Industrial Power Systems

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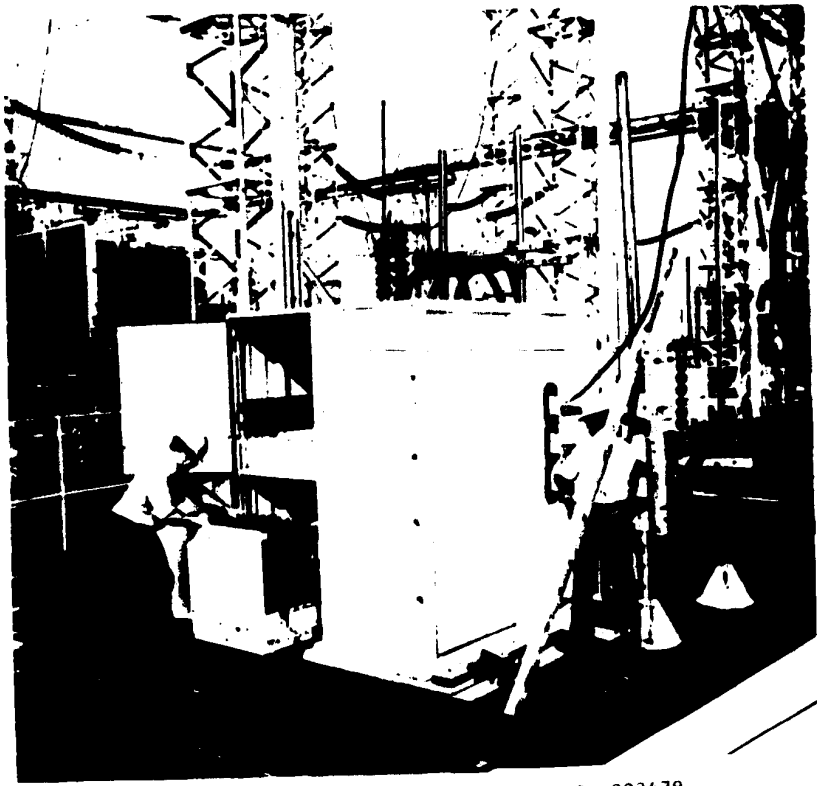

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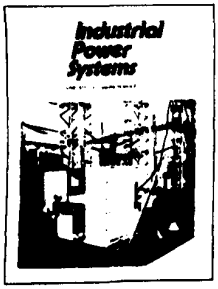

Within the General Electric Company, J.F. Young, Vice President-Technical Resources on the Corporate Staff, is "Mr. Engineer". On pages 3-5 he shares with us his understanding of how the codes of ethics can guide the conduct of the engineer.
Mr. Charles Titus on pages 10 and 11 reveals a number of potential changes that may effect the future of industrial power delivery systems. This is followed by an informative report on pages 12-14 (as well as the front cover) giving an update on the new POWER/VAC metalclad switchgear.

D. S. Brereton

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JAMES F. YOUNG
James F. Young is Vice-President-Technical Resources of General Electric Company. His office is at the Corporate Headquarters in Fairfield, Connecticut. Mr. Young attended Lafayette College, where he received a Bachelor's degree in mechanical engineering with honors in 1937. That same year he joined General Electric's Engineering Test Program. In 1944 he transferred to the Appliance and Merchandise Department and was named as Consultant on Engineering Studies and Surveys for the Vice President-Engineering in 1953. He was appointed General Manager of GE's Advanced Technology Laboratories and in February 1960 was named General Manager-Electric Utility Engineering Operation. In August 1963 he was named General Manager of the Nuclear Energy Division and was elected a Vice President in June 1965. Mr. Young became Vice President-Engineering in November 1966 and was named to his present position on June 1, 1970. Mr. Young is a member of Tau Beta Pi and Phi Beta Kappa. He was granted an honorary doctorate by Lafayette College in 1963. Mr. Young is a member of the National Academy of Engineering, Institute of Electrical and Electronic Engineers and National Society of Professional Engineers, and a Fellow in the American Society of Mechanical Engineers. His public service includes presidency of the Atomic Industrial Forum (AIF), trusteeships for several colleges and National Research Council activities. He is a licensed professional engineer in New York and Connecticut.

Influence of Engineering Codes on the Role and Work of Engineers

by James F. Young

How long has it been since you reviewed the code of ethics of your engineering society?

Whether recently or beyond recollection, a re-look may be in order for there are many indications that "ethics" are of growing concern to engineers and to the public.

The reasons are many. Some stem from startling disclosures of failures in meeting reasonably expected ethical standards of behavior among some businessmen, public officials and members of learned professions. Others derive from a growing recognition of society's dependence upon technology—and recognition that this dependence must continue to grow. So, it seems timely for engineers to give renewed attention to the codes of ethics that guide their conduct in responding to the public need and trust that this dependency entails.

Unfortunately, there are many different versions of a code of ethics for engineers. Separate codes have been adopted by the Institute of Electrical and Electronics Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Engineering Council for Professional Development, the National Council of Engineering Examiners, and the National Society of Professional Engineers. And variations have been certified or modified by the Engineering Registration Boards of each of the states. There have been calls for an umbrella code for years, and some codes are even designed to speak for the profession, rather than the uniqueness in the discipline or organization of the sponsor. Nagging problems that are delaying uniformity range from mere reconciliation of word interpretations, to pride of authorship or participation, to honest disagreement on scope or basic principles.

Despite the diversity, most codes address some common themes or purposes:

- To promote the safety, health, and welfare of the whole community.
- To provide a basis for regulating actions of the profession, and to establish standards for its members.
- To strengthen recognition of the public for engineers as professionals.
- To assure high standards of competence.
- To provide a basis for dealing with members who violate the ethics of the group.

Typical Relationships

The influence of these code purposes on the role and work of the engineer can be indicated by a look at the typical relationships. Public recognition will be omitted since it is earned through understanding of the engineer's contributions which flow

*To illustrate . . . the IEEE Code of Ethics is reproduced on page 5.

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from ethical concern in his relationship with other engineers, direct clients, and employers. In a broad sense:

The engineer-to-engineer relationship spans all roles: consultants, employees, and employers. The body of engineering knowledge is created, maintained and shared, and the ethical standards of the profession are perceived and upheld by these ethical concerns for fellow engineers singly and as a group.

The engineer-to-client relationship is at the very center of the moral responsibility that characterizes the learned professions: the client places his confidence and trust in the engineer and is dependent upon the engineer for depth of knowledge and judgment, or for clear disclosure of uncertainties and limitations. The client is gravely dependent upon the competence and integrity of the engineer.

The engineer-to-employer relationship involves a dual responsibility:

- As an agent of his employer, an engineer assumes the engineer-to-client role on behalf of his employer when he is providing direct-to-client engineering services for the employer.

- As with any employee, an engineer is responsible for diligent, competent and productive work in support of his employer. As a "professional" employee, the engineer is also a functional element of the enterprise, sharing in teamwork responsibilities with both engineers and non-engineers and serving in the decision-making structure of the organization.

I sense that the engineer-to-employer relationships are the least resolved and, therefore, of the greatest concern to engineers. And since the overwhelming majority of engineers are employees rather than consulting engineers, principals, partners, or officers of their firms, the area deserves more study.

The Engineer's Responsibility

The ultimate responsibility for products or services rests with the principals, officers and managers of the enterprise, or others to whom they have delegated special responsibility and authority. In this light, engineers in their specialist, manager, and officer roles have clear-cut responsibilities in support of their teammates and the enterprise:

- Where engineers have final decision-making responsibility and authority, most all of the codes of ethics are adequate in providing guiding principles.

- Where decision-making responsibility and authority reside elsewhere, the codes are not so clear. Here engineers have another duality in responsibility:

  — competent and complete information and advice to the decision-makers through the administrative channels of the enterprise;

  — loyalty and concern for the enterprise to the extent of volunteering information and taking the initiative in persuading the decision-makers where there is reason to believe that factors have been overlooked or judgment has been faulty.

This latter responsibility is an imperative for the engineer and the employer alike. In this age of specialization, an individual engineer may not see how the engineering process comes together to eliminate faults. By taking the initiative with decision-makers, he can, as he must, satisfy his concerns. On the other hand, the individual engineer's own work or observations may uncover limitations that might take time or resources to correct at a later date, so early disclosure is an imperative to the decision-maker.

The code of ethics scene is not at all clear on these matters. For example, state laws governing registered engineering practice give legal status to some code or title that may be enforced legally. The NSPE Code and those of some states forbid the engineer to solicit direct-to-client business on the basis of price — a matter now in the courts. Some legally enforceable codes require an engineer to report to the appropriate legal authority any incident where his judgment has been overruled and he feels that this could endanger the client or the public. No one would ever deny any engineer's basic moral responsibility for the safety and welfare of the public. However, the specific requirement is without regard to the respective accountability and qualifications in the engineer-employer relationship.

It is in these last areas that we need more study, discussion and documentation of principles in the codes.

Conclusion

By and large, engineers have had a good sense of their ethical standards. Recent public surveys show trust in engineers at the top of those in public service. But the ethic of the engineer is to keep it that way. The increasing dependence of society upon technology, and the added trust this entails, make engineering ethics a matter of public concern. As a response, it seems essential that the societies, associations and engineering organizations should undertake:

- Continued effort to develop one basic master or umbrella code of ethics that is accepted and understood by all.

