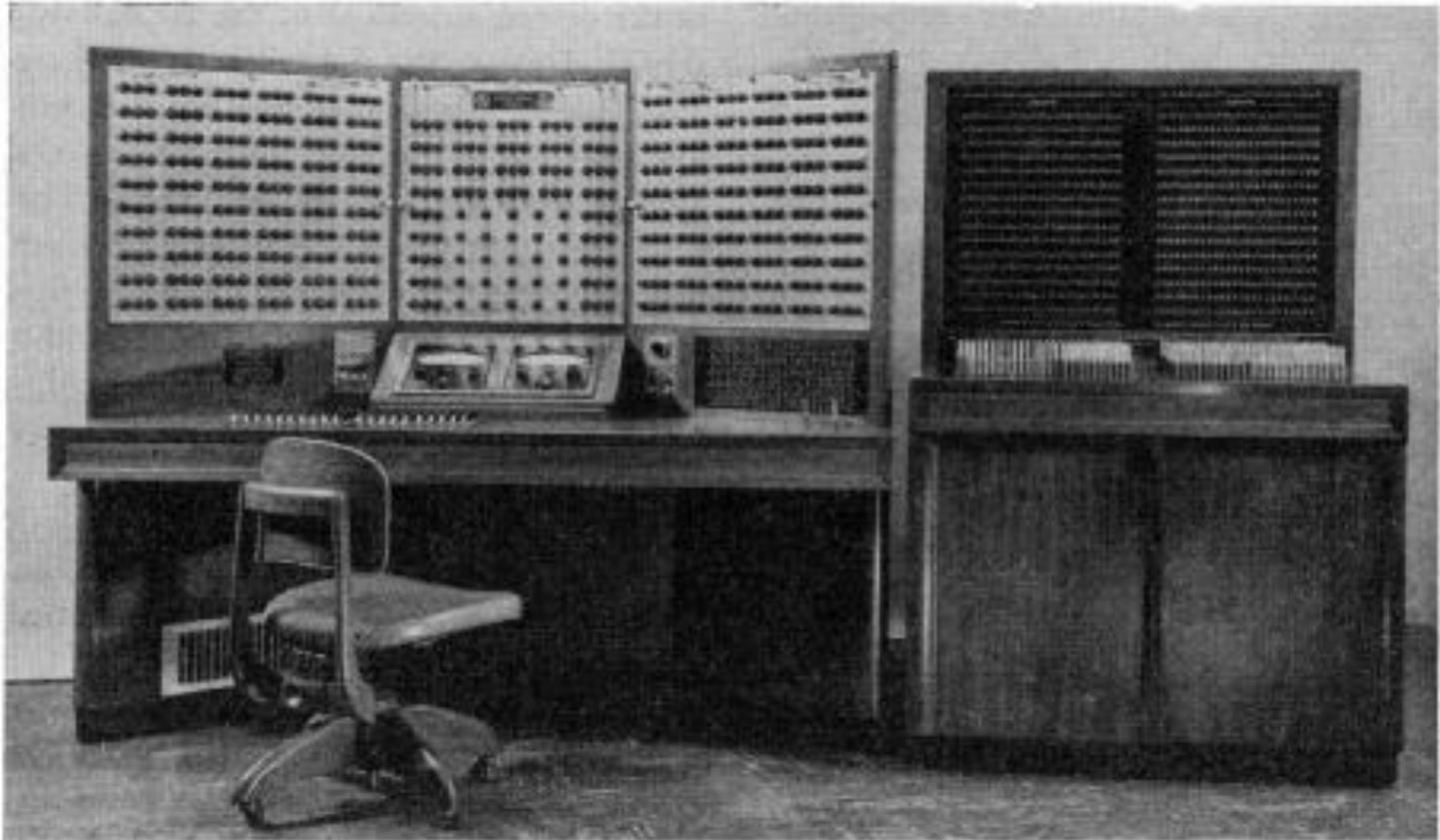


Fig. 1. One section of d-c network analyzer showing master console and connection unit

Breve Historia de los algoritmos para FPE

1. A DEVICE FOR CALCULATING CURRENTS IN COMPLEX NETWORKS OF LINES. *General Electric Review*, Schenectady, N. Y., vol. 19, 1918, pp. 901-02.
2. CALCULATION OF SHORT-CIRCUIT CURRENTS IN A-C SYSTEMS, W. W. Lewis. *Ibid.*, vol. 22, 1919, pp. 140-45.
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9. THE M.I.T. NETWORK ANALYZER, H. L. Hazen, O. R. Schurig, M. F. Gardner. *AIEE Transactions*, vol. 49, 1930, pp. 1102-14.
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Breve Historia de los algoritmos para FPE

~ 1955 Primeros algoritmos prácticos para computadoras digitales
(basados en la matriz Y)

J. B. Ward and H. W. Hale "Digital Computer Solution of Power Flow Problems" AIEE Trans., Vol. 75, pp. 398-404, June 1956.

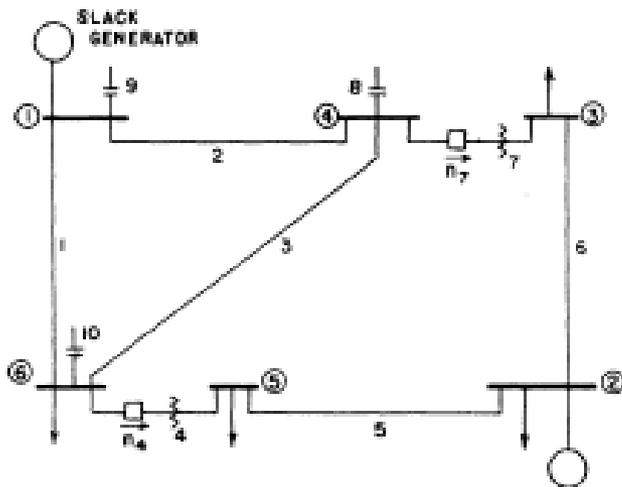


Fig. 1. Sample system

THE capabilities of automatic digital computers are receiving increasing attention in application to power system problems. This paper presents a method for solving on digital computers the power-flow problem which is probably the most frequently encountered type of problem in the field of power system network analysis. Digital solution of this class of problem can furnish a valuable tool to supplement the a-c network analyzer. In many system-planning studies, the network analyzer is still the best means for providing quickly and economically results of adequate accuracy. In some studies, such as analysis of losses and incremental losses, the network analyzer does not provide sufficient precision and, in such cases, the digital computer solution gains a distinct advantage.

In brief summary, the power-flow problem consists of imposing specified

Breve Historia de los algoritmos para FPE

~ 1960/70 Algoritmos basados en la matriz Z

H. E. Brown et al "Power Flow Solution by Impedance Matrix Iterative Methods" IEEE Trans. PAS, Vol. 82, pp. 1-10, Apr. 1963.

Summary: A new load flow program has been developed which employs the node-impedance matrix of a system. A special input routine was developed that allows the line data to be in any order desired. The program has the capacity to control generator voltages within a specified var (reactive volt-ampere) range, and also to incorporate off-nominal autotransformers. In every system studied using this program, the time for solution was less than that required by the usual nodal branch admittance iterative method.

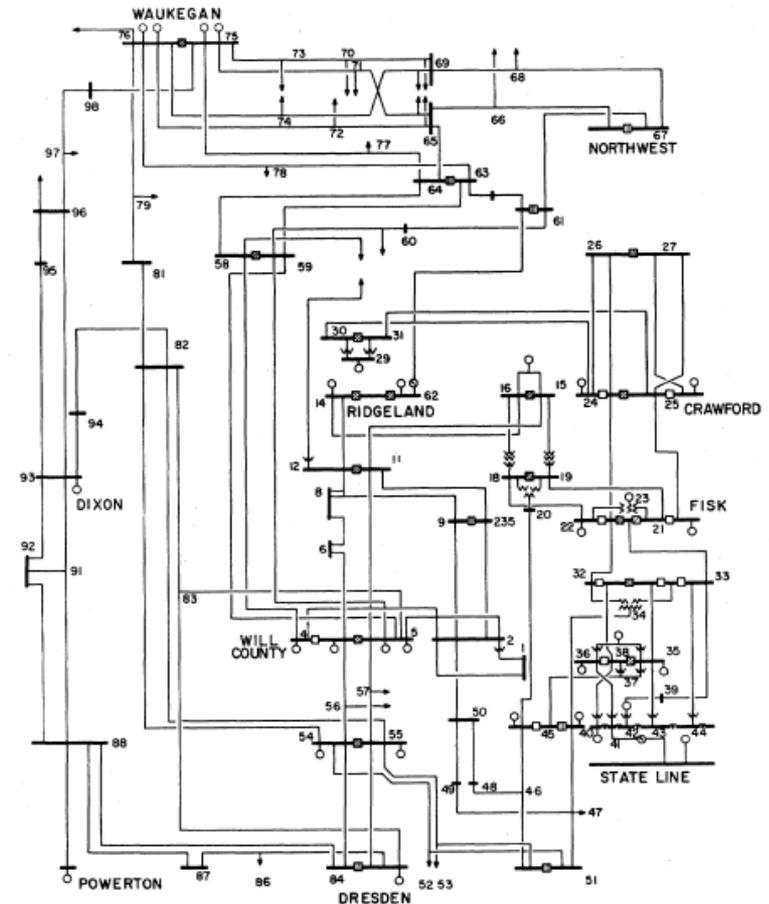


Fig. 2. One-line diagram of Commonwealth Edison Company major transmission system

Breve Historia de los algoritmos para FPE

1967 Desarrollo de Técnicas de matrices ralas y factorización LU

W.F. Tinney and J.W. Walker "Direct Solutions of Sparse Network Equations by Optimally Ordered Triangular Factorization " IEEE Proc., Vol. 55, pp. 1801-1809, Nov. 1967.

Abstract—Matrix inversion is very inefficient for computing direct solutions of the large sparse systems of linear equations that arise in many network problems. Optimally ordered triangular factorization of sparse matrices is more efficient and offers other important computational advantages in some applications. With this method, direct solutions are computed from sparse matrix factors instead of from a full inverse matrix, thereby gaining a significant advantage in speed, computer memory requirements, and reduced round-off error. Improvements of ten to one or more in speed and problem size over present applications of the inverse can be achieved in many cases. Details of the method, numerical examples, and the results of a large problem are given.

Breve Historia de los algoritmos para FPE

1967 Aplicación de Técnicas de matrices ralas y factorización LU al método de Newton-Raphson

W.F. Tinney and C.E. Hart "Power Flow Solution by Newton's Method" IEEE Trans. PAS, Vol. 86, pp. 1449-1456, Nov. 1967.

Abstract—The ac power flow problem can be solved efficiently by Newton's method. Only five iterations, each equivalent to about seven of the widely used Gauss-Seidel method, are required for an exact solution. Problem dependent memory and time requirements vary approximately in direct proportion to problem size. Problems of 500 to 1000 nodes can be solved on computers with 32K core memory. The method, introduced in 1961, has been made practical by optimally ordered Gaussian elimination and special programming techniques. Equations, programming details, and examples of solutions of large problems are given.

Breve Historia de los algoritmos para FPE

1972 Desarrollo del método de Newton-Raphson desacoplado

B. Stott "Decoupled Newton Load Flow" IEEE Trans. PAS, Vol. 91, pp. 1955-1959, Sep./Oct. 1972

Abstract—In Newton load-flow solutions the mathematical decoupling of busbar-voltage angle and magnitude calculations has several computational and conceptual attractions. A hybrid Newton formulation exploiting this principle has been developed and well tested. For moderately-accurate solutions the method has advantages over the formal Newton approach in terms of computer storage and speed, particularly in adjusted solutions, and is at least as reliably convergent.

THE FORMAL NEWTON APPROACH

In conventional Newton methods the equations of load flow are written as a single set $F(X)=0$ and solved by the formal application of the generalised Newton (-Raphson) algorithm:

$$F(X^k) = - J(X^k) \cdot \Delta X^{k+1} \quad (1)$$

The most popular and successful formulation is that in which F is the set of busbar active and reactive power mismatches and the solution variables are the unknown busbar-voltage angles and magnitudes. In this polar power-mismatch version, (1) becomes

$$\begin{bmatrix} \Delta P^k \\ \Delta Q^k \end{bmatrix} = \begin{bmatrix} H^k & N^k \\ J^k & L^k \end{bmatrix} \cdot \begin{bmatrix} \Delta \theta^{k+1} \\ \Delta V^{k+1} \end{bmatrix} \quad (2)$$

Breve Historia de los algoritmos para FPE

1974 Desarrollo del método de Newton-Raphson desacoplado rápido

B. Stott and O. Alsac "Fast Decoupled Load Flow" IEEE Trans. PAS, Vol. 93, pp. 859-869, May./June 1974.

ABSTRACT

This paper describes a simple, very reliable and extremely fast load-flow solution method with a wide range of practical application. It is attractive for accurate or approximate off- and on-line routine and contingency calculations for networks of any size, and can be implemented efficiently on computers with restrictive core-store capacities. The method is a development on other recent work employing the MW- θ /MVAR-V decoupling principle, and its precise algorithmic form has been determined by extensive numerical studies. The paper gives details of the method's performance on a series of practical problems of up to 1080 buses. A solution to within 0.01 MW/MVAR maximum bus mismatches is normally obtained in 4 to 7 iterations, each iteration being equal in speed to $1\frac{1}{2}$ Gauss-Seidel iterations or $1/5$ th of a Newton iteration. Correlations of general interest between the power-mismatch convergence criterion and actual solution accuracy are obtained.

