Appendix A7:
A Systems View of the Modern Grid

OPTIMIZES ASSETS AND OPERATES EFFICIENTLY

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EXECUTIVE SUMMARY

The systems view of the modern grid features seven principal characteristics needed to achieve a modern grid. (See Figure 1.) One of those characteristics is *optimizes assets and operates efficiently.* How we might attain this characteristic and contribute to positive returns on investment is the subject of this paper.

Figure 1: The Modern Grid Systems View provides an "ecosystem" perspective that considers all aspects and all stakeholders.

Unlike today's grid, the *modern grid* will apply the latest technologies to optimize the use of its assets. For example, optimized capacity can be attainable with *dynamic ratings*, which allow assets to be used at greater loads by continuously sensing and rating their capacities.

Maintenance efficiency involves attaining a reliable state of equipment or "optimized condition". This state is attainable with *condition-based maintenance*, which signals the need for equipment maintenance at precisely the right time.

System control devices can be adjusted to lower losses and eliminate congestion. Operating efficiency is increased by selecting the least cost energy delivery system available through these adjustments of system control devices. Optimized capacity, optimized condition and optimized operations will result in substantial cost reductions.

In the modern grid, asset optimization does not mean that each asset will reach its maximum operating limit. Rather, it means that each asset will integrate well with all other assets to

maximize function while reducing cost. For example, load-sharing would routinely adjust the loads of transformers or lighten loads of transmission line sections.

Optimized maintenance will be possible when, for example, equipment monitors send a "wear" signal as part of a *predictive maintenance* regime or a direct malfunction signal in a *condition-based maintenance* regime.

Key technologies to be applied by the modern grid will provide the infrastructure, processes and devices to support both these examples of optimized asset utilization and maintenance, plus many more.

This paper explores how the modern grid would make such optimization possible. We address these important topics:

- The present and future of asset utilization and maintenance.
- Requirements of its implementation in the modern grid.
- Barriers between today's reality and modern grid requirements.
- Expected benefits.
- Recommendations to move forward.

Although it can be read on its own, this paper supports and supplements "A Systems View of the Modern Grid," an overview prepared by the Modern Grid Initiative (MGI) team.

Current and Future States

Before we discuss how the modern grid will optimize assets and operate more efficiently, we need to understand this characteristic's current state and its future possibilities.

Current State

In today's grid, the data systems to ascertain real-time asset utilization are not typically available. The current utilization rate of assets within a utility, if it is measured at all, is mostly limited to transformers and transmission lines. Both assets use a load divided by capacity calculation for percent loading. A larger percentage is considered better.

At a few larger utilities, the average utilization of transformers at distribution substations was measured at about 40%. At transmission substations, utilization of transformers was measured at about 50%. Using a dynamic rating to measure and adjust loading improved the utilization of both groups by about 6%.

Operators only know the condition of equipment when they perform maintenance or when failures occur. For example, after a maintenance overhaul, they assume that the equipment has been refurbished to an almost new condition. Unfortunately, data systems to support better assessments of equipment conditions are not common, and data mining tools and wear algorithms are rare.

Predictive maintenance, which applies condition-based algorithms to predict future failures and signal the need for maintenance, is not commonly used by utilities.

More commonly, equipment maintenance occurs on a regular time interval or sometimes by diagnostic testing. Regular time interval maintenance is called preventative maintenance, whereas diagnostic maintenance involves performing a health checkup with limited testing on a regular basis.

Diagnostic testing requires taking equipment out of service. Key components are tested and, if all tests show positive results, the equipment goes back in service. If problems are found, then corrective maintenance occurs prior to restoring the equipment.

Critical technology tools to optimize assets and their maintenance are not widely used. Such technologies include a Common Information Model (CIM) and Substation Automation (SA). Likewise, Intelligent Electronic Devices (IED) may exist at Extra High Voltage (EHV) Substations, but presently have no widespread use.