- More study and discussion to crystallize concepts of the individual employee's responsibility and those of engineers in the employer's responsible management structure.

- Sustained effort to keep the code up-to-date by new concepts and modifications that reflect changing values and expectations of society. □

MONS 002482

IEEE Code of Ethics for Engineers

Preamble

Engineers affect the quality of life for all people in our complex technological society. In the pursuit of their profession, therefore, it is vital that engineers conduct their work in an ethical manner so that they merit the confidence of colleagues, employers, clients and the public. This IEEE Code of Ethics is a standard of professional conduct for engineers.

Article I

Engineers shall maintain high standards of diligence, creativity and productivity, and shall:

1. Accept responsibility for their actions;
2. Be honest and realistic in stating claims or estimates from available data;
3. Undertake engineering tasks and accept responsibility only if qualified by training or experience, or after full disclosure to their employers or clients of pertinent qualifications;
4. Maintain their professional skills at the level of the state of the art, and recognize the importance of current events in their work;
5. Advance the integrity and prestige of the engineering profession by practicing in a dignified manner and for adequate compensation.

Article II

Engineers shall, in their work:

1. Treat fairly all colleagues and co-workers, regardless of race, religion, sex, age or national origin;
2. Report, publish and disseminate freely information to others, subject to legal and proprietary restraints.
3. Encourage colleagues and co-workers to act in accord with this Code and support them when they do so;
4. Seek, accept and offer honest criticism of work, and properly credit the contributions of others;
5. Support and participate in the activities of their professional societies;
6. Assist colleagues and co-workers in their professional development.

Article III

Engineers shall, in their relations with employers and clients:

1. Act as faithful agents or trustees for their employers or clients in professional and business matters, provided such actions conform with other parts of this Code;
2. Keep information on the business affairs or technical processes of an employer or client in confidence while employed, and later, until such information is properly released, provided such actions conform with other parts of this Code;
3. Inform their employers, clients, professional societies or public agencies or *private agencies* of which they are members or to which they may make presentations, of any circumstance that could lead to a conflict of interest;
4. Neither give nor accept, directly or indirectly, any gift, payment or service of more than nominal value to or from those having business relationships with their employers or clients;
5. Assist and advise their employers or clients in anticipating the possible consequences, direct and indirect, immediate or remote, of the projects, work or plans of which they have knowledge.

Article IV

Engineers shall, in fulfilling their responsibilities to the community:

1. Protect the safety, health and welfare of the public and speak out against abuses in these areas affecting the public interest;
2. Contribute professional advice, as appropriate, to civic, charitable or other non-profit organizations;
3. Seek to extend public knowledge and appreciation of the engineering profession and its achievements.

In an important action, the IEEE Board of Directors adopted an IEEE Code of Ethics for Engineers at its meeting of December 4, 1974. The new code resulted from the combined efforts of a number of volunteer Committees and Boards within IEEE, specifically the United States Activities Board (USAB), USAB's Ethics and Employment Practices Committee, the Executive Committee and its ad hoc Committee on Ethics, and the Board of Directors. In addition, expert views were obtained from the Committee on Social Implications of Technology and many other IEEE organizational units.

The adoption of this Code is a significant step forward in the area of professionalism. It is responsive to the decision of the voting members in 1972 that one of the Institute's constitutional objectives should be the establishment of standards of ethical conduct. I urge every member to read and reflect on the contents of this living document with great care, and invite individual comments. □

Arthur P. Stern,
1975 Institute President

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Silicone Dielectric Fluid: A Replacement for Askarel

by John C. Crouse and James P. Kinney, Jr.

For over 40 years, the transformer industry has used a nonflammable dielectric liquid, known generically as "askarel", for indoor transformer installations or other locations where fire safety was important. Askarel which has been used by transformer manufacturers under several brand names consists, in part, of polychlorinated biphenyls with four or five chlorine atoms per molecule. It has been found that if allowed into the environment polychlorinated biphenyls will persist for a long period of time and have certain adverse effects on the environment. As a result, manufacturers have intensified their search for alternative liquids to replace the polychlorinated biphenyls.

In undertaking such a search, General Electric enumerated certain basic requirements that included not only the normal transformer operational and safety requirements, but also the expected environmental requirements. The safety and environmental needs require that the fluid:

- Be nonflammable or nonpropagating.
- Be environmentally acceptable.
- Have a low order of toxicity.



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The transformer operational application requires that the substitute fluid:

- Have satisfactory physical properties.
- Have adequate dielectric strength.
- Be compatible with the insulation system.

A great number of potential liquids were screened using the basic requirements noted above. Some of the more promising fluids were subjected to a series of comprehensive tests to determine their suitability as a substitute, or alternative, for askarel. As a result of the comprehensive testing, one fluid emerged as the leading alternative — 50 centistoke viscosity polydimethylsiloxane. This silicone fluid is a clear, colorless liquid having low surface tension, outstanding chemical resistance, good oxidation resistance, and small changes in viscosity with temperature. The chemical structure is shown in Figure 1.

Physical Properties

To form some judgment of the ability of silicone to meet the safety requirements for indoor transformer installation, a series of catastrophic failure tests were conducted. These were designed to test the tendency of hot (135C) liquid expelled from a transformer tank during a severe electrical failure to ignite combustible materials in the vicinity of the tank. The combustible materials used were panels of plywood, cardboard, and polystyrene foam.

The mineral oil test produced a large fire-ball and spread burning liquid in a 30-foot radius of the test tank. The cardboard and polystyrene panels were completely burned by the flaming mineral oil. There was some burning on the plywood panel.

Although all three panels were soaked with silicone liquid during the silicone tests, none of the panels showed any signs of burning. The performance of silicone in these tests was comparable to that of an askarel.

The photographs shown in Figures 2 and 3 were taken during the tests of mineral oil and silicone, SF-97(50), at the same elapsed time from the start of the test. One can easily see the marked difference in performance between mineral oil and silicone.

Silicone fluids have been used over a long period of time in non-electrical application; and from a paper published by the Office of Toxic Substances, it is apparent that these fluids present no appreciable threat to the environment.[1] As far as toxicity is concerned, this does not appear to present any problem as silicones have been used over a long time period in

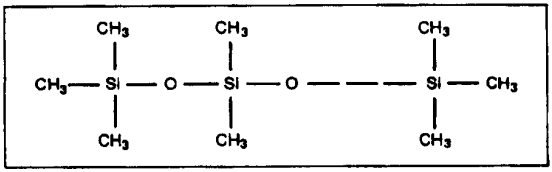

Fig. 1. The chemical structure of dimethyl silicone fluid, an alternative for askarel.

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Fig. 2. Results of the mineral oil test, where cardboard and polystyrene foam were completely burned.



Fig. 3. An identical test using silicone fluid, where none of the test panels showed signs of burning.

facial cosmetic applications and in applications involving direct contact with foods.[2]

To sum up, as far as the safety and environmental needs are concerned, silicone fluids are nonpropagating, environmentally acceptable, and have a very low order of toxicity.

Dielectric Strength

How does silicone fluid meet the requirements of a transformer dielectric? Table I gives a comparison of the physical properties of silicone fluid with mineral oil and a typical askarel.

A major difference between the fluids is the viscosity versus temperature characteristics.[3] The higher viscosity of silicone fluid at temperatures above 25C has a major effect on its heat transfer characteristics. By proper design of the transformer cooling equipment it is no problem to obtain the standard temperature rises over normal ambients. However, this difference in viscosity does present a serious problem when considering the retrofilling of an existing askarel transformer with silicone fluid.

The higher coefficient of thermal expansion for the silicone fluid requires an adjustment in the design to take into account the greater rise and fall of the liquid level over its expected temperature ranges. It is particularly important that this characteristic be considered so that under very cold start-up temperatures the live parts inside the tank will not be exposed. The pressure increase at the high temperature is minimized to a great extent by the greater solubility of the air, or nitrogen, in the silicone fluid.

Silicone fluid has considerably less lubricity than either transformer oil or askarel. While this may not seem of major importance, we have found that it was necessary to take this characteristic into consideration when designing a tap changer that must operate in silicone fluid. A characteristic

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TABLE I PHYSICAL PROPERTIES OF SILICONE, MINERAL OIL, AND ASKAREL

	Silicone	Mineral Oil	Askarel
Viscosity, centistokes at 25 C at 60 C	50 cs 20 cs	10.0 cs 2.7 cs	12.8 cs 4.2 cs
Flash point, open cup	290 C	145 C	no true flash point
Fire point, open cup	316 C	160 C	none to boiling point
UL flammability rating	4-5	10-20	2-3
Oxygen index	21.4	15.8	37.8
Specific gravity at 25 C	0.96	0.86	1.5
Coefficient of expansion cubic cent./cubic cent/C	0.00106 cc-C	0.0007 cc-C	0.0007 cc-C
Pour point	−55 C	−55 C	−40 C
Boiling range	none	260-370 C	209-361 C

that is important when considering retrofilling existing units is that some tap changer mechanisms used in oil and askarel transformers were found to bind or hang up when operated in silicone fluid.

