Economics Between Conventional and Gas Insulated Substation; A Project Decision

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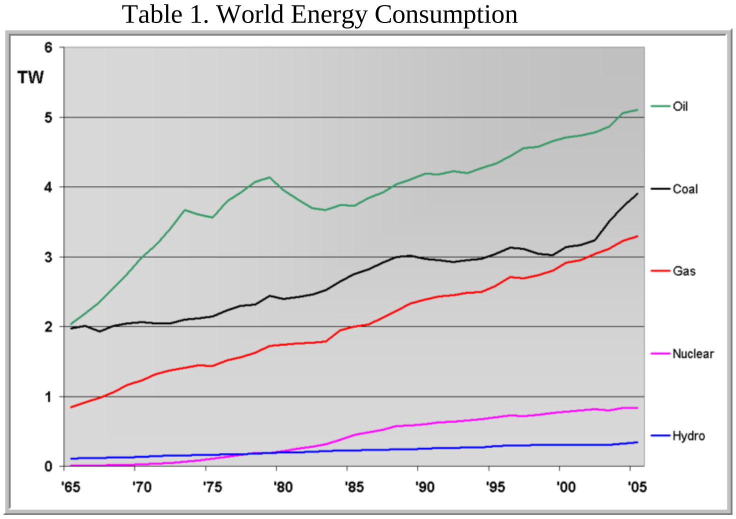
ABSTRACT *As the global economy continues to grow, the demand for power also rises. As a result, substation equipment had to be made more reliable and compact to cope with higher voltage and larger capacity ratings thus pushes most of the existing electrical utilities to improve and expand their physical infrastructure. A prominent problem these utilities are facing is the premium cost of land on which they have to build their expansion. Though current technology offers some solution, like resorting to GIS substations, somehow management team still clings on the question "Is it worth of investment?" aside from being costly than a conventional substation, there is an uncertainty of global acceptance of SF6 as dielectric medium. Inter-governmental Panel on Climate Change identified it as a green house gas which is twenty five times worse than Carbon Dioxide. Having identified the above issues, this paper provides vital information needed whether one wishes to pursue a GIS substation project.*

KEY WORDS: GIS, SF6

1. Introduction

In 2004, the average total worldwide power consumption of the human race was 15 Tera watts (TW) (= 1.5×10^{13} W) with 86.5% from burning fossil fuels. This is equivalent to 0.5 ZJ (= 5×10^{20} J) per year, although there is at least 10% uncertainty in the world's energy consumption.

Table 1. World Energy Consumption



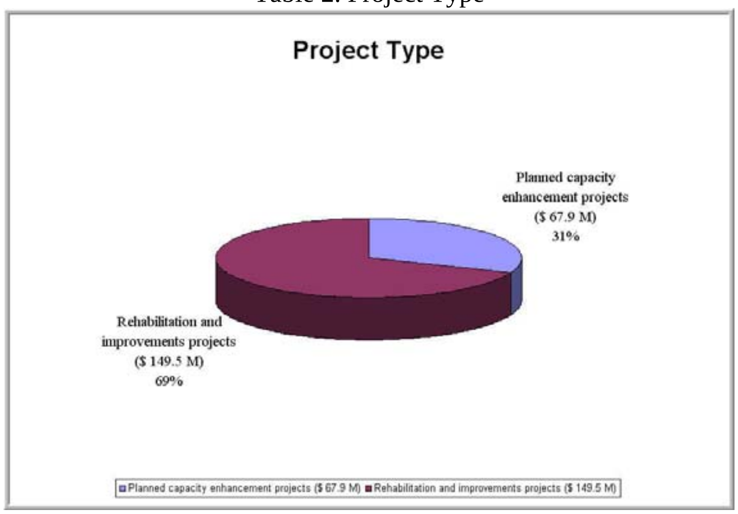
Source: http://en.wikipedia.org/wiki/Image:World_Energy_consumption.png

In the US alone, demand for electricity is forecast to increase by more than one trillion kilowatt-hour (kWh) by 2020. At the same time, growth in international demand for electricity is forecast to increase by almost 9 trillion kWh.