Complicating optimized asset management and efficient operations is the lack of standard communication systems in the industry. Widespread communication is limited because common communication systems are not available throughout the utility service area. Common systems were originally not required and the expense to upgrade is often prohibitive.

For larger utilities, there is no consensus on how to measure cost of maintenance. Most have done some benchmarking, but the performance of maintenance is usually based on the previous year's actual expenditures. The data and systems do not exist to predict future maintenance expenses.

A great number of sensors are in the marketplace, usually targeted at the transformers and circuit breakers. Nevertheless, many equipment types remain without the sensors to gather needed data for wear algorithms to process.

Probabilistic Risk Assessments (PRA) are presently only used in the nuclear sector of the electric utility industry. Current research offers ways to show a PRA presentation of overloads, voltage violations, and voltage stability warnings for Regional Transmission Organizations (RTO). Grid operations would benefit greatly from this kind of information, but widespread acceptance and implementation has yet to occur.

Future State

The future state of optimizing assets and operating efficiently would include the widespread installation of sensors to provide equipment condition in real-time. This information may be gathered as a direct reading, as with a vibration monitor or as a derived estimation using a wear algorithm. Automated analysis, such as comparing the wear to a threshold value, would signal an exceeded threshold to the asset manager. The asset manager would then perform maintenance, no sooner than necessary.

Using Common Information Model (CIM), Substation Automation (SA), and sensors with widespread communications enables "just-in-time" maintenance. (See Table 1.) These key technology tools help to accurately gather and transmit the required data to a processing center to develop an *equipment maintenance condition status*. Only those equipment units in immediate need of maintenance would have maintenance crews dispatched.

In operating the modern grid, optimization can occur when generation resources identify untapped capacity, thus avoiding the startup of more costly generator resources. Dynamic real-time data reveals when and where unused capacity is available. Finding and using that excess capacity avoids the cost of starting up more costly generation. The use of excess capacity also applies to transformers, transmission lines, and distribution lines. For example, avoiding the startup of a residentially placed Distributed Energy Resource (DER) on a cold winter night could be possible if the distribution system were capable of carrying the heavy load from the substation.

As modern grid sensors provide more data, asset planning is also optimized. The optimization in planning occurs in the selection and timing of the installation of new assets. Using the data from all grid sensors, planners can decide more economically when, where, what, and how to invest in modern grid improvements.

Technology Tools	Functions
Sensors/IEDs	Detect and measure conditions in near real--time to assess equipment.
Common Information Model (CIM)	Provides system-wide commonality of data used to measure the condition of equipment.
Widespread Communications	Provides system-wide exchange of data between equipment and asset managers.
Substation Automation (SA)	■ Provides the internal substation communications path as well as many of the IEDs required to effectively monitor the equipment. ■ Provides both a local and remote human-machine interface. ■ Provides monitoring (such as infrared imaging) of equipment for visible signs of health. ■ Scales up from substations to transmission and distribution facilities.

Table 1: Key technology tools provide important functions needed to optimize the use and maintenance of modern grid assets.

REQUIREMENTS

Moving from our current state to the future state of optimizing assets and operating efficiently requires employing technologies at several levels in the modern grid.

GATHERING AND DISTRIBUTING DATA

In the modern grid, the approach to asset utilization requires:

- **Gathering the data for processing by the optimization applications.**
- **Distributing the data widely in real-time.**

To accomplish these two functions, sensors must first be installed at the equipment and messages must be sent when defects or trends are discovered.

Asset managers would analyze high-risk areas and even individual pieces of equipment for immediate or contingency action. As new real-time information updates the model, operators of the grid will have advanced visualizations depicting congestion areas, probable equipment failures, and the potential consequences. Asset managers will be able to foresee the consequences of maintenance tasks (or lack of maintenance) and make informed business decisions.