The dielectric properties of silicone fluid and of kraft paper impregnated with and submerged in silicone fluid are summarized in Table II.[4,5]

In many of the tests, the dielectric strength of silicone fluid was similar to that of oil and askarel. However, significant differences were observed for some of the tests performed. The negative polarity rod-to-plane impulse strength of silicone was much higher than that of oil or askarel. The breakdown strength of silicone impregnated kraft paper was lower than that of oil or askarel impregnated paper. The positive polarity impulse creepage strength of kraft pressboard was lower than that of pressboard in oil or askarel. Since silicone fluids do exhibit different dielectric characteristics than oil or askarel, it is necessary to design a silicone fluid transformer taking these differences into account.

Because the negative impulse strength of silicone was found in many of the tests to be considerably higher than the positive polarity strength, it is suggested that the purchaser of a silicone filled transformer who wants an impulse test specify that a positive polarity impulse test be performed. Normally, negative polarity impulse tests are performed on oil and askarel transformers. The standard practice for positive polarity impulse tests is to apply chopped waves at the same level as full waves.

TABLE II DIELECTRIC PROPERTIES OF SILICONE, MINERAL OIL, AND ASKAREL

	Silicone	Mineral Oil	Askarel
Dielectric constant 25°C, 60 Hz	2.7	2.2	5.3
Impulse Breakdown			
Uniform field, 0.1 in. gap (ASTM D1816 electrodes)	136.4 kV	142.0 kV	153.3 kV
Non-uniform field Rod-to-plane, 0.5 in. gap			
Negative polarity	295.6 kV	107.0 kV	119.0 kV
Positive polarity	99.6 kV	90.9 kV	114.0 kV
Impregnated Kraft paper Round edge electrode, 2.0 in. diameter			
0.018 in. thickness	38.4 kV	43.0 kV	49.0 kV
0.092 in. thickness	134.8 kV	182.9 kV	163.0 kV
Impulse creepage on Kraft pressboard, (2) electrodes, 1.0 in. diameter, edge-to-edge spacing, 3.0 in.			
Positive polarity	89.6 kV	152.3 kV	130.6 kV
60 Hertz breakdown disk electrode, 0.100 in. gap	35.0 kV	35.0 kV	35.0 kV
Impregnated Kraft paper rounded edge electrode 2.0 in. diameter			
0.018 in. thickness	19.5 kV	22.1 kV	28.7 kV
0.092 in. thickness	84.3 kV	77.0 kV	85.5 kV

Insulation System Compatibility

Compatibility testing and thermal aging programs of the insulation systems were undertaken and showed that silicone fluids can be used with practically all materials commonly used in the construction of transformers. The one example of incompatibility is silicone rubber gasket material that is often used in askarel transformers. In contact with silicone fluid, the silicone rubber gasket material will disintegrate rather rapidly.

Accelerated thermal aging studies have shown the aging characteristics of the transformer insulation system in silicone is similar to that in mineral oil. Thus, it can be said that a properly designed silicone fluid transformer will have the same life expectancy as an oil or askarel transformer.

Silicone Success

We have recognized that, while the silicone fluid differs from transformer oil or askarel in some aspects, it can be used successfully as a liquid dielectric and coolant in a transformer. By proper design, the transformer will have the same electrical and thermal characteristics as an oil or askarel unit.

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A growing number of silicone filled transformers are now in service. Each has passed the normal tests that are performed on similarly rated oil and askarel transformers. At the time of this writing, there have been no service problems. Typical silicone filled transformers are shown in Figures 4 and 5.

In its Program Directive 100-54, the Occupational Safety and Health Administration permits the use of polydimethylsiloxane fluid transformers as equivalent to askarel transformers in its enforcement of the National Electric Code. The 1978 revision of that code to be printed this year will define, in section 450-23, a high fire point, nonpropagating liquid such as silicone fluid as suitable for indoor installation without vaults. Major insurance companies have developed tests for determining acceptability of high fire point, nonpropagating liquids for insurance when used in transformers installed indoors without vaults. Several dielectric grade, 50 centistoke viscosity silicones, including GE SF-97(50), meet the requirements of these tests. Transformers filled with silicone fluid meet the standard test codes, satisfy safety requirements, and are providing satisfactory performance in service. □

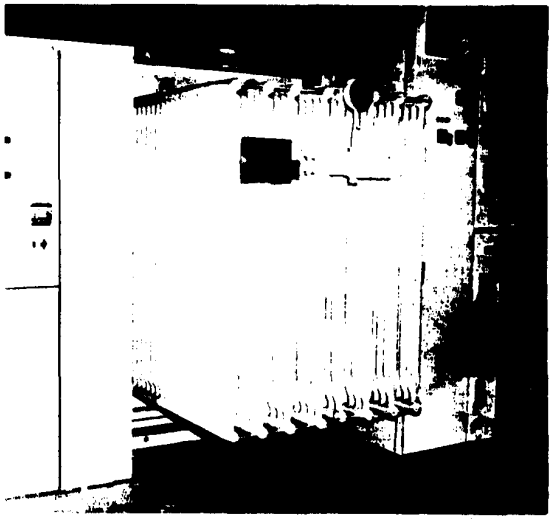

Fig. 4. This AKD-5 load-center unit substation uses a 1500 kVA silicone filled transformer.

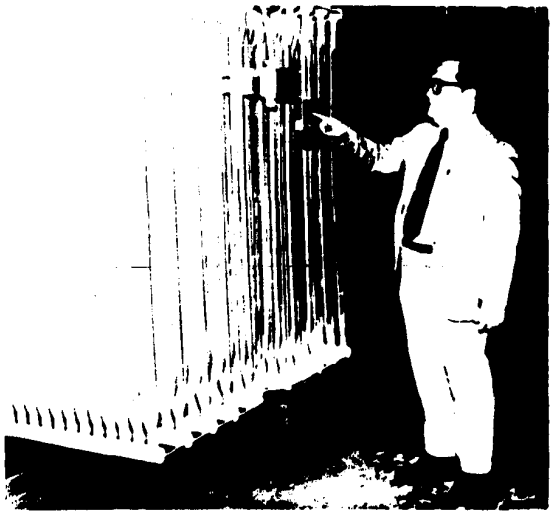

Fig. 5. This 2500-kVA silicone filled transformer is used in a 5 kV master unit substation.

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MONS 002487

The Future of Industrial Power Delivery Systems

by Charles H. Titus

Just as low voltage industrial distribution systems have increased from 208Y/120 volts to 480Y/277 volts, so have the primary industrial power delivery system voltages increased from 2.4 kV to 4.16 to 13.8 kV. There are indications that primary power system voltages will continue to increase to 34.5 kV (and possibly to 69 kV). This higher primary voltage evolution occurs under the following conditions:

- Reliable and economical cable and cable splicing techniques must be available.
- Extruded solid dielectric cables for 34.5 kV (as well as 69 kV) are now available.
- Switchgear should also be available to adequately protect and control whatever primary voltage is used in industrial power delivery systems.

Metalclad equipment using vacuum circuit breakers is now available from 4.16 kV through 34.5 kV. Figure 1 shows a new POWER/VAC® circuit breaker that permits the construction of metalclad equipment at voltages from 4.16 through 13.8 kV.

Through the use of special surge suppressors connected from the load terminal of each circuit breaker to ground, previous concern about transient voltages has been eliminated. Since POWER/VAC equipment limits transient voltages to values less than those encountered in previously used switchgear, this new POWER/VAC equipment may be applied to any type of load circuit without fear of abnormal dielectric stress.

When conserving energy and reducing electric power costs, the transformer banks may be switched off when output power from the transformer is not required. While POWER/VAC switchgear is suited for this service, the increased switching duty may have an effect on the life of transformers.

In the future, electronics will be playing an even greater role in the control of industrial plants and processes. Low-level integrated circuits may be key elements in many electronic control systems. These circuits may be adversely influenced by harmonics, voltage regulation and transients which are present in the power system. Additional care may be required to be sure that transients created by contact bounce and arc restrikes are minimized.

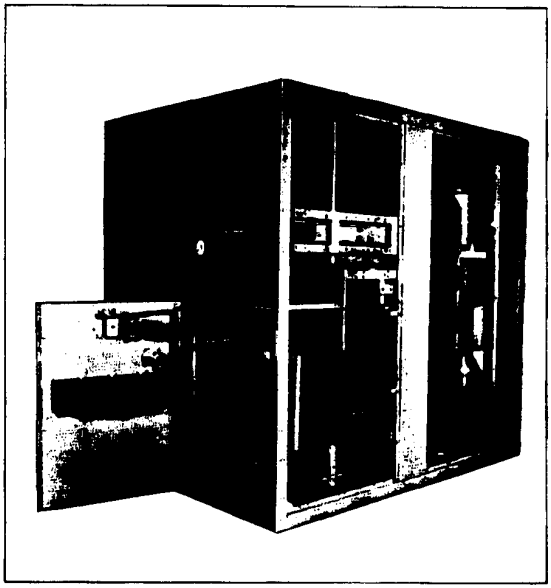

Fig. 1. This new POWER/VAC circuit breaker permits the construction of metalclad equipment of voltages from 4.16 through 13.8 kV.

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particularly when power-factor-correcting capacitors are used in the industrial power system.

The future of static circuit breakers is sometimes asked. Based on present technology, static circuit breakers for power applications will be larger and more expensive than similarly rated electromechanical circuit breakers. Their application will therefore be limited to cases where millions of operations or special control of the load current is a primary system requirement.