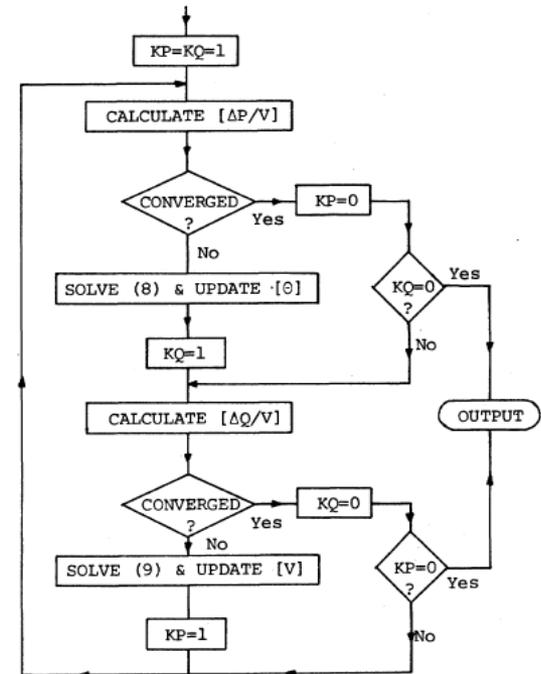
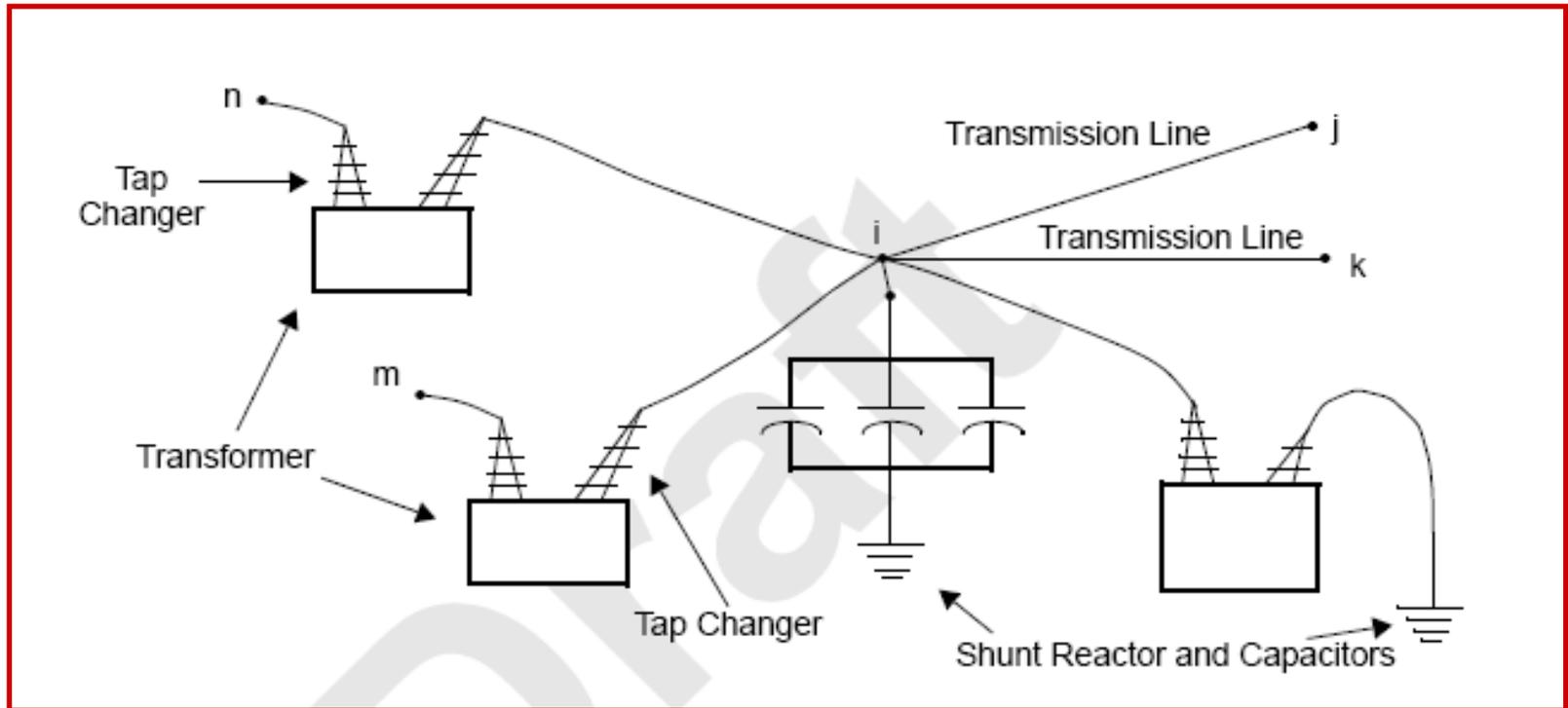


Fig. 1 Flow diagram of the iteration scheme

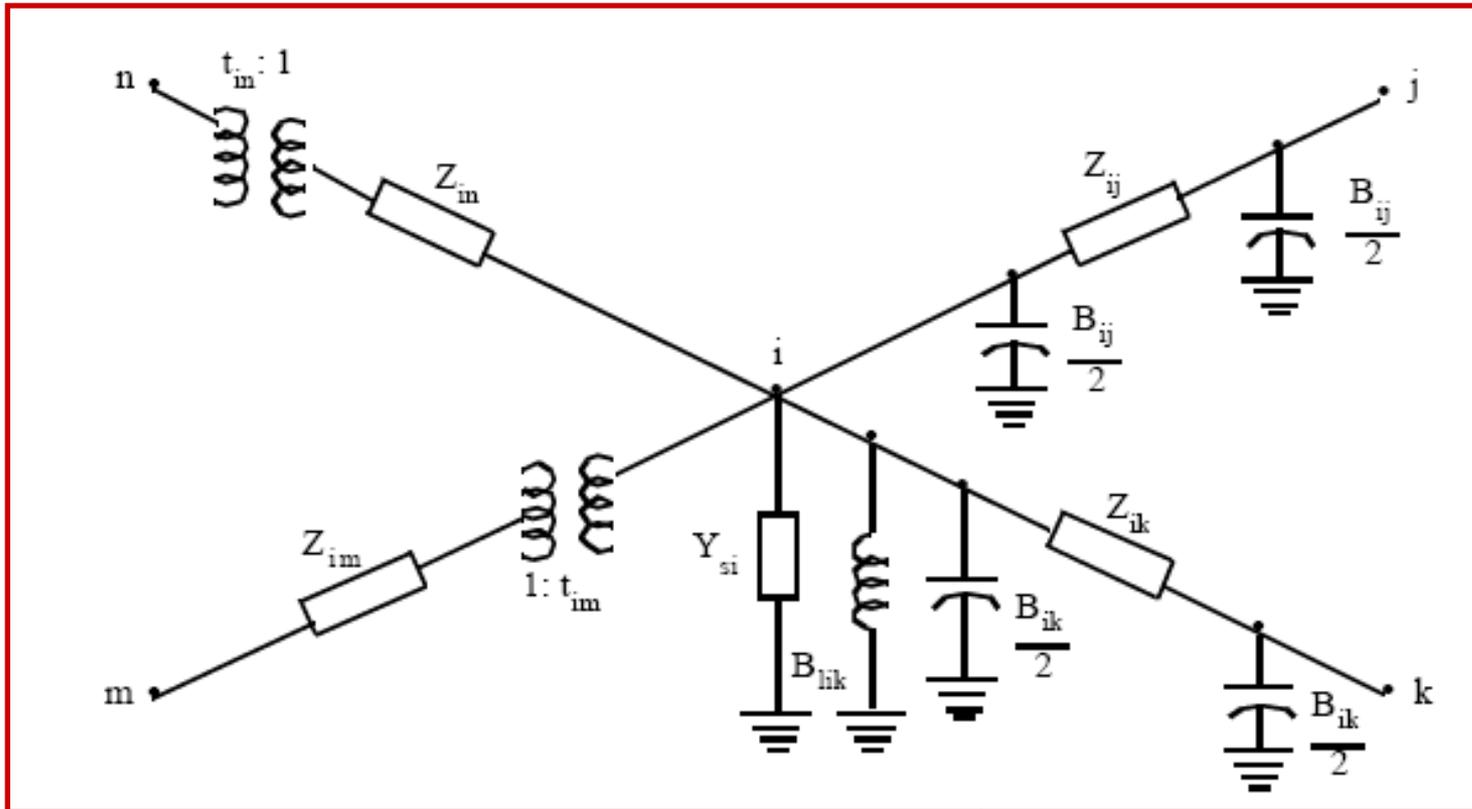
Breve Historia de los algoritmos para FPE

Matriz admitancia de barras



Equipamiento conectado a la barra i

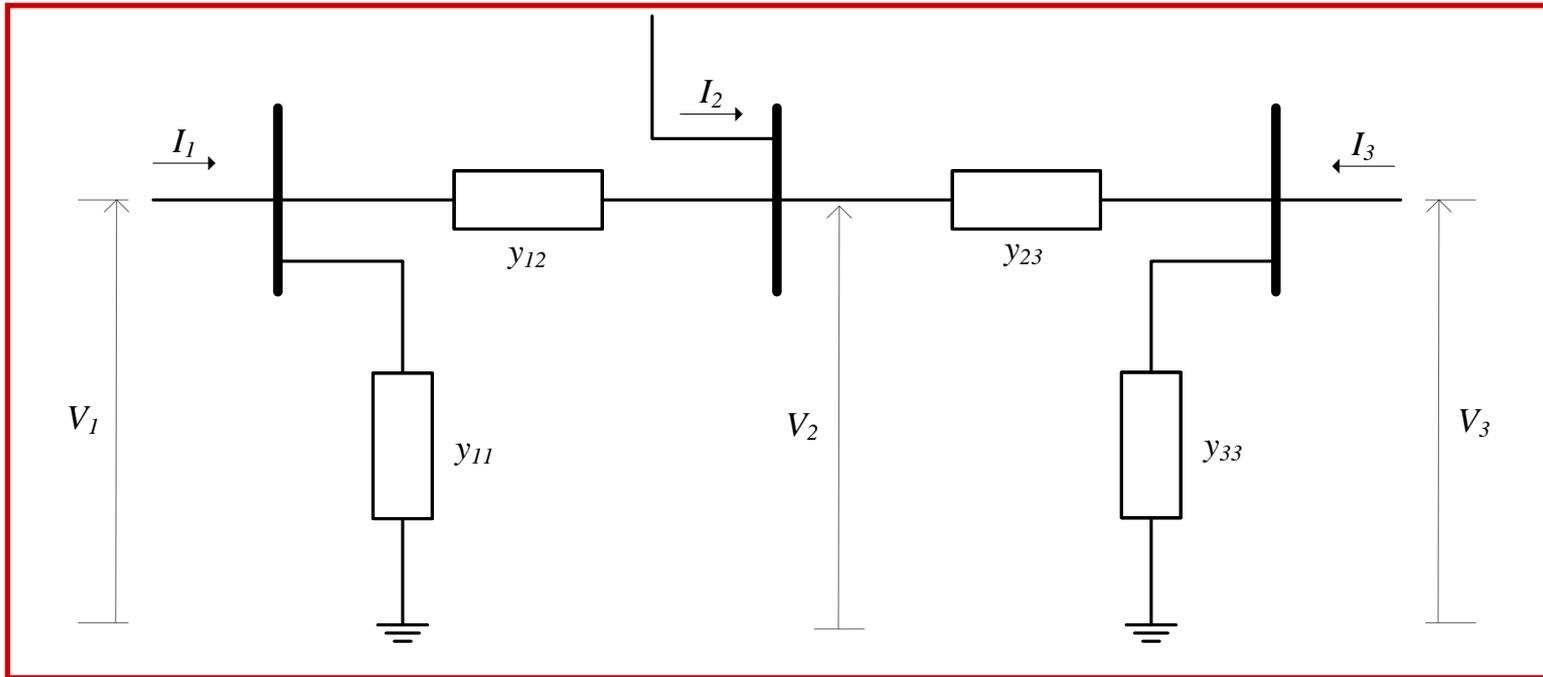
Matriz admitancia de barras



Circuito equivalente para la barra i del sistema de transmisión

Matriz admitancia de barras

El diagrama unifilar de la red:



Matriz admitancia de barras

La corriente a través de la admitancia y_{12} está dada por:

$$\mathbf{I}_{12} = \mathbf{y}_{12}(\mathbf{V}_1 - \mathbf{V}_2)$$

En forma genérica las corrientes serán:

$$\mathbf{I}_{ki} = \mathbf{y}_{ki}(\mathbf{V}_k - \mathbf{V}_i)$$

La sumatoria de las corrientes entrantes a un nodo debe ser igual a la sumatoria de las corrientes salientes, por lo tanto:

$$\mathbf{I}_k = \sum_{i=0}^n \mathbf{I}_{ki} = \sum_{i=0}^n \mathbf{y}_{ki}(\mathbf{V}_k - \mathbf{V}_i) \quad \longrightarrow \quad \mathbf{I} = \mathbf{YV}$$

Matriz admitancia de barras

En forma matricial:

$$\begin{bmatrix} \sum_{k=1, k \neq 1}^n \mathbf{y}_{1k} + \mathbf{y}_{11} & -\mathbf{y}_{12} & \dots & -\mathbf{y}_{1n} \\ -\mathbf{y}_{21} & \sum_{k=1, k \neq 2}^n \mathbf{y}_{2k} + \mathbf{y}_{22} & \dots & -\mathbf{y}_{2n} \\ \dots & \dots & \dots & \dots \\ -\mathbf{y}_{n1} & -\mathbf{y}_{n2} & \dots & \sum_{k=1, k \neq n}^n \mathbf{y}_{nk} + \mathbf{y}_{nn} \end{bmatrix}$$

y_{ii} : Suma de admitancias conectadas a la i -ésima barra.

y_{ik} : Negativo de la admitancia total directamente conectada entre la i -ésima y la k -ésima barra.

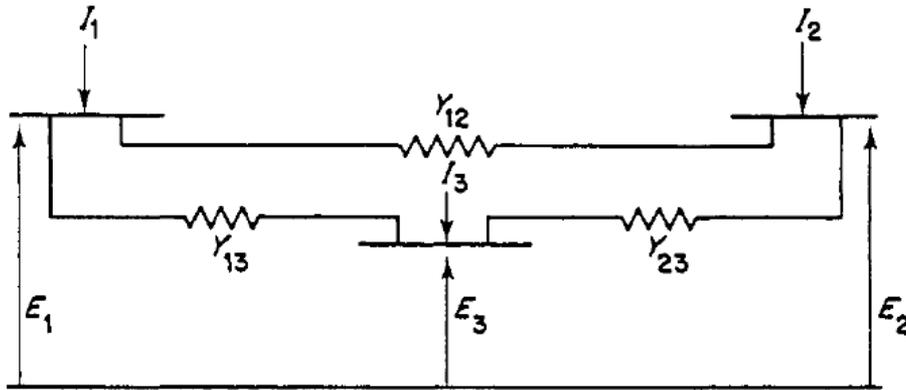
Matriz admitancia de barras

Propiedades de la matriz Y

- ✓ Cuadrada
- ✓ Simétrica
- ✓ A valores complejos
- ✓ Rala

Matriz admitancia de barras

Condicionamiento de la matriz Y

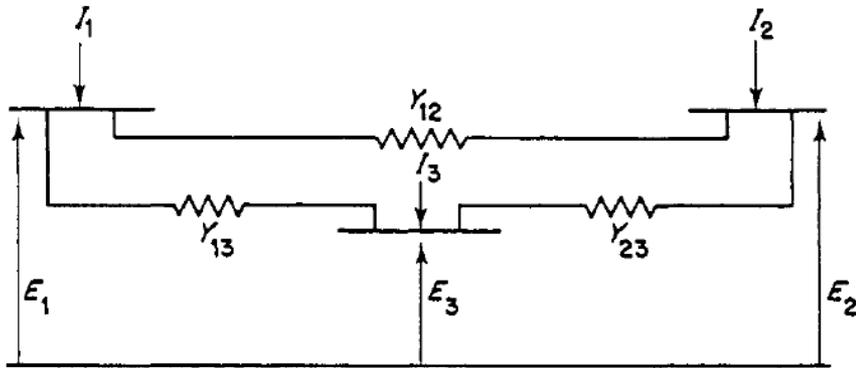


$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} y_{12} + y_{13} & -y_{12} & -y_{13} \\ -y_{12} & y_{12} + y_{23} & -y_{23} \\ -y_{13} & -y_{23} & y_{13} + y_{23} \end{bmatrix} \cdot \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

Supuesto conocidas las corrientes en cada barra, el sistema admite infinitas soluciones, dado que la matriz Y es singular (no es invertible).

