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# Turbine Generator Sets 101

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## Basic turbine generator set information

The most basic, easiest form of energy savings is to recoup electricity costs by burning something. This can be a fuel byproduct of the item being made (example, wood waste from a furniture maker), waste products (oil from auto or truck fleets), biomass products (sugar cane bagass or cornstocks), or even more exotic burnable things such as glycerin from biodiesel plants or flammable gases from petrochemical operations.

Energy costs are also decreased by utilizing steam turbines in place of pressure reducing stations in high pressure steam systems where plant process equipment requires lower pressure steam. Many plant processes require heat and/or steam, and in installations where high pressure steam is made (150 psig and up), and the process requires lower pressure steam (say 15 or 20 psig), a steam turbine can be installed in place of a pressure reducing station. The turbine acts the same as the pressure reducing device, and the energy removed from the steam is converted to mechanical energy in the turbine, which can then drive a generator.

Other energy costs saving similar to the manufacturing plant application can be seen in large institutional buildings where steam is used for heat, cooking, or air conditioning. High pressure steam can be distributed to a college campus for example, and at key points steam turbine generator sets can be installed as pressure reducing devices, and electricity generated for use on the campus. Eighty years ago, virtually all hospitals utilized the old reciprocating steam engines in their powerhouses to do exactly this type of energy production. (Back then, the concern was to simply make reliable power yourself, rather than save utility costs.)

A summary of this can be explained this way: The “fuel” was paid for once (lumber for the furniture maker, engine oil for the truck fleet, or gas or coal for the college heating system). The savings is in the “free” fuel, in that the waste lumber was already bought and paid for to originally make furniture, but the residual waste can be used in the boiler; the oil was purchased as a lubricant and is now used in the waste oil burner; and the gas or coal was purchased primarily for heating the school and the turbine replacing the reducing station is using “free” steam. It’s a matter of what you pay for the fuel costs and why and how you look at the application.

This should not be confused with the most efficient way to produce power, irregardless of cost. From an engineering standpoint, and practicality of the system, the easiest way and most efficient means of producing electricity is to use a standard combustion engine (diesel, gas, or natural gas). The energy in the fuel is more or less directly converted into power. Fuel in, power out, a little bit of heat as a byproduct. Since it is this simple, the total “package” is quite efficient.

With a system utilizing a steam boiler, there are energy losses in heating the steel in the boiler, the water, the piping and valves, the steam turbine, what to do with the exhaust or condensate (condenser equipment), the associated equipment costs (pumps, fans, foundations), operating considerations (chemical treatment of the water, ash residue, and air quality equipment), fuel source and handling, and labor costs to make these items work.

The limited type of fuels available to use in a combustion engine is its downfall. It’s costly and it is limited to what is available in a burnable medium (natural gas or a good quality liquid such as diesel. The boiler on the other hand, can burn just about anything, and that is what the appealing factor is in the long run. No one has yet made a diesel engine capable of burning a piece of a wood pallet or corn stock.

## General Steam Turbine Design

### Standard Nomenclature

Steam Turbine: prime mover, which converts the thermal energy of steam directly into mechanical energy of rotation.

Noncondensing Turbine: steam turbine designed to operate with an exhaust steam pressure equal to or greater than atmospheric pressure.

Condensing Turbine: steam turbine designed to operate with an exhaust steam pressure below atmospheric pressure.

Steam Turbine Stage: consists of a "matched set" of stationary nozzles and rotating blades. A pressure drop occurs in a steam turbine stage generating kinetic energy which is converted to mechanical work.

Impulse Stage: consists of stationary expansion nozzle(s) discharging the high-velocity steam jets on the rotating blades. A pressure drop occurs only in the stationary nozzle(s). Impulse stages consist of two types:

Pressure Impulse or Rateau Stage: consists of stationary expansion nozzle(s) and one row of rotating blades.

Velocity-Compounded Impulse or Curtis Stage: consists of stationary expansion nozzle(s) and two or more rows of rotating blades.

The pressure drop across a Rateau stage is relatively low in comparison to the pressure drop across a Curtis stage.

Reaction Stage: consists of stationary expansion nozzle(s) discharging high-velocity steam jets on the rotating blades. A pressure drop occurs in both the stationary and rotating elements.

Note: Rateau stage and reaction stage are normally applicable only to multistage turbines.

Single-Valve Single-Stage Turbine: steam turbine, which has one governor-controlled valve and one stage.

## Common Types of Steam Turbine Generator Sets

The most common type of turbine manufactured since its origins is the impulse type single stage turbine. It is also the most economical unit manufactured.