Arc furnaces and spot welders are known for their ability to produce electrical disturbance such as lamp flicker on both industrial and utility systems. These disturbances have restricted the use of arc furnaces on some utility systems. The new developments in static var control equipment, however, are changing this situation.

Figure 2 shows the solid state switching equipment as the heart of 13.8 kV 50 MVA static var control equipment. This equipment balances out the lagging vars of the load on each half cycle of each phase, thereby reducing the system voltage variations produced by rapidly fluctuating load current.

Minimizing voltage variations has always been important for industrial power systems. In the future it may be even more important. Vacuum circuit breakers and static var control equipment will be essential elements in the protection and control of future industrial power delivery systems.

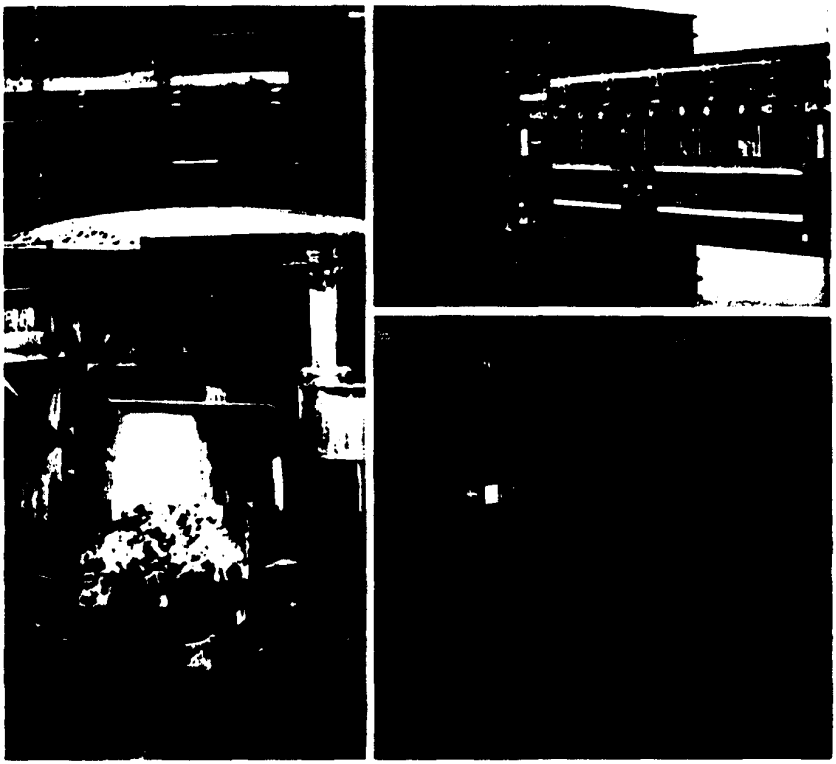

Fig. 2. A 13.8 kV thyristor controller is shown on the right. The upper of the two photos shows the thyristor panel in the drawn out position for maintenance. This equipment is used to minimize voltage fluctuations produced by furnaces like the one at Tagliaferri Italy.

MONS 002489

POWER/VAC Metalclad Switchgear Tests High in Reliability

by Dr. Josef Urbanek

Researchers at the Wilfred E. Skeats High Power Laboratory in Philadelphia have recently completed design tests on the first ratings of POWER/VAC* metalclad switchgear, the most significant medium-voltage equipment design in 40 years.

The Skeats Laboratory has the first test facility for 3200-MVA short-circuit capacity. It is also the first short-circuit laboratory with remote control circuits, the first laboratory with full-size synthetic circuits to test 20,000 MVA interrupters, and the first with magnetic tape recording systems.

POWER/VAC metalclad switchgear itself, (Figure 1) continues this innovative tradition. POWER/VAC switchgear is a significant step toward the future because it comprehensively meets the industry standards, as well as achieving a new dimension in reliability.

This new product line utilizes the technical features of the POWER/VAC circuit breaker while building upon the well-documented laboratory and field performance of General Electric vacuum interrupters.

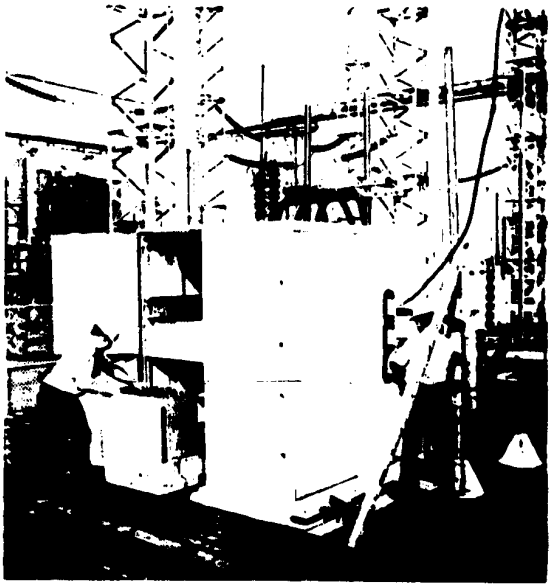

Fig. 1. POWER/VAC switchgear takes a step into the future by meeting industry standards and achieving a new dimension in reliability.

Short-circuit Capacity

POWER/VAC switchgear is being carefully tested in accordance with the American National Standard Institute's "Test Procedure for Power Circuit Breakers" (ANSI C37.09) and rules specified in ANSI C37.20, "Switchgear Assemblies and Metal-enclosed Bus".

POWER/VAC switchgear is also rated according to ANSI C37.06, "Preferred Ratings of Power Circuit Breakers". Table I lists part of these ANSI ratings, for which the qualification has already been completed. Testing for additional ratings will produce a complete line of POWER/VAC metalclad switchgear.

Table I illustrates all the interrupting duties as required by ANSI C37.09 demonstrating short-circuit capabilities for each breaker rating in each voltage class. Even though ANSI allows maintenance between tests, neither equipment nor breaker needed any maintenance during the test series that achieved these ratings.

The accumulated interrupted current in kA (KSI)* without mainte-

* Registered Trademark of General Electric



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*KSI is defined in ANSI C37.04-1964 (R1976) and consists of "K" being the rated voltage range factor, "S" being the ratio of circuit breaker asymmetrical to symmetrical interrupting capabilities and "I" is the rated short-circuit current.

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TABLE I

RATINGS COVERED BY TESTS, COMPLETED TO DATE

(Based on Table 2 of ANSI C37.06 Schedule of Preferred Ratings for Indoor Oilless Circuit Breakers)
(Symmetrical Current Basis of Rating)

Identification		Rated Values						Related Required Capabilities			
		Voltage		Insulation Level		Current			Current Values		
				Rated Withstand Test Voltage							
Nominal Voltage Class rms kV	Nominal 3 Phase MVA Class	Rated Max Voltage rms kV	Rated Voltage Range Factor, K	Low Frequency Voltage rms kV	Impulse Voltage Crest kV	Rated Continuous Current at 60 Hz rms Amperes	Rated Short-circuit Current (at Rated Max kV) rms kA	Rated Max Voltage Divided by K rms kV	Max Symmetrical Interrupting Capability (9) K Times Rated Short-Circuit Current rms kA	3 Second Short-time Current Carrying Capability (10) K Times Rated Short-Circuit Current rms kA	Closing and Latching Capability 1.6 K Times Rated Short-circuit Current rms kA
4.16	250	4.76	1.24	19	60	1200	29	3.85	36	36	58
4.16	250	4.76	1.24	19	60	2000	29	3.85	36	36	58
4.16	350	4.76	1.19	19	60	1200	41	4.0	49	49	78
4.16	350	4.76	1.19	19	60	3000	41	4.0	49	49	78
7.2	500	8.25	1.25	36	95	1200	33	6.6	41	41	66
7.2	500	8.25	1.25	36	95	2000	33	6.6	41	41	66
13.8	500	15	1.30	36	95	1200	18	11.5	23	23	37
13.8	500	15	1.30	36	95	2000	18	11.5	23	23	37
13.8	750	15	1.30	36	95	1200	28	11.5	36	36	58
13.8	750	15	1.30	36	95	2000	28	11.5	36	36	58

nance was 4100 percent KSI compared to the 400 percent required by the standards.

In addition, fault interruption data from thousands of sample tests of POWER/VAC interrupters have been accumulated to determine the statistical variation of this data. This might be the highest confidence level ever achieved in medium-voltage switchgear.

Capacitive Currents

Capacitive current switching capability is tested according to ANSI C37.073 reference.

However, twice the required number of tests must be performed to demonstrate a reliability similar to that of fault-current interruption. Though only the general-purpose circuit breaker ratings (as specified in ANSI C37.0732) are required, current was increased to 630 amperes so POWER/VAC could be qualified as *definite-purpose* breakers.

With sophisticated instrumentation in place, no overvoltages above 2.5 per unit were recorded in the testing. POWER/VAC switchgear has then qualified not only for general, but also for definite-purpose equipment.

The capacitor switching tests were conducted in actual three-phase circuits. Additionally, considerable single-phase data on individual POWER/VAC interrupters has been accumulated to improve the statistical confidence level.

The test circuits are designed to meet the requirements of ANSI C37.073. However, extensive system studies determine critical system parameters not specified in the standards. These special circuit situations were also tested satisfactorily.