Gathering useful data and distributing it where and when needed requires the use of these specific technology tools:

- **Sensors/Intelligent Electronic Devices**
- **Common Information Model**
- **Widespread Communications**
- **Substation Automation**

Sensors/Intelligent Electronic Devices (IED)

Wide varieties of sensors already exist for many of the equipment types employed by the modern grid. From a functional basis, the processing can be done locally or remotely, but the preference is to trend results and then to query in near real-time to assess equipment under investigation. Additional sensors will be required to fill in the gaps between what is known about the equipment and what needs to be known about the equipment. Such sensors may include monitors of vibration, chemical analysis, acoustics, temperature or any of the electrical parameters used in the delivery of electricity.

Common Information Model (CIM)

The CIM is a vital ingredient to the data collection from equipment. CIM will be the single most important data validation methodology in place because, by definition, it associates the equipment with the performance criteria to be measured. It thus enables validation of the equipment's quality parameters.

Widespread Communications

A communications path is required to get data and information from the equipment to the asset manager. Even Supervisory Control and Data Acquisition (SCADA) only covers about half of the substations, so large-scale communications will be required to implement this characteristic of the modern grid.

Substation Automation (SA)

Substation automation functionality must be extended to the distribution level. Predictive maintenance routines are greatly enabled by the implementation of a substation automation scheme. Applying SA technology more widely would allow monitoring more equipment and expand the base of power quality data.

SA would also provide both a local and remote human-machine interface. In addition, it will provide the ability to consolidate and prescreen data, thus reducing the data load on the communications system between the substation and the operations center.

Substation automation technologies would support wider use of remote cameras to help other elements of the modern grid resist attack. These same cameras can be used to view equipment for visible signs of health (such as infrared imaging and thermography). As asset optimization methods become more widely used, substation data will be sent to more control areas. As a result, the increased observations will reduce the time to estimate status of equipment throughout the grid.

LEVELS OF ASSET OPTIMIZATION

Asset optimization technologies must satisfy requirements at several levels of the electrical power system, namely:

- **Distribution level**
- **Operations level**
- **Regional Transmission Organization (RTO) and Control Area level**
- **Planning level**

Distribution

Asset optimization at the *distribution level* requires configuring circuits and operating capacities to minimize losses. Such software solutions already exist but are not common in the US.

Operations

Asset optimization in operations requires real-time dynamic ratings for both lines and transformers. While lines may have inconsistent temperature environments, average values may apply for the short term. Technologies are required that embed temperature sensors inside the conductor at regular intervals for a complete temperature profile of the line. Transformers should have a temperature sensor in the substation. Operating a transformer closer to its limit could save a re-dispatch of generation, thus increasing efficiency while increasing the utilization of the asset.

RTO and Control Areas

Asset optimization at the RTO and control area level requires data to be integrated to show the big picture. Loop flows, or the passing of energy through an area for use by others outside that area, may be avoided by an operating configuration only visible at the RTO level where multiple control area schemes are presented. That configuration may save costly upgrades, enable more economic dispatch, and enable greater asset utilization for all parties.

Planning

Planners need to know the options available to optimize asset loading. Maximum demand might be rarely needed. Conversely, it might be urgently needed during an emergency procedure. Having all the data showing different ways to optimize loads would provide planners with the details to manage assets more flexibly and effectively.

Applications and Device Technology Requirements

Key technologies applied by the modern grid will help close the gaps between the grid's current and future states. The modern grid infrastructure will be required to integrate both applications and device technologies.

Applications Technologies

Real-time dynamic rating - Real-time dynamic rating applications will allow existing assets to be used at greater loads under certain conditions. Since heat is a limiting factor in the operation of electrical equipment, heat-mitigating conditions such as cold weather or elevated wind may offer increased capacity during windows of opportunity.

Probabilistic Risk Assessment (PRA) - Probabilistic Risk Assessment (PRA) assists in *operations and maintenance* decisions because asset managers can know the *probability* of failure of their assets. However, unless they understand the *consequences* of that failure, the true risk is hidden. A PRA combines the probability of failure and the consequences of that failure to arrive at a real-risk factor.