As the demand for power continues to grow, so is for the construction of new electric utilities and while other diverge on expansion of existing infrastructures.

On a study conducted by Balducci, “An Examination of the Costs and Critical Characteristics of Electric Utility Distribuiton System Capacity Enhancement Projects ” on three utilities serving customers in the Western United States, one utility estimated that, from 1995 to 2002, roughly $67.9 million, or 31.2 percent, of its distribution system capital budget included planned capacity enhancement projects, which includes construction of new substation, while an additional $149.5 million in projects involved rehabilitation and improvements to the existing system.

Table 2. Project Type



Source: www. gridwise.pnl.gov(adopted)

A number of large utilities, Xcel Energy and Alabama power among them, are installing new High-Capacity transmission conductor as a way of pushing more power through existing rights of way, as opposed to acquiring more land to build new transmission corridors. Just like in case of Hawaiian Electric Co. (HECO) where they choose the High-Pressure Fluid-Filled (HPFF) underground cable termination. The HPFF cable system met HECO’s high-ampacity requirement and had the ability to obtain higher load-transfer capacity.

Though there are several ways to resolve space consideration, utilities also looks to make new switchgear purchases. According to a study by Newton-Evans Research Company of Ellicott City, Md,, (as cited) majority of utilities who are choosing gas-insulated over air-insulated switchgear are making those decisions based on space constraints.

2. Advantages of Using GIS substation

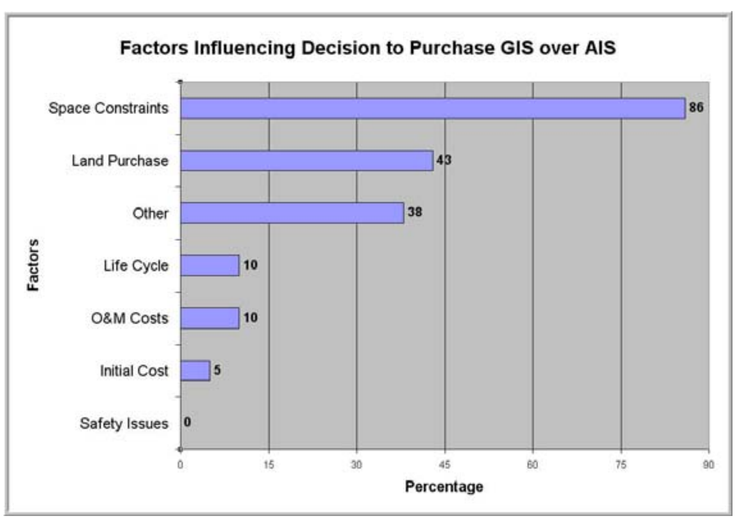
2.1 Compactness

One of the biggest challenges utilities are facing as they seek to improve and expand their physical infrastructure is acquiring land upon to which to build. Right of way acquisition is among the most difficult, time consuming steps in getting a new project completed. For that reason, utilities are trying to make the best use of the space they already have when embarking on a project to upgrade the grid. (Utility Automation T&D, 2006)

Gas-Insulated substation provides a solution to the space problem. It is ideal in dense urban areas where land for new facilities is limited and only available at prohibitive cost. (Oshiro, Ikeda, & Isler, 2002) The compact features of gas-insulated switchgear (GIS) makes it an ideal choice for areas where it is desirable to minimize the aesthetics impact of utilities (Oshiro, Ikeda, & Isler, 2002) and it is proving to be a positive for utilities tight on space. (Utility Automation T&D, 2006). In fact, the general direction of switchgear development throughout the entire quarter century was towards producing more compact designs, fulfilling higher voltage operation and improving gas seal integrity (Overstall, 2002).

