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<td>Tim Buttke Comments - Presentation Using Generators as Synchronous Condensers for Reactive Power, etc.</td>
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<td><strong>Description:</strong></td>
<td>Presentation by Morgan L. Hendry - SSS Clutch Company, Inc. previously submitted to Docket No. 12-AFC-02C - Using Generators as Synchronous Condensers for Reactive Power &amp; Aero-Derivative Gas Turbine Generators for Spinning Reserve</td>
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Using Generators as Synchronous Condensers for Reactive Power & Aero-Derivative Gas Turbine Generators for Spinning Reserve

Additional submitted attachment is included below.
Using Generators as Synchronous Condensers for Reactive Power
&
Aero-Derivative Gas Turbine Generators for Spinning Reserve

Presented to: California Energy Commission, Sacramento, California

Morgan L. Hendry – SSS Clutch Company, Inc.
November 9, 2016
1) Generators produce MW’s, Dynamic MVAR’s, Spinning Reserve, & Grid Inertia
2) When not generating, generator can be disconnected by SSS Clutch & left connected to grid for Dynamic MVAR’s, Spinning Reserve & Dynamic Inertia
3) SSS Clutches are supplied worldwide for Steam Turbine, Gas Turbine, and Reciprocating Engine driven generators for this purpose
4) Renewables do not produce MVAR’s or Inertia – CAISO - 50% by 2030
5) At CAISO direction, Legacy Huntington Beach Generating Station Units 3 & 4 were converted to synchronous condensers by disconnecting steam turbines and installing pony motor acceleration systems to connect generators to grid
6) Huntington Beach Expansion Project (12-AFC-02C) – CAISO - 2 X 1 combined cycle generating plant to include SSS Clutches for synchronous condensing
7) Installation of SSS Clutches in ST & GT technically feasible and proven
8) Owner bidding job objected - no payment for clutch capital cost and operation
9) California Energy Commission Final Staff Assessment (520 pages), issued Oct 2016, Docket #12-AFC-02C, Project Compliance, TN # 214127 – SSS Clutches
10) CEC hearings November 14 & November 30, 2016
SSS Clutches in Power Plant Applications

- Single-Shaft, Combined-Cycle Plant
- Cogeneration Plant
- Synchronous Condensing using the Generator of Peak Load Turbines
- Combined Heat and Power Plant
- Compressed Air Energy Storage (CAES) Plant
- Pumped Water Storage Plant
- Rotating Uninterruptible Power System (UPS)
- Auxiliaries
  - Gas and Steam Turbine Turning Gears
  - Gas Turbine Starting

Elements of Basic SSS Clutch
- A Pawl
- B Clutch Teeth
- C Sliding Component
- D Helical Splines
- E Input Shaft
- F Output Clutch Ring
- G Ratchet Teeth

SSS Clutch Principle of Operation

1
2
3
Synchronous Condensing - Provide Reactive Power, Provide Spinning Reserve & can help Maximize Renewable Energy

LOAD CENTER: Peak power LMS100 with SSS® Clutches synchronous condensing for intermittent renewable sources of energy. SSS® Clutches provide grid support for reactive power and grid inertia.
Regional Installations of SSS Clutches - 4 Size 272T SSS® Encased Clutches - GE LMS100 Synchronous Condensing/Spinning Reserve

One Installed in 2008 — GE LMS100 at Calpine’s Cumberland Energy Center, Millville, NJ
Two Installed in 2010 — GE LMS100 at LADWP’s Haynes Power Station, Long Beach, CA
Two Installed in 2014—GE LMS100 at LADWP’s Scattergood Power Sta., Playa Del Rey, CA

Two LMS100 Gas Turbine Generators with size 272T SSS® Encased Clutches at LADWP’s Haynes Power Station, Long Beach, CA

LMS100 Gas Turbine Generator with size 272T SSS® Encased Clutch at Calpine (formerly Conectiv) Cumberland Energy Center, Millville, NJ.

