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Distribution of Electrical Power Using GIS

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ABSTRACT: In the past few years there is a rapid improvement in power distribution sector, but the set of equipment require for controlling the transmission and distribution of electric power supply remains the same. This paper gives an overview about the design of gas insulated metalclad switchgear (GIS) and its technologies. The steps of technical development, stages of technical design, state of the art in the production, and quality insurance are explained with the help of practical example. This paper also highlights the difference between traditional sub- station i.e. Air Insulated Substation (AIS) and modern sub- station i.e. gas insulated metalclad switchgear (GIS). According to research, GIS is more reliable, multi-component and maintenance free as it need very less space. It also describes about the operational primary equipment such as switching, grounding, disconnecting, secondary system, gas handling, maintenance, and monitoring and the primary insulation medium SF_6 gas and its properties. This paper indicates numerous advantages of gas insulated metalclad switchgear and, GIS is not only used for indoor sub-stations but also can be used for outdoor sub-stations. There are some drawbacks that may occur in GIS, but with many advantages it is urged that at High voltage level of 12kv, 36kv, 72.5kv, 145kv, 245kv, 420kv and above GIS must be used from the point of view economic, low maintenance cost, easy installation, long life and it require very little space as compare to other conventional sub- station of same rating.

KEYWORDS: Transmission, Distribution, Electrical power supply, Gas Insulated metalclad switchgear (GIS), Air Insulated Substation (AIS), Sulphur hexafluoride (SF6), Gas handling unit, High voltage level, Kilovolt (KV).

I. INTRODUCTION

World economy and population continues to grow which may results, rise in electrical power requirements. For this purpose, substation equipment has to be made more efficient, flexible and reliable in order to meet increase in demand of electrical power supply. We all know that power is produced in a generating station, then transmitted and then distributed through Grid Stations or Sub-stations. For more efficiency the transmission and distribution sector has to be improved and it should have a property of adapting existing power distribution and transmission system.

Substation serve as sources of energy supply for the local areas of distribution in which these are located. Their main functions are to receive energy transmitted at high voltage from the generating station , reduce the voltage to a value appropriate for local distribution and provide facilities for switching. Some substation are simply switching station where different connection between various transmission line are made , others are converting substations which either convert A.C into D.C or vice-versa or convert frequency from higher to lower or vice-versa. They also provide points where safety devices may be installed to disconnect equipment or circuit in the event of fault, voltage on the outgoing distribution feeders can be regulated at a substation.

High voltage substation comprising high voltage switchgear and devices with different insulating system , air or gas. When planning high voltage substation, some basic question have to be answered to define the type of high voltage switchgear.

- What is the function and location within the power supply system ?
- What are the climate and environmental conditions ?
- Are there is a specific requirement regarding locations ?
- Are there is a space / cost restriction ?

Depending upon the answer substation may be traditional substation i.e. Air Insulated substation (AIS) or may be modern substation such as Gas Insulated substation (GIS)

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II. COMPARSION OF GIS AND AIS

Insulation Medium :- A GIS uses a superior dielectric gas, SF_6, at moderate pressure for phase to phase and phase to ground insulation. The high voltage conductors. circuit breaker interrupters, switches, current transformers, and voltage transformer are in SF_6 gas inside grounded metal enclosures. The atmospheric air insulation used in a conventional, AIS requires meters of air insulation to do what SF_6 can do in centimetre.

Dieletrical Strength :- The Dieletrical strength of the gas SF_6 increases with pressure and is more than that of dieletrical of oil at a pressure of 3kgf/cm^2 (or kg/cm^2). The density of gas is 5 times that of air at 20^{o}C at atmospheric pressure.

Compactness and Space :- The space requires by GIS installation is only about 10% of that of conventional outdoor substation (AIS). GIS can therefore be smaller than AIS by up to a factor of 10. A GIS is mostly used where space is expensive or not available. Minimum size required for Air Insulated Substation of 400 kV is 46,864.5m2 (235m*199m) and it is approximately equal to 11.6 acres. On the other hand if we use GIS the size of building required is 522.45m2 (12.15m*43m). Height of substation also plays a very vital role undertaking the structural size. In AIS height of highest element of substation is 28m high. Meanwhile GIS has building height equal to 11m for 400kV substation. Overall compound size is about 10,672m2. From the above stated analysis it is observed that GIS is much smaller than AIS in size.