GIS Substation also offers unique advantages over air-insulated applications. GIS substations use SF_6 gas that reduces the distance needed between active and non-active switchgear parts, resulting in smaller overall space requirements. Southern California Public Power Authority Awards ABB Order for GIS Substation Project. (2004, February)

Figure 1. Factors Influencing Decision to Purchase GIS over AIS



A couple of projects have been successfully completed by resorting to the use of GIS substation and among them are HESCO and Grayson Power Plant.

2.1.1 Case 1. HECO

GIS substation enables (HECO) to meet load growth at Honolulu business center. To supply new loads in the business center of Honolulu, the Hawaiian Electric Co. (HECO) was confronted with several problems. The space available for building and upgrading utility facilities in this area is increasingly scare. Located within the jurisdiction of Hawaii's Kakaako Community Development District, additional requirements for utility construction work are strictly regulated. To optimize the available land, HECO selected GIS equipment because it was compact and generally required only 10% to 25% of the foot-print area and 30% to 50% of the height needed for an open-air substation. (Oshiro, Ikeda, & Isler, 2002)

2.1.2. Case 2. Grayson Power Plant

The new GIS substation, with its associated disconnect switches, ground switches, control house and other equipment, was constructed in a (46-m by 20-m) area. It replaces a non-sectionalized air-insulated 69-KV switch rack at GWP's Grayson Power Plant, which occupied a (21-m by 62-m) space for nearly 34 years. The new substation saves 427 sq m of valuable land that can be used for future expansion of electrical distribution system or new generators. (Abueg, 2005). The new set-up provides less visual impact, because it is a height of 2.4m compared to the 7.6 m height of the old air-insulated station. (Abueg, 2005).

2.2 Dielectric and Arc Quenching strengths

Switchgear and its components are a vital link in the transmission and distribution chain. Gas insulated switchgear (GIS) using Sulphur hexafluoride (SF_6) has been in use since the 1960s, at high voltage (HV) application first and medium voltage (MV) much later. Air is also used for insulation but SF_6 has significant property advantages, notably its dielectric and arc quenching strengths. SF_6 gas allows smaller dimensions because the insulating properties are 2.5 times higher than air. (GIS technology does the talking)

2.3 SF_6 does not deplete

As the SF_6 does not age or deplete, operators do not need to top-up gas levels during the equipment's lifetime, taken as 40 years. For that reason as well there is no need for maintenance on any component within the switchgear. AIS has humidity, dust, and altitude to contented with. (GIS technology does the talking)

2.4 High operational reliability

It offers a great operational reliability because inside the enclosed gas compartments the primary conductors have complete protection against all external effects. The SF_6 insulation ensures complete freedom from oxidation for the contacts and screwed joints, which means that there is no gradual reduction in the current carrying capacity of the equipment as it ages. There is also no reduction in insulation capacity due to external factors. (Frequently asked Questions and Answers on SF_6)

The minimal use of synthetics reduces the fire load. The GIS station operated adequately without any glitches during the unprecedented heat wave in July 2006, with sustained temperatures reaching of 44°C (Abueg, 2005).

2.5 Important contribution to the security of supply

Total enclosure also means that the equipment is almost completely independent from the environment. SF_6 -insulated switchgear can also be used under difficult climatic conditions, for example: in humid areas with frequent condensations from temperature changes, and even in places with flooding potential.

Where the reliability of the insulation might otherwise suffer from contamination, e.g. dust from industry or agriculture or saline deposits in coastal areas. Gas-insulated switchgear completely eliminates this possibility throughout the whole service life of an installation.

In contrast to air insulation, whose insulating capacity reduces with increasing altitude, SF6-insulated switchgear retains its full insulating capacity regardless of height above sea level. So larger and more costly special designs, or equipment with higher insulation ratings - and therefore more costly - are avoided (Frequently asked Questions and Answers on SF_6)

2.6 Local operator safety

SF6-insulated switchgear makes a substantial contribution to reduce the accident risk. The total enclosure of all live parts in earthed metal enclosures provides immanent protection against electric shock and minimizes the risks associated with human errors The high-grade switchgear remains hermetically sealed for its whole service life. (Frequently asked Questions and Answers on SF_6)

3. Disadvantages

3.1 Green House Effect

Many resolute anti- SF_6 voices are being raised over the impact of the gas on the atmosphere. At a meeting of the Inter-governmental Panel on Climate Change – The international body recognized by the UN in these matters – it was reported that its effect is 25 times that of Carbon Dioxide. (Overstall, 2002).