Matriz admitancia de barras

Condicionamiento de la matriz Y



Si al menos una de las barras tiene una admitancia shunt (a tierra) el sistema de ecuaciones admite solución teóricamente, pero no necesariamente en la práctica. Los cálculos en computadora digital no pueden realizarse con precisión absoluta, y durante una secuencia de operaciones

aritméticas, los errores de redondeo debidos al hecho de trabajar con un número finito de decimales se acumulan. Si el problema (la matriz Y) está bien condicionado y el método numérico empleado para hallar la solución es adecuado, los errores de redondeo se mantienen pequeños y no enmascaran los resultados. Si el problema está mal condicionado, lo cual usualmente depende de las propiedades del sistema de potencia (parámetros y topología), cualquier error computacional se tornará excesivamente grande con respecto a la solución.

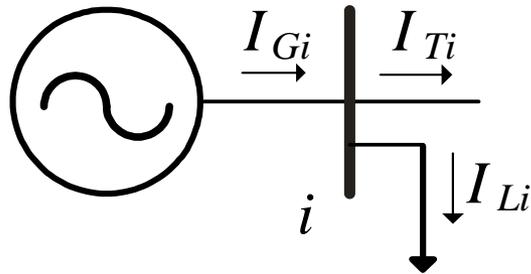
Matriz admitancia de barras

Condicionamiento de la matriz Y

Una red de transmisión con admitancias shunt muy pequeñas en comparación con las admitancias serie, probablemente esté mal condicionada y el condicionamiento tiende a mejorar con el aumento de las admitancias shunt, esto es, con la conexión eléctrica entre las barras y la tierra.

Formulación del problema del FPE

Corrientes en la barra i :



Tenemos que:

$$\mathbf{I}_{Gi} = \mathbf{I}_{Ti} + \mathbf{I}_{Li}$$

$$\mathbf{V}_i \mathbf{I}_{Gi}^* = \mathbf{V}_i \mathbf{I}_{Ti}^* + \mathbf{V}_i \mathbf{I}_{Li}^*$$

$$\mathbf{S}_{Gi} = \mathbf{S}_{Ti} + \mathbf{S}_{Li}$$

Formulación del problema del FPE

Cada una de estas potencias se pueden expresar de la siguiente manera:

$$S_{Gi} = P_{Gi} + jQ_{Gi}$$

$$S_{Ti} = P_{Ti} + jQ_{Ti}$$

$$S_{Li} = P_{Li} + jQ_{Li}$$

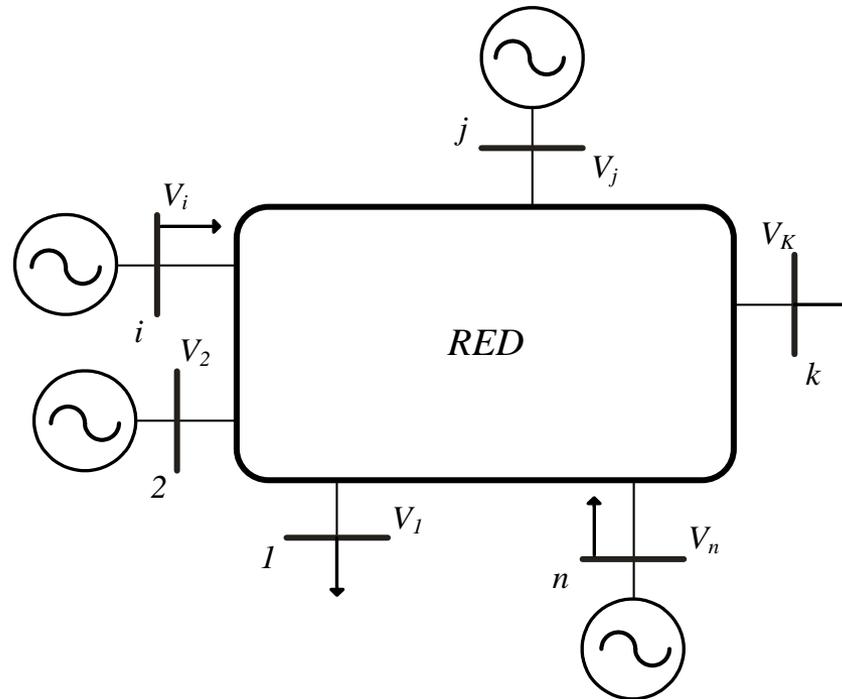
También se puede escribir lo siguiente:

$$P_{Gi} = P_{Ti} + P_{Li}$$

$$Q_{Gi} = Q_{Ti} + Q_{Li}$$

Formulación del problema del FPE

Sistema eléctrico de n barras:



$$\mathbf{I}_{Ti} = \mathbf{y}_{i1} \mathbf{V}_1 + \mathbf{y}_{i2} \mathbf{V}_2 + \dots + \mathbf{y}_{ii} \mathbf{V}_i + \mathbf{y}_{ij} \mathbf{V}_j + \dots + \mathbf{y}_{in} \mathbf{V}_n$$

Formulación del problema del FPE

$$I_{Ti} = \sum_{j=1}^n y_{ij} V_j \left| \underline{\delta_j + \gamma_{ij}} \right.$$

I_{Ti} : Corriente de la barra i que ingresa a la red.

V_j : Tensión de la barra j .

y_{ij} : Elemento i - j de la matriz de admitancia de barras.

δ_j : Ángulo de la tensión de la barra j .

γ_{ij} : Ángulo del elemento i - j de la matriz de admitancia de barras.

$$\bar{\mathbf{I}}_T = [\mathbf{Y}] \bar{\mathbf{V}}$$

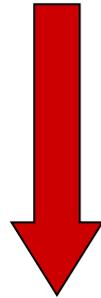
I_T : Vector de corrientes que ingresan a la red.

V : Vector de tensiones de las barras del sistema eléctrico.

Y : Matriz de admitancia de barras.

Formulación del problema del FPE

$$S_{Ti} = V_i I_{Ti}^* = \sum_{j=1}^n V_i y_{ij} V_j \left| \underline{\delta_i - \delta_j - \gamma_{ij}} \right.$$



$$\left\{ \begin{array}{l} P_{Ti} = \sum_{j=1}^n V_i y_{ij} V_j \cos(\delta_i - \delta_j - \gamma_{ij}) \\ Q_{Ti} = \sum_{j=1}^n V_i y_{ij} V_j \text{sen}(\delta_i - \delta_j - \gamma_{ij}) \end{array} \right.$$

Formulación del problema del FPE

$$\left\{ \begin{array}{l} P_{Gi} = P_{Li} + \sum_{j=1}^n V_i y_{ij} V_j \cos(\delta_i - \delta_j - \gamma_{ij}) \\ Q_{Gi} = Q_{Li} + \sum_{j=1}^n V_i y_{ij} V_j \text{sen}(\delta_i - \delta_j - \gamma_{ij}) \end{array} \right.$$

Parámetros de la
red de transmisión



y_{ij}, γ_{ij}

Variables del
problema



$P_{Gi}, Q_{Gi}, P_{Li}, Q_{Li}, V_i, \delta_i$

Formulación del problema del FPE

Tipos de barras

- Tipo 1: barra de carga (barra PQ)
- Tipo 2: barra de generación (barra PV)
- Tipo 3: barra de referencia (barra “slack” , barra “swing ”)

Formulación del problema del FPE

□ Variables de control

- Barra Tipo 1 : (PQ) P - Q son datos
- Barra Tipo 2 : (PV) P - V son datos
- Barra Tipo 3 : (referencia) V dato, $\delta = 0$

□ Variables de estado

- Barra Tipo 1 : V - δ
- Barra Tipo 2 : Q_G - δ
- Barra Tipo 3 : P_G - Q_G

Formulación del problema del FPE

Tipo de Barra	P_G	Q_G	P_L	Q_L	V	δ
<i>Carga</i>	0	0	Dato	Dato	?	?
<i>Generación</i>	Fijada	?	Dato	Dato	Fijada	?
<i>Referencia</i>	?	?	Dato	Dato	Fijada	0

Métodos Numéricos

- Gauss
- Gauss-Seidel
- Newton – Raphson
- Descomposición LU

Gauss

$$I = YV$$

$$I_i = y_{ii}V_i + \sum_{j, j \neq i} y_{ij}V_j$$

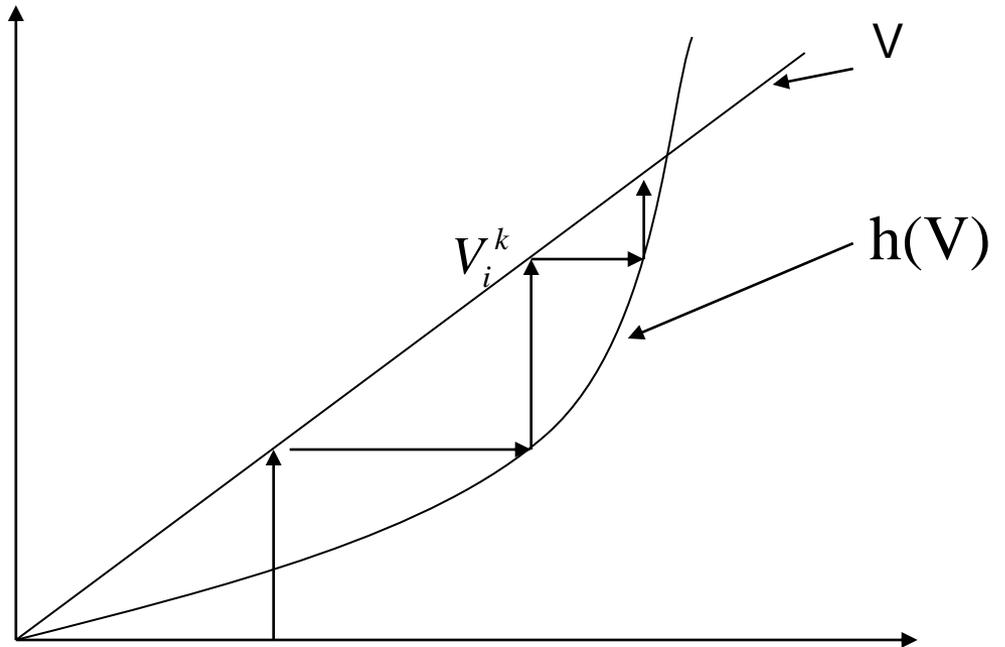
$$V_i = \frac{1}{y_{ii}} \left(I_i - \sum_{j, j \neq i} y_{ij}V_j \right)$$

$$V_i = \frac{1}{y_{ii}} \left(\frac{S_i^*}{V_i^*} - \sum_{j, j \neq i} y_{ij}V_j \right)$$

Gauss

$$V_i^{k+1} = h(V_i^k)$$

$$V_i^{k+1} = \frac{1}{y_{ii}} \left(\left(\frac{S_i}{V_i^k} \right)^* - \sum_{j, j \neq i} y_{ij} V_j^k \right)$$



Gauss

1. Asignar un perfil plano de tensiones inicial
 - $V=1$ p.u. , ángulo = 0
2. Calcular nuevo perfil de tensiones
3. Si la diferencia de tensiones $>$ error, volver al paso 2, caso contrario, salir del ciclo
4. Calcular pérdidas y flujos en cada línea

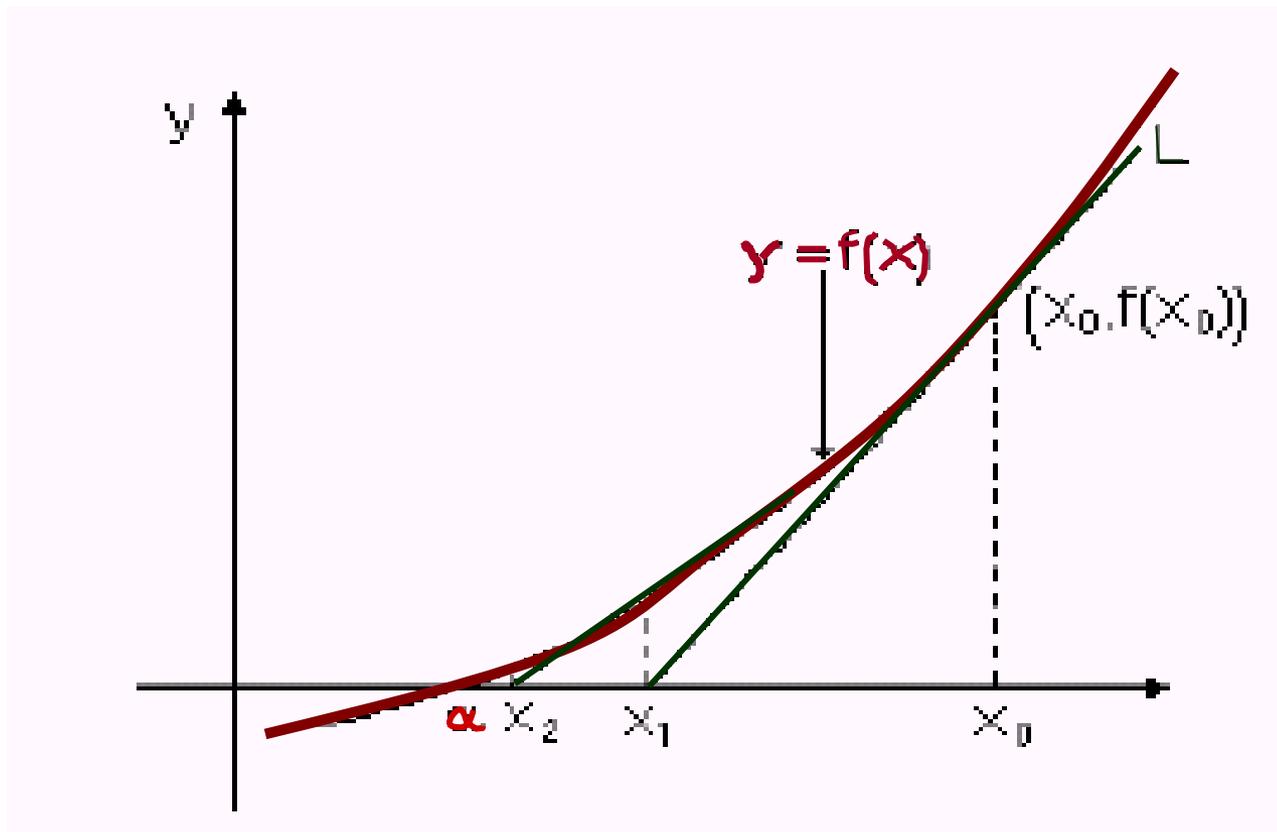
Gauss-Seidel

- Modificación del Método de Gauss
- Utiliza los cálculos ya realizados en el paso $k+1$

$$V_i^{k+1} = \frac{1}{y_{ii}} \left(\left(\frac{S_i}{V_i^k} \right)^* - \sum_{j \leq i} y_{ij} V_j^{k+1} - \sum_{j > i} y_{ij} V_j^k \right)$$