Fig:- Gas insulated substation (GIS) and Air insulated substation (AIS)

Protection from pollution :- The moisture , pollution , dust, etc. ,have little influence on SF_6 insulated substation . However, to facilitate and maintenance, such substation are generally housed inside a small building, The construction of the building need not be very strong like conventional power houses. Environmental factors don't effected by Gas Insulated Substation and it is even more suitable for harsh environmental and climatic conditions like humidity, saline, polluted atmosphere comprises of industrial exhaust.

Reduced switching over voltages :- The over voltage while closing and opening line , cables motors capacitors etc. are low in GIS as compare to AIS.

Reduced installation time :- The principle of building block construction reduces the installation time to a few weeks as in case of GIS. On the other hand conventional substation (AIS) requires few months for installation.

Life of substation :- Due to the chemical composition of SF6 gas it envelops the conductors and insulation and preserves them for long time of trouble free operation. Where as in AIS conductors, steel infrastructure gets rusty due to moisture. All these factors
make the operational life of GIS from 40to 50 years as compared to life of AIS of 25 to 30 years .

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Safety :- Isolated gas stations are very safe and operating equipment are protected by metal casings earthed. While workstation mode staff can affect the compartment. Whereas in AIS all equipment are open in air and their bodies are earthed.

Economic :- Initial investment required for installation of GIS is little bit high, but the cost can be comparable to lower maintenance of GIS, a reliable, and secure against conventional substation (AIS).

Location of GIS :- The GIS is preferred in following location :-

1. Major cities and towns
2. Under ground stations
3. Heavily contaminated environment and internal GIS occupies very little space
4. Substations and power plants located off shore
5. Mountains and valley regions etc.

Environmental effect :- SF_6 is a strong greenhouse gas that could contribute to global warming. At an international conference in Kyoto in 1997, SF_6 is one of the best greenhouse gases. SF_6 is a very minor contributor to the total amount of greenhouse gases due to human activity, but it has a very long life in the atmosphere is about 3200 year (appox)., so the effect of SF_6 released to the atmosphere is effectively and permanent. The contribution of SF_6 to global warming can be kept to less than 0.1% over a 100 year horizon. Our requirement for insulation media includes such a medium that is capable of providing effective insulation at the expense of less space. Similarly it should be capable of providing safety to equipment, it should be non-toxic and its atomic and molecular properties remain intact even at higher disturbance such as high voltage. Sulphur Hexafluoride (SF6) gas completely satisfies all above mentioned specifications. According to Global Environmental effects and Toxic By-product Formation more than 10,000 tons SF6 produced per year and round about 8,000 tons is used as gaseous dielectric medium in electric components which is about 80% of total production. Sulphur Hexafluoride has good cooling property and best arc quenching, results increase in life of components in which it is used. It is non-toxic in nature as it is very stable chemically and remains stable up to 500 degree centigrade of temperature. Its density is 6.12 g/L which is 5 times higher than 1.255 g/L of air Sulphur hexafluoride has not only a good dielectric strength but also it possesses the rapid recombination after the spark. This property makes it 100 times more effective than air in terms of arc quenching. When considering the global warming potential (GWP) of a representative network of urban distribution of cells that a minor contribution. Currently, emissions of SF6 MV switchgear contribute less than 0.005 % of the potential global warming in Germany. In addition, the following conclusions can be drawn from the results of the assessment of the life cycle.

III. NEED OF GIS

1. Non availability of sufficient space. It is very much required to establish a substation at load center. Establishing a substation at load center is quite economical and profitable in following ways:

- Reduction in length of feeders.
- Improvement of the quality of voltage regulation due to short length feeders.

Generally main load center of any place is situated at very congested place where, sufficient land for establishing conventional AIS is very hardly available. This problem can be solved by using GIS technology.

- Total space required for a GIS is 10% of that needed for a conventional substation.

2. Difficult climatic conditions at site, like high altitude and atmospheric pollution.
3. More "superior" to air insulated substations .
4. The higher the voltage, the more favorable gas insulated technology becomes. The footprint of 765kV, 800kV conventional substation is enormous, and GIS technology allows a significant size reduction.
5. GIS technology can be used for installations in areas where the cost of real estate is appreciable high.
6. Overcomes limitations of AIS site.