SF_6 has been identified as a "greenhouse gas" having a long atmospheric lifetime. The Kyoto Summit on Climate Change held in December 1997 included SF_6 in the "basket of greenhouse gases". [UNIPEDE Group of Experts NORM SF_6. (1998, June)]

According to March Mahoney, vice president of Transmission Network Asset Management of National Grid when they replace the outdoor 345 kilovolt Gas Insulated Substation at the Brayton Point generating station in Somerest, Mass, with a new indoor facility he mentioned that the project will reduce future emission of SF6 gas into the environment. This is a project decision when the GIS substation that was built in the early 1970's approaches the end of its useful life (National Grid Begins Series of GIS Substation Replacement).

3.2 Health Hazard

The gas has little or no odor, so under these conditions physical asphyxiation can occur. When exposed to an arc, such as might happen when a fault develops in electrical equipment, the gas molecule breaks down and harmful by-products are created. These consist of metal fluoride powders and various gases. The powdery substances cause irritation to the skin and mucous membranes, which at least warn the affected person that they have exposed (Overstall, 2002).

3.3 Potential Insulation Coordination Problem

The insulation coordination of GIS connected to an overhead line through an underground cable poses a particular problem. IEC 60071-2 considers that generally in such a configuration it is required to select the higher standard rated lightning impulse voltage from IEC 60071-2 and install surge arresters at the line cable junction.

The compact nature of GIS, when coupled with short sections of cable, complicates insulation coordination practice. The impact of a fast front transient can be worse, since a flashover in solid insulation or GIS can result in permanent faults which require long term outages before repairs can be made. (Osborne 2007)

4. **Investment Analysis**

Comparisons are essentially intended to shed light on how well a company is achieving its objectives. In order to decide the types of comparisons that are useful, we need first to consider what a business is all about - what its objectives are. Let us say, as generalization and *insofar as it can be measure quantitatively, that the overall objective of a business is to earn a satisfactory return on the funds invested in it, consistent with maintaining a sound financial position*. (Note that this statement is limited to facts that can be expressed numerically. However, employee satisfaction, social responsibility, ethical considerations, and other non-measurable objectives are also important and must be taken into account whenever possible in appraising the overall success of an enterprise. This generalized statement of objectives has two aspects: (1) earning a satisfactory return on investment and (2) maintaining a sound financial position.

And just like what have mentioned above, this study will focus on the *essential elements need to consider when deciding to construct a substation.*

4.1 Return on Investment (ROI)

It is broadly defined as net income divided by Investment (Figure 2). The term investment is used in three different senses in financial analysis, thus giving three different ROI rations: return on assets, return on owner's equity, and return on investment capital. For this paper, benchmark value for *Utilities Industries* is as shown on table 3

4.2 Return on assets (ROA)

It reflects how much the firm has earned on the investment of all the financial resources committed to the firm. Thus the ROA measure is *appropriate if one considers the investment in firm to include current liabilities, long-term liabilities, and owner's equity, which are the total sources of funds invested in the assets.* It is useful measure if one wants to evaluate how well an enterprise has used its funds, without regard to the relative magnitudes of the sources of those funds. The ROA ratio often is used by top management to evaluate individual business units within a multidivisional firm but in this case study asset referred is the utility substation.

4.3 Return on Owner's Equity (ROE)

This *reflects how much the firm has earned on the funds invested by the shareholders.* This ROE ratio is obviously of interest to present or prospective shareholders, and is also of concern to management, which is responsible for operating the business in the owner's best interest.

4.4 Return on Invested Capital (ROIC)

Invested capital is equal to noncurrent liabilities plus shareholders' equity and hence represents the funds entrusted to the firm for relatively long periods of time. ROIC focuses on the side of the permanent capital. It is presumed that the current liabilities will fluctuate more or less automatically with changes in current assets and that both very with the level of current operations.