PRA assists in *planning* decisions because planning managers often know the consequences of an asset failure, but few may know the probability of failure of their assets. As with maintenance and operations, a PRA combines the probability of failure and the consequences of that failure to arrive at a real-risk factor. Using true risk probabilities, the planner will have more information to arrive at more informed decisions.

Common Information Model (CIM) - The CIM ties the identification of equipment to its measurements. There are six different CIM categories: wires, SCADA, load, energy scheduling, generation, and finance. Each category has specialized formats to encompass the information being transmitted. CIM has been around for over a decade and its implementation in one or more categories is ongoing in most states. The requirement is that CIM be adopted as the industry standard and fully integrated into the modern grid.

Failure rate analysis - Failure rate analyses collect data about known equipment failures. Failure rate data includes the asset nameplate information, the failed component, the cause of failed component, utilization history, operating cycle, percent loading, environment, and location. The analyses by themselves can become a performance indicator and improvement tool.

Root-cause analysis of failure rates may provide insights to solutions to eliminate failure altogether. It requires a great deal of information to perform failure rate analyses. Filling the gaps between sensors, communications, and condition-based monitoring systems will enable this analysis to be automated and thus cost-effective.

Condition-based and predictive maintenance - Both condition-based maintenance and predictive-maintenance methodologies are dependent on meeting requirements for sensors and communications technologies. Software presently exists for detailed analysis and presentation applications. The solution lies in the implementation of monitoring technology, which will enable a just-in-time maintenance regime.

Application technologies and the solutions they provide are summarized in Table 2 below.

Application Technologies	Solutions
Real-time dynamic rating	Allows existing assets to be used at greater loads.
Probabilistic Risk Assessment (PRA)	Integrates Real-Time Contingency Analysis (RTCA) with the probability of failure determined by the condition-based monitoring system.
Advanced monitoring	Extension of SA functions to other grid elements.
Real-time visual observation	Remote-operated cameras in substations and other critical grid locations.
Sensors and IED	Usage expanded to equipment throughout the grid.
Communications	Wide communication connecting all substations and distribution switch locations.
Common Information Model (CIM)	Adoption as an industry standard.
Failure rate analysis	Applied throughout the grid by widespread sensors.
Condition-based and predictive maintenance	Monitoring technology and widespread communication will allow just-in-time maintenance.

Table 2: Filling the gaps between current and future states with modern grid solutions.

Device Technologies

Advanced monitoring technologies - Advanced monitoring, as applied in substation automation, could be integrated into other levels of the grid as well. Equipment state and parameters could then be viewed in real-time by other control elements of the grid such as central utility headquarters, distribution centers or even other substations.

Advanced monitoring technologies may also provide a needed solution to identifying the precursors to underground cable failure. This identification may lead to the execution of operating guides to reduce the effect of such failures on the grid. Advancements in Phasor Measurement Unit (PMU) technologies may offer real-time assessment of grid flows and help to determine whether system stability requires the opening of tie lines.

Real-time visual observation – Remotely operated cameras in substations and other grid critical locations can deter or warn of attack. Infrared scans can also offer real-time assessment of local heating of grid elements such as risers, connectors, and bushing terminals, as well as visual observations of transformer-cooling radiator operation.

Sensors & Intelligent Electronic Devices (IED) - The installation of IEDs in the substations provides extended protection as their primary function. They also provide a wealth of information available by the simple connection to a communications port. IEDs are common in EHV substations, but they have not yet been used at lower voltage class levels.

The grid can use a variety of existing sensors to implement many of the applications required to enable a full asset optimization program. These sensors include relay IEDs, oil pump monitors, vibration monitors, thermometers, pressure gauges, and specific gas detectors, to name just a few. There are some missing sensors in the sensor family, mostly due to cost or choice of maintenance policy. A low cost combustible gas analyzer would be an example of a sensor to yield real-time data.