Inductive Load Currents

Various transformer and motor loads were simulated, including small

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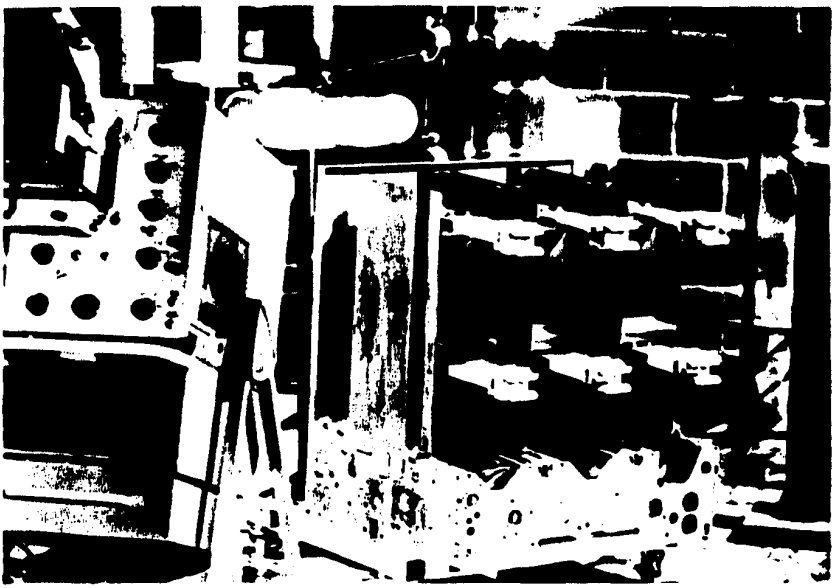

Fig. 2. Extensive dielectric tests on the breakers at full ANSI ratings are performed to ensure the reliability of the design.

inductive current switching loads, and tested with an extensive instrumentation, and computer analysis. Again, no unallowable overvoltages were detected.

As in the case of the capacitance switching program, the over-voltage protection of the POWER/VAC metalclad switchgear was connected during the test series. These surge suppressors provide power circuit loads with the highest quality voltage ever achieved from a transient standpoint. (See References 1, 2 and 3).

Insulation Level

Extensive dielectric test series on the various components, on the breaker and on the equipment are performed to ensure the reliability of the design. Tests were done at full ANSI ratings. During all the dielectric tests, the surge suppressors were disconnected according to ANSI standards. Since these suppressors actually limit surges to 15 to 37 percent of the ANSI ratings, this represents an extensive safety margin.

Other Tests

The qualification data reported here is only a part of that information compiled by the Skeats High Power Laboratory. (Test reports and complete documentation are on file with the Switchgear Business Department.) The testing of metalclad switchgear is an expensive and complicated procedure. A vast amount of data concerning continuous current carrying capacity, no-load switching capacity and seismic and environmental behavior has also been accumulated elsewhere by switchgear development engineers.

All qualification tests reported are part of a total program which has as its objective the assurance of the highest possible reliability for the new POWER/VAC metalclad switchgear product line. □

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MONS 002492

Co-location: An Economical Alternative Source of Steam and Power

by John M. Kovacik

The increased cost of energy has intensified efforts by all sectors of industry to use it more efficiently. Many industrials are also examining energy alternatives as gas and oil become progressively less available as industrial fuels.

Evaluations by most large industrials, including those in the petroleum and petrochemical industries, indicate that their future source of energy will be derived from coal. Whether that energy results from the direct combustion of coal or the conversion of coal to synthetic fuels which can be utilized in existing equipment will depend upon the industrials' geographic considerations. However, investment costs for coal use will be higher than those of gas and oil-fired installations.

Some locations, such as Texas City, Texas and Lake Charles, Louisiana, have a number of large industrials located adjacent to each other. In areas like these, there is a growing interest in the economics of co-location, or joint industrial-utility ventures, as an industrial energy supply system option. In this alternative, the "central station," either publicly or privately owned, would provide both steam and power to its industrial customers.

Certain industrials have been promoting co-location based on evaluations made years ago. Industry has been aware of the benefits of co-location, and co-generation, for heat and power long before our government's recent support of this concept. The principles involved in co-location are not new: they are an extension of sound engineering and economics which have been responsible for the installation of many in-plant power generation (IPG) systems in process plants requiring large quantities of both process heat and power.

Co-location evaluations illustrate that by-product power generation, the concept that has produced many economic IPG systems, is economical. Furthermore, co-location makes sense as both fuel and purchased power costs increase in the years ahead.

The merits of co-location become obvious when the favorable economics of integrating turbines supplying electrical energy and/or shaft power into the energy supply system providing the plant's process heating needs are examined. Furthermore, evaluations must factor the varied needs of a combination of industries, such as pulp and paper, metals, or chemical, into the development of the central heat (steam) and power supply.



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Industrial Energy Requirements

Generally speaking, most industrial plant energy requirements are grouped into two main categories: *electrical energy* and *process heat*. Electrical energy is defined as that required for such things as lighting, motors, controls, and for electrolytic processes such as aluminum reduction, and chlorine. Process heat is energy needed to perform functions at a specific temperature or range of temperatures such as drying operations in the paper industry, heating of process fluids in a refinery, or regeneration of catalysts. In process areas requiring heat at relatively low temperature levels, such as the 250F to 500F range, steam at a suitable pressure is commonly used to supply the required energy. When high temperature levels such as 1000F to 3000F are required, direct combustion of fuel is usually the source of this energy. However, since conventional industrial power plant systems do not supply high temperature energy, our reference to process heat will be that energy which can be supplied as steam.

Modern Facilities

The energy required for several industries that are large energy users is presented in Table I. This data is for facilities based on today's process technology and energy costs. Also given is the energy available from process or by-product fuels as well as the by-product power generation available by expanding the steam required before it is discharged into the process steam system(s).

This data implies that the refinery could provide most of its energy requirements from by-product fuels, whereas the petrochemical plant and the steel mill could be exporters of by-product fuels. However, this is not the case since all three industries use most of their by-product fuels for direct process heat, and that remaining for steam generation.

Much of the process steam demand for the refinery and petrochemical complex is generated through heat recovery associated with process units. This increased steam generation in process illustrates the gains in effectiveness of energy use which now can be economically justified since fossil fuels are no longer inexpensive. Since these industries are essentially steam sufficient, there is no apparent advantage of co-location unless these industries could generate excess power (at a more favorable fuel rate than the utility) which could be fed into the utility system.

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TABLE I ENERGY SYSTEM CONSIDERATIONS FOR MODERN INDUSTRIAL PLANTS

Industry	Size	Approx Total Energy Required (M Btu/hr)*	Avg Process Heat (Steam) Demand (1000 lb/hr / Steam Cond.)	Electric Power Required (MW)	Net Heat Available From By-product Fuels & Type	By-product Power Generation (MW)**
Pulp & Paper	2000 ton/day integrated kraft mill	1600	210 / 475 psig, 705 F 625 / 165 psig, 425 F 370 / 65 psig, 335 F	94	810 M Btu/hr (bark & black liquor)	71.3
Chemical	1000 ton/day chlorine 1100 ton/day caustic	890	240 / 150 psig, sat.	130	85 M Btu/hr (hydrogen)	10.6
Petroleum Refining	250,000 bbl/day crude input	1560	150 / 625 psig, 700 F 500 / 350 psig, 950 F 355 / 150 psig, 420 F 110 / 60 psig, 325 F	60	420 M Btu/hr (carbon monoxide)	37.0
Petrochemical	large mixed products complex	1400	65 / 600 psig, 700 F 680 / 200 psig, 485 F 160 / 70 psig, 370 F	110	2800 M Btu/hr (liquids & gaseous)	60.1
Steel Mill	6 million ton/year	1950	750 / 225 psig, 550 F	309	3060 M Btu/hr (coke oven gas, blast furnace gas, basic oxygen furnace gas)	38.7

*Electric power included based on 3412 Btu/kWh
**Turbine inlet steam conditions 1450 psig - 950 F except for the Chemical Industry which is based on 850 psig - 825 F

For the paper, chemical and steel industries, purchased fuels are required to provide at least 40 percent of their process steam demands. Thus these industries would be likely candidates for co-location.

Co-location at Existing Facilities

In existing industrial plants, the economics of co-location depend upon how effectively steam can be utilized in existing industrial equipment. Those plants having noncondensing or automatic extraction steam turbine-generators would naturally prefer retaining the benefits of by-product power generation. And in some plants, higher steam conditions are preferred to continue the use of mechanical drive turbines for critical process compressor drivers.

In most existing refineries and petrochemical plants, fossil fuel firing is required for process steam generation since these plants were designed and built in the era of low energy costs. Thus, co-location at existing facilities may include these industrials.

Energy Supply System Options

Base Case

The alternative of the industrial purchasing all of its electric power and generating process steam is normally referred to as the Base Case (Figure 1A). In areas where a reliable source of electric power is available, this alternative usually has the lowest industrial investment cost, but often operating costs are high relative to other alternatives available.

Generally speaking, this energy supply system will utilize several low-pressure boilers with sufficient *spare* capacity to permit continued plant operation at average and often peak plant steam demands when the largest boiler is out of service for inspection, maintenance and/or repair.

