GAS INSULATED SUBSTATION (GIS) Vs CONVENTIONAL OUTDOOR SUBSTATION (AIS)

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0 ABSTRACT

The author in his paper has made comparison of Gas Insulated Substation (GIS) with Conventional Air Insulated Substation (AIS). According to the author GIS are much more reliable, compact and maintenance free. Because of compactness of equipment, a very small area of land and civil work is required resulting in substantial savings and makes GIS compatible with AIS at higher voltages. They are at present mostly used in space constraint areas. The author strongly recommends that at 500 kV only GIS should be used while at 220 kV and 132 kV their selection should be based on economic viability of the sub-station compared with the conventional outdoor grid station.

1 INTRODUCTION

For the past three decades, SF-6 Sulfur hexa fluoride gas is being extensively used as a dielectric and extinguishing arc media in the area of high voltage electrical switchgear. SF-6 gas does not exist in the natural state and is a synthetic product, finds itself progressively adopted by all concerned users due to its improved performance characteristics and service quality which has reduced size and weight of the equipment. The reason for this choice lies in the fairly rare combination of dielectric and arc-extinction properties. The dielectric strength is several times greater than that of other known media, at the same pressure. The arc-extinction properties are also unique which even after much research carried out, could not discover a comparable media so far.

GIS are equally applicable for indoor and outdoor use for new and expansion of existing sub-stations. The GIS are manufactured over a wide range of voltages from 60 kV to 800 kV and capacity upto 4,000 amperes depending upon requirements in various designs suited to the particular requirements. In places where the cost of land or the cost of earthwork is high this can greatly influence the over all investment needed.

In case of GIS each individual item of switchgear is metal enclosed which is at earth potential. This metal encloser not only gives enhanced safety but is inherently reliable due its component being placed within a protective gas environment. Its major advantage is the small space, occupied by the equipment compared to air insulated equipment.

When new sub-stations are planned, there is the choice of different designs. Conventional outdoor sub-stations are a viable option when there is a plenty of space, land prices are low, environmental conditions are normal and maintenance labour costs are low. GIS are advantageous when the space available is limited, land prices are high, environmental conditions are more extreme, and reliability of power supply is of more importance.

2 SUB-STATION REQUIREMENTS

In addition to pure network requirements such as rated voltages, currents, short-circuit capacities and the number of bays, the layout of a substation is dependent on considerations such as:

- reliability
- operational flexibility
- future extensions
- network separation possibilities for short-circuit capacity limitation
- simplicity and selectivity of the protection equipment
- building and erection times (prefabrication or on-site assembly)
- maintenance
- personnel safety and equipment security during maintenance work
- site area
- geographical location and the associated environmental effects of temperature and humidity, industrial or coastal pollution, and earthquakes
- national and international standards
- historical developments and traditions within a power board authority
- total cost of the project

Consideration of appropriate factors leads to the substation concept and to the choice of conventional outdoor or SF₆-insulated high voltage installations. One of most important factor is the reliability and cost of the project which will be discussed next.

The switching scheme is also of great importance for the operational flexibility of the substation. The system availability, i.e. the percentage of time the system is in service, is strongly influenced by the degree of redundancy – alternative switching paths – available in and between substations. In order to increase redundancy and thus system availability, proven substation arrangements are used, examples being single or double busbars with by-pass and $1\frac{1}{2}$ circuit breaker scheme.

3 COST OF SUB-STATION USING METAL-ENCLOSED SF₆-INSULATED OR CONVENTIONAL OUTDOOR HIGH VOLTAGE SWITCHGEAR

Recent developments in the field of SF₆-insulated switchgear technology have raised the question whether substations using conventional out door high voltage switchgear are still economically attractive. There is no doubt today that the cost of high voltage installations employing metal-enclosed SF₆ technology is lower than for conventional outdoor switchgear for rated voltages of 420 kV and above. The site required is much smaller. In general, both circumstances lead to a considerable cost saving with complete substation projects when SF₆-insulated high voltage switchgear is used.

For rated voltages below 420 kV, this cost advantage in the favour of SF_6 technology is not so clear. This can be seen from the Figure-1 where the relative cost (cost ratio of SF_6 and conventional outdoor installations) is represented as a function of the rated voltage.

- a) for the high voltage installation alone (Figure-1); and
- b) for the complete substation project including all installations, land, civil works, erection, capital interest during erection and maintenance (Figure-3).

Cost varies from case to case dependent upon a range of factors; estimated maximum and minimum cost is therefore shown in the graphs below. The cost variation of the high voltage installation itself is relatively small and mainly influenced by the layout. The considerably larger variation for the complete substation is due to different site cost and other local conditions.



