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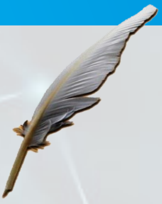
Editor's Note..



The editors are very pleased to introduce this 36th issue of this magazine that include three excellent articles that I would hope that they will be appreciated by the interested readers.

As much as we are excited to publish this issue to you, we are also in great despair to do this for the first time since the magazine launching in May 2012, without the name of the founder and father of this magazine who left the magazine and PGESCo late 2020. After a long journey of 9 years full of science, engineering and academic added value to PGESCo and to the Magazine.

On behalf of the entire community of PGESCo Engineering Magazine editorial board, its Authors and Readers, we would like to thank the outgoing chief editor and co-founder, **Dr. Mohamed ElBanhawy** who deserves a big round of applause and recognition for the enormous time and effort he has invested in this Journal, encouraging its growth and quality. We will miss Dr. El-Banhawy professionalism, empathy and technical strength and let's wish him all the best for his future endeavors.

The First paper by **Dr. Wael Youssef** and **Eng. Mohamed El Nady** is titled "*Experiences with Differential Protection for Three Single Phase Power Transformers Connected In Delta-Wye With Current Transformers Inside The Delta*" the white paper presents the appropriate connection of current transformers that used in differential protection function for bank of three single-phase power transformers with CTs inside transformer delta by using one CT or Two CTs. The configuration of this differential protection scheme has been tested in a three thermal power plant (Abu Qir, Sokhna, Suez, Cairo West, and Assiut) power transformers with two different manufactures relays.

The second article is by **Eng. Ahmed Ali** is titled "*Hydrogen Thinking (Production, Distribution and Economics)*" gives more insights in a simple way, about the process to produce hydrogen economically and in environmentally friendly ways.

The third article is by **Eng. Ahmed Essam** is titled "*basic introduction for Heat Recovery Steam Generators (HRSG)*" the article is an introduction to HRSG system and illustrate the design concept, operation, process, and different type including selection based on application.

I hope that you enjoy reading these articles, until our next issue after three months.

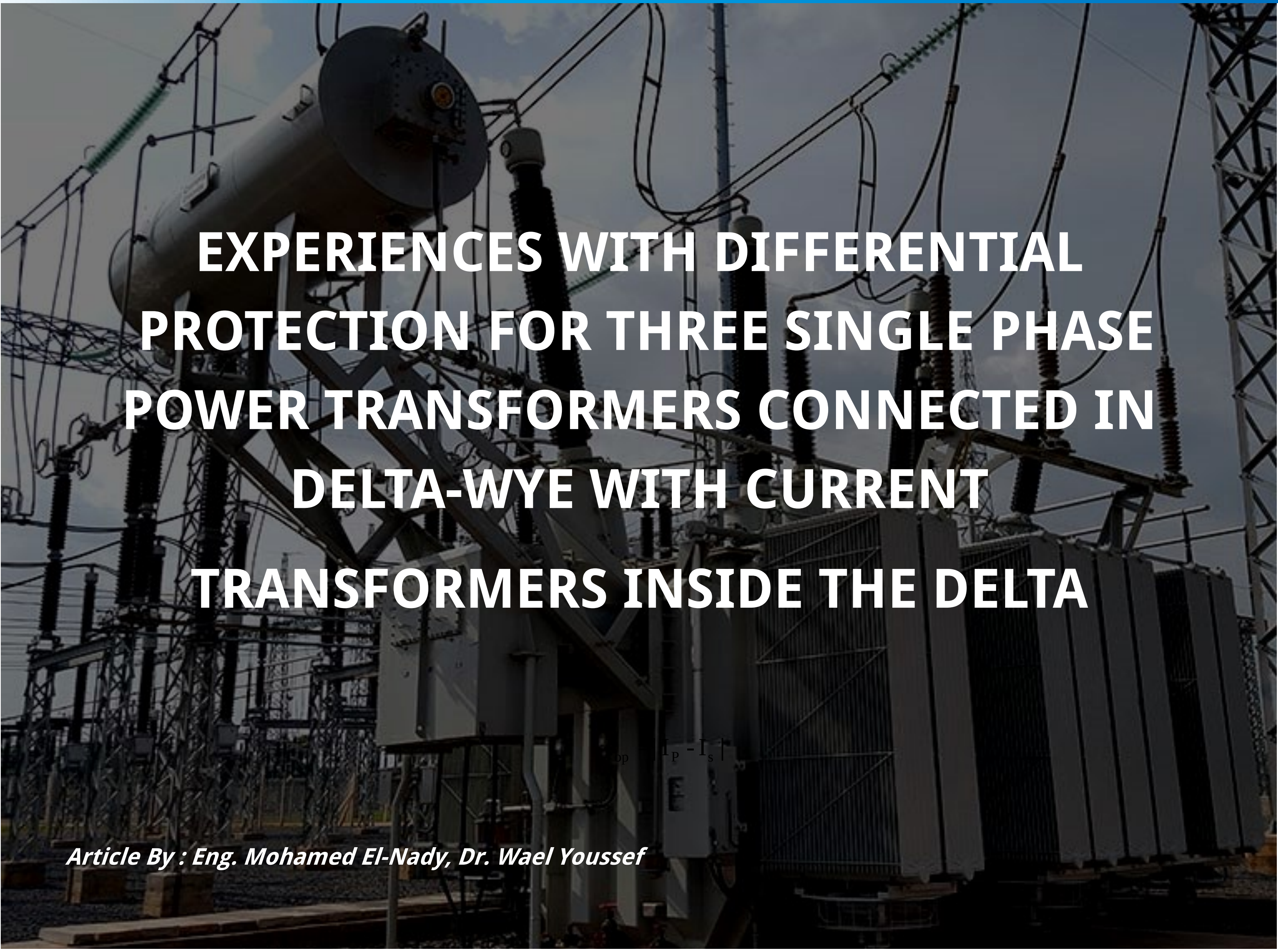
I'll be glad to hear your opinion, and expect your contributions in our next issues.

Dr. Wael Youssef

In This Issue

The Magazine Cover about

>>>> HEAT RECOVERY STEAM GENERATORS (HRSG)



EXPERIENCES WITH DIFFERENTIAL PROTECTION FOR THREE SINGLE PHASE POWER TRANSFORMERS CONNECTED IN DELTA-WYE WITH CURRENT TRANSFORMERS INSIDE THE DELTA

$_{op} \quad |I_P - I_s|$

Article By : Eng. Mohamed El-Nady, Dr. Wael Youssef

Abstract—This Article presents the appropriate connection of current transformers that used in differential protection function for three single-phase power transformers with CTs inside transformer delta and how the setting of microprocessor relays can be configured to make the secondary currents to the relay- restraint windings are in phase for through load or any external fault. The configuration of this differential protection scheme has been tested in Abu Qir thermal power plant 650MW, 500/24 KV generator power transformer. It's proved that the differential protection scheme can be possible and also this scheme can be modified to get fully differential protection function of three single-phase transformers as per the illustration inside this article.

Index Terms— Differential protection, power transformer

I. Introduction

Large power transformers are very expensive and vital components in electric power systems. Therefore, it is very important to minimize the frequency and duration of unwanted outages, that results in a high demand imposed on power transformer protective relays; this includes the requirements of dependability associated with no mal-operations, security associated with no false tripping, and operating speed associated with short fault clearing time to avoid extensive damage and/or to preserve power system stability and power quality. [1]

Three characteristics generally provide means for detecting transformer internal faults. These characteristics include an increase in phase currents, an increase in the differential current, and gas formation caused by the fault arc. When transformer internal faults occur, immediate disconnection of the faulted transformer is necessary to avoid extensive damage and/or preserve power system stability and power quality. Three types of protection are normally used to detect these faults: overcurrent protection for phase currents, differential protection for differential currents, and gas accumulator or rate-of-pressure-rise protection for arcing faults.

The traditional method of conventional differential protection scheme is based on the currents through the differential relay-restraint windings should be in phase, and there should be a minimum difference (operating) current for load and external faults. Ideally, this difference should be zero, but with different CT ratios on the different voltage levels; practically, this is usually impossible [2].

II. Differential protection

Differential protection is widely applied on power transformers protection, buses protection, large motors, generators protection and transmission lines protection. Considering power transformers above 10 MVA, the percentage differential relay with harmonic restraint is the most used protective scheme. A percentage differential function is applied to the fundamental component of the currents to decide whether an internal fault has occurred or not. It converts the primary and secondary currents to a common base and compares the operating current with a restraining current. The difference between the operating and restraining currents is small for normal operating conditions and external faults, while it becomes significant during internal faults [3].

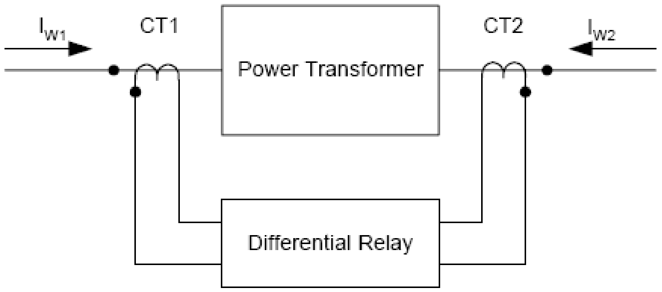


Fig. 1 Typical Differential Relay Connection Diagram.