130 MW rated Size 272T SSS® Encased Clutch installed in LMS100.

SSS® Encased Clutch on test prior to delivery

SSS® Encased Clutch (with turbine gear) to enable synchronous condensing for reactive power or spinning reserve duty
Thirty-six SSS Clutches Installed-LM6000’s: USA, Canada, New Zealand & The Netherlands

Installation Summary
In Operation
33 - 60 Hz
3- 50 Hz

About 400,000 Total Fleet Hours
Operation To Date

Two units in Lemoore, CA
Regional Installations of SSS Clutches in Power Plants

Single Shaft Combined Cycle Installations in Southwest Transmission Plan Area

Four 105 MW SSS Clutches @ La Paloma, CA in 2000
One 105 MW SSS Clutch @ Hermosillo, Mexico in 2000
Two 105 MW SSS Clutches @ Rosarito, Mexico in 2000
Two 1.9 MW SSS Clutches @ Phoenix, Az in 2001
One 2 MW SSS Clutch @ Phoenix, Az in 2005
Synchronous Clutch Retrofit of FT-4 Twin Pac: San Jose, CA for Reactive Power – Voltage Stability

Greenwich Air Systems, Inc. relocated a TP&M Twin Pac with two 34 MW FT4-CI gas turbines from Public Service of New Jersey, Linden Plant, to PG&E, San Jose Plant (one block west of airport). A size 214T SSS Clutch was installed between only one gas turbine and the generator at the non-excitier end to permit synchronous condensing. In service for more than 10 years for voltage stability in lower San Francisco Bay area grid.
3 GE Synchronous Condenser Systems with SSS Clutches in start motor to be installed at SCE Santiago Station, Irvine in December

Addition of SSS Clutch reduced losses of spinning start motor with savings of $13,000 per KW. Also savings in wear & maintenance associated with spinning start motor 24/7.
What is a Synchronous Condenser?

Definition

• Synchronous Machine Connected to Electrical System
• Driven from Electric System (Motoring)
• Absorbing or Supplying Dynamic VARs (with rotational inertia for the transmission system)

Automatic Voltage Regulator (AVR) on Low Voltage
• Adjusts Excitation
• VARs Supplied Increased
• Power Factor Restored
• Voltage Restored

Automatic Voltage Regulator (AVR) on High Voltage
• Adjusts Excitation
• VARs Supplied Reduced
• Normal Voltage Restored
Typical Generator Reactive Capability Diagram

- **Leading Power Factor**: 0.8, 0.85, 0.9
- **Lagging Power Factor**: 0.8, 0.85, 0.8

- **Capability Limit Under A.V.R. Control**
- **Theoretical Stability Limit**
- **Stability Limit Under Hand Control, with 10% Power Margin**

- **Stator Limit**
- **Rotor Limit**

- **MW**
- **MVAR**
- **Underexcited**
- **Overexcited**

- **Underexcited**
  - 20
  - 10
  - 0

- **Overexcited**
  - 10
  - 20
  - 30

- **Stator Limit**
  - 40
  - 30
  - 20
  - 10

- **Rotor Limit**
  - 20
  - 30
1. Provide/absorb VARs in small increments to correct lagging/leading power factor
2. Meet peak VAR requirements without reducing watts of generators in operation
3. Power factor/voltage support at end of long transmission lines provides stability and enables more watts to be transmitted
4. Power Factor/Voltage Support in Urban Centers and Industrial areas provides stability and enables more watts to be transmitted.
5. Synchronous Condenser is unique - can provide rotating inertia and “Dynamic VARs” to stabilize grid system, particularly when loads vary quickly
6. Generator operating as synchronous condenser could possibly qualify for spinning reserve requirements or credit
7. Complements Static Capacitors by providing finite adjustment of VARs reducing need to switch capacitors off and on, extending their service life.
8. Synchronous Condensers provide Reactive Power for both high and low voltage.
9. Can absorb VARs at the end of underground cables to correct high voltage problems.
10. Synchronous Condenser can be an additional source of revenue in a deregulated market.
Summary of Synchronous Condensing Clutch Installations

Total number of clutches installed 533
Total number of countries 55
Total aircraft-type gas turbines 203
Total industrial gas turbines 330
Total clutches over 100 MW 36

Note: Largest clutch in service is 300 MW at 3,000 rpm installed in 1976 on compressed air energy storage (CAES) plant, Huntorf, Germany, now owned by RWE.