Industrial Power Generation

Those industrials with large process steam demands have an opportunity to integrate power generation with their process steam needs. These energy supply systems (Figure 1B) generate steam at initial steam conditions higher than those required in process. (Typical boiler outlet steam conditions being considered today are 895 psig - 830F to 1525 psig - 955F). The steam generated is expanded in turbine-generators or mechanical drive turbines before being delivered to the process steam header or headers. Power generated in this manner – that is without condensing losses – is usually referred to as *by-product power.*

Noncondensing by-product power is generated at a fuel chargeable to power of approximately 4000 Btu/kWh HHV. This favorable fuel chargeable to power is the primary reason why many industrials have found IPG a profitable investment.

The amount of by-product power which can be produced in a specific application is a function of the process steam demand as well as the turbine inlet steam conditions and the process steam pressure or pressures required. Low process steam pres-

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sures, high initial steam conditions, and a good feedwater heating cycle all contribute toward industrial energy supply systems with large quantities of by-product power.

Some industrial plants include fossil-fuel-fired condensing steam turbine generating capacity in addition to by-product power. The condensing power usually provides the flexibility required in many industrial plants to meet normal load variations without increasing the demand on the utility tie. In other applications, condensing power may be considered necessary due to local conditions such as continuity of service required, or availability of purchased power.

Besides noncondensing by-product power, there may be some industrial plants where condensing power can be considered a by-product. This is the case in those plants where process heat recovery produces either steam quantities greater than process needs or at steam conditions not suitable for process use. In these instances, heat recovery reduces process energy losses and converts a portion of the energy into shaft power in either condensing steam turbine-generators or mechanical drive steam turbines.

Table I presents the amount of by-product power which can be generated for each industry based on initial steam conditions which are commonly used at the present time. Turbine initial steam conditions are 1450 psig - 950F except for the chemical plant which is at 850 psig - 825F.

Co-location

Another alternative would be to have a utilities company, either a electric utility or possibly an *industrial utility*, devoted to the simultaneous production of both steam and electric power or co-generation for a group of industrials coupled closely to the utility plant (Figure 1C). This approach would release the industrials from much of the investment cost for their process steam, and often, integrated power generating facilities. Supposedly, if properly implemented, economies might be realized which would benefit the industrials served. Also, the efficiency of energy utilization might exceed that expected if energy supply systems were developed at each industrial plant.

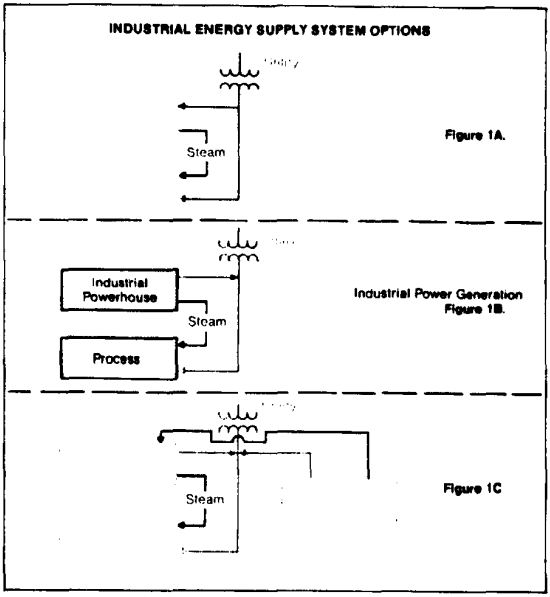

Fig. 1. Three energy supply system alternatives: *A. Base Case*—the industrial purchases all electric power and generating process steam, *B. By-product Power*—the industrial integrates power generation and process steam functions, *C. Co-location*—an industrial utility produces steam and electric power simultaneously for a group of industrials closely to the utility plant.

Co-location Considerations

Co-location of industrials with a central utilities plant providing process steam and power introduces considerations not encountered in the design of either base case or industrial power generation alternatives, or utility power generation facilities. Some of the major considerations follow.

The Central Plant

- The central plant must distribute steam at a pressure suitable for the tenant with the highest steam pressure needs. Based on examination of pressure requirements for new as well as existing facilities of energy intensive industries, a distribution pressure of 650 to 750 psig should be adequate for most potential applications.
- Economics should favor by-product power generation in the central facilities. Thus, it is expected that initial steam conditions of 1450 psig-950F or higher can be justified.
- The amount of by-product power which can be generated in the central facility will probably be less than the power required by the large industrial plants. Thus, either condensing power generation and/or a tie to the utility grid will be required to supply the balance of the power required.

It is conceivable that co-location could attract many small industrial plants that normally could not justify in-plant power generation. The increased central plant steam base would result in increased by-product power generation. The total

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amount of by-product power generated will be a function of the industrial steam demands and the distribution pressure selected.

- The merit of co-location will depend on the disposition of the by-product power generated in the central plant. Thus, alternatives where the central plant by-product power generation is not credited to the co-located industrials will detract from the economics.
- Economics of most large industrial plants require an essentially uninterruptable process steam supply system for profitable plant operation. Thus, the steam supply system must be developed to assure a continuous supply of steam, even with a major equipment item such as a boiler out of service for maintenance and/or repair.
- Although no detailed studies have been made, it is believed that the minimum total industrial steam demand for co-located arrangements should be approximately 1 million lb-h. Since most large industrial plants are base load operations, the steam demand should be relatively constant with expected variations of ± 10 percent of the average value.
- Detailed steam distribution piping studies are required to define the *maximum economic* length of the steam distribution system. It is expected *that two to three miles* will be economically justifiable in many locations.
- Many industrial processes use the latent heat from the process steam and have relatively hot condensate (≥ 180F) available for return to the central plant. At today's increasing energy costs, economics favor the return of this condensate to the central plant even if polishing is required before injection into the boiler feedwater system.

The Industrial Plant

- Those industrials having by-product fuels in excess of that required for their direct process heating needs will have to evaluate how to dispose of the excess. Some may find that the by-product fuels are saleable. Others may find it economic to install steam generating equipment, thus reducing the process steam demands on the central steam and power facility. In still other instances, the by-product fuel may be supplied to the central plant for use in their boilers.
- Grass roots facilities will probably have steam supply pressures higher than that required for the initially planned tenant industrials. This would permit expansion of the number of industrials with a high probability that the steam pressure would be suitable for use by the new industrials.

In most instances, it is expected that the central plant and the steam distribution systems will be designed to provide steam at a relatively high pressure, such as 600 psig. Since most industrial processes require steam at pressures less than 200 psig, the opportunity to install steam turbine-generators and/or mechanical drive steam turbines permitting some by-product power generation in the industrial plant exists. And economics should favor this approach.

Co-located arrangements for existing industrials with in-plant power generation systems will favor continued use of the steam turbine units providing by-product power.

TABLE II ENERGY REQUIREMENTS CO-LOCATION EXAMPLE

Net Process Heat Required (M-Btu/h)

@165 psig	2730
@115 psig	980
@ 65 psig	1140
Net Energy from By-product Fuels (M Btu/h)	2600
Net Heat from Co-located Plant (M Btu/h)	2995

CASE	BASE	IPG	CO-LO
Fuel Required (M Btu/h HHV)	5640	6905	6915
By-product Power Generated (MW)	0	296.7	297.5

BASIS:

1. *The data presented are the total requirements for a group of industrials adjacent to a central facility.*
2. *The net heat from the co-located plant includes the energy required for by-product power generation associated with steam received from the central plant.*
3. *Fuel requirements are based on 87 percent boiler efficiency. Figures include influence to net heat from by-product fuels converted to equivalent energy from purchased fuels.*
4. *IPG and Co-lo cases use 1450 psig - 950F initial steam conditions. The central facility exhausts steam at 660 psig into the steam distribution system. Steam is received at the industrial sites at 600 psig and is expanded to process pressure levels in noncondensing steam turbine-generators.*
5. *Heat loss in the steam distribution system is 0.3 percent (~4 Btu/lb).*

Economics of Co-location

The economic merit of co-location relative to the other alternatives available to a group of close-coupled industrials is illustrated in Tables II and III, and Figure 2. This example is based on grass roots facilities being within one mile of the central utility plant. The average net heat required in process, the contribution of by-product fuels to the net heat required, the energy required from the central facility, as well as the by-product power generation, are given in Table II.

The annual costs given in Table III illustrate that co-location can be attractive compared to the traditional in-plant power generation alternative even if the central facility costs are based on a fixed charge rate (FCR) identical to that for the industrial plants. The favorable influence of a lower FCR (18 percent versus 25 percent) is also illustrated. The sensitivity of the results to both fuel costs and purchased power credits other than the values used to develop Table III is illustrated in Figure 2.

The annual cost comparisons given in Table III and Figure 2 are based on no spare turbine-generator capacity. Thus, any turbine outage in either the in-plant power generation or co-location alternatives would require an increase in purchased power or curtailment in plant operations. If back-up was provided through purchased de-

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mand at a cost of $5/kW/mo., the influence of 50 MW additional demand to cover the largest steam turbine-generator out of service would increase the cost of in-plant power generation and co-location alternatives approximately 7¢/million Btu required in process. This does not significantly alter the economic comparisons presented.

Other Considerations

Results illustrate that a co-located arrangement of industrial plants with a central power and steam supply facility can be an economically attractive alternative, providing a sufficiently large process steam demand is developed and other considerations which often govern the location of industrial plants can be satisfactorily resolved. Some of these considerations include:

- Cost of raw materials and delivery of products to markets.
- Availability of water for process use.
- Environmental considerations of a group of industrials at a single location.
- *Right-of-way* for steam and condensate piping systems, roadways, as well as fuel transport and power distribution.

