INTRODUCTION

Most gas turbine generators rely on a mechanical starting system to accelerate the gas turbine generator from zero to some intermediate speed to enable gas turbine ignition and then provide torque assistance to a higher speed until the gas turbine is self-sustaining. In the past, both automatic and non-automatic methods of disconnecting the starting system from the turbine have been used. This paper presents the reasons for and details of the retrofit of automatic synchronous self-shifting clutches into existing starting systems of General Electric MS-5001 gas turbine generator sets at Consolidated Edison Company, Brooklyn, New York.

HISTORY

Consolidated Edison's Gas Turbine Department was formed in the early 1970's and consists of four major gas turbine sites totaling over 100 gas turbine units. These sites contain General Electric and Westinghouse manufactured heavy-duty industrial gas turbine generators and Pratt & Whitney aircraft derivative-type units. This department also has fifteen "satellite" gas turbine units located throughout the service area. All of these gas turbine units were originally installed to supply black start power to the main generating stations in the event a blackout might occur and to provide peak load power generation. The combined output of Consolidated Edison's Gas Turbine Department is over 2,500 megawatts.

The gas turbine units owned by Consolidated Edison are of a simple cycle configuration; no exhaust stack heat recovery systems exist. The units were purchased and installed in the early 1970's because of very high system peak demand relative to their existing capacity at that time and as a result of a major electrical system blackout in New York in 1965. The units were mandated by the Public Service Commission (PSC) when they ruled that Consolidated Edison had to have inner city generation capabilities to sustain system requirements during a system-wide emergency if electrical transmission tie lines importing economical hydro power from Canada were broken. Simple cycle units were the types of units which could be delivered and installed in the shortest period of time and which could be used to meet the requirements.

CONSORTIUM EDISON'S GOWANUS & NARROWS POWER STATIONS

Forty-eight General Electric MS-5001 Model N gas turbine generators operated by Consolidated Edison are mounted on barges floating in New York Harbor at two sites in Brooklyn, New York. These units represent 1,100 megawatts of peaking power for the system and were relied on heavily in the early 1970's to supply peaking power. However, these units have been used less in recent years except for 1989 when New York experienced some seasonal power shortages.

Since these units are utilized for peak load generation, they must be started and on line quickly, typically within 30 minutes. These units take approximately seven minutes to accelerate from standstill to full speed and synchronize with the grid, and an additional four minutes to bring up to full load. These units currently have an average starting ratio of one fired start per two hours of generation. This operating mode causes accelerated wear to the combustion and turbine section components as well as the unit auxiliaries and starting devices. Internal components experience thermal shock due to high-firing temperatures (1,750°F) and the ambient temperature swings of New York Harbor. Improvements in component (super alloy) materials and the application of thermal barrier coatings have helped to reduce, but not eliminate, the effects of thermal cycling.
The jaw clutch shown in Figure 1 (and in more detail in Figure 2) is used to connect the starting diesel/torque converter to the accessory gear in order to start the turbine and to disconnect it when the turbine is above its self-sustaining speed. The jaw clutch has an output half rigidly mounted to the accessory gear input shaft and an input half mounted on straight splines of the torque converter's gear. Only when the entire gas turbine and starting system is stationary should the input half be shifted axially to engage both halves of the jaw clutch using two horizontal servos controlled by a two-position, 4-way actuating valve. A limit switch is used to indicate the clutch position and a zero speed sensor with control interlock prevents clutch engagement and diesel engine start-up if the machinery is rotating.

The design and age of this system lends itself to a variety of problems, all of which hamper a successful start-up when generation is required. Specifically, the following are typical start-up problems associated with the jaw clutches:

1. Due to wear on the splines, the jaw clutch may not slide on the torque converter shaft splines and therefore does not engage.
2. The jaw clutch face does not engage properly due to wear.
3. The gas turbine control system does not have the required permissive to start because the limit switch (which indicates clutch position) is grounded, open, or has moved out of position due to vibration or clutch hang-up.
4. The jaw clutch does not engage because the hydraulic pistons are leaking (not holding) or have sheared off due to misalignment.
5. The jaw clutch does not disengage and the start must be aborted.

In addition to these scenarios, the jaw clutch arrangement has one additional operational drawback. If the gas turbine start-up is aborted for any reason (loss of flame, vibration trip, high exhaust temperature, etc.), the unit cannot be re-started until the gas turbine rotor comes to a complete rest (zero rpm). The time delay could exceed fifteen minutes if the gas turbine trips close to its full speed of 5,100 rpm.
RETROFIT JUSTIFICATIONS

Consolidated Edison studied their jaw clutch maintenance costs during the period of May, 1990, to June, 1992, as well as the cost of repairing and/or replacing jaw clutches and associated components. They also considered the advantage of being able to re-start the gas turbine at speed. In their evaluations of a potential retrofit, a re-start at speeds up to 500 rpm gas turbine speed was determined to be of significant benefit as the turbine speed drops from 5,100 rpm to 500 rpm relatively quickly, but the majority of the time to decelerate to zero speed occurs below 500 rpm.