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IV. LAYOUT / SINGLE LINE DIAGRAM OF GIS

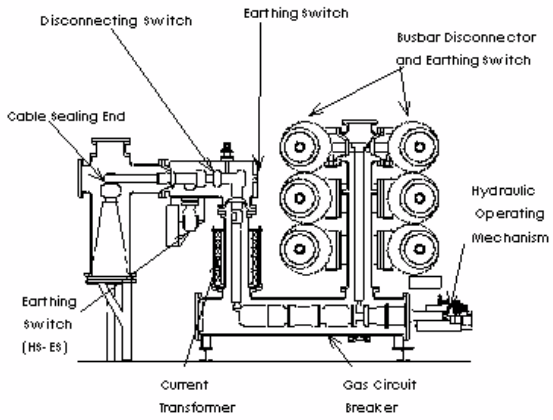

Fig :- Layout of GIS

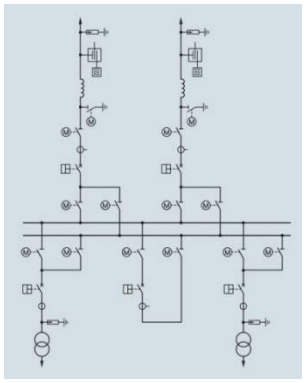

Fig:- "a"

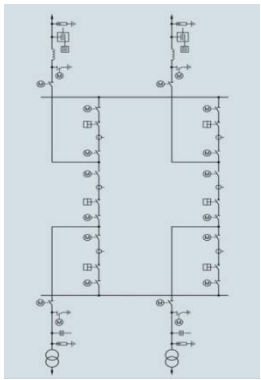

Fig :- " b"

Fig :- 'a' - SLD of GIS with double Bus Bar (2BB).
'b' - SLD of GIS with one- half Bus Bar (1.5 BB)

V. MAIN COMPONENT OF GIS

There are the following main component of GIS , which is generally used :-

1. Gas / Air Bushing with Insulator disc
2. Bus Bar
3. Insulation Medium (gas) ; SF_6 gas
4. SF_6 Circuit Breaker
5. Disconnectors / isolators switch
6. Earthing Switch
7. Instrument Transformer (C.T & P.T)
8. Surge / lightening Arrestor
9. Gas handling system
10. Controlling system (panel) And Gas monitoring devices etc...

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1. **Gas / Air Bushing with Insulator disc** :- High-Voltage cables of various types are connected to SF6 switchgear cable connection assembly and also it enables the GIS & Cables to be tested separated Transformer connection consists of Oil/SF6 bushing, the enclosure, the main circuit end terminal and removable connection.

Figure :- cable termination of SF_6 transformer

For High-Voltage test on GIS, transformer is isolated from switchgear or by removable of cable connection.

2. **Bus Bar** :- The conductors of bus bar are made up of aluminium tabular section which are joined between different section by using plug in tulip contacts which fit automatically during field connections. Enclosures are made from non- magnetic aluminium stainless steel material. As the resistance of stainless steel is higher that of aluminium the losses in stainless enclosures in therefore higher.

3. **Sulphur hexafluoride gas (SF_6 gas)** :- SF_6 or sulphur hexafluoride gas molecules are combined by one sulphur and six fluorine atoms. This gas was first realized in the year of 1900 in the laboratories of the Faculty de Pharmacie de,Paris.
In the year of 1937, General Electrical Company first realized that SF_6 gas i.e. sulphur hexafluoride gas can be used as insulating material.
After second world war, i.e. in the middle of 20^{th} century, popularity of using sulphur hexafluoride gas as insulating material in electrical system was rising very rapidly.
Allied chemical Corporation and Pennsalt were the first American industries, who began to produce this gas commercially in 1948. During 1960, using of sulphur hexafluoride gas in H.V switchgear became popular. As the demand of this gas was increasing many manufacturers in Europe and America started producing SF_6 gas in large scale, during that time.
At the beginning sulphur hexafluoride gas only used for insulating purpose in the electrical system. But soon it was realized that this gas has tremendous arc quenching property. Hence, this gas also began to be used in circuit breaker as arc quenching medium. World's first SF_6 GIS was established in Paris in the year of 1966. Sulphur hexafluoride medium voltage circuit breakers launched into market from 1971.