The operating current of percentage current differential protection can be obtained by:

$$I_{op} = | I_P - I_s | \qquad (1)$$

Where: IP and IS are the primary and secondary currents respectively. The restraining current, Irt in most common modes can be obtained by:

$$I_{rt} = k \, | I_P + I_s | \qquad (2)$$

Where: k is a compensation factor, usually taken as 1 or 0.5.

The differential relay generates a tripping signal if the operating current, Iop, is greater than a percentage of the restraining current, Irt as follows:

$$I_{op} > SLP.I_{rt} \qquad (3)$$

Where: SLP is the straight line defining the relay minimum pickup current. The relay operating region is located above the SLP characteristic (Equation 3), and the restraining region is below the SLP characteristic. Digital differential protection relay uses Discrete Fourier Transformation (DFT) filtration to extract Iop and Irt fundamental differential current every sample using the above equation [2]. [4,5]

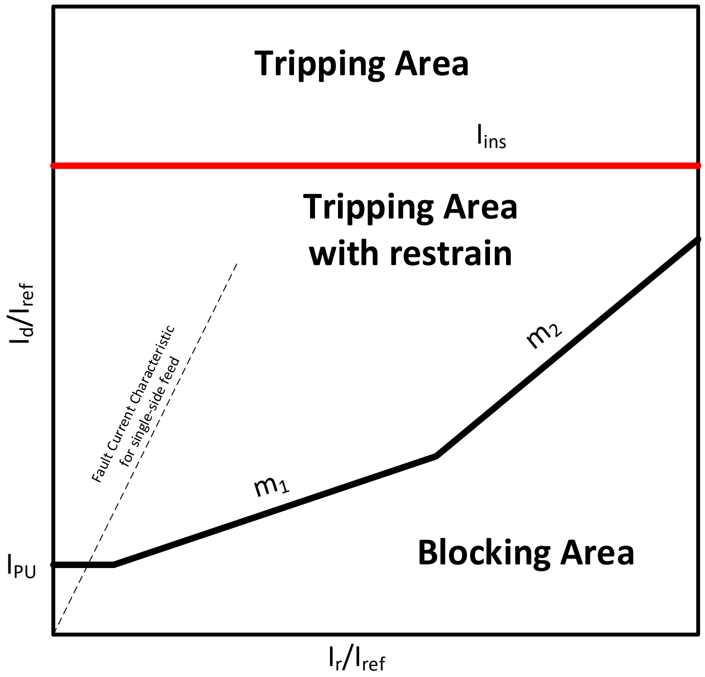


Fig. 2 Differential Relay Slope Characteristic.

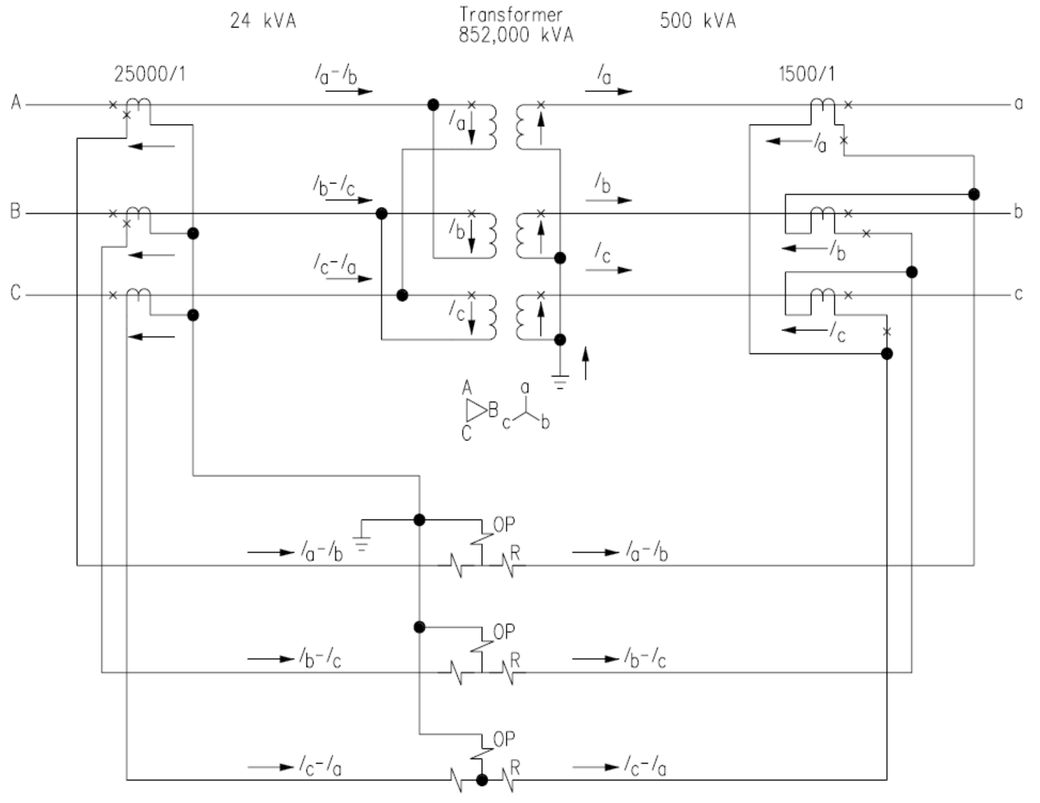


FIGURE 1 Differential relay connection for the protection of a two-winding trnsformer bank.

Fig. 3. Differential relay connection for the protection of a two-winding transformer bank.

III. System Description

Consider a delta-wye transformer bank Fig. 3 with the following data:
High voltage side 500kv wye connection abc
Low voltage side 24 kv delta connection ABC
Connection: Ynd1, HV winding CT 1500/1A, LV winding CT 25000/1A.

IV. Setting transformer

This suggests two steps for correctly connecting and setting transformer differential relays:

Phasing: By connecting the CTs wye or delta, to assure that the secondary currents to the differential relay are in phase.

Ratio adjustment: By selecting CT ratios or relay taps, or both, to minimize the difference current that will flow in the operating circuit.

A. Phasing

The two sets of CTs must be connected so that the secondary currents to the relay- restraint windings are in phase for through load or any external fault. This could be provided by connecting the ABC set of CTs in wye or in delta with the ABC set of CTs in delta or wye, respectively However, connecting the ABC CTs in wye would result in incorrect operation for external ground faults. Zero-sequence current supplied by the transformer-grounded wye to external faults in the abc system can flow through the wye-connected abc CTs to the relay-restraint coil returning through the operating coil. This is because the zero-sequence current circulates in the transformer delta and does not flow in the ABC system to provide proper external fault-balancing restraint. Therefore, the CTs on wye transformer windings should be connected in delta. This provides a zero-sequence circulating path within the CT connection so that it cannot flow in the relays.

- ABC set of CTs connected wye
- abc set of CTs connected delta

Assume that Ia, Ib, and Ic flow in the wye and to the right into the abc system as shown in Fig. 3. With transformer polarity as shown, these currents appear in the Low-voltage windings ABC system as Ia – Ib, Ib – Ic, and Ic – Ia, flowing consistently to the right in the A, B, and C phases, respectively. With the abc, CTs to be connected in delta, the ABC CTs will be connected in wye. With the CT polarity as shown, secondary Ia – Ib, Ib – Ic, and Ic – Ia flow to the differential relay-restraint coils. For the external condition, these currents should flow out of the other restraint coils and to the right. Back to the wye abc side, Ia, Ib, and Ic currents flow to the left in the CT secondary.

Tip: Delta connection is considered as filter for zero sequence currents

B. Ratio adjustment

It is important to minimize the unbalanced current flowing through the operating coils for loads and external faults. Most transformer differential relays have taps available to assist in the process. These provide for differences in the restraint current in the order of 2:1 or 3:1. The percentage mismatch (M) can be expressed as.

$$M = \frac{\frac{I_H}{I_L} - \frac{T_H}{T_L}}{S} \qquad (4)$$

I_H and TH secondary current and relay tap associated with the high voltage winding IL and TL secondary current and relay tap associated with the low voltage winding S the smaller of the current or tap ratios

We can select the taps of the relay to minimize the mismatched ratios of the CTs [6, 7].