Newton – Raphson

- ✓ Trata con todas las barras simultáneamente
- ✓ Calcula los ceros de una función no lineal: $f(x) = 0$



Newton – Raphson

$$f(\mathbf{x}) \cong f(\mathbf{x}_k) + \mathbf{J}(\mathbf{x}_k)(\mathbf{x} - \mathbf{x}_k) = 0$$

$$\mathbf{J}(\mathbf{x}_k)\Delta\mathbf{x}_k = -f(\mathbf{x}_k)$$

Matriz Jacobiana: $\mathbf{J}(\mathbf{x}_k) = \begin{bmatrix} \frac{\partial f_1(\mathbf{x}_k)}{\partial x_1} & \dots & \frac{\partial f_1(\mathbf{x}_k)}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_n(\mathbf{x}_k)}{\partial x_1} & \dots & \frac{\partial f_n(\mathbf{x}_k)}{\partial x_n} \end{bmatrix}$

Newton – Raphson

$$\left\{ \begin{array}{l} \mathbf{P}_{Ti} = \sum_{j=1}^n V_i y_{ij} V_j \cos(\delta_i - \delta_j - \gamma_{ij}) \\ \mathbf{Q}_{Ti} = \sum_{j=1}^n V_i y_{ij} V_j \text{sen}(\delta_i - \delta_j - \gamma_{ij}) \end{array} \right.$$

$$\bar{\mathbf{P}}_G - \bar{\mathbf{P}}_L - \bar{\mathbf{P}}_T(\bar{\boldsymbol{\delta}}, \bar{\mathbf{V}}) = \bar{\mathbf{0}}$$

$$\bar{\mathbf{Q}}_G - \bar{\mathbf{Q}}_L - \bar{\mathbf{Q}}_T(\bar{\boldsymbol{\delta}}, \bar{\mathbf{V}}) = \bar{\mathbf{0}}$$

Newton – Raphson

$$\overline{\Delta P}_T = \overline{P}_T(\overline{\delta}, \overline{V}) - \overline{P}_T(\overline{\delta}_0, \overline{V}_0)$$

$$\overline{\Delta Q}_T = \overline{Q}_T(\overline{\delta}, \overline{V}) - \overline{Q}_T(\overline{\delta}_0, \overline{V}_0)$$

$$\overline{\Delta \delta} = \overline{\delta} - \overline{\delta}_0$$

$$\overline{\Delta V} = \overline{V} - \overline{V}_0$$

Newton – Raphson

$$\begin{cases} \overline{\Delta P}_T = \frac{\partial \overline{P}_T}{\partial \overline{\delta}} \overline{\Delta \delta} + \frac{\partial \overline{P}_T}{\partial \overline{V}} \overline{\Delta V} \\ \overline{\Delta Q}_T = \frac{\partial \overline{Q}_T}{\partial \overline{\delta}} \overline{\Delta \delta} + \frac{\partial \overline{Q}_T}{\partial \overline{V}} \overline{\Delta V} \end{cases}$$

$$\underbrace{\begin{bmatrix} \frac{\partial \overline{P}_T}{\partial \overline{\delta}} & \frac{\partial \overline{P}_T}{\partial \overline{V}} \\ \frac{\partial \overline{Q}_T}{\partial \overline{\delta}} & \frac{\partial \overline{Q}_T}{\partial \overline{V}} \end{bmatrix}}_J \begin{bmatrix} \overline{\Delta \delta} \\ \overline{\Delta V} \end{bmatrix} = \begin{bmatrix} \overline{\Delta P}_T \\ \overline{\Delta Q}_T \end{bmatrix}$$

Cada una de las submatrices del Jacobiano hereda de la matriz de admitancias de barras su condición de matriz rara

Newton – Raphson

$$\frac{\partial P_{Ti}}{\partial \delta_j} = V_i V_j Y_{ij} \text{sen}(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial P_{Ti}}{\partial \delta_i} = - \sum_{\substack{j=1 \\ j \neq i}}^n V_i V_j Y_{ij} \text{sen}(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial P_{Ti}}{\partial V_j} = V_i Y_{ij} \text{cos}(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial P_{Ti}}{\partial V_i} = V_i Y_{ii} \text{cos}(\gamma_{ii}) + \sum_{j=1}^n V_j Y_{ij} \text{cos}(\delta_i - \delta_j - \gamma_{ij})$$

Newton – Raphson

$$\frac{\partial Q_{Ti}}{\partial \delta_j} = -V_i V_j Y_{ij} \cos(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial Q_{Ti}}{\partial \delta_i} = \sum_{\substack{j=1 \\ j \neq i}}^n V_i V_j Y_{ij} \cos(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial Q_{Ti}}{\partial V_j} = V_i Y_{ij} \sin(\delta_i - \delta_j - \gamma_{ij})$$

$$\frac{\partial Q_{Ti}}{\partial V_i} = V_i Y_{ii} \sin(-\gamma_{ii}) + \sum_{j=1}^n V_j Y_{ij} \sin(\delta_i - \delta_j - \gamma_{ij})$$

Newton – Raphson

$$\overline{\delta}^{k+1} = \overline{\delta}^k + \Delta \overline{\delta}^{k+1}$$

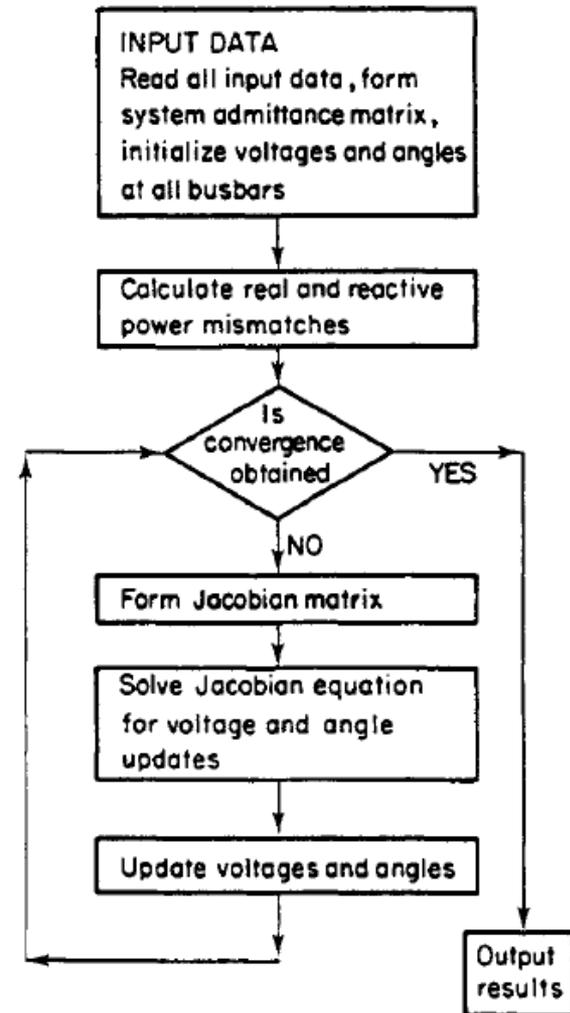
$$\overline{V}^{k+1} = \overline{V}^k + \Delta \overline{V}^{k+1}$$

$$Q_{Gi} = Q_{Li} + \sum_{j=1}^n V_i y_{ij} V_j \text{sen}(\delta_i - \delta_j - \gamma_{ij})$$

$$Q_{Gi}^{\text{Min}} \leq Q_{Gi} \leq Q_{Gi}^{\text{Max}}$$

Newton – Raphson

1. Asignar un perfil de tensiones inicial
 - $V=1$ p.u., ángulo = 0
2. Calcular el nuevo perfil de tensiones
3. Si $\max \Delta P > \text{error}$ ó $\max \Delta Q > \text{error}$ volver a paso 2
4. Calcular flujos en líneas y pérdidas



Algoritmos para la solución del FPE

- Completo (flujo AC)
- Desacoplado
- Desacoplado rápido
- Lineal (flujo DC)

Flujo desacoplado

Una característica inherente de cualquier sistema de transmisión en alta tensión real operando en una condición de régimen permanente es la fuerte interdependencia entre el flujo de potencia activa y los ángulos de fase de las tensiones de barras, y entre el flujo de potencia reactiva y el módulo de las tensiones de barras.

Correspondientemente, el acoplamiento entre los lazos $P - \delta$, y $Q - V$ es relativamente débil.

Flujo desacoplado

$$\frac{\partial Q_i}{\partial V_k} \gg \frac{\partial P_i}{\partial V_k} \quad \longrightarrow \quad \frac{\partial P_i}{\partial V_k} \approx 0$$

$$\frac{\partial P_i}{\partial \delta_k} \gg \frac{\partial Q_i}{\partial \delta_k} \quad \longrightarrow \quad \frac{\partial Q_i}{\partial \delta_k} \approx 0$$

$$\begin{bmatrix} \frac{\partial \bar{P}_T}{\partial \bar{\delta}} & \frac{\partial \bar{P}_T}{\partial \bar{V}} \\ \frac{\partial \bar{Q}_T}{\partial \bar{\delta}} & \frac{\partial \bar{Q}_T}{\partial \bar{V}} \end{bmatrix} \quad \longrightarrow \quad \begin{bmatrix} \frac{\partial \bar{P}_T}{\partial \bar{\delta}} & 0 \\ 0 & \frac{\partial \bar{Q}_T}{\partial \bar{V}} \end{bmatrix}$$

Flujo desacoplado

$$\begin{bmatrix} \frac{\partial \bar{P}_T}{\partial \bar{\delta}} & 0 \\ 0 & \frac{\partial \bar{Q}_T}{\partial \bar{V}} \end{bmatrix} \begin{bmatrix} \bar{\Delta \delta} \\ \bar{\Delta V} \end{bmatrix} = \begin{bmatrix} \bar{\Delta P}_T \\ \bar{\Delta Q}_T \end{bmatrix}$$

Flujo de potencia activa



$$\begin{bmatrix} \frac{\partial \bar{P}_T}{\partial \bar{\delta}} \end{bmatrix} \begin{bmatrix} \bar{\Delta \delta} \end{bmatrix} = \begin{bmatrix} \bar{\Delta P}_T \end{bmatrix}$$

Flujo de potencia reactiva



$$\begin{bmatrix} \frac{\partial \bar{Q}_T}{\partial \bar{V}} \end{bmatrix} \begin{bmatrix} \bar{\Delta V} \end{bmatrix} = \begin{bmatrix} \bar{\Delta Q}_T \end{bmatrix}$$

Flujo desacoplado

$$\left[\frac{\partial \bar{P}_T}{\partial \bar{\delta}} \right]$$

$$\begin{aligned} \frac{\partial P_{Ti}}{\partial \delta_j} &= V_i V_j Y_{ij} \operatorname{sen}(\delta_i - \delta_j - \gamma_{ij}) = V_i V_j Y_{ij} \{ \operatorname{sen}(\delta_i - \delta_j) \cos(\gamma_{ij}) - \cos(\delta_i - \delta_j) \operatorname{sen}(\gamma_{ij}) \} = \\ &= V_i V_j \{ G_{ij} \operatorname{sen}(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j) \}; \quad \text{para } i \neq j \end{aligned}$$

$$\frac{\partial P_{Ti}}{\partial \delta_i} = - \sum_{\substack{j=1 \\ j \neq i}}^n V_i V_j Y_{ij} \operatorname{sen}(\delta_i - \delta_j - \gamma_{ij}) = -(Q_{Gi} - Q_{Li}) - V_i^2 B_{ii}$$

$$Q_{Gi} = Q_{Li} + \sum_{j=1}^n V_i y_{ij} V_j \operatorname{sen}(\delta_i - \delta_j - \gamma_{ij})$$

Flujo desacoplado

$$\left[\frac{\partial \bar{Q}_T}{\partial \bar{V}} \right]$$

$$\begin{aligned} \frac{\partial Q_{Ti}}{\partial V_j} &= V_i Y_{ij} \text{sen}(\delta_i - \delta_j - \gamma_{ij}) = \frac{V_i V_j Y_{ij}}{V_j} \text{sen}(\delta_i - \delta_j - \gamma_{ij}) = \\ &= \frac{V_i V_j}{V_j} \{G_{ij} \text{sen}(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)\}; \quad \text{para } i \neq j \end{aligned}$$

$$\begin{aligned} \frac{\partial Q_{Ti}}{\partial V_i} &= V_i Y_{ii} \text{sen}(-\gamma_{ii}) + \sum_{j=1}^n V_j Y_{ij} \text{sen}(\delta_i - \delta_j - \gamma_{ij}) = \\ &= -B_{ii} \frac{V_i^2}{V_i} + \frac{(Q_{Gi} - Q_{Li})}{V_i} \end{aligned}$$

Flujo desacoplado

Flujo de potencia activa

$$\left[\frac{\partial \bar{P}_T}{\partial \bar{\delta}} \right] \left[\overline{\Delta \delta} \right] = \left[\overline{\Delta P}_T \right]$$

$$\frac{\partial P_{Ti}}{\partial \delta_j} = \frac{\partial Q_{Ti}}{\partial V_j}; \quad \text{para } i \neq j$$

Flujo de potencia reactiva

$$\left[\frac{\partial \bar{Q}_T}{\partial \bar{V}} \right] \left[\frac{\overline{\Delta V}}{\bar{V}} \right] = \left[\overline{\Delta Q}_T \right]$$

$$\frac{\partial P_{Ti}}{\partial \delta_i} = -B_{ii} V_i^2 - (Q_{Gi} - Q_{Li})$$

$$\frac{\partial Q_{Ti}}{\partial V_i} = -B_{ii} V_i^2 + (Q_{Gi} - Q_{Li})$$

Flujo desacoplado rápido

Posteriores simplificaciones al Flujo de Potencia desacoplado, basadas en propiedades físicas de los sistemas de transmisión en alta tensión reales, hacen que los Jacobianos sean constantes.