Table 3. Ratios for Selected Industries

Industries	Percent Return on Equity	Percent Return on Sales	Price Earnings Ratio
Aerospace	14	3.2	9
Airlines	-0.5	0.1	
Appliances	16.9	4.8	11
Automotive	16.4	4.7	6
Banks and bank holding companies	-7.7	-2.8	
Beverages	19.9	7.2	16
Building Materials	21.5	7.1	9
Chemicals	15.7	7.0	12
Conglomerates	17.1	4.7	10
Containers	15.3	4.4	12
Drugs	23.5	12.3	18
Electrical and Electronics	13.4	5.0	17
Food Processing	20.7	4.1	15
Food and Lodging	20.5	5.9	15
General Machinery	3.5	1.6	41
Leisure time industries	13.6	5.9	18
Metals and metals mining	7.7	4.8	14
Office equipment and computers	14.3	8.2	14
Oil and Coal	4.8	1.9	30
Oil service and supply	-1.1	-0.2	
Paper and Forest product	14.2	6.2	12
Personal Care products	13.5	4.1	21
Publishing, radio and television	16.8	7.4	21
Railroads	7.9	6.2	13
Retailing, food	16.7	1.4	17
Retailing, nonfood	13.7	3.0	15
Service Industries	11.8	2.7	19
Steel	6.9	2.5	23
Telecommunications	13.3	8.0	13
Textiles and apparel	14.4	4.3	12
Tire and rubber	20.1	3.9	10
Tobacco	22.4	6.6	12
Trucking	9.1	2.4	18
Utilities	**11.6**	**10.6**	**10**
All industries composite	11.6	4.6	15

Source: Accounting: Text & Cases

4.5 Measurement for this study

The principal value of analyzing financial statement information is that it suggests questions than need to be answered. Such us how much worth of expenses with respect to revenue will be needed to get be inline with Industry standard such as those shown in Table 3.

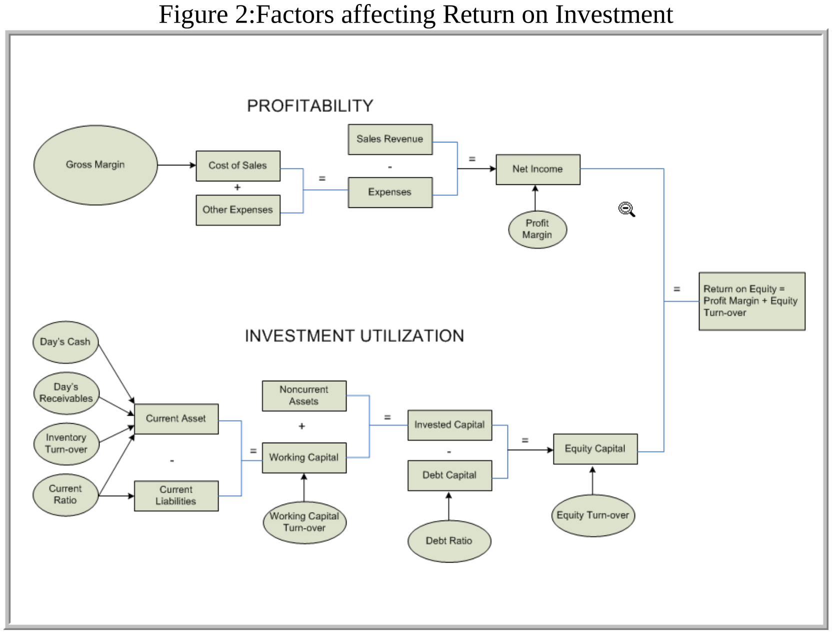
Table 4: Cost values associated with Utility Investments

Study Subject	Cost and Critical Characteristics of Electric Utility Distribution System Capacity Enhancement Projects.
Time Duration	7 years (1995 - 2002)
Number of Respondents	172 Electricity Distribution system
Capital Cost (average)	$51/kVA
New Substation cost	$112/kVA
New Transformer cost	$87/kVA
Substation capacity increase	$21/kVA

Source: An Examination of the Costs and Critical Characteristics of Electric Utility Distribution System Capacity Enhancement

Considering the data taken from the study of cost and critical characteristics of utility Distribution system capacity enhancement project (Table 4) and applying that to the cost analysis on a hypothetical scenario of investment between GIS and AIS substation (Table 5), the deciding factor may lay only on how much Utility firm may tolerate such amount of operational expenses.