First SSS Clutch supplied for Synchronous Condensing about 40 years ago
Options for Synchronous Condensing

Candidates for MW’s & MVAR’s

Generators of Aero-derivative of Frame Type Gas Turbines: Peak demand, located near load centers or end of long transmission lines.

Large Steam Turbine Generators: Operated seasonally or decommissioned

Requirements: a) Means to accelerate generator to synchronous speed

b) Means to detach Prime Mover from generator after synchronization (SSS Clutch)
One is by placement of the synchronous clutch between the Generator and its corresponding Steam or Gas Turbine.
Six GE LMS100 Packages are Installed At LADWP, Haynes Generating Station; Two have SSS Encased Clutches (Units 12 & 14)
GE LMS100 Package Layout Showing Generator, Lubrication System and Size 272T SSS Encased Clutch

- Size 272T Encased SSS Clutch
- Concrete Foundation for SSS Clutch
- Lubrication System for Generator and SSS Encased Clutch
LMS100 with SSS Encased Clutch Installed at LADWP, Haynes Power Station, Long Beach, California

Size 272T SSS Encased Clutch Installed in Unit #14 at LADWP, Haynes Generating Station. Generator is to the Left and Turbine to the Right. In the Foreground is the Generator Flexible Coupling Guard
Synchronous Condensing Project for Kansas City Power & Light

SSS Clutch model 280T between gas turbine and generator in Siemens model V84.3A, at Hawthorne Station, Kansas City Power & Light, Kansas City, Missouri. Generator has variable frequency and can be connected to the grid for synchronous condensing without starting the turbine.

Since plant startup in 1997, its capacity has been 170 MW of power and, with turbine stopped and generator functioning as a synchronous motor, a MVAR range of +150 and -87.
Florida Municipal Power Authority, Orlando, Florida, installed two Frame 5 gas turbine generators in 1998 to guarantee 60% of normal power would always be available in Key West. One is equipped with an SSS Clutch as back up to their GE 44 MVA synchronous condenser.

Through 2003, the Frame 5 with SSS Clutch has generated power for 2285 hours and operated as a synchronous condenser for 4660 hours.
Ancillary Markets in the United States. Example - PJM & MISO
Tier II Synchronous (Spinning) Reserve Markets

- Induce response by on-line, marginal resources through compensation
- Introduce competition for spinning capacity
- Compensate providers of spinning capacity on the basis of a clearing price rather than cost
Synchronous Reserve - To support System Frequency

Operating Reserve

• **Primary Reserve** (full power in ten minutes)

  Spinning Reserve (generator must be connected to grid)
  – Tier I—supports system frequency
  – Tier II—responsive to system frequency (PJM and MISO)

  **Quick Start Reserve** (generator not connected to grid, but full power in ten minutes)

• **Secondary Reserve** (Quick start—full power in thirty minutes)

• **Black Start Capability**

• **Reactive Power**
  – Active sources
  – Passive sources
PJM–East: Total Required Spinning & Spinning Provided by Generators Operating in Synchronous Condensing Mode Only

Required Spin Provided by Condensing

MW

Jan-99 Feb-99 Mar-99 Apr-99 May-99 Jun-99 Jul-99 Aug-99 Sep-99 Oct-99 Nov-99 Dec-99 Jan-00 Feb-00 Mar-00 Apr-00 May-00 Jun-00 Jul-00 Aug-00 Sep-00 Oct-00 Nov-00 Dec-00 Jan-01 Feb-01 Mar-01 Apr-01 May-01 Jun-01 Jul-01 Aug-01 Sep-01 Oct-01 Nov-01

- Required Spin
- Spin Proved by Condensing (MW)
PJM East–Average Total Synchronous Condensing by Hour
PJM – Total Condensing Payments per MW per hour

Total Condensing Credits Per MW

$/MW

Economic Justification to Retrofit LM6000 with SSS Clutch to Enable Participation in PJM Tier II Compensated Spinning Reserve Market