$$\delta_i - \delta_j \approx 0$$



$$\cos(\delta_i - \delta_j) \approx 1$$

$$\text{sen}(\delta_i - \delta_j) \approx 0$$



$$G_{ij} \text{sen}(\delta_i - \delta_j) \ll B_{ij} \cos(\delta_i - \delta_j)$$



$$\frac{\partial P_{Ti}}{\partial \delta_j} = \frac{\partial Q_{Ti}}{\partial V_j} \cong V_i V_j (-B_{ij}) \quad \text{para } i \neq j$$

Flujo desacoplado rápido

$$(Q_{Gi} - Q_{Li}) = Q_{Ti} \ll V_i^2 B_{ii}$$



$$\frac{\partial P_i}{\partial \delta_i} = -Q_{Ti} - B_{ii} V_i^2 \cong -B_{ii} V_i^2$$

$$\frac{\partial Q_i}{\partial V_i} = Q_{Ti} - B_{ii} V_i^2 \cong -B_{ii} V_i^2$$

Flujo desacoplado rápido

Flujo de potencia activa



$$\left[\overline{\mathbf{V}} \mathbf{B}' \overline{\mathbf{V}} \right] \left[\overline{\Delta \delta} \right] = \left[\overline{\Delta P_T} \right]$$

Flujo de potencia reactiva



$$\left[\overline{\mathbf{V}} \mathbf{B}'' \overline{\mathbf{V}} \right] \left[\frac{\overline{\Delta \mathbf{V}}}{\overline{\mathbf{V}}} \right] = \left[\overline{\Delta Q_T} \right]$$

Flujo desacoplado rápido

$$r_{ik} \ll X_{ik}$$

Omitimos el equipamiento que afecta el flujo de potencia reactiva



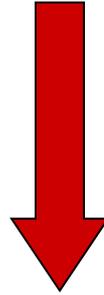
$$[B'] [\overline{\Delta\delta}] = \left[\frac{\overline{\Delta P_T}}{\overline{V}} \right]$$

$$b'_{ik} = \frac{1}{X_{ik}}$$

$$b'_{ii} = \sum_k \frac{1}{X_{ik}}$$

Flujo desacoplado rápido

Omitimos el equipamiento que afecta el flujo de potencia activa



$$[B''] [\overline{\Delta V}] = \left[\frac{\overline{\Delta Q_T}}{\overline{V}} \right]$$

$$b''_{ik} = \frac{X_{ik}}{r_{ik}^2 + X_{ik}^2}$$

$$b''_{ii} = \sum_k \frac{X_{ik}}{r_{ik}^2 + X_{ik}^2}$$

Flujo desacoplado rápido

Flujo de potencia activa



$$[B'] [\overline{\Delta\delta}] = \left[\frac{\overline{\Delta P_T}}{\overline{V}} \right]$$

Flujo de potencia reactiva



$$[B''] [\overline{\Delta V}] = \left[\frac{\overline{\Delta Q_T}}{\overline{V}} \right]$$

Flujo desacoplado rápido

El método originalmente propuesto por:

✓ *B. Stott and O. Alsac "Fast Decoupled Load Flow " IEEE Trans. PAS, Vol. 93, pp. 859-869, May./June 1974.*

despreciando los efectos de la resistencia serie en B' se denomina **esquema XB**.

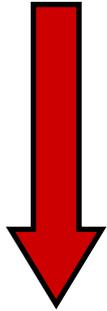
El método propuesto posteriormente por:

✓ *R. Van Amerongen "A General-Purpose Version of the Fast Decoupled Load Flow " IEEE Trans., Vol. PWRS-4, pp. 760-770, May. 1989.*

despreciando los efectos de la resistencia serie en B'' se denomina **esquema BX**.

Flujo lineal (Flujo DC)

Resistencias = 0; y omitimos el flujo de potencia reactiva
($V=1$)



$$[B'] [\overline{\Delta\delta}] = [\overline{\Delta P_T}]$$

$$P_{ij} = \frac{1}{X_{ij}} (\delta_i - \delta_j)$$

Comparación

□ Gauss-Seidel

- Tolerante a errores en los datos
- Fácil de detectar áreas que causan problemas
- Número de iteraciones se incrementa con tamaño de la red
- Muy útil cuando el perfil inicial es desconocido

Comparación

□ Newton – Raphson

- Converge cuadráticamente si las funciones son continuamente diferenciables, la matriz J no singular y la aproximación inicial esta cerca de la solución.
- No tolera errores en los datos
- Los valores iniciales de perfiles de tensión deben ser próximos a la solución
- Número de operaciones del orden de $n^3/3$ por iteración

Comparación

□ Newton-Raphson desacoplado.

- Disminuye el tiempo de cálculo a una cuarta parte del tiempo requerido para el Newton-Raphson completo.

$$\frac{2 \frac{(n/2)^3}{3}}{n^3/3} = \frac{1}{4}$$

- No presenta grandes diferencias de convergencia con respecto al Newton-Raphson completo.
- Las ventajas del método se producen a costa de una pérdida de precisión en los resultados pero generalmente la diferencia es muy pequeña.

Comparación

- Newton-Raphson desacoplado rápido.
 - Simplificaciones al flujo desacoplado originadas fundamentalmente en las características de la red de transmisión en alta tensión.
 - Disminuye notoriamente los tiempos de cálculo (Jacobiano constante).

Ejemplos de aplicación utilizando ETAP®12.5

ETAP 12.5.0 - [OLV1 (Edit Mode)]

File Edit View Project Library Rules Defaults Tools RevControl Real-Time Window Help

Base OLV1 OLV1 Normal

Análisis de FPE

U1 1000 MVA_{asc}

Bus1 34.5 kv CB1

T1 30 MVA 7 %Z

Bus2 13.8 kv

CAP1 1000 kvar

T2 15 MVA 6.5 %Z

Bus3 13.8 kv CB5

Cable1

Gen1 10 MW

Bus4 4.16 kv

Syn1 3000 HP

Mtr1 4x700 HP

CB2

Z1

Bus5 4.16 kv

Bus6 4.16 kv

Load1 3 MVA

Open

Mtr2 600 kW

Bus3 13.8 kv

Bus10 13.8 kv

T3 5 MVA 6.5 %Z

Bus3

Z1

Lump2 5 MVA

Network1

T4 3 MVA 5.75 %Z

Bus8 0.48 kv

Base

X: 110 Y: 201

06:43 p.m. 08/02/2014

Ejemplos de aplicación utilizando ETAP®12.5

Editor Caso de Estudio

Load Flow Study Case

Info Loading Adjustment Alert

Study Case ID
LF

Method
 Adaptive Newton-Raphson
 Newton-Raphson
 Fast-Decoupled
 Accelerated Gauss-Seidel

Max. Iteration 99
Precision 0,0001

Report
Rated Voltage kV
Operating Voltage %
Power MVA

Equipment Cable
 Exclude Load Diversity Factor

Options
Initial Voltage
 Bus Initial Voltages
 User-Defined
 Apply Transformer Phase Shift

Update
 Initial Bus Voltages
 Cable Load Amp
 Operating Load & V
 Inverter Operating Load
 Transformer LTCs

Study Remarks

LF Help OK Cancel

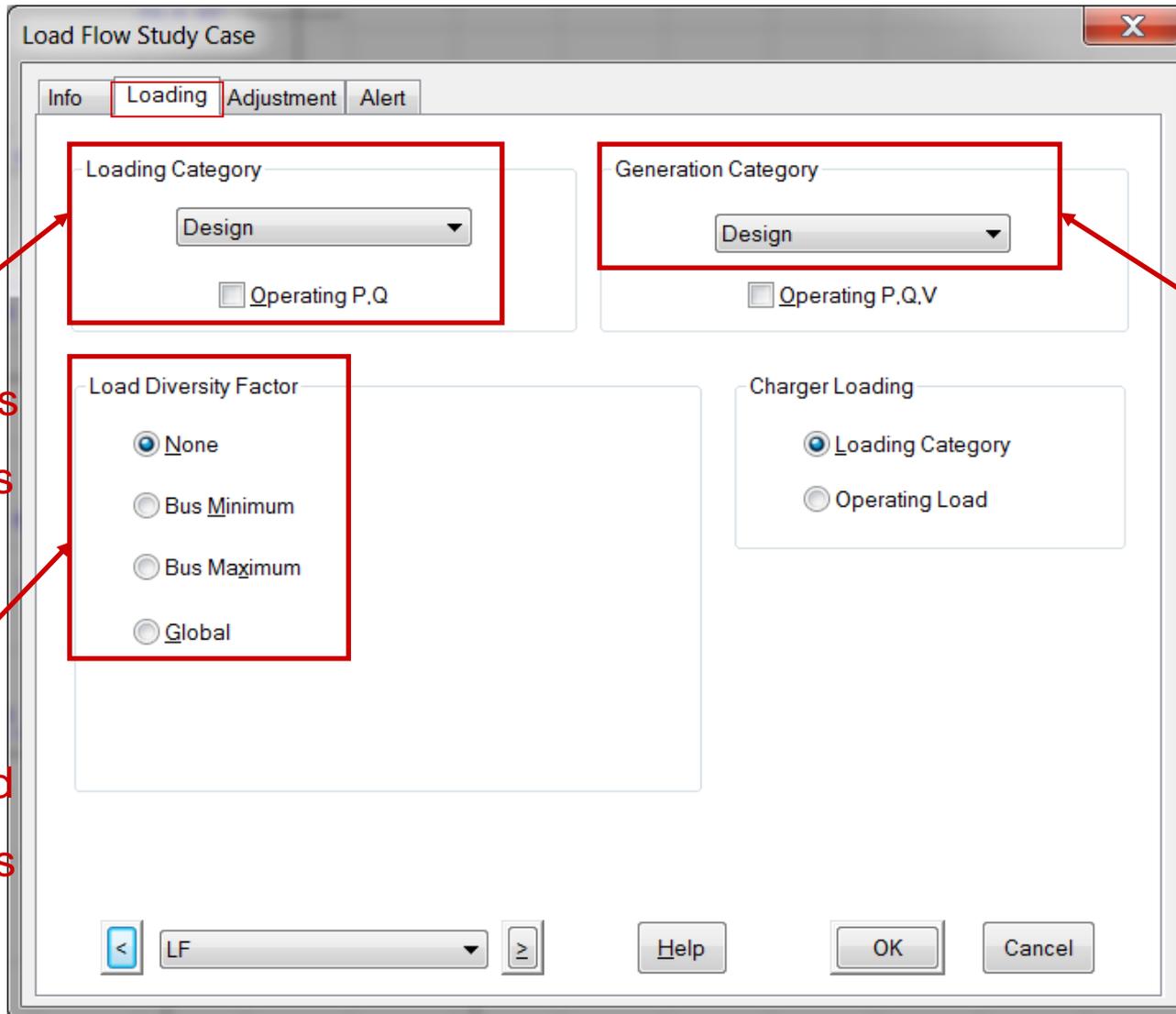
Ejemplos de aplicación utilizando ETAP®12.5

The screenshot shows the 'Load Flow Study Case' dialog box in ETAP 12.5. The 'Info' tab is selected. The 'Study Case ID' is 'LF'. The 'Method' section is highlighted with a red box, showing 'Newton-Raphson' selected. The 'Max. Iteration' is set to 99 and 'Precision' is 0.0001, also highlighted with a red box. A red arrow points from the text 'Algoritmo para resolver un FPE' to the 'Method' section. Another red arrow points from the text '“Cierre” del algoritmo iterativo FPE' to the 'Max. Iteration' and 'Precision' fields.