The single stage impulse turbine takes the inlet steam, and through a nozzle, expands the steam while increasing its velocity. It does this one time, hence the term single stage turbine. In the simplest explanation of how this works, the inlet steam goes into the turbine, expands through the nozzle, the steam impulses on the turbine wheel, configured somewhat like an old water wheel or fan, makes the power, and exhausts out the case at the exhaust pressure.

It does this one time, with one pressure drop across the turbine, very similar to a pressure reducing valve.

In a multistage turbine, there are a number of these inlet, expansion, exhaust chambers, which produce a much better use of the steam, but at a penalty of cost. A relatively inexpensive single stage turbine rated at 800 HP may cost $ 50,000. A multistage turbine in that range may cost upwards of $ 400,000 or more. A good rule of thumb to consider is a 1 MW single stage turbine generator set (basic package) may cost $ 325,000; a comparable 1 MW multistage turbine may run as high as $ 1.5 million or more.

Current installed project costs of even small multistage turbines are currently estimated at 1.25 - 1.5 million dollars per megawatt. As you can see, single stage turbines are much less expensive to purchase. They are simply less efficient, and limited in the actual horsepower output they can achieve, usually at a maximum design potential of 3000 HP.

## Turbine Operating Conditions in a Single Stage Turbine

The heart and soul of any steam turbine generator installation is the steam conditions and power output that must be matched together. In most cases where existing steam plants are utilized, the inlet pressure is already determined by the boiler. Typically, most boilers are rated at 250 psig, a fairly common number. Some applications can use steam pressures as low as 80 psig, while other more specialty applications may see pressures of 400, 600, or even 900 psig. The inlet pressure of the steam is the first factor in the term ***TURBINE OPERATING CONDITIONS***.

The second part of these conditions is the temperature of the steam. This again is a function of the boiler. For most applications, this will be the saturation point at the operating pressure. For example, a 250 psig boiler has a steam temperature of $406^0$ F. At 300 psig operating pressure, the steam temperature is $422^0$ F.

Temperature can be increased in the steam by applying superheat to the boiler. Essentially, this is simply creating a higher than normal steam temperature. By adding $100^0$F superheat to 300 psig steam, the temperature would then be $522^0$F.

The third consideration in turbine operating conditions is the exhaust pressure, the pressure at which the steam will leave the turbine. This is usually predetermined by the facility. The majority of plants operate steam process equipment anywhere from 5 psig to as much as 175 psig. The norm is usually closer to 50 psig, more or less.

The more the plant needs heat in its processes, the more likely the exhaust pressure from the turbine will be higher rather than lower. For the most part, few plants require exhaust pressure above 100 psig, but certain applications do.

From a design point, and practicality of the turbine design, exhaust pressures are limited to about 175 psig no matter what, and, usually limited to certain size models. This is an engineering criterion, in that it would be very impractical to build a large single stage turbine with a very high backpressure. It would simply not work.

The fourth part of the turbine operating conditions equation is the speed the turbine needs to run at.

Depending where you live in the world, many turbines have one of these operating speeds: 1500 rpm, 1800 rpm, 2900 or 3000 rpm, and 3600 rpm. These numbers correspond to standard electric motor speeds.

The exceptions are if the driven equipment needs to operate a different speed, or if the driven equipment requires a gear reducer for the turbine to produce the horsepower or efficiency. Again, the rule of thumb is the faster the turbine rotates, the higher the horsepower and the less steam it takes to make that horsepower. For example, in the synchronous generator applications, 1500 or 1800 rpm generators are standard, are the most cost affective speed for generators, and cannot be engineered to operate at higher speeds. The turbine may require a speed of 4000 rpm to not only be efficient, but must run at the high speed to make the horsepower.

Induction generator sets are either 1500/1800 rpm or 3000/3600 rpm. The difference in generator types will be explained shortly.

The turbine speed where the unit is direct coupled to the generator (or pump), will be determined by the driven equipment. If the pump needs 3600 rpm, the turbine will be built for 3600 rpm. In applications where a gear reducer is warranted, Skinner will pick the turbine speed for the most efficient use of the steam.

The fifth and last turbine operating condition that needs to be determined is horsepower. This again is a requirement of the driven equipment stating a horsepower rating, or what amount of steam is available to convert into horsepower. For example, a generator rated at 500 Kwe will require 27603 #/hr of steam at 300 psig, 500$^0$F inlet temperature, 50 psig exhaust, and a speed of 3830 rpm. If the plant boiler can only produce 15000 #/hr of steam at 300 psig, 500$^0$F inlet temperature, 50 psig exhaust, and a speed of 3830 rpm, the turbine will only produce 367 HP or 260 Kwe.

The operating conditions a turbine must operate in and the amount of steam required to meet the desired output is the balancing act the turbine manufacturer must perform. The efficiency of how well we do accomplish this is what determines the size of the turbine, speed, controls, and encompasses the engineering package of any turbine. Some are simple to determine, others may have many considerations.