Communications - Widespread communications infrastructure to all substations and distribution switch locations has not occurred. Communication types include telephone, fiber optics, microwave, cellular, and broadband over power line carrier (BPL).

PERFORMANCE STANDARDS

Asset Optimization has many ways to define performance. The most common ones measure reliability and economics. Some examples include:

Reliability

- CAIDI — A weighted CAIDI average of differing construction types (i.e. overhead, underground, network) and various penetration levels of modern grid elements to arrive at a uniform measure of local grid reliability.
- Forced Outage Rate — How often a power plant is out of service due to non-planned events.
- Equipment Failure Rate — How often equipment fails in service.

Economics

- Cost per delivered MW — O&M dollars spent to serve a megawatt.
- Cost per installed MW — Capital cost to serve a megawatt.
- Cost per MW transformed — O&M cost of transformers per MW.

BARRIERS

There are examples of making asset optimization and operating efficiencies work, yet they have not spread throughout the industry. The near-term payback and ROI do not compete well with alternate investment opportunities.

Barriers to full-scale implementation of needed applications and device technologies include risky investments, the existing outdated equipment base, and reluctance to change.

- **Weak Business Cases** – The quantity of required sensors and their attendant communications infrastructure demands large financial investment. By itself, the business case for achieving asset optimization is weak. On the bright side, there have been many pilot programs implementing partial solutions confined to small demonstration areas. When the sensors and communications infrastructure are integrated with the other characteristics of the modern grid, the benefits increase from the addition of the self healing, power quality and enabling market benefits, resulting in a viable business case.
- **Incompatible Equipment** – Some of the older equipment types do not have the embedded sensors to enable a predictive methodology, and in some cases, it may not be cost-effective to install it. With a mix of some automated maintenance equipment and some manual maintenance equipment, the benefits are diluted, further weakening any business case.
- **Reluctance to Change Processes** – It will be a hard sell to change long standing maintenance practices and beliefs. Some equipment types may require equipment modeling research and development while a great many equipment types will surely require improvement and refining of the wear models, predictive analytics and dynamic rating algorithms currently in use. While automation will replace many human labor tasks, it will still require process change to achieve success.

BENEFITS

The benefits of optimizing assets and operating efficiently can be viewed in the context of the modern grid's key success factors.

Optimizing asset utilization and introducing efficiencies in operation and maintenance will have a positive impact on key success factors of the modern grid. (See Table 3.)

Key Success Factors	Impact of Optimizing Assets & Operating Efficiently
Reliable	Advanced Monitoring Components provide data for: ▪ Dynamic equipment ratings. ▪ Level-loading assets. ▪ Predictive maintenance.
Secure	Substation Automation provides remotely monitored real-time surveillance devices that can also be used in other parts of the grid.
Economic	Advanced sensors and software provide: ▪ Failure rate analysis and Root Cause Analysis for performance improvement. ▪ Opportunities for greater power densities in existing assets.
Efficient	The combined improvements in asset utilization, operations and maintenance help to: ▪ Retire inefficient equipment. ▪ Put more energy through current assets. ▪ Obtain higher reliability of equipment with a lower cost of maintenance
Environmentally Friendly	Decrease pollutants through the prediction and removal of potential sources of toxic leaks and spills
Safe	Reducing the exposure to accident through reduced maintenance effort

Table 3: Asset optimization and reduced maintenance will have a positive impact on each key success factor of the modern grid.

RELIABLE

The use of advanced monitoring technologies will provide the information for asset management programs to realize substantial cost savings through improvements in reliability. The detailed awareness of component and equipment condition reduces human errors in performing maintenance, and helps to avoid outages for unnecessary maintenance.

Advanced monitoring technologies will:

- Allow for dynamic (continuous) equipment ratings, enabling greater use of existing assets.
- Enable better level-loading of assets by removing overloads and high stress conditions through the increased use of other assets.
- Attain some improvements in CAIDI because those monitoring technologies integrate with a communications path and process algorithms to enable the condition-based and predictive maintenance regimes.