During this two-year period, Consolidated Edison spent 96 hours performing annual preventive maintenance checks on jaw clutches (an average of one hour per unit per year for 48 gas turbines). An additional 769 hours during this period was spent trouble shooting and/or replacing jaw clutch components as a result of 37 turbine trips or failures to make power. The approximate direct annual cost of this preventative and actual maintenance exceeded $40,000 per year. These costs, however, did not account for the cost associated with loss of power generating capability of these affected units.

Efforts to reduce the possibility of failed starts and the time required for a re-start have resulted in the removal of the original jaw clutch hardware, the installation of a synchronous self-shifting clutch, and a modification to the GE Mark I Speedtronic controls to permit a re-start of the gas turbine at speeds up to 500 rpm.

SYNCHRONOUS SELF-SHIFTING CLUTCH BASIC PRINCIPLE

The synchronous self-shifting clutch is a freewheel-type overrunning clutch which transmits torque through the full surface contact of surface-hardened, involute-shaped, gear coupling teeth. Unlike the jaw clutch, this clutch engages and disengages automatically. No external control or actuation is required, since clutch engagement is automatic and takes place only when the input is at the same speed as the output.

On start-up, the clutch engages automatically to drive the turbine generator and disengages automatically when turbine speed exceeds that of the starting gear. When disengaged with the clutch output at full speed and the starting engine at rest, there is no mechanical contact between the clutch input and output. If needed, a re-start of the gas turbine can be done without waiting for the generator to be stationary.

By installing a synchronous, self-shifting clutch, the following items can be eliminated:

- The jaw clutch and its associated guard.
- Actuating cylinders used to engage the jaw clutch.
- The two-position, four-way valve used for cylinder actuation.
- Switches to prevent diesel start unless the jaw clutch is engaged.
- Zero-speed sensor and interlock.

The principle of operation of the synchronous self-shifting clutch can be seen in Figure 3. When the speeds of the clutch input and output pass through synchronism, the pawls on one clutch element engage with ratchet teeth on the other to phase the teeth precisely for inter-engagement. Further shaft relative rotation causes the pawls to provide the small force to move the sliding component along helical splines, thereby engaging the driving and driven clutch teeth smoothly and positively.

The pawls do not transmit any driving torque because they move out of contact with the ratchet teeth by axial movement before the clutch teeth have shifted into full driving engagement. The clutch completes its travel when the sliding component moves against a shaft abutment and then full torque passes through the helical splines and the fully engaged clutch teeth. As soon as the clutch input speed reduces relative to the clutch output speed, the clutch automatically disengages due to the reversal of torque on the helical splines.

To enable the clutch to engage at low and high speeds, but prevent sustained ratcheting action of the pawls with the clutch output at speed and the input stopped, primary and secondary pawls (PRISEC) are used (not shown in Figure 3).

The primary pawls are mounted on the clutch sliding component which is mounted on the clutch output. These pawls are spring-loaded into engagement with ratchet teeth in the bore of the input component. Unbalance relative to the pawl central pivot pin enables the primary pawls to retract from the ratchet teeth due to centrifugal force when the output exceeds a predetermined speed; usually about 500 rpm.
The secondary pawls, which are mounted on the clutch input and engage with ratchet teeth on the sliding component, are used to engage the clutch in the high-speed range; that is when the clutch input accelerates to the same speed as the output. Unbalance relative to the pawl central pivot pin gives the pawl centrifugal movement toward the ratchet teeth when the input rotates. However, when there is high relative speed between the pawls and ratchet teeth, the pawls skim on the oil within the clutch until the differential speed between input and output is small.

With PRISEC pawls, both sets of pawls are inert when the clutch output is rotating at high speed and the clutch input is at rest or at low speed.

**RETROFIT OF SYNCHRONOUS SELF-SHIFTING CLUTCH**

Although there is only 1.312 inches axial space between the end of the torque converter gearbox output shaft and the input shaft of the accessory gearbox, retrofit of the synchronous self-shifting clutch, as shown in Figure 4, was not difficult because the respective shafts were relatively long and there was no existing turbine auxiliary equipment in close radial proximity which might interfere with the new clutch. Actual jaw clutch removal and new clutch retrofit is relatively easy since the original offset torque converter gearbox is still utilized and therefore the starting system does not need to be moved for the retrofit. The torque converter gearbox is rotated 90° on its mounting spigot to achieve axial access to each respective clutch mounting shaft. Shaft end mounting holes were drilled and tapped in each shaft end with the machinery in place. Prior to the new clutch installation, a re-alignment of the diesel/torque converter to accessory gear was done and the torque converter and its gearbox were dowelled together to help maintain future alignment.