Other factors which will influence the decision include the possibility of process obsolescence.

Although the co-location example was based on the combustion of coal, other alternatives might prove economic for certain site situations. For example, in highly industrialized areas presently using gas and/or oil as their energy source, economics may favor development of a large central facility which would gasify or liquify coal and distribute this synthetic fuel to the industrial sites for use in their existing equipment. Or, fluid bed technology developments may result in lower cost solutions compared to direct combustion of coal with SO_2 scrubbing of boiler stack gases.

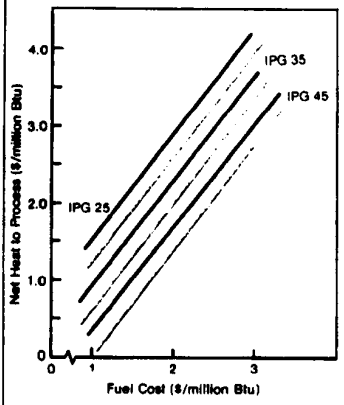
Regardless of the type of co-located energy supply system which might be developed, the application of prime movers in these systems should contribute to economic solutions which conserve our energy resources. □

TABLE III ANNUAL COST SUMMARY – CO-LOCATION EXAMPLE

CASE	BASE	IPG	CO-LO
Estimated Total Installed Cost — $ millions	130	225	53 Industrial 162 Central Plant
Annual Costs — $ millions			
Fuel @$1/M Btu	47.4	58.0	58.1
Labor	1.1	1.8	2.7
Makeup Water	1.2	1.8	2.0
Limestone & Ash Disposal	2.2	3.2	3.2
Maintenance @2.5 percent	3.3	5.6	5.4
Power Generation Credit @25 mills/kWh	NA	(62.3)	(62.4)
Fixed Charges @25 percent	32.8	56.3	53.8
Total	88.0	64.2	62.8
Total @25 percent FCR Industrial @18 percent FCR Central Plant			51.6
Cost/M Btu Net Heat to Process @25 percent FCR	2.16 ($/M)	1.58 ($/M)	1.54 ($/M)
Cost/M Btu Net Heat to Process @25 percent FCR Industrial @18 percent FCR Central Plant			1.27 ($/M)

BASIS:

1. *Costs given are based on 1976 estimates. No interest during construction or escalation are included. Spare boiler capacity permits operation at peak steam demands with largest boiler out of service (peak is 10 percent greater than average values). SO_2 scrubbing system cost is approximately $10,000 per M Btu boiler duty. Since by-product fueled boilers are included in all cases, only the incremental increase in the cost of these units for power generation is included.*
2. *8400 hours per year operation at average process heat demands.*
3. *Coal, 12,000 Btu/lb, 3 percent sulfur, 10 percent ash.*
4. *Total net heat to process is 4850 million Btu/h.*



BASIS:

1. *Industrial plant fixed charge rate (FCR) 25 percent. Utility plant FCR 18 percent.*
2. *Total net heat to process for both industrial sites is 4850 million Btu/h.*
3. *Figure following IPG and Co-lo identification is the credit assigned to the by-product power generated in mills per kwh.*
4. *See Tables II and III for other supporting data.*

Fig. 2. The net heat to process cost for various alternatives is sensitive to both fuel costs and purchased power credits.

MONS 002497

STEP: A Program of Improved Industrial Turbine-generator Maintenance

by Donald W. Brause

Today's high value on production time and energy cost places constantly greater emphasis on reliability and availability of major power plant equipment. Because of this, the General Electric Company, in cooperation with industrial users, has developed a Steam Turbine Evaluation Program (STEP) which can improve turbine-generator reliability and availability.[1]

Today's demanding economic conditions increase the need for longer intervals between major inspections and for selective sectionalized planned outages of relatively short duration. In addition, the need to maintain the improved efficiency designed into the equipment at or near new unit levels has become a primary maintenance consideration. This change in mode of operation and equipment employed, has made necessary better plans for turbine-generator maintenance. Also, properly operated and monitored units should not require shut-down and opening as frequently as in the past.

STEP Scope

STEP was first applied in 1972 and is now in use on 46 industrial steam turbine-generator units in 27 paper mills, representing over 1,000,000 kW in generating capacity. STEP is designed for industrial units because the turbine-generator set, with its controlled extractions and/or straight non-condensing and condensing turbines, represents a thermodynamic and electrical model in which the steam pressures, temperatures and flows, and kW measurements are commonly available, permitting analysis of unit performance.



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Turbine-generator outages are predominantly caused by the effects of steam path deposits, water induction, lubrication and hydraulic system malfunctions, and control system deterioration. STEP makes regular checks and surveillance of components and auxiliary systems where it concentrates on detecting deteriorating trends and conditions, and identifying probable causes to determine corrective and preventive actions.

Some of the operating characteristics that reflect equipment condition can be obtained quantitatively by on-line measurements with tools or instruments currently available. Other characteristics must be obtained by qualitative operational observations of wear patterns, system instability, leakages, etc. The data and observations are analyzed and interpreted, with the interpretation generally a comparison to acceptance values and standards, or the application of experienced judgment.

The STEP System

STEP consists of six segments.

• *Equipment analysis*—Initially, STEP involves a careful study of a unit and plant conditions to determine whether a unit is suitable for STEP or needs action to upgrade the unit and plant auxiliaries, and operating conditions. Maintenance of station instruments in good working order or the provision of additional station-type instrumentation is important since a major portion of STEP centers on systematic data taking and comparison to base or previously acquired data.

• *Establishing the base data*—Once a unit is placed on STEP, base data establishes a reference point from which all future comparisons of unit performance and auxiliary system monitoring will be evaluated. Base data should be established as soon as normal stabilized conditions develop following startup or after each major internal inspection. Internal inspections are usually performed consistent with normal customer maintenance policy, although other segments of STEP might indicate that an internal inspection is in order. Any known or marginal problems or conditions reported during prior STEP activities should be resolved at the time of internal inspection. The data base is generally re-established after each major inspection. STEP can also be applied before an internal inspection by taking data, examining the results, upgrading where necessary, and retaking related data.

• *Periodic operating surveillances*—This segment is the heart of STEP. It generally consists of three surveillance inspections per year. These surveillance inspections identify and evaluate deteriorating trends, or significant, persistent step changes in operating parameters for the turbine-generator and its auxiliaries.

• *Comparison and trend analysis*—After each surveillance, operating data comparisons are made to both the previous surveillance and to the base reference data. The results are then trended. These trend comparisons are the basis for the engineering appraisal of all results, trends and their interrelationships.

• *Shut-down or start-up surveillances*—This segment allows accumulation and observation under other than normal operating conditions. In ad-

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dition, protective devices which cannot be tested during normal operation can be exercised. Performing checks as the unit is being shutdown allows the use of corrective measures during a planned outage. Start-up checks, while covering the same areas as shut-down data and observation, allow observation of any areas worked on during the outage.

• *Sectionalized maintenance plan*— Regular operating checks and surveillance, and the troubleshooting experience gained should point to more intelligent planning and scheduling of maintenance. Priority attention can be directed to components or systems in which a "need to inspect" appears to be real. Initially, a sectionalized maintenance plan concentrates on establishing major internal maintenance and inspection intervals for the turbine and removal of the generator rotor which are consistent with existing user commitments and/or policies. With time, such a plan based upon time intervals can be tailored to suit unit experience and time available where this is practical. Sub-system inspection intervals are also established.

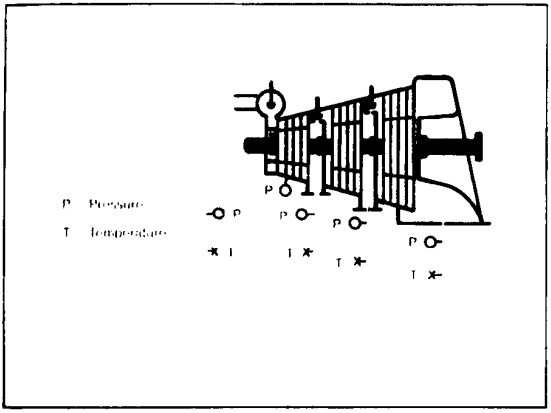

Fig. 1. The process measurements required for an analytical performance evaluation.

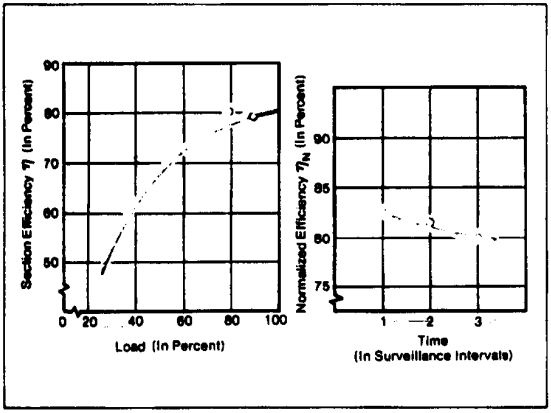

Fig. 2. Analysis of section efficiency results.