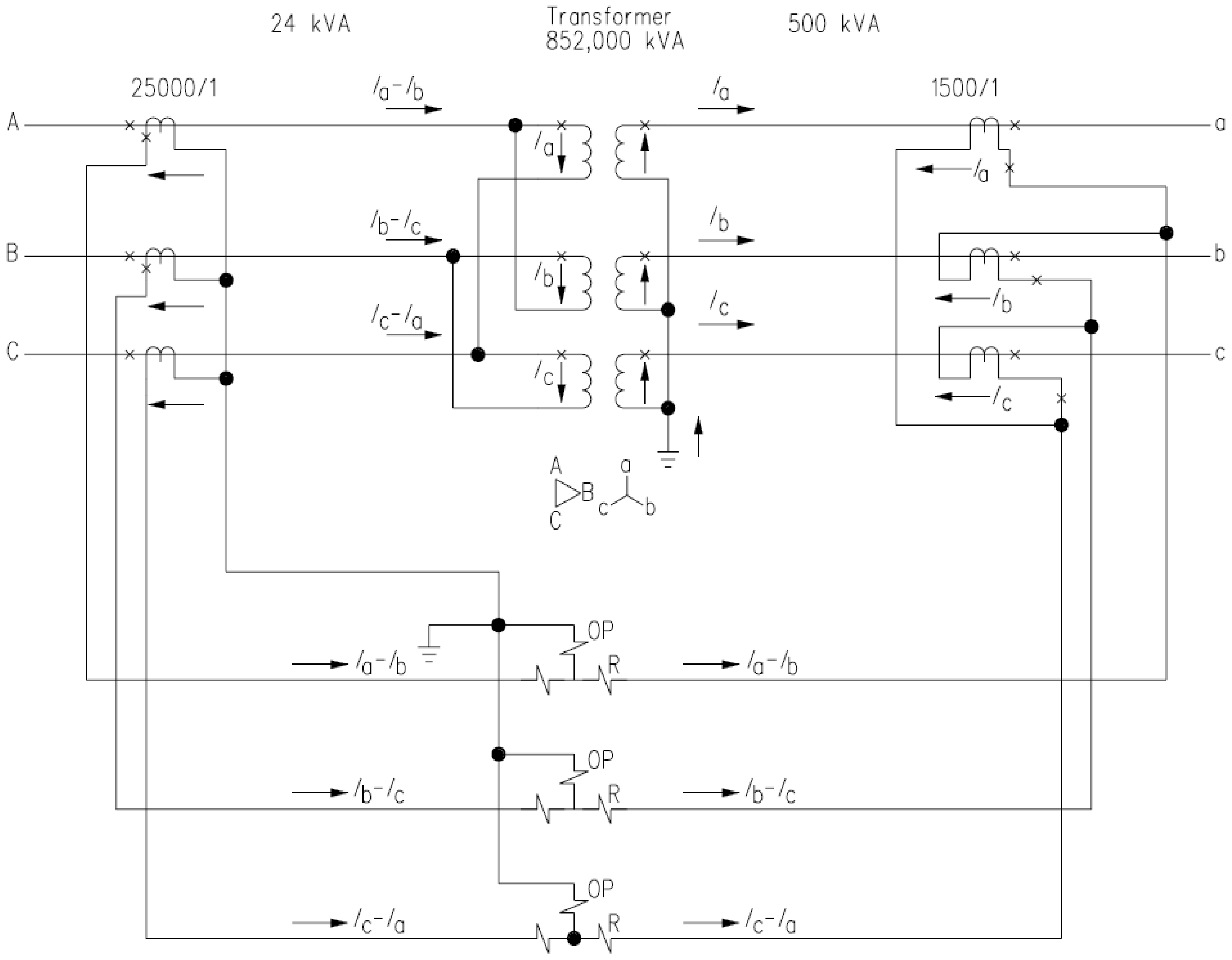


FIGURE 1 Differential relay connection for the protection of a two-winding trnsformer bank.

Fig. 4 Differential relay connection for the protection of three single phase power transformers connected in Delta-Wye configuration and placing CT inside transformer delta.

V. Proposed scheme

Contrary to the traditional method, modern micro processor relays apply factors internally in setting that compensate for the connections of the transformer and the CT'S on the high and low sides of the protected transformer. There are 3 compensation factors the relays shall consider.

•Magnitude compensation factor

•Phase angle and Zero sequence compensation factor

In our case study the current transformers on HV and LV winding are connected to the relay in Y-Y configuration and the current transformers on LV winding of main transformer are located inside the transformer delta as shown in Fig. 4.

The currents measured by the CTs on LV winding are the phases currents (Iap, Ibp, and Icp) while the current measured by the CTs on the HV winding are the line currents (Ial, Ibl, and Icl) therefore the secondary currents to the relay- restraint windings are not in phase, there is magnitude difference and phase shift between the two currents where:

$$\left(I_{Phase} \angle 30 = \frac{I_{Line}}{\sqrt{3}} \angle 0 \right) \qquad (5)$$

In our case the secondary currents will be calculated as the following:

Winding 1, Full Load Current = 20,497A, secondary current to relay=0.819A

Winding 2, Full Load Current = 11834.2A, secondary current to relay=0.473A (current in winding 2 is phase current as CTs located inside transformer delta).

Due to the placement of CTs inside delta winding ,the value of secondary currents will lead to mal-operation, we can set the relay to compensate the difference of the current by adjust the ratio of on LV winding to be (25000√3/1) in the relay setting to convert the phase current measured by the CT to the line currents read by the relay also there is a phase 30o between the line and phase current this angle will be added to -30o between two transformer windings which cancel each other, therefore there is no phase shift between HV and LV winding in the and the transformer in this case will be as Wye –Wye configuration.

VI. Tests and Results

VII. Disadvantages of this scheme

This differential relaying scheme will not detect internal bushing flashovers if the power system is grounded or ungrounded, as illustrated in Fig 4.

The relay scheme also will not detect external ground fault on another phase.

To provide protection for ground faults in these windings it's recommended to use two sets of CTs connected in parallel as illustrated in Fig. 4.

VIII. Conclusion

A Use the Differential Protection Relay as a retrofit for any percentage differential application using the existing current transformer connections. If residual overcurrent elements are desired, use wye connected current transformers. For applications where current transformers are inside the delta of the power transformer.

This connection method does not detect delta-side bushing ground faults. Additional local or remote protection is required to detect and clear these faults.

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1) Walter A. Elmoare “Protective Relaying Theory and Applications”, 2nd Edition revised and expanded.
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3) David Costello "Lesson learned through commissioning and analyzing data from transformer differential installation", IEEE Transactions on Industry Applications, vol. 44, 2008.
4) IEEE Std C37.91™-2008, “IEEE Guide for Protecting Power Transformers”.
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Author Biography:

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15 years of engineering experience with PGESCo in power generation projects, received the B.Sc. degree in electrical power & Machines engineering from Ain shams university in 2006 and granted MBA degree in 2020.

Dr. Wael Youssef:

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. He is a reviewer in IEEE-PES Committee.

HYDROGEN THINKING (PRODUCTION, DISTRIBUTION AND ECONOMICS)

Article By : Eng. Ahmed Abd Elfattah

Introduction

Hydrogen is the simplest element on earth—it consists of only one proton and one electron and it is an energy carrier, not an energy source. Hydrogen can store and deliver usable energy, but it does not typically exist by itself in nature and must be produced from compounds that contain it.

we tried to give more insights in a simple way, about the process to produce hydrogen economically and in environmentally friendly ways hope to be useful

Why Study Hydrogen Production

Hydrogen can be used in fuel cells to generate power using a chemical reaction rather than combustion, producing only water and heat as byproducts. It can be used in more industrial, power generation, vehicles, in houses, for portable power, and in many more applications.

How Hydrogen Production Works

Hydrogen can be produced using diverse, domestic resources—including fossil fuels, such as natural gas and coal (with carbon sequestration); nuclear energy; and other renewable energy sources, such as biomass, wind, solar, water, geothermal, and hydro-electric power—using a wide range of processes.

Hydrogen can be produced :

- At or near the site of use in distributed production
- At large facilities and then delivered to the point of use in central production
- At intermediate scale facilities located in close proximity (25–100 miles) to the point of use in semi-central production

Production ways

Hydrogen can be produced from diverse, domestic resources including fossil fuels, biomass, and water electrolysis with electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced. Several projects are underway to decrease costs associated with hydrogen production.

There are a number of ways to produce hydrogen:

1- Natural Gas Reforming / Gasification:

Synthesis gas, a mixture of hydrogen, carbon monoxide, and a small amount of carbon dioxide, is created by reacting natural gas with high-temperature steam. The carbon monoxide is reacted with water to produce additional hydrogen. This method is the cheapest, most efficient, and most common. Natural gas reforming using steam accounts for the majority of hydrogen produced in the United States annually.

A synthesis gas can also be created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier, which is converted into gaseous components—a process called gasification. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to separate the hydrogen.

Fig.1 Hydrogen production from natural gas, Although today most hydrogen is produced from natural gas, the Fuel Cell Technologies Office is exploring a variety of ways to produce hydrogen from renewable resources

How does it Work?

Natural gas contains methane (CH4) that can be used to produce hydrogen with thermal processes, such as steam-methane reformation and partial oxidation.

Why is this pathway being considered?

Reforming low-cost natural gas can provide hydrogen today for fuel cell electric vehicles (FCEVs) as well as other applications. Over the long term, we expects that hydrogen production from natural gas will be augmented with production from renewable, nuclear, coal (with carbon capture and storage), and other low-carbon, domestic energy resources.

2- Electrolysis:

Electrolysis is a promising option for hydrogen production from renewable resources. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

An electric current splits water into hydrogen and oxygen. If the electricity is produced by renewable sources, such as solar or wind, the resulting hydrogen will be considered renewable as well, and has numerous emissions benefits. Power-to-hydrogen projects are taking off, where excess renewable electricity, when available, is used to make hydrogen through electrolysis.