Figure-1 – Rated Voltage Note: Figure-1, 2 and 3 are reproduced from the documents prepared by Sprecher Energie

If only the high voltage installation is considered, it is obvious that the cost for SF_6 -insulated installations is higher for rated voltages of 72.5 kV to 245 kV. On the other hand there is no clear cost advantage for either technology if complete substation cost is considered. For this reason, in the voltage range 72.5 kV to 245 kV the choice of high voltage switchgear technology is generally determined on a purely technical basis such as site area requirements or environmental considerations.

Total Cost of a Substation

A further point not to be neglected when considering the prime cost of installation is the cost of main tenance and repair. Extremely high quality and reliability of the installation would lead, of course. to low maintenance and repair cost but would also mean high prime cost which, with high capital interest charges, might be uneconomical. On the hand, other low installation prime cost with an associated low equipment quality and reliability would be



Figure-2 – Quality, reliability

coupled with high maintenance and repair cost. The Figure-2 depicts this interrelation.

The minimum total cost of the substation results from а compromise between quality and reliability on the one hand, and maintenance and repair cost on the other. Because of the high maintenance and repair charges, low quality of installation s very often more expensive in the long run.



Figure-3 - Rated Voltage

4 ADVANTAGES OF GIS OVER OUTDOOR CONVENTIONAL GRID STATION

- i. **Low area requirement.** 550 kV models, for example, take only fraction of the space required by conventional air types.
- ii. *Environmental adaptability.* GIS is suitable for installation almost anywhere: in or out of doors, even underground; near the sea, in mountainous areas, in regions with heavy snowfall, etc.
- iii. *High margin safety.* The high voltage conductors are securely enclosed in grounded metal.
- iv. *High reliability.* The chemically inert SF₆ enveloping the conductors and insulators preserves them for years of trouble free operation.
- v. **Long maintenance intervals.** SF₆ gas's arc-quenching properties reduce contact wear. Technological advancements over the years have seen GIS continues to grow smaller and lighter.
- vi. *Low Maintenance Cost:* GIS are highly reliable and maintenance free. No inspection is required before ten years.
- vii. **Long Life:** The operating life of GIS is 40 to 50 years compared to 25 to 30 years of conventional outdoor grid station.
- viii. *Personnel Safety:* GIS causes no risk of injury to operating personnel.
- ix. **Short Circuits by Wildlife:** Fully encapsulated enclosures reduces risk of outages caused by lizards and vandalism.
- x. **Unbeatable Performance:** Factory assembled and tested units offers unbeatable performance in terms of reliability and continuity of power supply.
- xi. **Unaffected by Environmental Conditions:** GIS is unaffected by environmental factors. It is most suitable for harsh environmental conditions i.e. where humid, saline, polluted atmosphere laden with industrial exhausts prevails.
- xii. **Economical:** SF₆ plants are more economical than conventional equipment despite the higher cost of switchgear.

5 DESIGN REQUIREMENTS AND SALIENT FEATURES OF GIS

5.1 Plant Arrangement of SF₆ Gas Insulated Switchgear

A modular system provides utmost flexibility in satisfying the wide-ranging requirements in the most economical fashion. The range of modular components allow to permit virtually any desired switchgear layout by appropriate combination of modules. Aluminum alloy construction results in comparatively low component weight and therefore reduced loading requirements on foundations and on erection equipment (cranes, etc.). The salient features of SF₆ switchgear from the plant viewpoint should be as follows:

- The circuit breaker must be easily accessible from the operating passage to facilitate inspection and maintenance, and arranged to allow horizontal withdrawal and insertion of the active unit at a convenient height.
- Bushbars should preferably be arranged vertically above the breaker, providing maximum accessibility.
- Bushbar dismantling and reassembly should be possible with minimum disturbance to neighbouring equipment (e.g. additional of busbar section dis-connector in future extension)
- Bushbar gas compartments much be segregated according to bay (prevents fault propagation to healthy bays).
- Entry of high voltage cables should be possible without a cable basement. A flexible modular component system allows optimal combinations of switchgear to meet any requirement. Circuit breakers are easily accessible for inspection and maintenance. A typical arrangement of SF₆ plant sub-station with various busbar arrangements is show in Figure-4.

5.2 Phase Segregation Concept

Today three-phase bus bar and circuit breakers are being accommodate in the same chambers upto 420 kV due to economical reasons, although single-phase enclosers have some obvious advantages over three-phase, as discussed hereunder.

One of the most important factors in ensuring reliability of SF_6 switchgear is segregation into single-phase enclosures. The rotationally symmetric configuration thereby achieved is clearly defined, both electrostatistically and electrodynamically. This leads to the following advantages.