Algoritmo para resolver un FPE

“Cierre” del algoritmo iterativo FPE

Ejemplos de aplicación utilizando ETAP®12.5

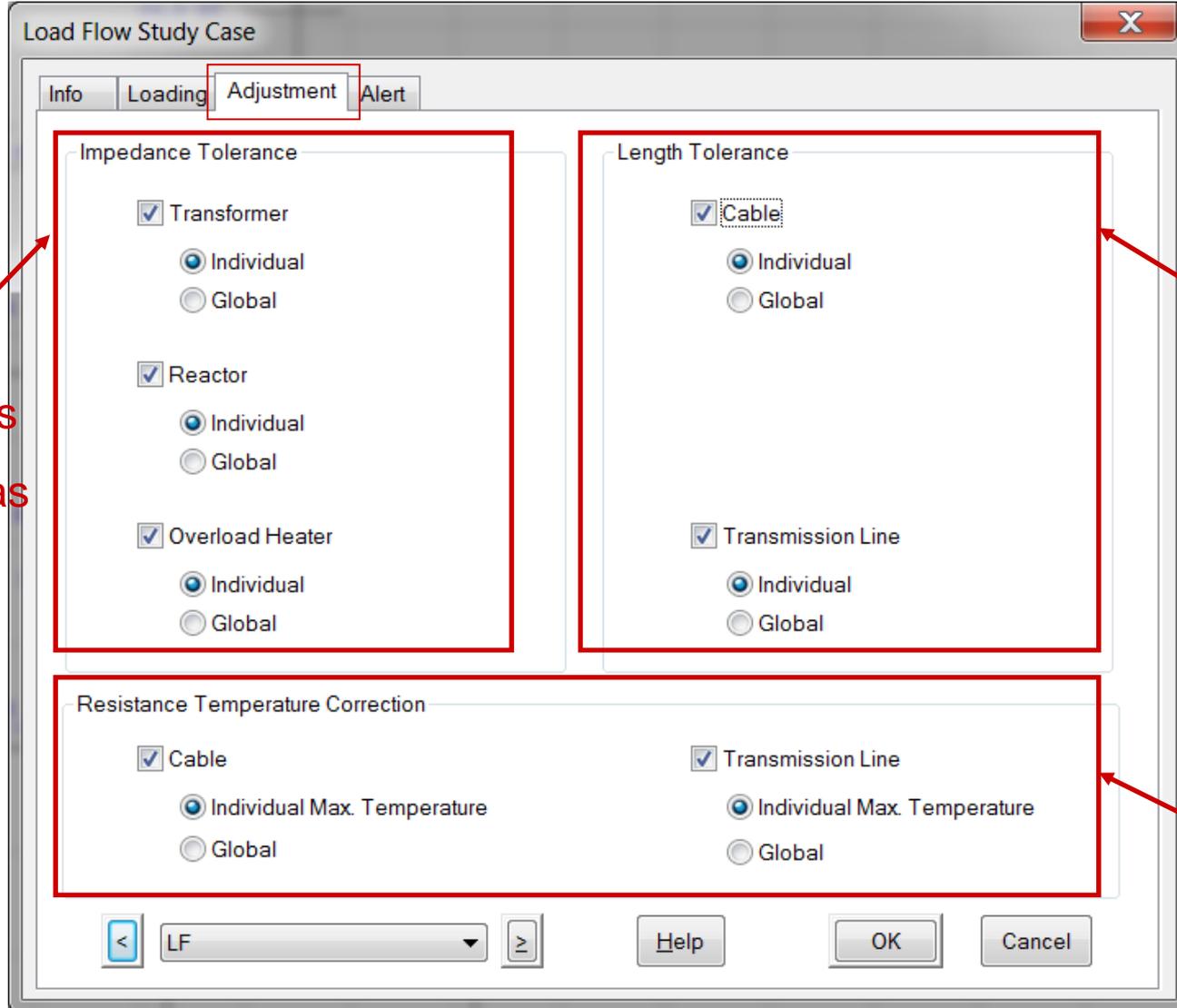


Categorías
demandas

Factor
diversidad
demandas

Categorías
generación

Ejemplos de aplicación utilizando ETAP®12.5

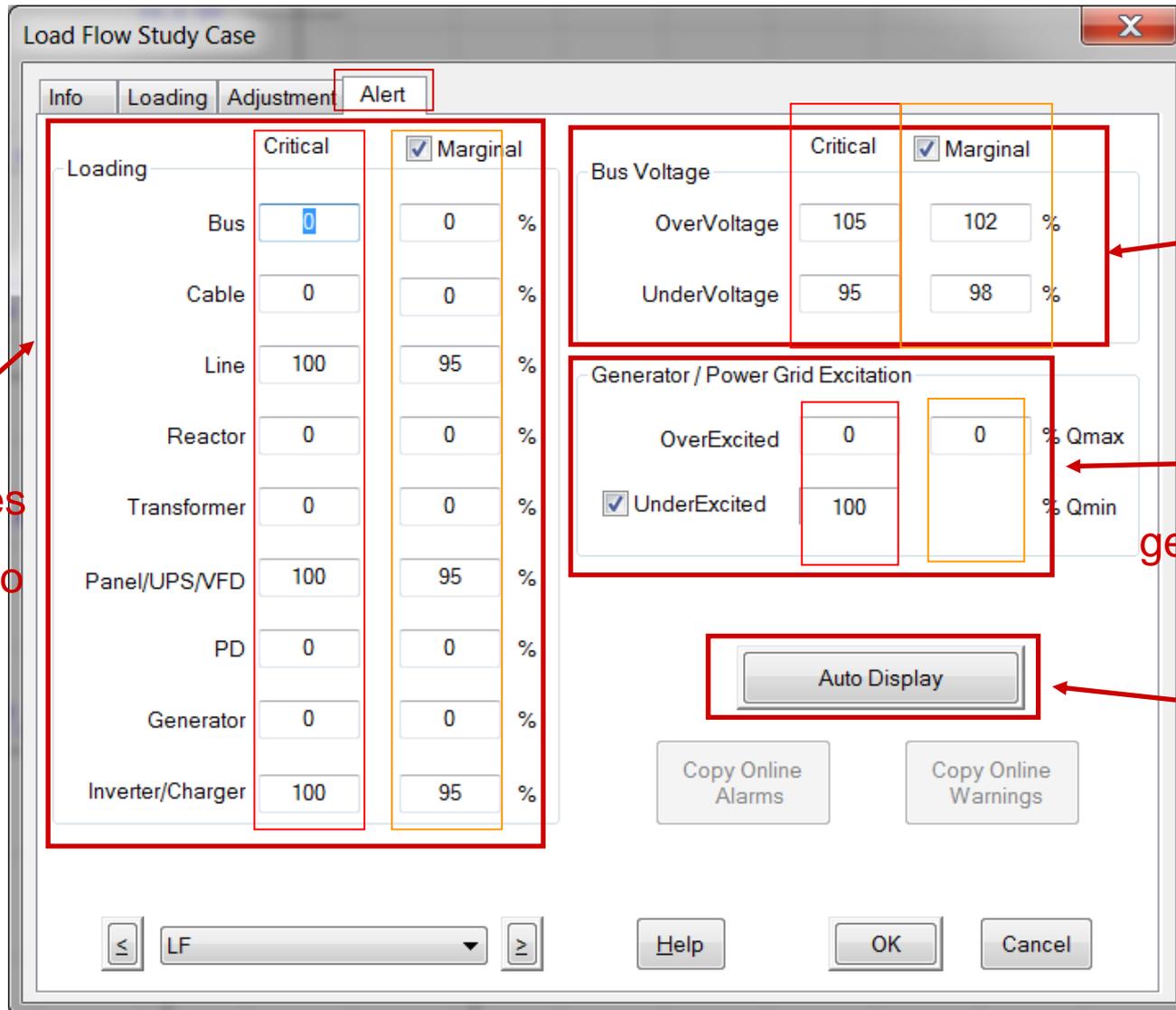


Tolerancias
impedancias

Tolerancias
longitud

Corrección
resistencias
por
temperatura

Ejemplos de aplicación utilizando ETAP®12.5



Alarmas
barras

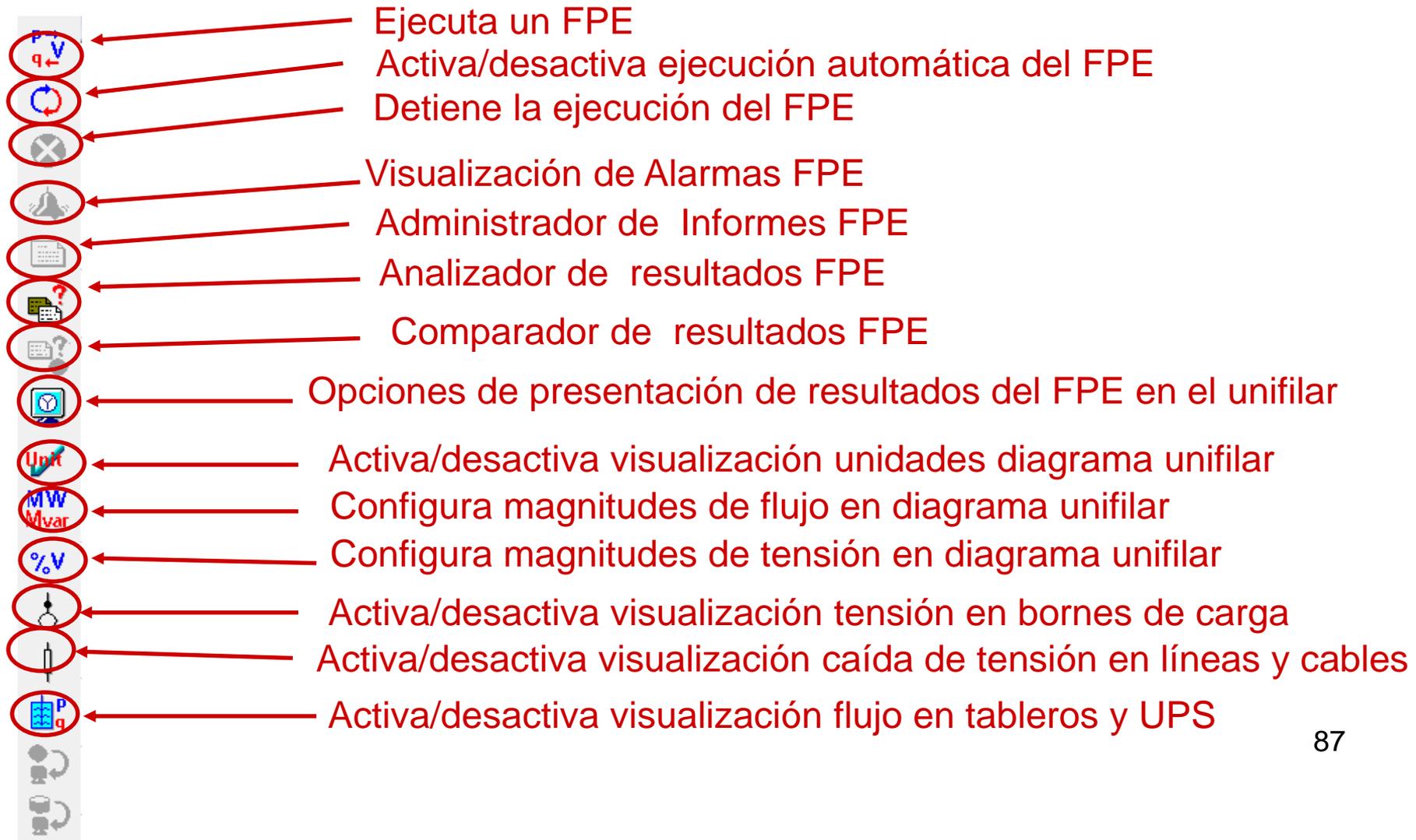
Alarmas
excitación
generador/Red

Presentación
automática de
informe
alarmas

Solicitaciones
equipamiento

Ejemplos de aplicación utilizando ETAP®12.5

Barra de herramientas del FPE:



Ejemplos de aplicación utilizando ETAP®12.5

The image displays the ETAP 12.5.0 software interface for a Load Flow Analysis. The main window shows a complex power system diagram with various components including buses (Bus1 to Bus10), transformers (T1, T2, T3, T4), generators (Gen1), loads (Load1, Mer1, Mer2, Lump2), and cables (Cable1, Cable2). The diagram is set against a grid background. A red arrow points from the top toolbar to a dialog box titled "Output File Name". The dialog box has a text input field containing "Caso_Base" and three buttons: "Help", "OK", and "Cancel". The software's menu bar includes File, Edit, View, Project, Library, Rules, Defaults, Tools, RevControl, Real-Time, Window, and Help. The status bar at the bottom indicates the current project name is "Base" and the system time is 08:26 p.m. on 08/02/2014.

Ejemplos de aplicación utilizando ETAP®12.5

ETAP 12.5.0 - [OLV1 (Load Flow Analysis)]

File Edit View Project Library Rules Defaults Tools RevControl Real-Time Window Help

Base OLV1 OLV1 Normal LF Untitled Adjustments

Load Flow Analysis Alert View - Output Report: Untitled

Study Case: LF Data Revision: Base
 Configuration: Normal Date: 02-08-2014

Zone Filter Area Filter Region Filter

1 1 1

Critical						
Device ID	Type	Condition	Rating/Limit	Operating	% Operating	Phase Type
Marginal						
Device ID	Type	Condition	Rating/Limit	Operating	% Operating	Phase Type
Bus4	Bus	Under Voltage	4,16 kV	4,061	97,6	3-Phase
Bus5	Bus	Under Voltage	4,16 kV	4,052	97,4	3-Phase
Bus7	Bus	Under Voltage	0,48 kV	0,468	97,5	3-Phase
Bus8	Bus	Under Voltage	0,48 kV	0,468	97,5	3-Phase
Bus9	Bus	Under Voltage	4,16 kV	4,052	97,4	3-Phase

For Help, press F1

Base

ES 08:00 p.m. 08/02/2014

Ejemplos de aplicación utilizando ETAP®12.5

The image displays the ETAP 12.5.0 software interface for a load flow analysis. The main window shows a complex power system diagram with multiple buses (Bus1 to Bus8), transformers (T1, T2, T3, T4), generators (Gen1), motors (Mtr1, Mtr2), and loads (Load1). The diagram includes various electrical parameters such as voltage levels (e.g., 34.5 kV, 13.8 kV, 4.16 kV), power ratings (MW, Mvar), and efficiency percentages (e.g., 99.41%, 97.63%, 97.4%, 98.37%, 97.49%).

Overlaid on the right side of the diagram is the 'Load Flow Report Manager' dialog box. This dialog has four tabs: 'Complete', 'Input', 'Result', and 'Summary'. The 'Result' tab is active, showing a list of report types: 'Load Flow Report', 'Panel Report', and 'UPS Report'. The 'Load Flow Report' option is selected and highlighted with a red box. To the right of this list are radio button options for the report format: 'Viewer', 'PDF' (which is selected), 'MS Word', 'Rich Text Format', 'MS Excel', and 'Set As Default'. Below these options, there are fields for 'Output Report Name' (set to 'Untitled') and 'Path' (set to 'C:\Users\Usuario\ETAP\WORKSHOP_2014\ETAP 115\EJERCICIOS\FLUJO_EQUILIBRAD'). At the bottom of the dialog are 'Help', 'OK', and 'Cancel' buttons. A red arrow points from the right edge of the dialog box towards the 'PDF' radio button.

The bottom of the screen shows the Windows taskbar with various application icons and the system tray displaying the time as 08:07 p.m. on 08/02/2014.

Ejemplos de aplicación utilizando ETAP®12.5

Project:	Flujo de Potencia Equilibrado	ETAP	Page:	1
Location:	ARGENTINA	12.5.0D	Date:	02-08-2014
Contract:	Curso de Capacitacion ETAP		SN:	RAIENDLRCL
Engineer:	Diego Moitre	Study Case: LF	Revision:	Base
Filename:	Ejercicio 1 FPE ANSI		Config.:	Normal

LOAD FLOW REPORT

Bus	Voltage			Generation		Load		Load Flow					XFME	
	ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus1		34.500	100.000	0.0	7.443	2.286	0	0	Bus2	7.443	2.286	130.3	95.6	
Bus2		13.800	99.409	-1.0	0	0	0.000	-0.988	Bus3	0.563	-0.684	37.3	-63.5	
									Bus1	-7.437	-2.145	325.7	96.1	
									Bus4	6.874	3.817	330.9	87.4	
Bus3		13.800	99.408	-1.0	5.000	4.000	0	0	Bus2	-0.563	0.684	37.3	-63.5	
									Bus10	4.224	2.620	209.2	85.0	
									Bus6	1.339	0.695	63.5	88.7	
Bus4		4.160	97.629	-2.7	0	0	4.612	1.890	Bus5	2.248	1.657	396.9	80.5	
									Bus2	-6.860	-3.547	1097.8	88.8	
Bus5		4.160	97.405	-2.7	0	0	2.277	1.708	Bus4	-2.244	-1.651	396.9	80.5	
									Bus9	-0.033	-0.057	9.4	50.3	
Bus6		4.160	98.372	-2.0	0	0	0.643	0.271	Bus3	-1.336	-0.665	210.6	89.5	
									Bus8	0.693	0.395	112.5	86.9	
Bus7		0.480	97.489	-2.7	0	0	0.380	0.222	Bus9	0.033	0.057	81.1	50.3	
									Bus8	-0.414	-0.278	615.0	83.0	
Bus8		0.480	97.489	-2.7	0	0	0.279	0.104	Bus6	-0.692	-0.382	975.4	87.5	
									Bus7	0.414	0.278	615.0	83.0	
Bus9		4.160	97.407	-2.7	0	0	0	0	Bus5	0.033	0.057	9.4	50.3	
									Bus7	-0.033	-0.057	9.4	50.3	
Bus10		13.800	99.381	-1.0	0	0	4.224	2.618	Bus3	-4.224	-2.618	209.2	85.0	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

Indicates a bus with a load mismatch of more than 0.1 MVA

Ejemplos de aplicación utilizando ETAP®12.5

The image displays the ETAP 12.5.0 software interface for a Load Flow Analysis. The main window shows a complex power system diagram with various components including buses (Bus1 to Bus10), transformers (T1, T2, T3, T4), cables (Cable1, Cable2), generators (Gen1), motors (Mtr1, Mtr2), and loads (Load1). The diagram includes numerical data for power flows, voltages, and losses. A 'Load Flow Report Manager' dialog box is open in the foreground, with the 'Summary' tab selected. The 'Summary' tab contains a list of report sections: Alert Complete, Alert Critical, Alert Marginal, Branch Loading, Bus Loading, Losses, and Summary. The 'Losses' section is highlighted with a red box. To the right of this list are radio buttons for output formats: Viewer, PDF (selected), MS Word, Rich Text Format, MS Excel, and Set As Default. Below the list, there are fields for 'Output Report Name' (Untitled) and 'Path' (C:\Users\Usuario\ETAP\WORKSHOP_2014\ETAP 115\EJERCICIOS\FLUJO_EQUILIBRAD). The dialog box has 'Help', 'OK', and 'Cancel' buttons. A red arrow points from the 'Summary' tab in the dialog box to the 'Losses' section in the list. The Windows taskbar at the bottom shows the system clock as 08:14 p.m. on 08/02/2014.