➢ **Manufacturing of Sulphur Hexafluoride Gas** :-
SF_6 or sulphur hexafluoride gas commercially is manufactured by reaction of fluorine (obtained by electrolysis) with sulphur.

$$\mathbf{S + 3F_2 = SF_6 + 262KCal + by\ product}$$

During process of producing of this gas, other by products like SF_4, SF_2, S_2F_2, S_2F_{10} are also produced in small percentages. Not only these by products, impurities like air, moisture, CO_2 are also present in the gas, during production. All these by products and impurities are filtered at different stages of purification to get pure and refine SF_6.

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➢ **Gas Properties** :-

Density at 20°C	6.14Kg/m^3
Colour of Gas	Colourless
Molecular Weight	146.06
Thermal Conductivity	0.0136w/mk
Critical Temperature	45.55°C
Critical Density	730 kg/m^3
Critical Pressure	3.78MPa
Sound Velocity in SF_6 gas	136m/s . It is less than 3 times that of air
Specific Heat	-1221.66kg/mol
Breakdown field Relative to pressure	89 v/m Pa
Relative Dielectric constant at 25°C and 1 bar absolute	1.00204

➢ **Chemical Properties :-**

a. Stable upto 500°C
b. Does not react with structural material upto 500°C
c. This is inert gas. The inertness of this gas is advantageous in switchgear. The life of metallic parts, contacts is longer in SF_6 gas.
d. The component do not get oxidised.
e. Moisture is very harmful to the properties of the gas. In the presence of moisture, hydrogen fluoride is formed during arcing which can attack the metallic and insulating parts in the circuit breaker.
f. This is electronegative gas.
g. During arc extinction process SF_6 is broken down to some extent into SF_4, SF_2 (Metallic Fluorides).
h. The metallic fluorides are good dielectric materials, hence are safe for electrical equipment.

➢ **Electrical properties :-**

SF_6 gas is highly electronegative. Due to high electro negativity, it absorbs free electrons which produced due to arcing between contacts of circuit breaker. Combination of free electrons with molecules produces heavy and big ions, which have very low mobility. Because of absorption of free electrons and low mobility of ions. Sulphur hexafluoride has very excellent dielectric property. Dielectric strength of sulphur hexafluoride gas is about 2.5 times more than that of air.

4. **Circuit Breaker or SF_6 circuit breaker** :- A circuit breaker in which the current carrying contacts operate in sulphur hexafluoride or SF_6 gas is known as an SF_6 circuit breaker.

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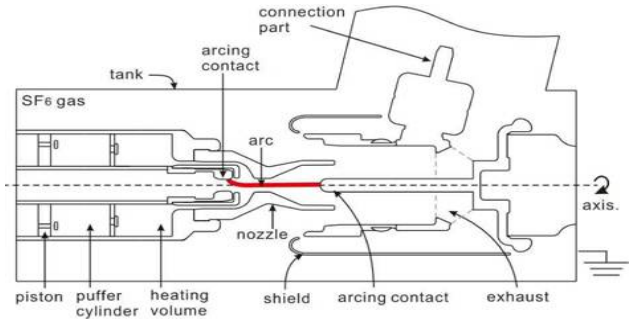

Fig :- construction of SF_6

SF_6 has excellent insulating property. SF_6 has high electro-negativity. That means it has high tendency of absorbing free electron. Whenever a free electron collides with the SF_6 gas molecule, it is absorbed by that gas molecule and forms a negative ion. The attachment of electron with SF_6 gas molecules may occur in two different ways,

$$SF_6 + e^- = SF^-_6$$
$$SF^-_6 + e^- = SF^-_5 + F$$

These negative ions formed are much heavier than free electron and hence under the influence of an electric field, the ions do not get sufficient energy to have cumulative ionization in the gas. Thus electrons from contact space are easily removed and electron avalanche breakdown is avoided. Hence SF_6 gas possesses excellent dielectric strength but also it has the unique property of fast recombination after the source is removed. The gas has also very low **time constant, due to electro negativity of SF_6 gas .** Time constant of medium is defined as the time between current zero instant and the instant the conductance of contact space reaches zero value. Even though the current reduces to Zero, heat produced in the medium between the contact of the circuit breaker is sufficient enough to ionize air or oil which will act as conductor and arc is struck between contacts. This arc should be extinguished as quickly as possible with low arc time constant. Thus SF_6 circuit breaker are suitable for switching condition with large rate of Transient Recovery Voltage (TRV). The SF_6 circuit breaker workers on "**Puffer Principle**"