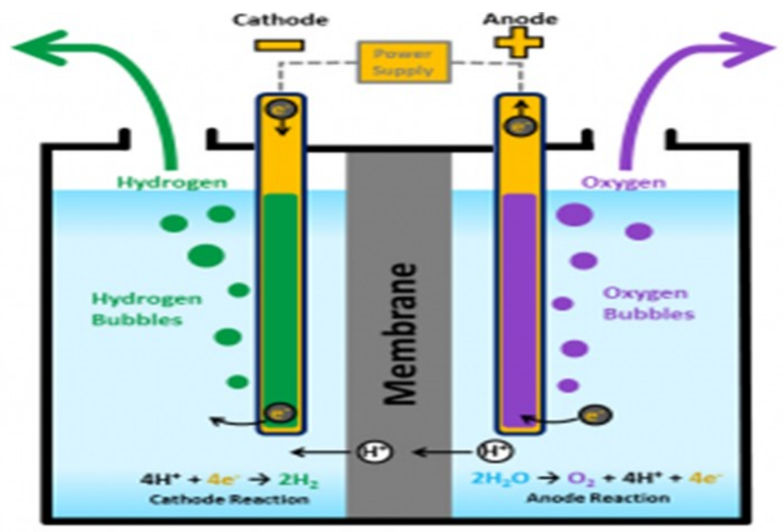


Fig.2 Electrolysis option for hydrogen production

How does it Work?

Like fuel cells, electrolyzers consist of an anode and a cathode separated by an electrolyte. Different electrolyzers function in slightly different ways, mainly due to the different type of electrolyte material involved.

POLYMER ELECTROLYTE MEMBRANE ELECTROLYZERS

In a polymer electrolyte membrane (PEM) electrolyzer, the electrolyte is a solid specialty plastic material.

- Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).
- The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode.
- At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas. Anode Reaction: $2H2O \rightarrow O2 + 4H+ + 4e-$ Cathode Reaction: $4H+ + 4e- \rightarrow 2H2$

Why is this Pathway Being Considered?

Hydrogen produced via electrolysis can result in zero greenhouse gas emissions, depending on the source of the electricity used. The source of the required electricity—including its cost and efficiency, as well as emissions resulting from electricity generation—must be considered when evaluating the benefits and economic viability of hydrogen production via electrolysis. In many regions of the country, today's power grid is not ideal for providing the electricity required for electrolysis because of the greenhouse gases released and the amount of fuel required due to the low efficiency of the electricity generation process. Hydrogen production via electrolysis is being pursued for renewable (wind) and nuclear energy options. These pathways result in virtually zero greenhouse gas and criteria pollutant emissions

3- Renewable Liquid Reforming :

Renewable liquid fuels, such as ethanol, are reacted with high-temperature steam to produce hydrogen near the point of end use.

Liquids derived from biomass resources—including ethanol and bio-oils—can be reformed to produce hydrogen in a process similar to natural gas reforming. Biomass-derived liquids can be transported more easily than their biomass feedstocks, allowing for semi-central production or possibly distributed hydrogen production at fueling stations. Biomass-derived liquid reforming is a mid-term technology pathway.

Fig.3 This Thermochemical Process Development Unit at the National Renewable Energy Laboratory (NREL) can pyrolyze biomass into bio-oil for conversion to hydrogen. Photo from NREL

How does it Work?

Biomass resources can be converted to cellulosic ethanol, bio-oils, or other liquid biofuels. Some of these liquids may be transported at relatively low cost to a refueling station or other point of use and reformed to produce hydrogen. Others (for example, bio-oils) may be reformed on-site.

Steam reforming reaction (ethanol)

$C_2H_5OH + H_2O \text{ (+ heat)} \rightarrow 2CO + 4H_2$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2 \text{ (+ small amount of heat)}$

Biomass-derived liquids, such as ethanol and bio-oils, can be produced at large, central facilities located near the biomass source to take advantage of economies of scale and reduce the cost of transporting the solid biomass feedstock. The liquids have a high energy density and with some upgrading can be transported with minimal new delivery infrastructure and at relatively low cost to distributed refueling stations, semi-central production facilities, or stationary power sites for reforming to hydrogen.

Why is this Pathway Being Considered?

Biomass is an abundant domestic resource.

There is more biomass available in USA as an example than is required for food and animal feed needs.

A recent report projects that with anticipated improvements in agricultural practices and plant breeding, up to 1 billion dry tons of biomass could be available for energy use annually. This equates to around 13–14 quadrillion Btu/year potential (in 2030). Biomass has the potential to be a major contributing source of renewable energy. For more information, see U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.

4- Fermentation:

Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen.

Microbial biomass conversion processes take advantage of the ability of microorganisms to consume and digest biomass and release hydrogen. Depending on the pathway, this research could result in commercial-scale systems in the mid- to long-term timeframe that could be suitable for distributed, semi-central, or central hydrogen production scales, depending on the feedstock used

Fig.4 Bacteria convert corn stover to hydrogen in a fermentation reactor at the National Renewable Energy Laboratory. Photo by Sarah Studer, DOE

Why is this Pathway Being Considered?

Biomass is an abundant domestic resource, and many microbes have evolved to efficiently break down biomass to produce hydrogen and other products. Fermentation has already been used as an industrial technology to generate biofuels and other products, and many of the challenges to scaling up systems have been addressed for different products, allowing hydrogen researchers to focus on the challenges unique to hydrogen production. MEC-based systems have the potential to produce hydrogen from resources that otherwise can't be used for fuel production, and could reduce the large amount of energy normally needed for wastewater treatment while producing a valuable fuel in the form of hydrogen. These two pathways can be combined to maximize the hydrogen yield from the starting biomass feedstock.

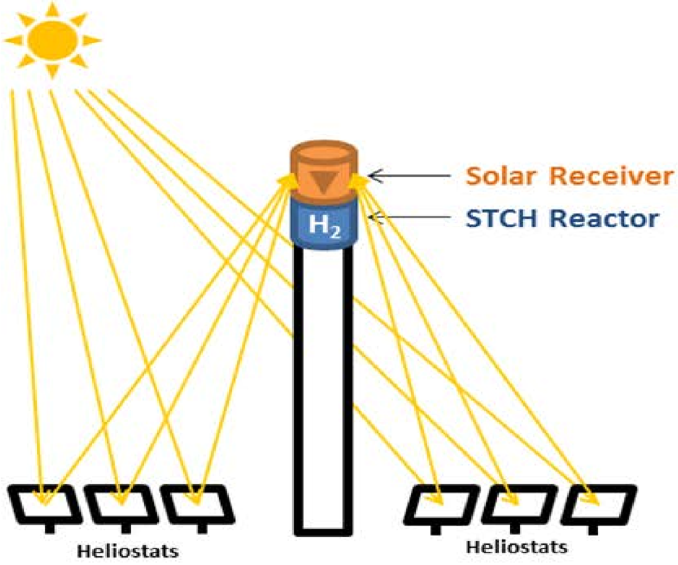
5. High-Temperature Water Splitting:

Biomass is an abundant domestic resource, and many microbes have evolved to efficiently break down biomass to produce hydrogen and other products. Fermentation has already been used as an industrial technology to generate biofuels and other products, and many of the challenges to scaling up systems have been addressed for different products, allowing hydrogen researchers to focus on the challenges unique to hydrogen production. MEC-based systems have the potential to produce hydrogen from resources that otherwise can't be used for fuel production, and could reduce the large amount of energy normally needed for wastewater treatment while producing a valuable fuel in the form of hydrogen. These two pathways can be combined to maximize the hydrogen yield from the starting biomass feedstock.

How does it Work?

Thermochemical water splitting processes use high-temperature heat (500°–2,000°C) to drive a series of chemical reactions that produce hydrogen. The chemicals used in the process are reused within each cycle, creating a closed loop that consumes only water and produces hydrogen and oxygen. The necessary high temperatures can be generated in the following ways:

- Concentrating sunlight onto a reactor tower using a field of mirror "heliostats," as illustrated in Figure 1. For more information, see Chapter 5 of the SunShot Vision Study.
- Using waste heat from advanced nuclear reactors. For more information, you can visit the U.S. Department of Energy's Nuclear Hydrogen site in internet to see R&D Plan.