- Losses to spin LM6000 with SSS Clutch are less than 500 kW
- Assume $0.06/kWh to purchase power to spin generator
- Therefore, cost in spinning reserve mode ($0.06 \times 500 \text{ kW}) = $30 per hr
- 2002 spinning reserve payment was: $12.00/MW \times 40 \text{ MW} \text{ (rating of LM6000)} = \$480 per hr revenue

- Assume 15 hours per day potential spinning reserve duty
- Therefore $7200 ($480 \times 15 \text{ hr}) per day gross revenue produced and $450 ($30 \times 15 \text{ hr}) per day cost

- POTENTIAL NET REVENUE: $7200 - $450 = $6750 per day
- Assume: cost to retrofit SSS Clutch = $1,000,000
- Return on Investment (ROI): About 148 DAYS
- Conclusion: Pay for investment - Less than one-half year
An SSS Clutch installed between the turbine and the generator enables four machines to qualify for Tier II Spinning Reserve.

Units could be used for Schedule 2 Reactive Power by maintaining the generator synchronized with the grid while the turbine is stationary and on standby.
# Size 260T SSS Clutches Installed in 60 Hz LM6000 Gas Turbine Generator Sets

<table>
<thead>
<tr>
<th>Utility</th>
<th>Location</th>
<th>GT Number</th>
<th>Drawing No.</th>
<th>Serial No.</th>
<th>SSS Ref.</th>
<th>Installation Date</th>
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<td>Grand Prairie, Alberta, Canada</td>
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<td>SL18492</td>
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## Size 260T SSS Clutches Installed in 60 Hz LM6000 Gas Turbine Generator Sets

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<th>Installation Date</th>
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Total Number Size 260T SSS Clutches in 60 Hz LM6000 Gas Turbine Generators, 1999-2013: **33 SSS Clutches**
Completed Retrofit of FT-4 Twin Pac at Great River Energy, St. Bonifacous, Minnesota, now equipped with SSS Clutches between the Generator and the Gas Turbines on either side.
And the other one is inclusion of the SSS Clutch in an “acceleration system”, placed at exciter end of either:

Stand-alone generator

Generators with the coupling between the generator and turbine removed

1) To accelerate the generator to synchronous speed and

2) Disconnect the acceleration system to enable the generator to be used for synchronous condensing
Case Histories

Synchronous Condensing Conversion Achieved by Use of “Acceleration Packages”:

• B.C. Hydro, Vancouver, British Columbia, Canada
• Zion Nuclear Plant, Zion, Illinois, USA
• City Electric System, Key West, Florida, USA
B.C. Hydro, Vancouver, British Columbia, Canada

10,800 MW total
9,700 MW hydro—base
900 MW thermal—peak
140 MW gas turbine
60 MW other generation
B.C. Hydro Burrard Thermal Plant

Four 150 MW English Electric steam turbines and generators prior to installation of synchronous condensing acceleration packages.

Generators used in winter for power generation and summer for synchronous condensing.
B. C. Hydro Burrard Thermal Plant Acceleration System
Synchronous condensing starting package.
SSS Encased Clutch - SSS Starting System Clutch, SSS Turning Gear Clutch, and new generator thrust bearing.
**B.C. Hydro Burrard Thermal Plant**

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<th>4 of 6 x 150 MW Units</th>
<th>Operating Hours (Periods as Indicated)</th>
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<td>Nov/88 to Dec/02</td>
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<td>Synchronous condensing</td>
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**CONCLUSION**

The improved power factor and increased voltage stability across transmission lines as a result of the conversion of these 4 machines to synchronous condensers have allowed:

B.C. Hydro to sell additional MW valued at $100,000 Canadian per machine per day to customers in the U.S. during six months (summer + parts of spring & fall) of the year.
Zion Nuclear Plant: Aerial View of Portable Acceleration Package Arrangement. The result: production of 825 MVAR per machine, for a total of 1650 MVAR, which stabilizes voltage north of Chicago. Both units run in summer at half VAR capacity and one runs in winter.
It became necessary for the company to choose between an increase in costly local generation or an increase in MW import capability from the mainland, 185 miles away.
Stand-Alone Generator Turned Into Synchronous Condenser for Key West - $1 Million annual benefit

Graph of transmission capacity before and after conversion of generator to synchronous condenser. Work was completed in July of 1997.