Ejemplos de aplicación utilizando ETAP®12.5

Project:	Flujo de Potencia Equilibrado	ETAP	Page:	1
Location:	ARGENTINA	12.5.0D	Date:	02-08-2014
Contract:	Curso de Capacitacion ETAP		SN:	RAIENDLRCL
Engineer:	Diego Moitre	Study Case: LF	Revision:	Base
Filename:	Ejercicio 1 FPE ANSI		Config.:	Normal

Branch Losses Summary Report

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag	
	ID	MW	Mvar	MW	Mvar	kW	kvar	From		To
T1		7.443	2.286	-7.437	-2.145	6.0	141.3	100.0	99.4	0.59
Cable1		0.563	-0.684	-0.563	0.684	0.1	0.1	99.4	99.4	0.00
T2		6.874	3.817	-6.860	-3.547	14.6	270.7	99.4	97.6	1.78
Z1		4.224	2.620	-4.224	-2.618	0.0	2.5	99.4	99.4	0.03
T3		1.339	0.695	-1.336	-0.665	2.5	29.8	99.4	98.4	1.04
Cable2		2.248	1.657	-2.244	-1.651	3.8	5.7	97.6	97.4	0.22
Cable3		-0.033	-0.057	0.033	0.057	0.0	0.0	97.4	97.4	0.00
T4		0.693	0.395	-0.692	-0.382	1.2	12.5	98.4	97.5	0.88
T5		0.033	0.057	-0.033	-0.057	0.0	0.1	97.5	97.4	0.08
						28.1	462.7			

Ejemplos de aplicación utilizando ETAP®12.5

The image displays the ETAP 12.5.0 software interface for a Load Flow Analysis. The main window shows a complex power system diagram with various components including buses (Bus1 to Bus9), transformers (T1, T2, T3, T4), cables (Cable1, Cable2), generators (Gen1), loads (Load1), and motors (Mtr1, Mtr2). The diagram is annotated with numerical values for power (MW), reactive power (Mvar), and voltage levels (kV). For example, Bus1 is at 34.5 kV, Bus2 at 13.8 kV, and Bus5 at 4.16 kV. Transformer T1 is rated at 30 MVA, and T2 at 15 MVA. A generator Gen1 is rated at 10 MW. Loads include a 3000 HP motor (Mtr1) and a 600 kW motor (Mtr2). The diagram also shows a network connection (Network1) and a lumped load (Lump2).

Overlaid on the right side of the diagram is the "Load Flow Report Manager" dialog box. The "Summary" tab is selected, and the "Summary" report type is chosen from the "Report" list. The "Output Report Name" is "Untitled" and the "Path" is "C:\Users\Usuario\ETAP\WORKSHOP_2014\ETAP 115\EJERCICIOS\FLUJO_EQUILIBRAD". The "PDF" option is selected under the "Format" section. A red arrow points to the "Summary" report type in the list.

At the bottom of the screen, the Windows taskbar is visible, showing the system tray with the time 08:17 p.m. on 08/02/2014.

Ejemplos de aplicación utilizando ETAP®12.5

Project:	Flujo de Potencia Equilibrado	ETAP	Page:	1
Location:	ARGENTINA	12.5.0D	Date:	02-08-2014
Contract:	Curso de Capacitacion ETAP		SN:	RAIENDLRCL
Engineer:	Diego Moitre	Study Case: LF	Revision:	Base
Filename:	Ejercicio 1 FPE ANSI		Config.:	Normal

Bus Loading Summary Report

Bus	Directly Connected Load										Total Bus Load				
	ID	kV	Rated Amp	Constant kVA		Constant Z		Constant I		Generic		MVA	% PF	Amp	Percent Loading
				MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar				
Bus1	34.500			0	0	0	0	0	0	0	0	7.786	95.6	130.3	
Bus2	13.800			0	0	0	-0.988	0	0	0	0	8.359	89.0	351.8	
Bus3	13.800			0	0	0	0	0	0	0	0	6.851	81.2	288.3	
Bus4	4.160			4.612	1.890	0	0	0	0	0	0	7.722	88.8	1097.8	
Bus5	4.160			0	0	2.277	1.708	0	0	0	0	2.846	80.0	405.6	
Bus6	4.160			0.643	0.271	0	0	0	0	0	0	1.493	89.5	210.6	
Bus7	0.480			0.267	0.142	0.113	0.080	0	0	0	0	0.498	83.0	615.0	
Bus8	0.480			0.241	0.104	0.038	0	0	0	0	0	0.791	87.5	975.4	
Bus9	4.160			0	0	0	0	0	0	0	0	0.066	50.3	9.4	
Bus10	13.800			2.125	1.317	2.099	1.301	0	0	0	0	4.969	85.0	209.2	

Ejemplos de aplicación utilizando ETAP®12.5

The screenshot shows the ETAP 12.5.0 interface with the 'Load Flow Result Analyzer' window open. The window contains the following data:

Study ID	Caso_Base
Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Cat	Design
Generation Cat	Design
Diversity Factor	Normal Loading
Buses	10
Branches	10
Generators	1
Power Grids	1
Loads	12
Load-MW	12,443
Load-Mvar	6,286
Generation-MW	12,443
Generation-Mvar	6,286
Loss-MW	0,028
Loss-Mvar	0,463
Mismatch-MW	0
Mismatch-Mvar	0

Report Type options:

- General Info
- Bus Results
- Branch Results
- Loads
- Sources

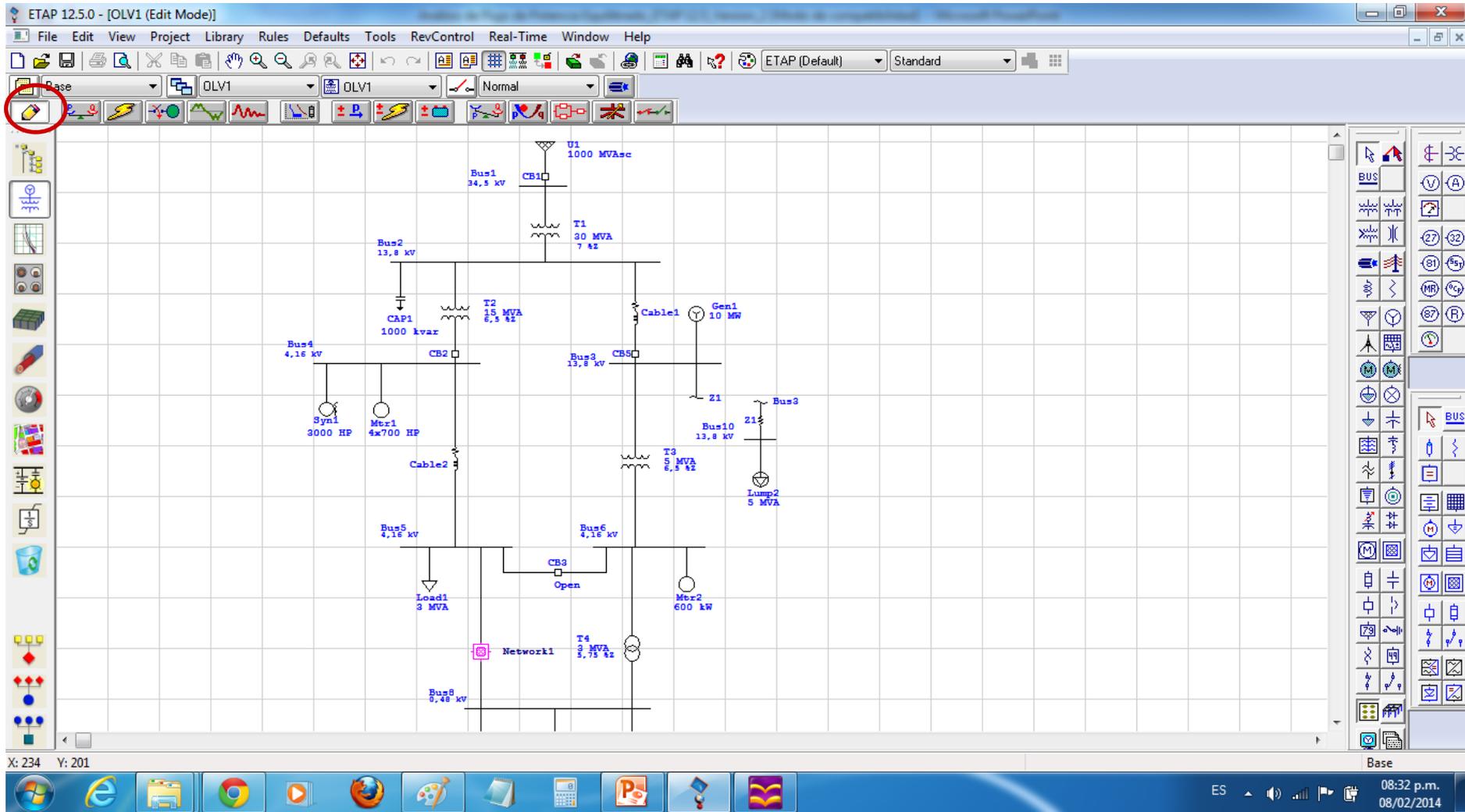
Project Report options:

- Active Project: Ejercicio 1 FPE ANSI
- All Project in Active Directory

Buttons: Export..., Help, Close

Red text annotation: **Analizador de resultados** with a red arrow pointing to a help icon in the right sidebar.

Ejemplos de aplicación utilizando ETAP®12.5



Ejemplos de aplicación utilizando ETAP®12.5

The screenshot displays the ETAP 12.5.0 software interface in Edit Mode for a project named OLV1. The main workspace shows a power system diagram with various components: Bus1 (34.5 kV), Bus2 (13.8 kV), Bus4 (4.16 kV), Bus5 (4.16 kV), Bus6 (4.16 kV), Bus8 (0.48 kV), Bus9 (0.48 kV), Bus10 (0.48 kV), Bus11 (0.48 kV), Bus12 (0.48 kV), Bus13 (0.48 kV), Bus14 (0.48 kV), Bus15 (0.48 kV), Bus16 (0.48 kV), Bus17 (0.48 kV), Bus18 (0.48 kV), Bus19 (0.48 kV), Bus20 (0.48 kV), Bus21 (0.48 kV), Bus22 (0.48 kV), Bus23 (0.48 kV), Bus24 (0.48 kV), Bus25 (0.48 kV), Bus26 (0.48 kV), Bus27 (0.48 kV), Bus28 (0.48 kV), Bus29 (0.48 kV), Bus30 (0.48 kV), Bus31 (0.48 kV), Bus32 (0.48 kV), Bus33 (0.48 kV), Bus34 (0.48 kV), Bus35 (0.48 kV), Bus36 (0.48 kV), Bus37 (0.48 kV), Bus38 (0.48 kV), Bus39 (0.48 kV), Bus40 (0.48 kV), Bus41 (0.48 kV), Bus42 (0.48 kV), Bus43 (0.48 kV), Bus44 (0.48 kV), Bus45 (0.48 kV), Bus46 (0.48 kV), Bus47 (0.48 kV), Bus48 (0.48 kV), Bus49 (0.48 kV), Bus50 (0.48 kV), Bus51 (0.48 kV), Bus52 (0.48 kV), Bus53 (0.48 kV), Bus54 (0.48 kV), Bus55 (0.48 kV), Bus56 (0.48 kV), Bus57 (0.48 kV), Bus58 (0.48 kV), Bus59 (0.48 kV), Bus60 (0.48 kV), Bus61 (0.48 kV), Bus62 (0.48 kV), Bus63 (0.48 kV), Bus64 (0.48 kV), Bus65 (0.48 kV), Bus66 (0.48 kV), Bus67 (0.48 kV), Bus68 (0.48 kV), Bus69 (0.48 kV), Bus70 (0.48 kV), Bus71 (0.48 kV), Bus72 (0.48 kV), Bus73 (0.48 kV), Bus74 (0.48 kV), Bus75 (0.48 kV), Bus76 (0.48 kV), Bus77 (0.48 kV), Bus78 (0.48 kV), Bus79 (0.48 kV), Bus80 (0.48 kV), Bus81 (0.48 kV), Bus82 (0.48 kV), Bus83 (0.48 kV), Bus84 (0.48 kV), Bus85 (0.48 kV), Bus86 (0.48 kV), Bus87 (0.48 kV), Bus88 (0.48 kV), Bus89 (0.48 kV), Bus90 (0.48 kV), Bus91 (0.48 kV), Bus92 (0.48 kV), Bus93 (0.48 kV), Bus94 (0.48 kV), Bus95 (0.48 kV), Bus96 (0.48 kV), Bus97 (0.48 kV), Bus98 (0.48 kV), Bus99 (0.48 kV), Bus100 (0.48 kV). The diagram includes transformers (T1, T2, T3, T4), capacitors (CAP1), and loads (Load1). A red circle highlights the 'Load1 3 MVA' component in the diagram. Another red circle highlights the 'Static Load Editor - Load1' dialog box, which is open over the diagram. The dialog box shows the following data:

Static Load Editor - Load1

Info Loading Cable/Vd Cable Amp Harmonic Reliability Remarks Comment

1 4 MW 3 Mvar 4.16 kV Cable Info not available

Ratings

kV	MVA	MW	Mvar	% PF	Amps
4.16	5	4	3	80	693.9

Grounding

Calculator...