- **Puffer Principle :-**

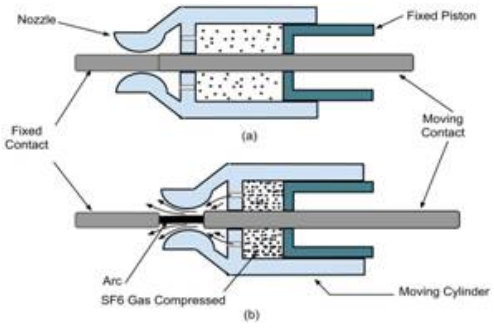

Fig:- Internal working of SF_6 Circuit Breaker

As the puffer cylinder moves downward for the opening stroke, the pressure ratio rise. The pressure rise depend upon the throat diameter of nozzle and speed of puffer cylinder. The pressure ratio increases to about five time during opening condition. The compressed gas is released through the convergent divergent nozzle. The arc quenched at a current zero . For higher interrupting ability , the flow pattern is optimised. There are two main types of circuit breaker depend upon the working are :-

1. Single pressure puffer type SF_6 C.B

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a) with insulating nozzle
b) with conducting nozzle
2. Double pressure puffer type SF_6 C.B

5. Dissconnector / Isolator Switches or Earthing Switches :-

Fig:- combined Dissconnector/ Earthing Switch Module TPS

An Earthing switch is used for the protection and it has the slowest operation. These switches are to be vertically broken switches. The earthing arm interlocked with main isolator moving contact. When the main contact of isolator will be close, then it will be open. Similarly the main contact of isolator will be open when earthing arms will be in close position. It operated only when it is a High voltage system is not energized.

6. **Instrumental Transformer (C.T & P.T)** :- Potential transformer encapsulated its own housing which forms a separate gas tight module. The pressurized gas inside the enclosure with the insulating film. The insulating film provides the protection against the over voltage. The connection of the high voltage is directly connected to the switchgear. The primary and secondary connections are connected from gas tight bushing plate to terminal. The current transformer the primary is connected to the power line in the series. So the primary is nothing it is only the current which flow through the power line and it does not depend on the load. Gas compartment reduces the access of moisture and to suppress gas tight bushing for secondary connections.

7. **Surge / Lightening Arrestor** :- Surge arrester can be connected directly if it is required. The function of its limit to over voltages. Their active part consists of metal oxide resistors with a strongly nonlinear voltage current characteristic. Surge arresters are flange joint to the switch gear through a gas tight bushing. In a tank of arrester module, it has an inspection hole in which a conductor inspected and at the bottom there are the connection for monitoring, arrester testing and operation counter.

8. **Gas Handling System** :- The close circuit gas system is employed in SF_6 C.B. Since the gas is costly, it is reconditioned and reclaimed after each operation of the breaker. Necessary auxiliary system is provided for such purpose. The low and high pressure system are provided with Low pressure alarms which monitor the gas pressure drops, falling which Dieletrical strength will be reduced and arc quenching ability of the circuit breaker will be endangered. The gas is stored in the high pressure chamber at 16 atmospheres while the gas pressure on the low pressure side is 3 atmospheres. Lot of care is required to prevent gas leakages at joints by providing sealing. The temp. is kept 20^oC. A heater backed with a thermostat at 16^oC is provided in the high pressure chamber to prevent liquefaction of the gas in the high pressure chamber at low temp.