Figure 2:Factors affecting Return on Investment



And assuming a great difference in premium paid per footprint of a substation, this amount still insignificant overtime if allowed the expansion is limitless.

As mentioned above, GIS substation requires very much little maintenance which somehow can be equated to lower operational expenses; but this thing is not true in real sense. In the era of TPM and plethora of maintenance philosophy, for this type of equipment, run to wreck maintenance wouldn’t be applied just to capitalize of minimum maintenance issue over GIS. Somehow, somebody still needs to check and keep that equipment in vital shape, even apply preventive maintenance because of its vitality to customer’s demand.

Comparing ROIC of both GIS Substation and AIS Substation, it can be easily seen in the table below that there is a significant difference between two values. GIS being compact takes lesser foot print and thus reduces the cost in terms of capital investment. It also has lesser cost in terms of maintenance which, as it claims can be attributed to non-deteriorating property of the gas medium.

On other hand, if capital intensity will be consider, there seems no significance value between the two. This financial measurement is less encompassing than investment turnover but this focuses heavily on the property, plant and equipment item which is ideal for this type of industry. Capital intensity ratio, sometimes called fixed asset turnover focuses on tangible investment such those above mentioned equipments. Companies that have a high ratio of plant to sales revenue are particularly vulnerable to cyclical fluctuations in business activity. Because the costs associated with this plant are relatively fixed, when their sales revenue drops in a recession, they are unable to cover these costs. Conversely, a company that is not capital intensive can reduce its cost as its revenues decline and therefore has less difficulty in a recession.

Table 5. Consolidated Statement of Income

	GIS Substation	AIS Substation
Substation size	48,000	48,000
Substation Cost	$5,376,000	$5,376,000
Lot Size	4,000	5,000
Cost of prime per sqm.	500	500
Prime Lot Cost	$2,000,000	$2,500,000
Investment Cost	$7,376,000	$7,876,000
Expenses (Operational Cost)	$1,000,000	$1,125,000
Income	$945,120	$820,120
Sales Revenue	$1,945,120	$1,945,120
ROIC	12.81%	10.41%
Capital Intensity	0.26	0.25

5 Conclusions

The choice between GIS substation and AIS depends largely on the advantages versus disadvantages of the two equipments. GIS being compact is the obvious choice of many utilities because of its many technological advantages over AIS.

And though most industry are getting conscious about global warming issues, until such time SF6 is banned, like those chlorofluorocarbons (CFCs) before for being identified as greenhouse gas, it is still worthy investment for a utility upgrade.

When it comes to financial aspect of an investment, overall performance measure, suggest GIS has significantly edges AIS. This can be attributed on the lesser investment as results to lesser footprint and operational cost requirement.

BIBLIOGRAPHY

ABB Completes GIS Installation for SCPPA. (2005, April). *Transmission & Distribution World*, Retrieved December 11, 2007, from Business Source Corporate database.

Abueg, R. (2005, April). Glendale Installs Its First GIS substation. *Transmission & Distribution World*, Retrieved December 11, 2007, from Business Source Corporate database.

Balducci, P., Schienbein, L., Nguyen, T., Bronwn, D., & Fathelrahman, E. (2004, September). An Examination of the Costs and Critical Characteristics of Electric Utility Distribuiton System Capacity Enhancement Projects. *Proceedings of 2004 PES PSCE Meeting* Retrieved December 11, 2007, from www.gridwise.pnl.gov

Bell, R., Charlson, C., Halliday, S., Irwin, T., Lopez-Roldan, J., & Nixon, J. (2004, September). GIS on-site testing. *International Power Generation, 27*(5), 25-26. Retrieved December 11, 2007, from Business Source Corporate database.