[Graph showing transmission capacity before and after conversion, with labels for months Jan to Dec and system load range from 100 to 250.]
Stand-Alone Generator Turned Into Synchronous Condenser: the City of Key West

Installation of a new Acceleration System in place of steam turbine at end of 44 MVA hydrogen-cooled generator to permit generator to be used for synchronous condensing at Ralph Garcia Generating Station on Stock Island, Florida.

Completed by GE in January, 1998, it can produce 34 MVAR or absorb up to 22 MVAR.

It enables up to 34 MW additional power to be transmitted from Florida mainland to Florida Keys through existing 138 kV transmission line.

Through February 2004, this unit has operated as a synchronous condenser for 44,952 hours.

$10 million benefit first ten years of service
Acceleration Systems - Information Needed to Design Generator Acceleration System

1. MVA and MW Rating of Generator
2. Speed of Generator
3. Inertia of Generator
4. Generator Rotor Weight and Diameter of all Bearings
5. Do Generator Bearings have Jacking Oil?
6. Is Generator Air or Hydrogen Cooled?
7. Generator Windage Losses at Full Speed?
8. Generator Excitation Losses?
9. Maximum Time Required to Accelerate Generator to Connect to Grid?
10. Details of Shaft End of Generator to Connect to the Acceleration System.
SSS Regional Case Studies - Ecuador

- Transmission Line Grid
- Name and Location of Thermal and Hydroelectric Power Generation Plants
- Current Summary of Leading Candidates for Synchronous Condensing Conversion
- Power Stations Considered for Conversion to Synchronous Condensing Capability
Ecuador Grid System – CELEC ep – Load growth and mix of Country’s generation prior to massive renewable energy investment.
Since 2007, the nation has invested US $4,900MM in its electricity grid, necessitated by a doubling of consumption in the last decade, from 7,904 GW in 2002 to 19,377 GW in 2012.

Ecuador’s hydroelectric potential was developed, with eight major new projects to increase power production from 30% to nearly 93% of consumption with cheap and clean hydroelectric sources by late 2016.

CELEC studied the transmission grid and needed reactive power support in Quito and Guayaquil areas and have converted one Frame 5 and GE has contract to convert two more Frame 5’s and one Frame 6 to Synchronous Condensing by retrofitting SSS Clutches

A Westinghouse W501-D5 and several FT-4 Power Pacs may also be converted
Three Size 194T SSS Clutches installed in Frame 5’s at Termopichincha, Santa Rosa Plant, near Quito

Size 194T SSS Clutch installed in load gear on gas turbine side with quill shaft through Low speed gear to generator
With increasing renewable generation, shutting down of nuclear and coal fired plants, and transmission constraints north to south, power redistribution being considered with addition of peak load gas turbine generators near Manheim with synchronous condensing SSS Clutches.
German National Electric Grid
Opportunities for Reciprocating Engines / Generators

Additional Revenues for Generators:

Generator de-clutched from stationary engine:
- Burns no fuel
- Produces zero emissions
- STILL receives payments for:
  1 - Synchronous Condensing
  2 - Spinning Reserve
  3 - Grid inertia

Generator producing MWe:
- STILL receives payments for:
  1 - Synchronous Condensing
  3 - Grid inertia

Driving Engaged
Producing MWe
(Reciprocating Gas Engine) Clutch Synchronous Generator

Shut down
Disengage
Remains synchronised and spinning
SSS Clutch Company, Inc. Regional Case Studies - Mexico

- Transmission Line Grid
- Name and Location of Thermal and Hydroelectric Power Generation Plants
- Current Summary of Leading Candidates for Synchronous Condensing Conversion
- Power Stations Considered for Conversion to Synchronous Condensing Capability
## Other Candidates for Synchronous Condensing Conversion