Figure-4:



- Electric filed distribution in the single-phase case can be calculated to high accuracy with computer assistance, for any desired scale magnification. The field distribution in a three-phase enclosure with complicated junctions represents a 3-dimension problem which cannot be so accurately modeled.
- Dielectric test results for a single-phase enclosure can always be adopted with confidence, since only 2-electrodes in a phase-to-earth configuration are involved. A three-phase enclosure, however, represents a 4-electrode configuration, generally with 3 different voltages opposed to the earthed enclosure. Simulation of these conditions exceeds the bounds of economical testing procedures. Dielectric reliability can be practicably demonstrated and confirmed on site only for single-phase enclosures.
- The central conductor is a coaxial single-phase system is subject to negligible dynamic forces under short-circuit conditions. The conical supporting insulators are not exposed to stresses which could cause cracking and subsequent flashover.
- In the unlikely event of an internal flashover, a single-phase enclosure experiences an earth-fault only. Where the system is non-effectively earthed, as is often the case, a small and relatively harmless current flows through the arc to earth. Every flashover in a three-phase enclosure, however, spreads immediately and develops into a heavy current, three-phase short circuit.



Figure-5 (a) a Simple field distribution for a single-phase enclosure similar to that of the B-212 design (coaxial equipotentials, independent of applied voltage).



Figure-5 (b) Complex field distribution for a three-phase enclosure. Three-phase rated voltage was applied to the 3 conductors, and an impulse equivalent to the lightning impulse withstand voltage applied to conductor 3, with the enclosure maintained at earth potential (refer to 5c).

• The probability of a heavy current internal arc is lower in a single-phase enclosure, and the prospective energy dissipation is also markedly less. The total length of the multiple arcs in a three-phase enclosure fault is much greater than that of the single arc in a single-phase enclosure fault. The arc voltage is consequently higher in the three-phase case, and greater energy is dissipated with the same fault current.



Figure-5 (c) Operating voltages on conductors 1 and 2, superimposed lightning impulse on conductor 3 and earthed enclosure in reference with figure 5 (a) and (b)

5.3 Gas Monitoring

The overall principle of phase segregation should be consistently observed, including the gas monitoring system. Risk of failure due to complicated gas piping is thus avoided. Each sealed gas compartment should be equipped with a gas filling arrangement and safety device for the latter normally two set points are provided. The First signals that top-up is required at approximately 93% of rated gas density. The second set-point initiates the "alarm / trip / lock-out" emergency signal when minimum operating pressure is reached, i.e. at approximately 90% rated gas density. If desired, a third set-point operating approximately 110% rated gas density can also be provided to signal overpressure conditions. Experience in service has shown that gas losses can be restricted to less than 0.5% per year without any additional measures, thereby rendering automatic gas refill superfluous.

5.4 GIS for outdoor use

- a. GIS for outdoor use is a compact switchgear solution for a rated voltage upto 245 kV, used mainly for renewal or expansion of air insulated outdoor subs-stations. They are also equally used for new outdoor substations. With the introduction of outdoor GIS, replacement and expansion of sub-stations can be carried out with ease and convenience with minimum disturbance of supply. GIS outdoor has the same feature as GIS indoor.
- b. GIS for outdoor use, is the combination of metal encapsulated, gas insulated modules with air insulated components such as bus bars, etc and are mounted on a separate frame on foundation. All modules fit together at the same height. Only supporting structures, foundations, and termination gantries are required. The quantities and equipment for outdoor bushings, foundations and support structures is very small compared to air insulated conventional sub-station.

c. One concept of GIS outdoor switchyard is the horizontally positioned modules. Normally such modules are rated upto 145 kV. Such outdoor arrangements results in more than 50% of space savings and is very useful for modification and extension of existing distribution at grid station.

6. Space Requirement

The Modular System not only allows all customary circuit arrangements, but also provide individual solutions for specific building dimensions and system extensions. Typical arrangements for a double bus bar 220KV bay (fig 6) and one and a half breaker lay out scheme for 500kV station (Figure-7) are enclosed, to give idea of space requirements to the readers.

7 SUMMARY

- **7.1** GIS offer an attractive solution in contaminated and space constraints areas at all voltage levels. At 420kV and above ratings installation of GIS is fully justified due its low project cost, higher reliability and little maintenance over life of the project. So it is strongly recommended that in future 500kV Stations should be GIS.
- **7.2** Outdoor GIS is also an attractive supplement to expansion and replacement of existing conventional outdoor distribution sub-stations. There are numerous advantages including ease of installation, accommodation of more bays within the same area, long life of equipment low maintenance cost and higher reliability compared to conventional grid station.

REFERENCES

Reproduction and free use from the following catalogues is hereby acknowledged.

- 1. *M/s Sprecher Energie* product catalogues
- 2. *M/s Siemens* product catalogues
- 3. *M/s Alsthan* product Catalogs

One circuit breaker and a half diagram, Lay-out



Figure-7



Figure-6