Analytical Procedures

The process measurements required for an analytical performance evaluation are shown in Figure 1, a double automatic extraction turbine. These processes involve temperatures, pressures, and flows in each steam lead to and from the turbine, plus the factory-provided first stage pressure indication. All of these measurements are normally available in modern industrial plants.

Most calibrated station instruments in good working condition are suitable for detecting significant changes and trends. It should be noted that the repeatability is much more relevant than absolute accuracy.

The analytical procedures used are structured to provide for the evaluation of the condition of the unit and of the probability of continuing reliable operation.

Section Efficiency

Turbine efficiency is calculated by the enthalpy drop method using pressure and temperature data from measurements in process piping.

Efficiency losses occur because of steam path roughness and area changes caused by deposits, steam path damage from ingestion of loose or foreign material and worn steam path packings.

A change in section efficiency is significant when there is a 10 percent change from base reference data, or a 5 percent change from last surveillance data.

Figure 2 illustrates analysis of actual section efficiency results. The data is not only calculated as shown on the characteristic (left hand) curve; it is also normalized, corrected to a common percent load point, to achieve a proper evaluation of the clearly deteriorating trend, as shown on the right.

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Stage Flow/Pressure Relationship

Another normal trend is decreasing efficiency caused by deposits as shown in Figure 3. The stage pressure and flow relationships are calculated using first stage shell pressure and flow data from the process. Losses can be from the same causes as for section efficiency deterioration.

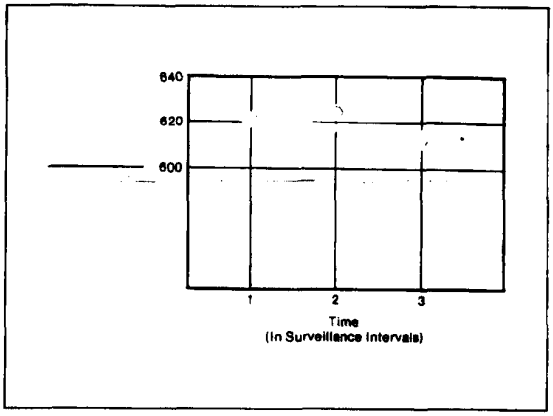

Fig. 3. Decreasing efficiency caused by deposits.

Kilowatt Check

This compares metered kilowatts to calculated kilowatts. The kilowatt output of non-condensing turbines can be calculated by means of an energy balance. This comparison checks the repeatability of almost all of the measurements in the process against a single stable watt hour meter.

Figure 4 demonstrates that unit *A* instruments are more reliable than those of unit *B*. The unit *A* kilowatt check is more consistent, its trend approximately a straight line. The check for unit *B*, on the other hand, shows no trend at all. While this information tells nothing about the unit's condition directly, the kilowatt check is a powerful correlative tool.

Since the same temperature, pressure, and flow measurements are used to calculate section efficiency and stage flow/pressure, good checks as in unit *A* indicate that analysis of other results and trends are trustworthy. Indeed, they are reinforced. Scattered checks as in unit *B*, bring other results into question and might signal a need for instrument checks.

Capability Check

A comparison of maximum power output under duplicate operating conditions is a quick way to establish whether performance changes of any type have occured, since almost all physical degradations of the steam path affect either its flow passing capability or the efficiency or energy conversion. This comparison quantifies the aggregate effect of all of the changing factors affecting the machine's output. When all instruments yield good data, it is possible to correlate the sum of individual effects with the aggregate effect as measured by the capability results.

Correlation of Results

A good correlation (Figure 5) might show gradually decreasing section efficiency, with a a slowly decreasing stage flow/pressure function, reduced capability, and a kW check with insignificant variations. Steam path deposits are the correlative factor. Steady kW checks tell the analyst that instrument repeatability is good and reinforces the analysis, which is also rational, since it agrees with experience.

Figure 6 is a duplicate of the previous analysis with the obvious ex-

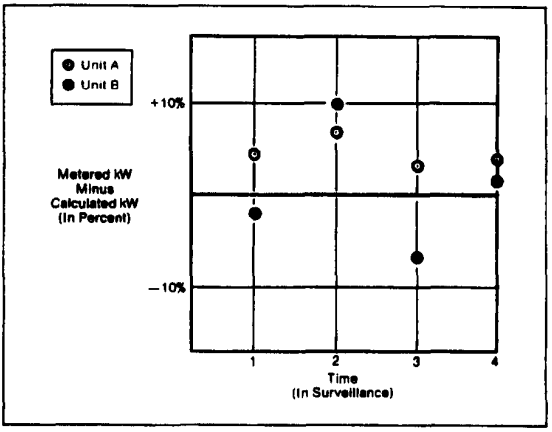

Fig. 4. Unit A instruments are more reliable than those of unit B.

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ceptions of the sharp excursions in stage flow/pressure and the kW check.

The previous analysis may appear to be weakened because the new results do not seem to correlate well. However, a common denominator for both of the affected functions (and of no other) is flow. Therefore, flow measurements are primary candidates for instrument rechecks. Finding a bad flow measurement establishes that the analysis and correlation are sound and convincing.

Thus, it is possible to monitor the condition of instrumentation as well as that of the apparatus.

Borescopic Inspections

Borescopic inspection can be considered within the context of analytical procedures. While the examination requires a shutdown, it can be brief, without opening casings, and largely justified by prior analytical review of performance results. The examination, in turn, has the potential for validating and reinforcing the analysis. Thus, the borescopic inspection and analytical appraisal complement each other.

To properly accommodate the use of the borescope, the turbine must be equipped with adaptor fittings. Most GE Medium Steam Turbine Department industrial units have been so equipped since 1973. Earlier units can be adapted in the field during a planned major inspection outage.

The borescope access openings also allow remote deposit gathering for chemical analysis. Thus information is available not only on efficiency degradation, but also corrosion and stress corrosion problems associated with carryover of caustics, sulfides, and chlorides.

The final step in the analysis is the interpretation of all the results. This is based on a knowledge of machine and process characteristics and practical experience in applying that knowledge to the specific field of steam turbine diagnostics.

Conclusion

STEP performance evaluations can be a valuable addition to a steam turbine-generator maintenance program. The information provided in the STEP process assists plant maintenance personnel and management in making planned performance evaluations, improving existing maintenance programs and extending major inspection intervals. This will aid in anticipating operating problems, minimizing maintenance costs, and anticipating parts needs that may develop. □

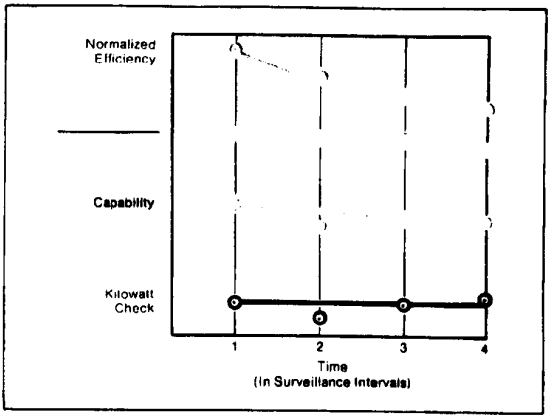

Fig. 5. A good correlation of results showing gradually decreasing section efficiency, a slowly decreasing stage flow/pressure function, reduced capability, and a kW check with insignificant variations.

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1. "Systematic Monitoring and Performance Evaluation Can Increase Turbine Generator Availability," by R.E. Sperry, J.A. Carcich and C.J. Isak (GER-3058)

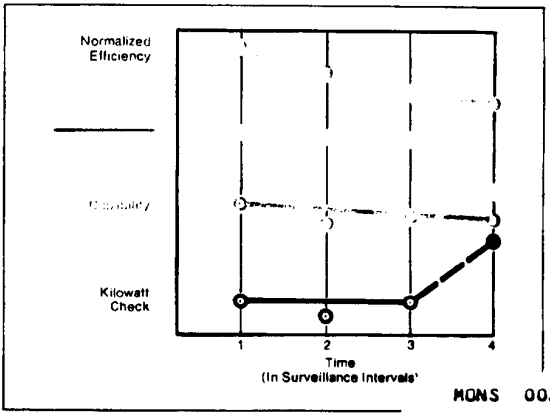

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Fig. 6. A duplicate of the previous analysis with the obvious exceptions at the sharp excursions in stage flow/pressure and the kW check.

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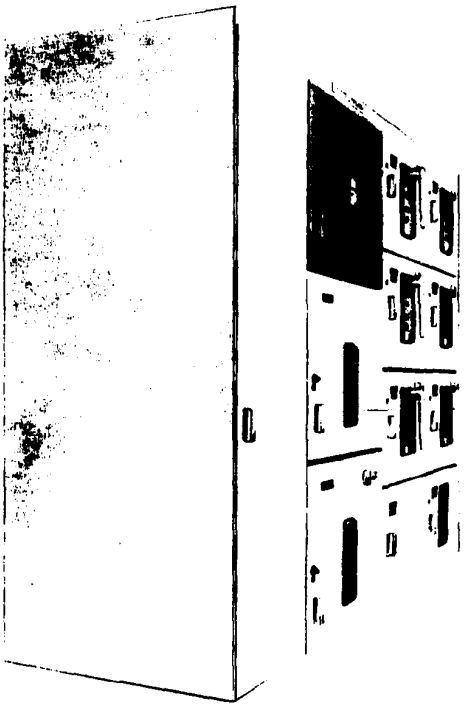

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