(a) Central receiver/reactor tower with heliostats

Fig.5 Two mirror-based approaches for focusing sunlight on a thermochemical reactor to produce temperatures up to 2,000°C are illustrated: (a) a field of heliostat mirrors concentrates sunlight onto a central reactor tower; and (b) dish mirrors focus sunlight onto an attached reactor module. The solar-generated high-temperature heat can be used to drive thermochemical reactions that produce hydrogen

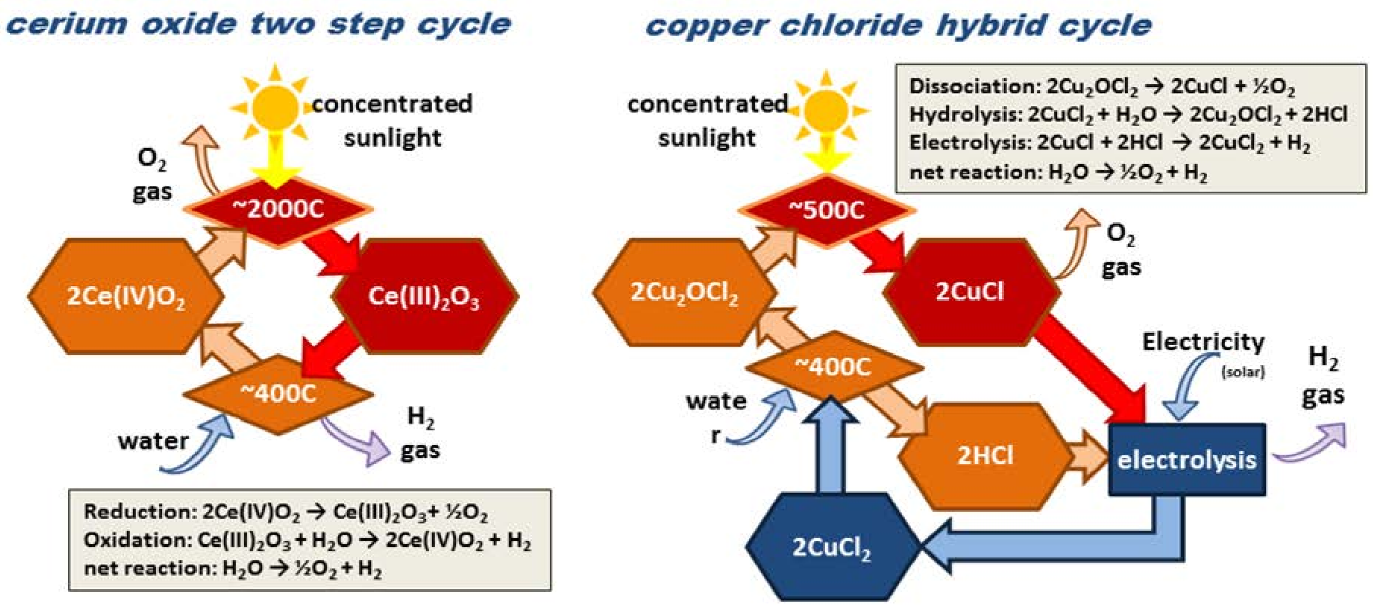
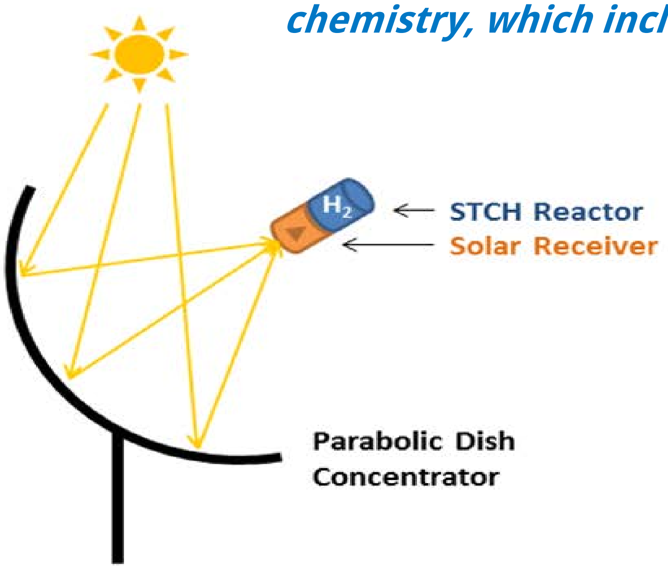


Fig.6 This illustration shows two example water-splitting cycles: (left) a two-step "direct" thermochemical cycle based on oxidation and reduction of cerium oxide particles; and (right) a multi-step "hybrid" thermochemical cycle based on copper chloride thermo-chemistry, which includes an electrolysis step that needs some electricity input.



(b) Modular dish-mounted receiver/reactor

Why is this Pathway Being Considered?

Solar- and nuclear-driven high-temperature thermo-chemical water-splitting cycles produce hydrogen with near-zero greenhouse gas emissions using water and either sunlight or nuclear energy.

6. Photo-biological Water Splitting :

Microbes, such as green algae, consume water in the presence of sunlight, producing hydrogen as a byproduct.

The photo-biological hydrogen production process uses microorganisms and sunlight to turn water, and sometimes organic matter, into hydrogen. This is a longer-term technology pathway in the early stages of research that has a long-term potential for sustainable hydrogen production with low environmental impact.

How does it Work?

In photolytic biological systems, microorganisms—such as green microalgae or cyanobacteria—use sunlight to split water into oxygen and hydrogen ions. The hydrogen ions can be combined through direct or indirect routes and released as hydrogen gas. Challenges for this pathway include low rates of hydrogen production and the fact that splitting water also produces oxygen, which quickly inhibits the hydrogen production reaction and can be a safety issue when mixed with hydrogen in certain concentrations. Researchers are working to develop methods to allow the microbes to produce hydrogen for longer periods of time and to increase the rate of hydrogen production.

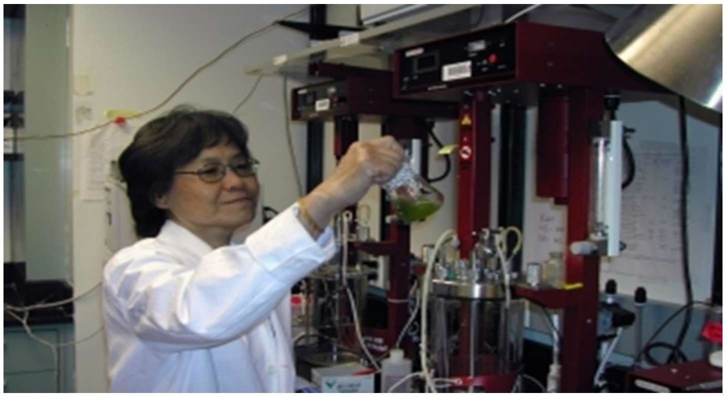


Fig.7 A researcher examines a natural cyanobacterial culture for hydrogen production using sunlight and water in a bench top bioreactor. Photo from the National Renewable Energy Laboratory

Some photosynthetic microbes use sunlight as the driver to break down organic matter, releasing hydrogen. This is known as photofermentative hydrogen production. Some of the major challenges of this pathway include a very low hydrogen production rate and low solar-to-hydrogen efficiency, making it a commercially unviable pathway for hydrogen production at this time.

Researchers are looking at ways to make the microbes better at collecting and using energy to make more available for hydrogen production, and to change their normal biological pathways to increase the rate of hydrogen production.

Why is this Pathway Being Considered?

In the long term, photobiological production technologies may provide economical hydrogen production from sunlight with low- to net-zero carbon emissions. The algae and bacteria could be grown in water that cannot be used for drinking or for agriculture, and could potentially even use wastewater.

7. Photo-electrochemical Water Splitting:

Photo-electrochemical systems produce hydrogen from water using special semiconductors and energy from sunlight.

In photo-electrochemical (PEC) water splitting, hydrogen is produced from water using sunlight and specialized semiconductors called photo-electrochemical materials, which use light energy to directly dissociate water molecules into hydrogen and oxygen. This is a long-term technology pathway, with the potential for low or no greenhouse gas emission

The major hydrogen-producing states are California, Louisiana, and Texas. Today, almost all of the hydrogen produced in the United States is used for refining petroleum, treating metals, producing fertilizer, and processing foods.

The primary challenge for hydrogen production is reducing the cost of production technologies to make the resulting hydrogen cost competitive with conventional transportation fuels. Government and industry research and development projects are reducing the cost as well as the environmental impacts of hydrogen production technologies. Learn more about hydrogen production from the Hydrogen and Fuel Cell Technologies Office.

How does it Work?

The PEC water splitting process uses semiconductor materials to convert solar energy directly to chemical energy in the form of hydrogen. The semiconductor materials used in the PEC process are similar to those used in photovoltaic solar electricity generation, but for PEC applications the semiconductor is immersed in a water-based electrolyte, where sunlight energizes the water-splitting process. Watch a laboratory-scale demonstration of this process performed at the National Renewable Energy Laboratory.

Why is this Pathway Being Considered?

PEC water splitting is a promising solar-to-hydrogen pathway for hydrogen production at semi-central and central scales, offering the potential for high conversion efficiency at low operating temperatures using cost-effective thin-film and/or particle semiconductor materials.

Distribution

Most hydrogen used in the United States is produced at or close to where it is used—typically at large industrial sites. The infrastructure needed for distributing hydrogen to the nationwide network of fueling stations required for the widespread use of fuel cell electric vehicles still needs to be developed. The initial rollout for vehicles and stations focuses on building out these distribution networks, primarily in southern and northern California.

Currently, hydrogen is distributed through three methods:

- **Pipeline:**

  This least-expensive way to deliver large volumes of hydrogen is limited as only about 1,600 miles of U.S. pipelines for hydrogen delivery are currently available. These pipelines are located near large petroleum refineries and chemical plants in Illinois, California, and the Gulf Coast.