Loading

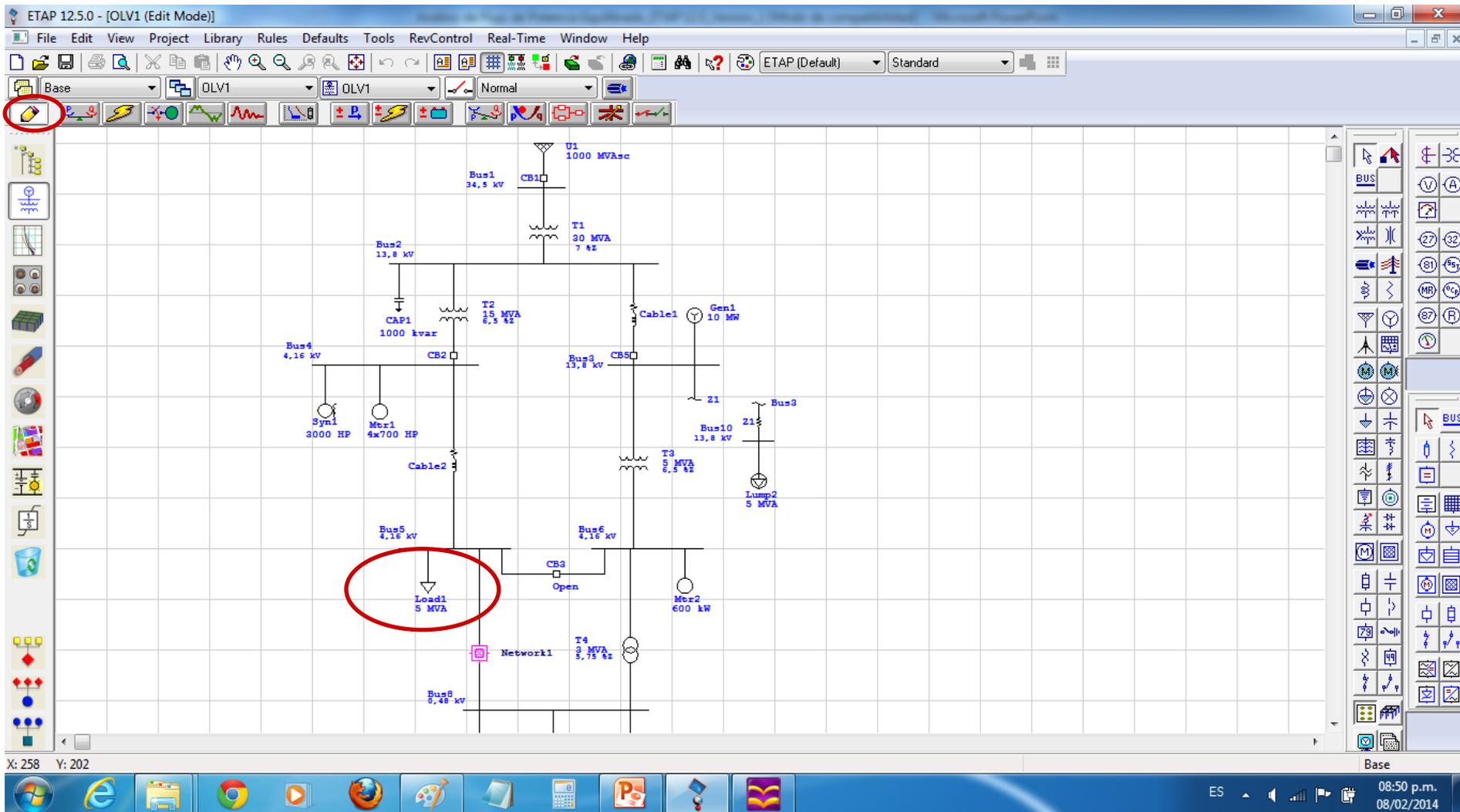
Loading Category	% Loading	Load		Feeder Loss	
		MW	Mvar	MW	Mvar
1 Design	100	4	3	0	0
2 Normal	100	4	3	0	0
3 Winter Load	0	0	0	0	0
4 Summer Load	0	0	0	0	0
5 Backup	0	0	0	0	0
6 Fl Ld Rejec	0	0	0	0	0
7 Emergency	0	0	0	0	0
8 Shutdown	0	0	0	0	0
9 Accident	0	0	0	0	0
10 Load Cat 10	0	0	0	0	0

Operating Load: 2.277 MW +j 1.708 Mvar

Load1

OK Cancel

Ejemplos de aplicación utilizando ETAP®12.5



Ejemplos de aplicación utilizando ETAP®12.5

The image displays the ETAP 12.5.0 software interface for a Load Flow Analysis (OLV1). The main workspace shows a complex power system diagram with various components including buses (Bus1 to Bus8), transformers (T1, T2, T3, T4), cables (Cable1, Cable2), generators (Gen1), loads (Load1, Mtr1, Mtr2, Lump2), and a network connection (Network1). The software's menu bar includes File, Edit, View, Project, Library, Rules, Defaults, Tools, RevControl, Real-Time, Window, and Help. The toolbar contains numerous icons for editing and analysis. A red arrow points from the 'Prompt' button in the toolbar to an 'Output File Name' dialog box. This dialog box has a text field containing 'Cambio_Carga' and buttons for 'Help', 'OK', and 'Cancel'. The Windows taskbar at the bottom shows the system tray with the time 08:52 p.m. on 08/02/2014.

Ejemplos de aplicación utilizando ETAP®12.5

ETAP 12.5.0 - [OLV1 (Load Flow Analysis)]

File Edit View Project Library Rules Defaults Tools RevControl Real-Time Window Help

Base OLV1 OLV1 Normal LF Cambio_Carga Adjustments

Load Flow Result Analyzer

Study Reports

Ref.	Select	Reports
	<input checked="" type="checkbox"/>	Cambio_Carga
	<input checked="" type="checkbox"/>	Caso_Base

Project Report

Active Project All Project in Active Directory

Ejercicio 1 FPE ANSI

Report Type

General Info

Bus Results

Branch Results

Loads

Sources

	Study ID	Cambio_Carga	Caso_Base
Study Case ID	LF	LF	LF
Data Revision	Base	Base	Base
Configuration	Normal	Normal	Normal
Loading Cat	Design	Design	Design
Generation Cat	Design	Design	Design
Diversity Factor	Normal Loading	Normal Loading	Normal Loading
Buses	10	10	10
Branches	10	10	10
Generators	1	1	1
Power Grids	1	1	1
Loads	12	12	12
Load-MW	13,889	12,443	12,443
Load-Mvar	7,595	6,286	6,286
Generation-MW	13,889	12,443	12,443
Generation-Mvar	7,595	6,286	6,286
Loss-MW	0,045	0,028	0,028
Loss-Mvar	0,692	0,463	0,463
Mismatch-MW	0	0	0
Mismatch-Mvar	0	0	0

Export... Help Close

For Help, press F1

Base

ES 08:54 p.m. 08/02/2014

Ejemplos de aplicación utilizando ETAP®12.5

Load Flow Result Analyzer

Study Reports

Ref.	Select	Reports
<input type="radio"/>	<input checked="" type="checkbox"/>	Cambio_Carga
<input checked="" type="radio"/>	<input checked="" type="checkbox"/>	Caso_Base

Project Report

Active Project Ejercicio 1 FPE ANSI

All Project in Active Directory

Report Type

General Info

Bus Results

Branch Results

Loads

Sources

Bus Type

Source Buses

Nodes

MCC & SWGR

Load Buses

Bus Info

Nominal kV

Amp Rating

Type

Unit

kVA

MVA

Voltage

Bus ID	Nominal kV	Cambio_Carga	Caso_Base
Bus1	34,5	100	100
Bus2	13,8	99,1	99,41
Bus3	13,8	99,09	99,41
Bus4	4,16	96,81	97,63
Bus5	4,16	96,46	97,4
Bus6	4,16	97,87	98,37
Bus7	0,48	96,72	97,49
Bus8	0,48	96,72	97,49
Bus10	13,8	99,07	99,38

Load Flow Results

Voltage

MW Loading

Mvar Loading

Amp Loading

% Loading

Alert

Critical **Marginal**

Loading 100 % 95 %

OverVoltage 105 % 102 %

UnderVoltage 95 % 98 %

Display Options

Actual Value Skip If Same

Differences with Ref.

Export... Find Help Close

Ejemplos de aplicación utilizando ETAP®12.5

The screenshot displays the 'Load Flow Result Analyzer' window. The main table shows results for various components under two cases: 'Cambio_Carga' and 'Caso_Base'. The 'Caso_Base' column is highlighted in green. The 'Branch Results' report type is selected, and the 'Alert' section shows critical and marginal values for loading and voltage drop.

ID	Type	Cambio_Carga	Caso_Base
Cable1	Cable	37,56	37,29
Cable2	Cable	634,4	396,9
Cable3	Cable	35,26	9,363
T1	Transf. 2W	160,5	130,3
T2	Transf. 2W	403,5	330,9
T3	Transf. 2W	71,49	63,49
T4	Transf. 2W	138,9	112,5
T5	Transf. 2W	305,6	81,14
Z1	Impedance	209,2	209,2

Study Reports

Ref.	Select	Reports
<input type="radio"/>	<input checked="" type="checkbox"/>	Cambio_Carga
<input checked="" type="radio"/>	<input checked="" type="checkbox"/>	Caso_Base

Project Report

Active Project: Ejercicio 1 FPE ANSI
 All Project in Active Directory

Report Type

General Info
 Bus Results
 Branch Results
 Loads
 Sources

Branch Type

Transformer
 Cable
 Line
 Reactor
 Impedance
 Equip Cable

Branch Info

From Bus
 To Bus
 Type
 Rating 1
 Rating 2
 Allowable

Unit

kVA
 MVA
Voltage: %

Load Flow Results

MW Flow
 Mvar Flow
 Amp Flow
 % PF
 % Loading
 % Voltage Drop
 KW Losses
 kvar Losses

Alert

Critical
Loading 100 %
Voltage Drop 5 %

Marginal
Loading 95 %
Voltage Drop 4 %

Display Options

Actual Value
 Skip If Same
 Differences with Ref.

Buttons: Export..., Find, Help, Close

Ejemplos de aplicación utilizando ETAP®12.5

Load Flow Result Analyzer

Study Reports

Ref.	Select	Reports
<input type="radio"/>	<input checked="" type="checkbox"/>	Cambio_Carga
<input checked="" type="radio"/>	<input checked="" type="checkbox"/>	Caso_Base

Project Report

Active Project Ejercicio 1 FPE ANSI

All Project in Active Directory

Report Type

General Info

Bus Results

Branch Results

Loads

Sources

Load Type

Induction

Synchronous

Lumped

Static

MOV

Capacitor

SVC

Filter

Load Info

Terminal Bus

Type

Rating

Rated kV

Unit

kVA Voltage

MVA %

Load Flow Results

kW Loading

kvar Loading

Amp Loading

% PF

% Loading

Terminal Voltage

Alert

Critical **Marginal**

Loading 100 % 95 %

OverVoltage 105 % 102 %

UnderVoltage 95 % 98 %

Display Options

Actual Value Skip If Same

Differences with Ref.

Export... Find Help Close

ID	Rating	Rated kV	Cambio_Carga	Caso_Base
CAP1	-1000 kvar	13,8	99,1	99,4
Load1	3000 kVA	4,16	96,5	97,4
Load2	100 kVA	0,48	96,7	97,5
Load3	40 kVA	0,48	96,7	97,5
Lump1	200 kVA	0,46	99,5	99
Lump2	5000 kVA	13,8	100	100
MOV1	1,4 HP	0,46		
Mtr1	2800 HP	4	99,3	98,5
Mtr2	600 kW	4	98,3	97,8
Mtr3	150 HP	0,46	99,1	98,3
Mtr4	100 HP	0,46	99,1	98,3
Syn1	3000 HP	4	99,3	98,5
Syn2	200 HP	0,46	99,1	98,3

Ejemplos de aplicación utilizando ETAP®12.5

Study Reports

Ref.	Select	Reports
<input type="radio"/>	<input checked="" type="checkbox"/>	Cambio_Carga
<input checked="" type="radio"/>	<input checked="" type="checkbox"/>	Caso_Base

Project Report

Active Project

All Project in Active Directory

Report Type

General Info

Bus Results

Branch Results

Loads

Sources

Source Type

Power Grid

Synchronous

Wind Turbine

Source Info

Terminal Bus

Type

Rating

Rated kV

Unit

kVA

MVA

Voltage: %

Load Flow Results

MW Generation

Mvar Generation

Amp

% PF

% Generation

Display Options

Actual Value Skip If Same

Differences with Ref.

Buttons: Export..., Find, Help, Close

ID	Rating	Rated kV	Cambio_Carga	Caso_Base
Gen1	10 MW	13,8	5	5
U1	1000 MVA	34,5	8,889	7,443

Efectos sobre el equipamiento

IEEE Std 18™-2002
(Revision of
IEEE Std 18-1992)

IEEE Standard for Shunt Power Capacitors

5.3 Maximum continuous operating voltage, current, and kvar

Capacitors are intended to be operated at or below their rated voltage. Capacitors shall be capable of continuous operation under contingency system and bank conditions provided that none of the following limitations are exceeded:

- a) 110% of rated rms voltage
- b) 120% of rated peak voltage, i.e. peak voltage not exceeding $1.2 \times (\text{square root of two}) \times$ rated rms voltage, including harmonics, but excluding transients
- c) 135% of nominal rms current based on rated kvar and rated voltage
- d) 135% of rated kvar

Efectos sobre el equipamiento

IEEE Std C57.12.00™-2006
(Revision of
IEEE Std C57.12.00-1999)

IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

4.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit. Harmonic factor is defined in IEEE Std C57.12.80.

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of the following:

- a) Operating continuously above rated voltage or below rated frequency, at maximum rated kVA for any tap, without exceeding the limits of observable temperature rise in accordance with 5.11.1.1 when all of the following conditions prevail:
 - 1) Secondary voltage and volts per Hertz do not exceed 105% of rated values.
 - 2) Load power factor is 80% or higher.
 - 3) Frequency is at least 95% of rated value.
- b) Operating continuously above rated voltage or below rated frequency, on any tap at no load, without exceeding limits of observable temperature rise in accordance with 5.11.1, when neither the voltage nor volts per Hertz exceed 110% of rated values.