Brown, S. (2005, January). Utility Automation & Engineering T&D Looks Back on its First Decade. *Utility Automation & Engineering T&D, 10*(1), 16-22. Retrieved December 11, 2007, from Business Source Corporate database.

ComEd Buys as Part of $200M Reliability Project. (2006, June). *Utility Automation T&D*, Retrieved December 11, 2007, from Business Source Corporate database.

Foata, M., Beauchemin, R., Vincent, C., Roy, M., & Talbot, S. (2001, March). GIS Equipment Sounds Off…Are You Listening?. *Transmission & Distribution World, 53*(3), 70. Retrieved December 11, 2007, from Business Source Corporate database.

OMAN Awards AREVA T&D the Country's Largest High-Voltage GIS Contract Ever. (2004, December). *Transmission & Distribution World*, Retrieved December 11, 2007, from Business Source Corporate database.

SDG&E Upgrades Miguel Station. (2005, March). Hidden Within View. (Cover story). *Transmission & Distribution World* Retrieved December 11, 2007, from Business Source Corporate database.

Oshiro,E., M. Ikeda, L., & Isler, D. (2002, April). Tight on Space? Consider GIS. *Transmission & Distribution World, 54*(4), 100. Retrieved December 11, 2007, from Business Source Corporate database.

Outdoor GIS Switchgear for Puerto Rico. (2004, August). *Transmission & Distribution World, 54*(4), 100. Retrieved December 11, 2007, from Business Source Corporate database.

Overstall, C. (2002, Augustl). Recalling the rise of GIS. *International Power Generation, 25*(7), 40. Retrieved December 11, 2007, from Business Source Corporate database.

Osborne, M., Xemard, A., Prikler, L., Martinez (2007, June). Points to consider regarding the insulation coordination of GIS substations with cable connections to overhead lines. Retrieved December 10, 2007.

Ring, I. (1999, March). Epoxy Coating Speeds SF_6 Leak Repair. *Transmission & Distribution World, 51*(3), 131. Retrieved December 11, 2007, from Business Source Corporate database.

Salinas, A. (2001, May). Detecting Trouble Through Diagnostic Techniques. *Transmission & Distribution World*, *53*(5), 60. Retrieved December 11, 2007, from Business Source Corporate database.

Shizuoka 500-kV GIS Substation. (2004, August). *Transmission & Distribution World,* Retrieved December 11, 2007, from Business Source Corporate database.

Space Considerations Driving GIS Purchasing Decisions. (2006, November). *Utility Automation T&D*, Retrieved December 11, 2007, from Business Source Corporate database.

Southern California Public Power Authority Awards ABB Order for GIS Substation Project. (2004, February). Tight on Space? Consider GIS. *Transmission & Distribution World*, *54*(4), 100. Retrieved December 11, 2007, from Business Source Corporate database.

Substation and Heavy-Duty GIS. (2004, Augustl). *Transmission & Distribution World,* Retrieved December 11, 2007, from Business Source Corporate database.

Taghavi, J., & Tieszen, K. (2007, April). Hidden Within View. (Cover story). *Transmission & Distribution World, 59(4)*, 24-28. Retrieved December 11, 2007, from Business Source Corporate database.

UNIPEDE Group of Experts NORM SF_6 . (1998, June). *Guide to the safe use of* SF_6 *in gas insulated electrical equipment.* Retrieved December 14, 2007,

United Illuminating Co. Celebrates GIS Project Milestone. (2006, November). *Utility Automation T&D*, Retrieved December 11, 2007, from Business Source Corporate database.

Yucha, R. (2007, January). Utility Develops an Economy GIS Solution. *Transmission & Distribution World, 59(1),* 44-48. Retrieved December 11, 2007, from Business Source Corporate database.