- **High-Pressure Tube Trailers:**

  Transporting compressed hydrogen gas by truck, railcar, ship, or barge in high-pressure tube trailers is expensive and used primarily for distances of 200 miles or less.

- **Liquefied Hydrogen Tankers:**

Cryogenic liquefaction is a process that cools hydrogen to a temperature where it becomes a liquid. Although the liquefaction process is expensive, it enables hydrogen to be transported more efficiently (when compared with using high-pressure tube trailers) over longer distances by truck, railcar, ship, or barge. If the liquefied hydrogen is not used at a sufficiently high rate at the point of consumption, it boils off (or evaporates) from its containment vessels. As a result, hydrogen delivery and consumption rates must be carefully matched.

Creating an infrastructure for hydrogen distribution and delivery to thousands of future individual fueling stations presents many challenges. Because hydrogen contains less energy per unit volume than all other fuels, transporting, storing, and delivering it to the point of end-use is more expensive on a per gasoline gallon equivalent (per-GGE) basis. Building a new hydrogen pipeline network involves high initial capital costs, and hydrogen's properties present unique challenges to pipeline materials and compressor design. However, because hydrogen can be produced from a wide variety of resources, regional or even local hydrogen production can maximize use of local resources and minimize distribution challenges.

There are tradeoffs between centralized and distributed production to consider. Producing hydrogen centrally in large plants cuts production costs but boosts distribution costs. Producing hydrogen at the point of end-use—at fueling stations, for example—cuts distribution costs but increases production costs because of the cost to construct on-site production capabilities.

Government and industry research and development projects are overcoming the barriers to efficient hydrogen distribution. Learn more about hydrogen distribution from the Hydrogen and Fuel Cell Technologies Office.

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Conclusion

We tried in this article to give more insights in a simple way, about the process to produce hydrogen economically and in environmentally friendly ways

- Biomass-derived liquid reforming
- Electrolysis
- Biomass gasification
- Thermochemical water splitting
- Photoelectrochemical water splitting
- Photobiological processes
- Microbial biomass conversion.

From economically wise we can say that:

All of the current methods and the projected technologies of producing hydrogen from solar energy are much more expensive (greater than a factor of 3) when compared with hydrogen production from coal or natural gas plants. This is due partly to the lower annual utilization factor of about 20 percent (as compared with say, wind, at 30 to 40 percent). This high cost puts enormous pressure on the need to reduce the cost of a solar energy recovery device. While an expected Future installed module cost of about $1/Wp is very attractive for electricity generation and deserves a strong research effort in its own right, this cost fails to provide hydrogen at a competitive value. The raw material cost for crystalline silicon-wafer-based technologies is a large fraction of the $1/Wp value and is therefore less likely to provide hydrogen economically. On the other hand, thin-film technologies do not use much raw material in thin films themselves but require tremendous progress in the deposition technology. There is a need for a robust deposition method that would have a potential to reduce cost much below $1/Wp. Emerging polymer-based technologies have a potential to provide low-cost devices to harness solar energy. It is apparent that there is no one method of harnessing solar energy that is clearly preferable. However, it appears possible that new concepts will emerge that would be competitive. The benefits of such developments would be very substantial. In the future, as the cost of the fuel cell approaches $50 per kilowatt, the cost of an electrolytic cell to electrolyze water is also expected to approach a low number (about $125/kW). With such low-cost electrolyzer units, the electricity cost of about $0.02 to $0.03/kWh is expected to result in a competitive hydrogen cost. It is also estimated that for aphotoelectrochemical method to compete, its cost must approach $0.04 to $0.05/kWh. The order-of-magnitude reductions in cost for both hydrogen processes are similar.

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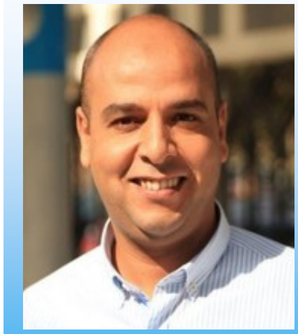

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BASIC INTRODUCTION FOR HEAT RECOVERY STEAM GENERATORS (HRSG)

Article By : Eng. Ahmed Essam

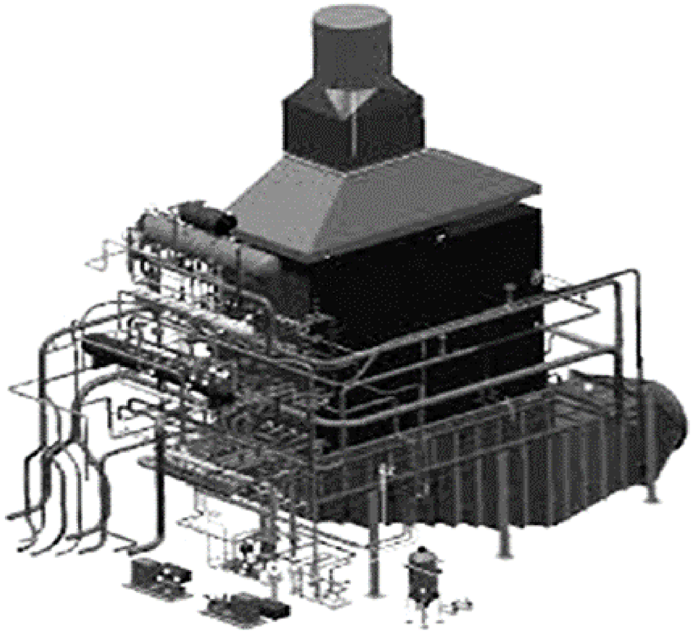
1. Introduction to HRSGs and its Configurations

Heat recovery steam generators (HRSGs) are designed and operate to produce superheated steam at certain desired conditions, it acts as a heat exchanger between two streams; hot stream (exhaust gas flue), and cold stream (water). The process of converting the water to steam is done by convection type heat transfer.

HRSGs are used to produce steam in several applications, e.g., Power plants, cogeneration plants,

HRSGs are constructed in either Horizontal or vertical configurations, it depends on the direction of the gas turbine exhaust gas flue. Selection of HRSG configuration depends on the site layout limitations, as the vertical HRSGs require less area for construction.

Horizontal HRSGs



Vertical HRSGs

HRSGs are sized according to the amount of steam required for the application, and the size of the Gas Turbines. Hence, the number of pressure levels in HRSG will differ, three pressure levels, two pressure levels, or single pressure level.

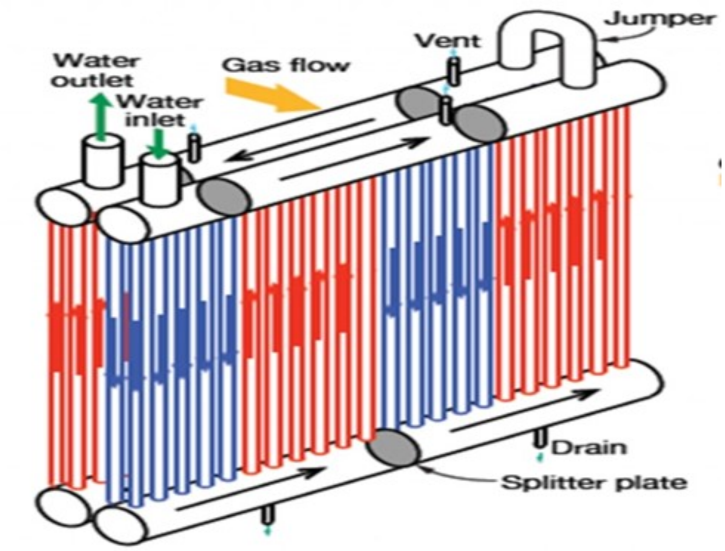
Gas Turbine Power (MW)	No. of Pressure Levels
250 or more	3 (HP, IP, and LP)
125 to 250	2 (HP and LP)
Less than 125	1

However, HRSGs can be compromised to operate at wider ranges, for best efficiency and cost reduction.