The five basic operating conditions and how they eventually relate to the system is one of the primary aspects of determining how much the turbine will cost.

Recapping, the five turbine operating conditions are:

Inlet pressure in psig
Inlet temperature in degrees F
Exhaust pressure in psig
Speed in rpm
Horsepower or Kw output

## Induction versus Synchronous Generator

In the most simplistic explanation of an induction generator, consider it nothing more than a standard electric motor being driven by a steam turbine. If the motor is rated at 3600 rpm, the turbine simply drives the motor a few rpm higher (3610 rpm for example), and the motor now becomes a generator.

In operation, the turbine is started and run up to a speed of a few rpm less than 3600 rpm. The motor is actually put on line as a motor, which brings the speed of both to 3600 rpm. The motor is now drawing power from the plant electric system. The turbine speed is slowly brought up, and at just a few rpm above the 3600, the motor is now making power instead of consuming electricity. Think of this as the electricity flowing in the opposite direction.

The advantage of an induction generator is it is simple to operate, simple to install, controls and safety devices are much less, and is a good application for peak shaving of the electric bill. The disadvantage of the induction generator is that is must be connected to the local utility grid (incoming power), to operate. The frequency synchronizing of the electricity is accomplished by the external power source. If there is a utility outage outside the plant, the motor will not operate and will not generate power. There must be outside power for this to work, so any application of using an induction motor as a backup generator is not possible.

The synchronous generator is a true stand alone machine. You only need to synchronize with the grid when you are sharing power. The synchronous generator requires no external matching of frequency, voltage, nothing. You can be your own island or independent utility if you want. Synchronous generators are a little more expensive, but the real added costs are in the controls and safety devices. Since this type of generator is totally separate from the utility, safety devices are mandated by your local utility to prevent any electricity generated in your facility to be sent into their power grids during outages. This prevents the accidental electrocution of linemen who may be working on power lines in your area.

Up to about 250 kW, synchronous generators are available in 1800 and 3600 rpm speeds. Above 250 kW, and the only models available are 1800 and below. 3600 rpm generators are referred to as 2 pole machines, 1800 rpm generators are 4 pole machines. Poles refer the electric wiring internally on the generator. The higher the number of poles, the slower the speed of the generator.

## Technical Explanation of Induction vs. Synchronous Generator Operation

### A. Synchronous Generator

Frequency control is applicable to the initial startup of the turbine-generator. The speed must be such that the frequency is correct, or the same as that of the electrical system (synchronized) before the generator is connected to the electrical system.

It is then applicable to an "operating" turbine-generator only when the electrical system is independent of any other electrical system and a single turbine-generator is providing the electrical power.

A NEMA Class D speed-governing system is generally considered appropriate even for stand-alone units.

Power generated control is applicable for turbine-generators operating in parallel with an electric utility type electrical system, or one or more synchronous generators with any type of driver.

The frequency is maintained by the utility. After the turbine-generator has been synchronized with and connected to utility, the generator speed is fixed, i.e., the generator cannot rotate at a speed other than that corresponding to the frequency of the electric utility system.

The speed-governing system can then control the torque developed by the turbine only by varying the power developed by the turbine. Closing or opening the governor valve will still decrease or increase, respectively, the steam flow through the turbine and, therefore, the power developed.

The function of the speed changer is to permit changing the electrical power output of the turbine-generator. Adjusting the speed changer for a higher speed will result in the governor valve opening. The amount the governor valve opens is a function of the speed regulation characteristic of the speed-governing system.

When a turbine-generator is operated in parallel with another generator(s) with any type of driver, the electrical system frequency is normally controlled by only one of the units - the unit with the most precise speed-governing system. The other unit(s) will then furnish electrical power as required through the adjustment of the speed changer(s).

A NEMA Class C speed-governing system is appropriate. It provides sufficient regulation to obtain proper positioning of the governor valve; and is accurate enough for ready synchronization.

B. Induction Generator

The speed-governing system must control the speed precisely above a value corresponding to the frequency of the electric utility system to which it is connected. The power generated is a function of the speed of the generator.

A NEMA Class D speed-governing system is recommended.

C. Standby Turbine-Generator

Turbine-generators can be required for emergency or standby service in the event of disruption of the normal electrical power supply. The Class of governor should be a function of the electrical equipment to be supplied during a power outage and the resultant frequency control required.

A NEMA Class D speed-governing system should be considered.

## Project Scope

The typical plant steam turbine generator system requires the minimum hardware requirements:

Steam Boiler
Steam Boiler Accessories (stack, plumbing, foundations, monitoring equipment)
Fuel Source
Fuel Handling Equipment
Steam Turbine Generator Set
Electrical Switchgear Package
Condenser or Makeup Tank if a closed loop system to return water to boiler
Piping
Valves and Safety Devices on Piping

This is only a partial list of what may be required at any particular site. It would be a worthwhile endeavor to utilize local engineering firms for determining specific details.