9. **Gas monitoring unit** :- The insulating and interrupting capability of the SF6 gas depends on the density of the SF6 gas .The pressure of the SF6 gas varies with temperature, so a mechanical or electronic temperature compensated pressure switch is used to monitor the equivalent of gas density. Gas Density Monitor is directly mounted on the enclosure. The gas pressure acts on metal bellows, with a reference volume for compensation of the temperature. In

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case of gas leakage a micro-switch is actuated. Thresholds for refilling (first stage) or lock-out alarm(second stage) can be mechanically set. The response character is shown in the Moliere diagramme.
Gas Insulated Substation (GIS) SF6 contains the same compartments in conventional outdoor substations. All live parts are enclosed in metal boxes filled with SF6 gas. The active parts are supported on insulators molten resin. Some of these bushes are designed as barriers between adjacent modules such that the gas does not pass through them. The entire system is divided into compartments which are relative to the other gas-tight. Thus, the gas detection system in each compartment can be independent and simpler. The housings are of nonmagnetic materials such as aluminium or stainless steel and are connected to ground. The gas seal is provided with 'O' static seal positioned between the machined flanges. The " O- rings are placed in the slots such that, after assembly, the ' O- ring to shrink 20%. The quality of materials, the dimensions of grooves and ' O- rings are important to ensure sealing performance of the gas-insulated gas station. Gas Insulated station has a gas detection system (or Gas monitoring system). The gas inside of each compartment should have a pressure in the range of the density of the gas in each compartment is controlled 5kg/cm^2 (same as kgf/cm^2) to 6kg/cm^2,if the pressure drops slightly, 4.5kg/cm^2 the low pressure alarm is triggered automatically. And if pressure fall below 4kg/cm^2 then automatic trip lockout or shutdown the system.

VI. CASE STUDY

Fig:- 400/220 KV GIS substation at Maharani Bagh , New Delhi

PGCIL, Maharani bagh, New Delhi , has state of the art sub- station facilitating 400/220 KV GIS substation with automation, and it is used to supply upto to 1000 MW to the city of Delhi from Northern and eastern grid. This substation is design and manufactured by ABB ltd. and commissioned in 2007.It include 400 kV/ 220 kV Greenfield Substation with 5 bays at 400 kV and 7 bays at 220 kV with 2 nos. 315 MVA, 400/220/33 kV three phase Auto Transformers Gas Insulated Switchgear ELK type at 400 kV and 220 kV from ABB Switzerland. Complete civil work including 400kV and 220kV GIS buildings, control room building and foundation of switchyard equipment. The foundations were constructed over piles as site is located close to river bed. It has the following features :-

- Compact substation ensuring 65% space saving compared to conventional substations.
- Reduction in T&D looses due to proximity of substation to load centres.
- Remote controlled operation for 400kV system from PGCIL Ballabgarh control centre.
- Maintenance free Gas Insulated Switchgear.
- Substation automation system with IEC 61850 compliance
  - — High system availability with redundancy
  - — Guaranteed system openness for future expansion and integration
- Fully interoperable system with IED 670 for protection and control.
- The combined dissconnector and earthing switch assembly guarantees maximum operational safety.
- All live parts are enclosed and effectively protected against negative external influences.
- The ELK-14 and ELK-3 range require 40% less space than ABB's previous GIS systems.

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VII. SUGGESTION AND FUTURE SCOPE OF DEVELOPMENT

a. Improve the Circuit-breaker technology, which reduce the number of interrupter units despite the increasing braking capability.
b. Progress of machining technology of aluminium cast parts uses for the minimized shapes and volumes
Use of computerized production of high quality standards and testing equipment.
c. Integrated components Design which has the several functions such as grounding switch, dis-connectors within one gas compartment
d. To avoid the unnecessary tasks and maintaining the activities for use of intelligent monitoring and diagnostic tools.

VIII. CONCLUSION

GIS or gas insulated switchgear system available for the high voltage, only SF6 (sulphur hexafluoride) is used both for interruption medium and insulation because dielectric strength is so excellent of SF6. In some areas to be studied include more conservative designs, better particle control & improved gas handling & decomposition product management techniques Achieving & maintaining high levels of availability requires a more integrated approach to quality control by both users and manufactures. In the future we can see the gas insulated current transformer work in this substation and the compact size will be less and it will be more economical.

The evaluation study of the life cycle presented here demonstrate the advantages of SF6 insulation (GIS) compared to air insulated switchgear (AIS) to a level distribution . Equipment is, however, only to a very small for a global warming potential contribution. The design and use of the capacity of electricity distribution networks have a much greater influence, whether used or AIS GIS technology. Therefore, prohibitions and restrictions on the application of the use of insulated medium voltage SF6 cannot be justified from an ecological point of view.

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