The new clutch output sleeve is mounted on the existing accessory gearbox input shaft, the clutch sliding component with main torque transmitting teeth is mounted on the clutch output, and both are contained by an end plate bolted to the shaft. The clutch input hub is rigidly mounted to the existing torque converter gearbox shaft and retained with an end plate bolted to the shaft. Mounting either of these clutch components with a shrink fit was not attempted due to the uncertain degree of wear on the respective shaft splines.

The synchronous self-shifting clutch is oil lubricated whereas the jaw clutch needs no lubrication. The jaw clutch guard and servos were removed and replaced with an oil tight horizontally split clutch cover. A one-piece adaptor plate is bolted to the accessory gear in place of a labyrinth seal and the cover with input end floating seals is cantilevered from this adaptor plate. An oil feed connection is provided on this plate for the 2 U.S. gpm ISO 32 turbine oil provided from the existing accessory gear supply. A drain in the bottom of the cover was connected to an existing accessory gear drain pipe. A proximity switch is provided to indicate when the clutch is engaged and to give a control signal when the clutch disengages so that the diesel can be shut down.

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The clutch was initially designed to incorporate an input shaft disc brake to hold the torque converter/gearbox output shaft stationary against the 1 ft lb viscous torque which occurs when the clutch is disengaged and overrunning at 5100 rpm. This brake, however, proved to be unnecessary and will not be installed on future units. One of the Size 64T synchronous self-shifting clutches for the MS-5001-N gas turbines installed at Consolidate Edison, Gowanus Power Station is shown in Figure 5.

Figure 4. Size 64T SSS Clutch in Casing for MS-5001-N Gas Turbine Starting Drive

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MODIFICATIONS TO GAS TURBINE CONTROLS

The forty-eight GE MS-5001-N gas turbine generators at Consolidated Edison use a GE Mark I Speedtronic control system. In the event that an initial attempted start has been aborted and in order to re-start the gas turbines at speeds up to 500 rpm utilizing the synchronous, self-shifting clutches, the control systems have had to have the following alterations:

1. An additional speed pick-up Speedtronic control card is added to give the control system a signal when the gas turbine is at or below 500 rpm.

2. A modification is made to the permissive circuit to allow a re-start at up to 500 rpm.

3. A provision is made so the unit can automatically change to quick start mode to eliminate the normal three-minute warm-up cycle for the starting diesel engine.

4. The circuit wiring for the clutch starting solenoid (CS Control Wire No. 20) which previously activated the jaw clutch is removed. The wiring for the hydraulic ratchet turning gear is not altered.

5. The zero speed sensor (Control Wire 14-HR) is eliminated to permit re-start of gas turbine at speed without first engaging the hydraulic ratchet.

6. The clutch starting circuit (CS Control Wire No. 30) which previously was used for a limit switch to indicate when the jaw clutch was engaged is re-allocated for a limit switch for the synchronous, self-shifting clutch to provide a signal and light a panel lamp when the clutch is engaged. More importantly, this same limit switch also signals when the clutch automatically disengages so the diesel can be shut down.

BENEFITS AND FUTURE IMPROVEMENTS

To date, three clutches have been installed and are currently in operation. Additional clutches are in production to be installed in 1993. The first of the new clutches has successfully operated for approximately one year and they all have allowed automatic turbine re-starts at approximately 500 rpm.

The benefits realized with the new synchronous self-shifting clutch are:

1. Improvement in gas turbine generator starting reliability.

2. Reduced annual preventative maintenance efforts and cost.

3. Reduction in trouble-shooting and corrective action efforts.

4. Capability to reduce time needed to respond to system requirements for a "quick start" in the event a first attempt to start is aborted.

Since initial installation, refinements in the synchronous self-shifting clutch design for General Electric MS-5000 gas turbine generators have been made and a similar clutch has now been introduced to suit accessory gear shafts with either external splines or keyways. A clutch with axial shaft spacing of .530 inch for later model MS-5000 and MS-6000 units is now available and being supplied.

CONCLUSION

This new synchronous self-shifting clutch design is based on more than thirty years of application experience in similar industrial gas turbine starting drive systems as well as thousands of gas turbine main drive disconnect applications in power generation and marine applications. The synchronous self-shifting clutch installed in place of the servo-actuated jaw clutch in General Electric MS-5001 units is, however, the first in the industry in this type of gas turbine generator. The conversion will continue at Consolidated Edison until all barge-mounted gas turbine units have received this new starting arrangement and all the benefits associated with it and it is a candidate for both existing and all future MS-5000 and MS-6000 gas turbine generators.

REFERENCES

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