<table>
<thead>
<tr>
<th>No.</th>
<th>Central</th>
<th>Lugar</th>
<th>Fecha Visita SSS</th>
<th>Fabricante Turbina</th>
<th>Fabricante Generador</th>
<th>Capacidad MW</th>
<th>Activo/Inactivo</th>
<th>Capacidad MVAR del generador</th>
<th>Conversión propuesta</th>
<th>Beneficio</th>
<th>Observaciones</th>
<th>Equipo solo (SSS) US $</th>
<th>Instalado en US $</th>
<th>Tiempo requerido para completar la obra</th>
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<td>4-6 semanas</td>
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<td>General Electric</td>
<td>37.5</td>
<td>Activo</td>
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<td>Soporte del voltaje</td>
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<td>6 meses</td>
<td>4-6 semanas</td>
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<td>ACEC</td>
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<td>Westinghouse</td>
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<tr>
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<td>Nbuc</td>
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<td>4-Feb-07</td>
<td>Pratt &amp; Whitney FT4C-3F</td>
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<td>Activo</td>
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<td>6 meses</td>
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<tr>
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<td>Mitsubishi</td>
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<td>A</td>
<td>03-126</td>
<td>Soporte del voltaje</td>
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</tbody>
</table>

* - Embague interpuesto entre turbina y generador
**B** - Rique de aceleración a generador solo
*** - Al 24/04/03, había 3 unidades en inventario mundial.
# - Hay muchas unidades en inventario.

- En la actualidad, existe una unidad en stock. Al agotarse, son 7 meses de fabricación. —n.
### Other Candidates for Synchronous Condensing Conversion

<table>
<thead>
<tr>
<th>#</th>
<th>Central</th>
<th>Lugar</th>
<th>Fecha Visita SSS</th>
<th>Fabricante Turbogenerador</th>
<th>Fabricante Generador</th>
<th>Capacidad MW</th>
<th>Activo/ Inactivo</th>
<th>Capacidad MVAR del generador</th>
<th>Conversión propuesta</th>
<th>Beneficio</th>
<th>Observaciones</th>
<th>Estimado de Costo Total</th>
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<tbody>
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<td>+21</td>
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<td>03-126 Soporte del voltaje</td>
<td>Entrega e instalación</td>
<td>$150,000 11 meses 4-6 semanas</td>
</tr>
<tr>
<td>23</td>
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<td>Acapulco, Gro.</td>
<td>25-Mar-07</td>
<td>BB11L - 750</td>
<td>Brown Boveri</td>
<td>14</td>
<td>Activo</td>
<td>+21</td>
<td>A</td>
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<td>Entrega e instalación</td>
<td>$150,000 11 meses 4-6 semanas</td>
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<td>Entrega e instalación &amp; caja de aceite</td>
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</table>

* A - Embrague interpuesto entre turbina y generador
**B - Requisito de aceleración a generador solo
### Observaciones
- A - Embrague interpuesto entre turbina y generador
- **B - Requisito de aceleración a generador solo

---

### Notes
- *A* - Aembrague interpuesto entre turbina y generador
- **B** - Requisito de aceleración a generador solo
- # - Hay muchas unidades en inventario.
- *** - Al 24/04/03, había 3 unidades en inventario mundial.
- - En la actualidad, existe una unidad en stock. Al agotarse, son 7 meses de fabricación. —n.
Retrofit of Size 160FT into Brown Boveri BB11-L at CFE in Monterrey, Mexico – Project won Power Magazine “Marmaduke” Award for 2012

Installation of size 160FT SSS Clutch into BB11-L
Synchronous Condensing Study for CFE, Caborca, Mexico

Visit to CFE, Caborca, Mexico in March 2003 to consider retrofit of SSS Clutch into reduction gear of Westinghouse W 251B-8 to enable synchronous condensing to produce up to 38 MVAR or absorb up to 15 MVAR.
Synchronous Condensing Study for CFE, Ciudad Constitución

Visit to CFE, Ciudad Constitución, in March 2003 to consider retrofit of an SSS Clutch into reduction gear of Fiat TG-20 to enable synchronous condensing to produce up to 25 MVAR or absorb up to 17 MVAR.

SSS Clutch Company also visited CFE, Cancún, to one of the other two Fiat TG-20s in Mexico for possible conversion as well.
SSS Clutch Model 194T proposed for installation in load gear of 30 MW John Brown Frame 6 gas turbine generator for reactive power.

Generator is capable of supplying 35 MVAR or absorbing 15 MVAR @ 15°C ambient temperature.