The steam turbine generator set is actually one of the least expensive items in this list. By far, the boiler is the most expensive piece of hardware. The second most expensive item is the installation costs for this equipment.

## What Is Required By Your Application

Every customer and potential customer who contacts us is either at the beginning of the process of considering installation of a steam turbine generator set (what do I need) or the end (what I want).

To get to either point, we need to know the following:

Boiler Conditions – We do not manufacture boilers. A boiler company can tell you what is possible from your fuel source, or can tell you what your present boiler can produce. The boiler manufacturer will need to address what accessory equipment needs to be in place (fuel handling equipment, stack requirements, etc).

If you presently have an existing boiler, this process is shortened considerably. The size of the turbine generator set is determined by what you have. We simply need to know the pressure (psig), temperature (F), and the exhaust pressure you need or require.

If you do not have a boiler presently, the process gets quite a bit longer. Based on your fuel source, the boiler maker will be able to provide you with sizing based on how much fuel you have available. The BTU's produced by the fuel will allow them to size the boiler, based on pressure, temperature, and flow. For example, if you have 8 tons of day of burnable waste, the boiler can be sized at low pressure and temperature (150 psig) which will produce a high flow of steam, or can be sized for a higher pressure (300 psig), but at a lower flow ( in pounds per hour). By working with the turbine builder, the best overall combination of pressure, temperature, and flow can achieve the best turbine selection for your application, taking into account turbine efficiency and turbine costs.

At the end of the boiler selection process, we need to know from you what pressure steam (psig), temperature of the steam, what the steam flow is (pounds per hour), and what your exhaust pressure requirement is. By working with a boiler designer and Skinner, we can achieve a practical boiler size for application with a steam turbine generator set.

Plant Electrical Characteristics: The kind of voltage (480V, 2400V, etc.), frequency (60 Hz), phases (single or 3 phase), and any other information available.

Type of Generator: Induction or Synchronous: The key question is if there is a desire to operate the turbine when the local utility is down. If you want to operate a turbine generator set during a utility outage, you must have a synchronous generator.

Electrical Switchgear Package: These are the controls that tie the turbine gen set into your plant, taking into account your internal buss, the utility requirements for safety, and just what you want the controls to do. The switchgear can be simple or complicated. We traditionally avoid switchgear packages with our equipment, due to the local requirements in your location. The switchgear is best left to your local electrical contractor to supply. Since the controls on a diesel engine gen set are frequently the same type used on steam turbines, a contractor familiar with diesel gen set installations (hospitals use diesels as emergency backup sources) will be of great help in your project.

A good general contractor or engineering firm can design the necessary piping for your installation. Again, local building codes will dictate many of the details you will need to address.

The design firm can also be of great help in the overall plant steam system design. If you require a condenser, they can provide options on the most efficient type, location, interconnection, and operating details.

The general contractor will also address installation of the components.

## What Does This Mean in Savings

The one issue you want to know is what is this going to save me in electricity costs.

A simple 100 kw turbine gen set does not seem that big, and you may not think of 100 kw in relation to a dollar figure. Analyze it this way:

If you were a large plant that had steam available to install a 100 kw generator set, and produced 100 kw constantly for year, the avoided cost of purchased power (what you didn't need to buy) is:

100 kw (amount of power producer per hour) x 24 hours per day x 365 days =
876,000 kw/hrs of electricity produced in one year X your current electric rate
(for example: $ 0.12/kw-hr). That equals 876,000 x .012 = $ 87,600.00 savings per year.
If the electric rate is less, your savings are less per year; if the rate is higher, it's a greater savings.

A turbine has a typical lifespan of 40 to 50 years. Installation of a turbine generator set can easily pay for itself in a few short years, in many times, less than 2 years if you have an existing steam plant.

This was an example of a small 100 kw gen set. If you have the steam capacity to generate 1000 kw electrical savings could be in the neighborhood of a million dollars a year.

Typically, in facilities where the capacity to make electricity is greater than the internal requirement of the plant, excess electricity can be sold off to the utility. In most circumstances, the electric company will purchase electricity from your plant at a considerably lower cost than your current purchased price. The real savings is still in avoided costs, not the revenue from selling to your utility.

## Summary

The task at hand for most potential turbine generator projects is getting a good handle on just what is necessary to make the system work as anticipated. A very good local contractor can provide you with the various engineering requirements for your facility. Once we have the particulars on your steam conditions and utility requirements, we can provide you or them with recommendations on how best to proceed, and pricing to meet your budget.