2. Introduction to HRSG Components and Pressure Parts

HRSGs pressure parts are designed based on the number of pressure levels:

Economizers: is the first stage in the water cycle, economizers increase the water temperature few degrees below the saturation temperature of water. Number of economizers in each pressure level is depending on the required conditions and the capacity of water

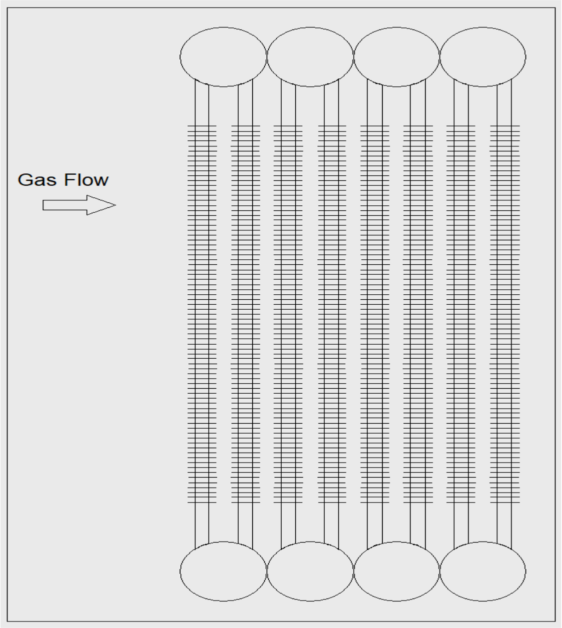


Upward or horizontal water flow in economizer is preferable to decrease the damage of steaming resulted from reduced gas turbine loads. Downward flow can result in hammering, flow turbulence, flow disturbance,
or undistributed heat transfer

Evaporators: used for a process of converting water to saturated steam, this process is either done by natural circulation or forced circulation

Natural Circulation

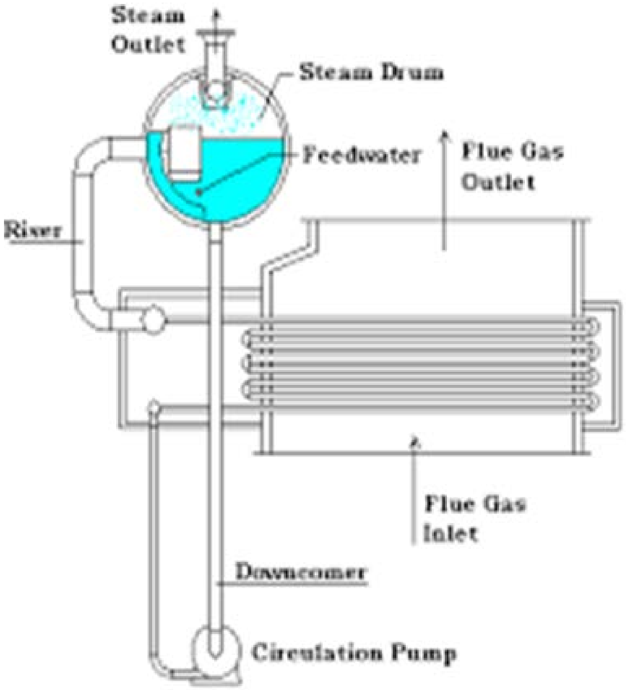
Natural circulation in an evaporator is caused by the thermal difference between the medium in the heated part and the cooler liquid. This thermal change is called "thermo-siphon action". Sufficient heat must be available to provide the necessary flow



Forced Circulation

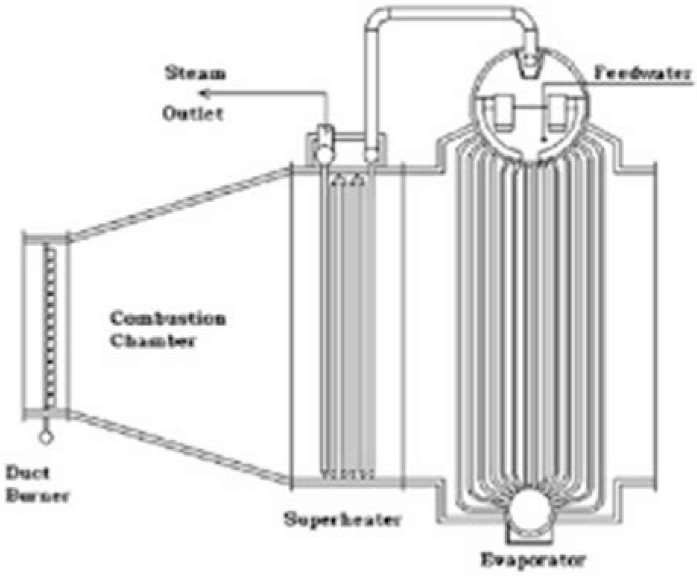
Forced circulation are required when the fouling characteristics of a liquid will cause problems if the liquid boils on a heating surface.

Evaporators are also used for liquids with a high solids content and a high viscosity.



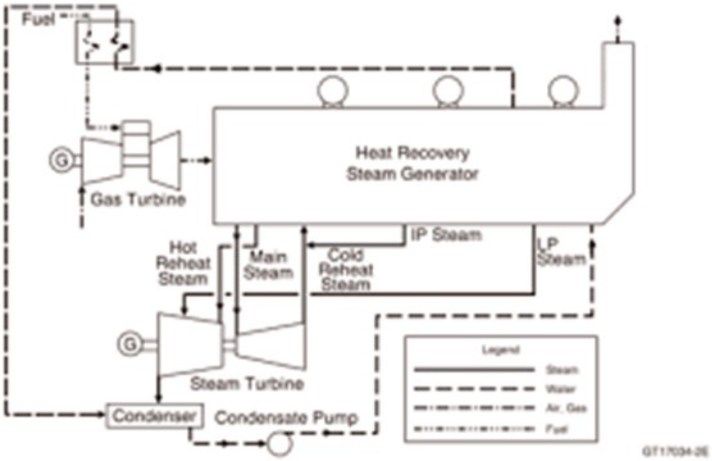
Forced Circulation Evaporator

Superheaters: is used to increase the temperature of the saturated steam generated from evaporators to superheated degree. Superheaters transfer the steam from steam drums to the main steam system at the required operating pressure and temperature

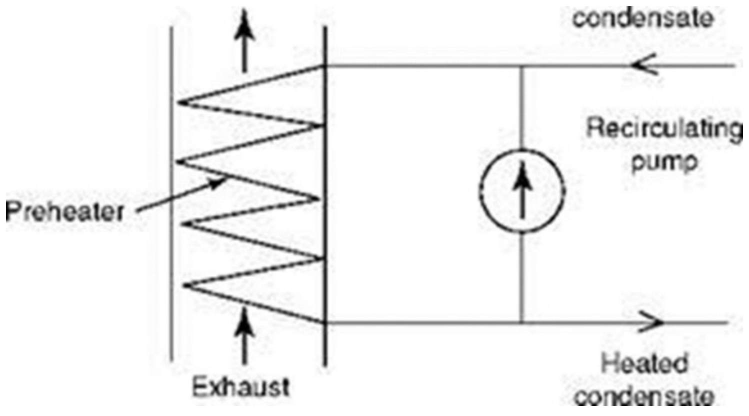


Reheaters: is used to increase temperature of cold reheat from HP turbine outlet, to be mixed with the IP superheater outlet. Hot reheat is then piped to IP turbine section. Reheaters are used only in three pressure levels HRSGs, it is an intermediate stage to redirect the exhaust steam from HP steam turbine at high flow, pressure and temperature, again to the turbine, providing additional power and increasing the steam turbine efficiency.

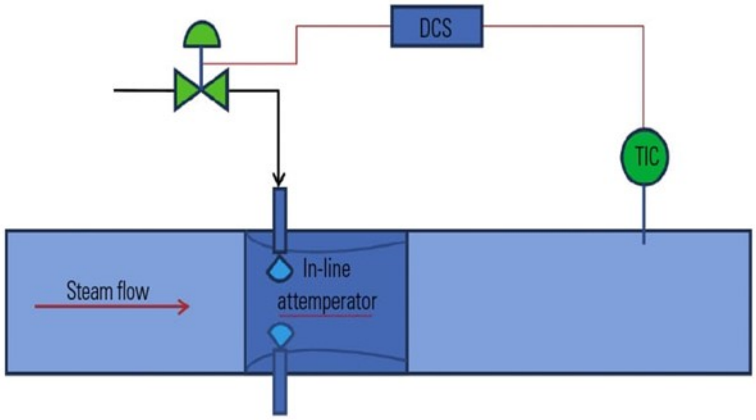
During two level HRSG operation, reheaters are removed as the HP pressure and temperature at HP turbine outlet is not sufficient to operate IP turbine.



Condensate Preheater: Condensate preheater/recirculation is used to maintain the inlet water temperature of the economizer at 3 to 5.5 °C above dew point. This is used to prevent condensation of vapors on piping, and limiting corrosions. During solar oil firing, condensate pH will be bypassed to protect heater tubes from high content of Sulphur or condensation of acid gases on piping that may lead to dew point corrosion.



Attemperators (Desuperheaters): are used to protect HRSG components and steam turbines from temperature transients that occur during startup or load changes. The attemperator sprays water droplets into the superheated steam from feedwater pump discharge. The attemperators also prevent thermal damage to superheater and reheater tubes, and to outlet steam piping and downstream equipment.

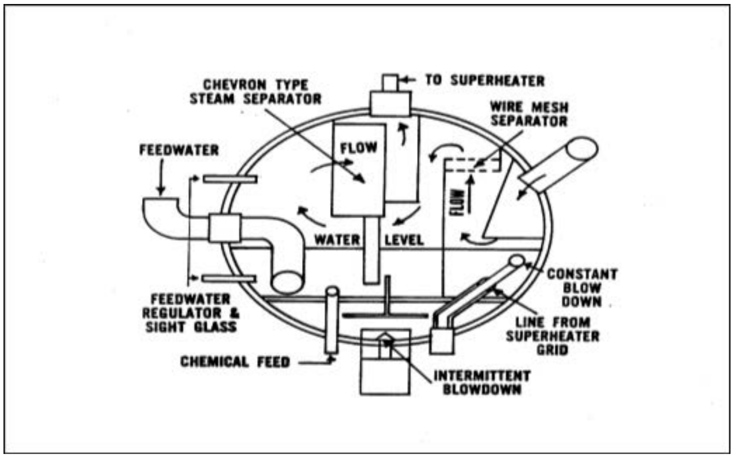


Finned Tubes: Heat transfer in HRSG is accomplished by convection through finned tubes. Fins could be either serrated or solid. Serrated tubes have lower stress than solid tubes but highly affected by turbulent flow. Type, height, pitching of fins are selected based on type of fuel, Heavy fuel requires more space between fins and more pitching distance

Serrated Fins

Solid Fins

Steam Drums: Steam Drums are used to convert water to steam. Drums are sized to provide the minimum storage capacity at full loads. Drum sizing shall be considered to prevent swell or shrink during startup, shutdown, and transient loads. Minimum continuous rate (MCR) is considered during drum sizing. Drums may be used to adjust steam quality through chemical injections.



Once Through Type: Separators are used to separate steam from water instead of drums. Evaporator design differs from drum type HRSG evaporators, in once through type, evaporators are designed to increase the temperature of water above the superheated temperature converting the water to superheated steam without the use of drums. Vertical separators are part of HP section only

Once through type has wide advantages over the drum type, in terms of:

- Shorter startup duration
- Lower thermal stresses
- Lower cost
- Extended Life time duration

However, once through type requires more complex water treatment, material, and control

3. Design and Construction

HRSG is constructed in different Modules, each module has its relevant pressure parts (e.g. superheaters, evaporators, etc.), and its relevant liners and insulations. Pressure parts are arranged in HRSG modules to gain energy required for heat transfer, based on exhaust gas temperature in each module.

Each HRSG module is delivered and installed separately, then each pressure part is placed in position inside HRSG

4. Water Chemistry Summary

Quality of water used inside HRSG may affect HRSG performance and durability over time, controlling water chemistry is essential to prevent damages caused by corrosion, scaling, and steam purity. Inappropriate water chemistry control may lead to increasing oxygen dissolved in water, incorrect pH operation limits, increasing TDS, and fouling.

Controlling water quality can be achieved by, but not limited to:

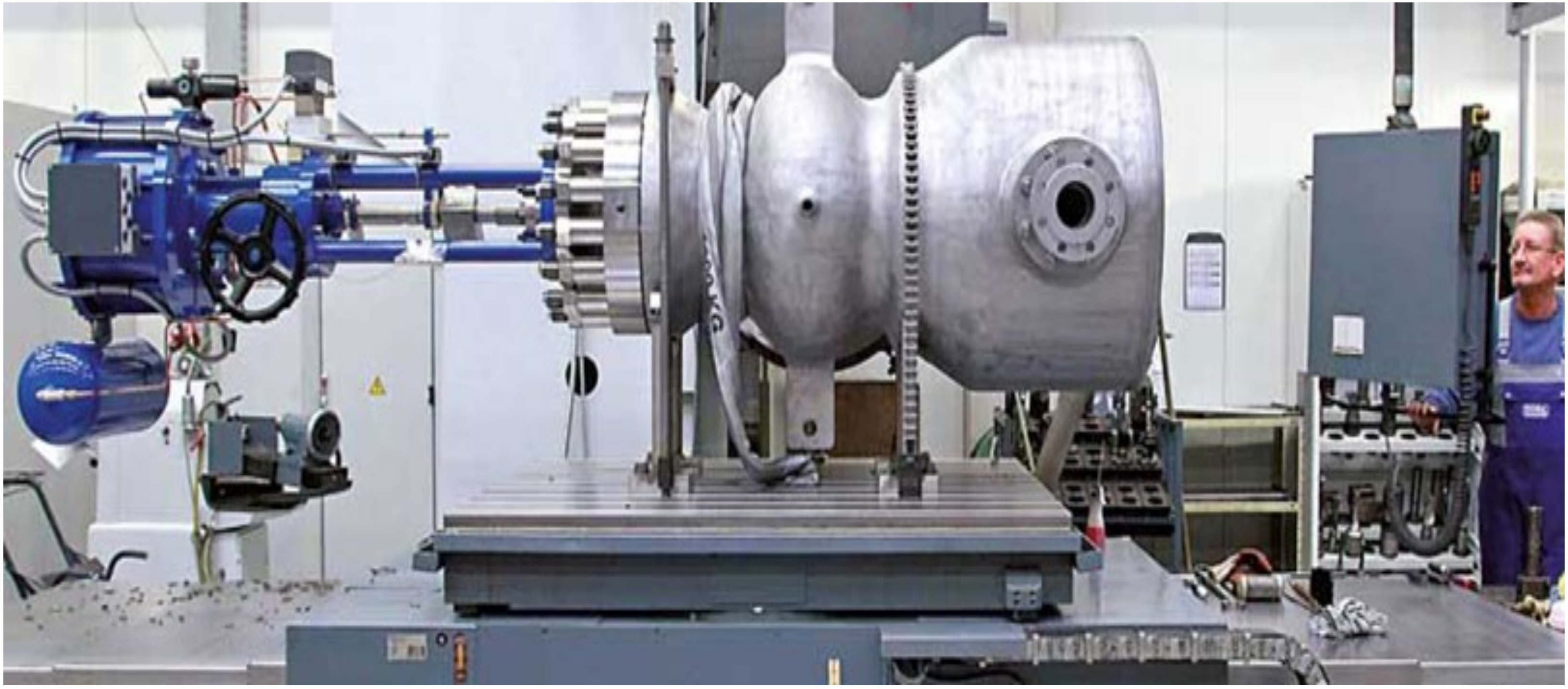
- pH control
- silica control
- oxygen scavenging
- blowdown

Incorrect control of water chemistry may leed to piping and tubing failure, or losing heat transfer efficiency

5. Supporting Mechanical Equipment

Deaerators: when needed, are used to physically remove dissolved oxygen and carbon dioxide from the condensate/make-up water stream feeding an HRSG. High levels of oxygen in the HRSG feedwater can cause corrosion and premature failure of HRSG tubes and other components. In addition, deaerators provide feedwater storage and proper suction conditions for boiler feedwater pumps. Deaeration could also be carried out in condenser or a special vessel by reducing the operating pressure to decrease the oxygen concentration in water.

Sky Valves: are designed to vent the steam generated during initial operation until vacuum is established in the condenser. Sky valves also may control the ramp rate of the HRSG, ensuring plant piping and equipment do not rise in temperature too quickly; thus, protecting plant equipment from thermal induced stresses. Sky vent valves are required to withstand full process pressure and are installed in the highest-cost energy systems in the plant. If these valves do not isolate fully, high-cost energy passes directly to the atmosphere, decreasing plant efficiency during all hours of plant operation.



Bypass Valves: are used to dump steam to condenser during steam turbine unavailability, and during warm-up of the turbine. Bypass valves also used during startup, ST trip, or switching to simple cycle operation to bypass steam generated from HRSG. Without a bypass system, the steam generated in the HRSG has to be discharged to the atmosphere until the STG is available to accept steam. Steam is discharged by means of vent valves and/or atmospheric sky valves installed on the HRSG steam headers. The dumping of steam to atmosphere is not desirable as it results in loss of valuable condensate and also raises environmental concerns due to noise pollution.

Safety Relief Valves: are designed to maximum steaming capacity as maximum allowable pressure of HRSG, to avoid over pressure of HRSG tubing and piping. Safety relief valves shall open if ERVs were not able to provide a sufficient relieving capacity.

Electromatic Relief Valves (ERVs): are a power operated relief valves, sized at a lower set pressure than the safety relief valves to prevent safety relief valves from lifting. That take place during STG trip and bypass is in operation

6. HRSG Startup Summary

The start-up procedures depend on HP drum residual pressure.

Depending on plant status, three start-up procedures are defined:

- Cold start-up: when the HP drum residual pressure is lower than 2 barg
- Warm start-up: when the HP drum residual pressure is between 2 bargs and 12 barg
- Hot start-up: when the HP drum residual pressure is more than 12 barg

Startup procedure differs from each HRSG depends on number of pressure levels. HRSG startup duration decreases with the increase in residual pressure and temperature in HRSG.

HRSG ramp up rate is limited with the drum temperature increase rate, which affect the duration of startup.

During hot startup, the temperature of steam turbine metal is affecting the startup duration, and the

HRSG ramp up rate has low effect on duration as the pressure and temperature is high.

The total duration of HRSG shutdown period results in selecting the startup procedure.

Before startup, limitations and permissive shall be reviewed and checked according to supplier's standards

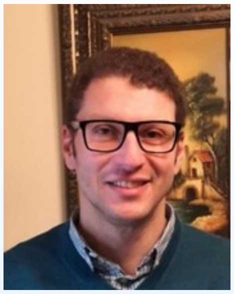
7. HRSG Performance Test Summary

The HRSG duty is critical power plant performance parameter to evaluate. It is the rate of heat transfer from the gas turbine exhaust gases to the water cycle. Optimizing HRSG duty means more energy is recouped and used in generating electricity and revenue. "ASME PTC 4.4"

HRSG Performance test is conducted before plant operation to ensure that HRSG is designed and constructed based on plant's specified objectives.

Performance Testing is required to confirm HRSG full operable conditions, and to resolve any technical issues before plant start-up

Author Biography:



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