SECURE

A security benefit resides in Substation Automation with the installation of low cost remote cameras that can monitor equipment. This function can be scaled to other grid elements.

ECONOMIC

Asset optimization has the opportunity for gaining economic benefits because greater power densities can be attained using the same existing assets. In an energy market, this increase in utilization increases revenue for the asset owner, and at the same time lowers energy costs for load-serving entities. This win-win scenario offers economic incentive to both asset owners and users of energy.

EFFICIENT

Modern grid assets will remain in service longer and have a lower maintenance profile, thus attaining a higher asset utilization. Asset utilization measures performance, loads carried, and maintenance costs. Heavily loaded assets that perform for long times with little maintenance are best utilized.

While there is no known goal for standard cost per equipment item, an obvious benchmark is the "best-in-class" performer. Drill-down analyses of all other performers will further aid in the asset optimization process because economic analyses can identify previously undiscovered improvement opportunities.

ENVIRONMENTALLY FRIENDLY

As asset utilization optimizes, environmental quality becomes easier to maintain and improve. For example, leaks from sulphur hexafluoride equipment decrease as do leaks from oil-filled equipment. Avoiding spills and harmful emissions from inefficient equipment contributes to a cleaner environment.

SAFE

Optimizing maintenance results in performing less maintenance. Less maintenance work equates to less exposure to accident and thus increased safety to maintenance personnel.

Recommendations

The optimization of modern grid assets, like other principal characteristics of the modern grid, will depend on motivating investors, thorough planning, and changing the way the industry performs its operations.

Successful pilot programs and demonstrations in the past indicate some fundamental actions needed to pave the way for the long-term benefits of asset optimization and efficient operations.

1. **Develop investment criteria that acknowledge the systems view of the modern grid and its long-term benefits to the national economy.** Business cases that are based on returns to local providers or distributors are too narrow in scope and often too short term in duration.
2. **Provide incentives to replace older equipment with equipment designed to operate in a 21st century communication and information system infrastructure.** Too many necessary upgrades are proven non-cost effective due to high costs of purchase.
3. **Replace Equipment with 'no maintenance' versions.** Where equipment replacement is warranted because of depreciation and obsolescence, asset managers should consider 'maintenance elimination'. In this final maintenance process, high maintenance equipment is replaced by equipment that requires little to no maintenance at all.
4. **Install Sensors to Assess Equipment.** Until the utility environment is populated with self-maintained equipment, there will be a need to develop a myriad of low cost sensors that monitor equipment/system health. While vendors may invest in the research to develop such devices, utilities might also invest in common research with regulator approval.
5. **Begin training in the industry that will prepare operators to use the new maintenance tools available.** Business-as-usual operations will not exploit the technologies needed to optimize and efficiently maintain modern grid assets.
6. **Adopt the Common Information Model (CIM)** - The CIM ties the identification of equipment to its measurements. This validates the data source thus eliminating the source of many present day errors. The recommendation is that CIM be adopted as an industry standard and fully integrated into the modern grid.

SUMMARY

Whether optimizing assets or operating efficiently, information is the key. Gathering that information is one challenge for the modern grid, communicating it widely is a second, and processing it usefully is a third.

Gathering the information is the function of sensors and Intelligent Electronic Devices (IED) comprising advanced monitoring technologies. Sensing and measurement technologies of the type employed in substation automation must extend their reach in the modern grid to other control elements of the electrical power system, including transmission and distribution.

Communicating the information requires both a common language such as the Common Information Model (CIM) and a widespread communications infrastructure. A common suite of advanced communications components and protocols will characterize the modern grid solution to this need.

Processing information usefully is the domain of software applications for predictive and condition-based maintenance as well as dynamic load ratings for efficient asset utilization and operations. Though these applications exist today, they are effectively starved for usable information from most elements of the electrical power system.

To meet these three challenges, the modern grid will apply elements of its five key technology areas as presented in the systems view:

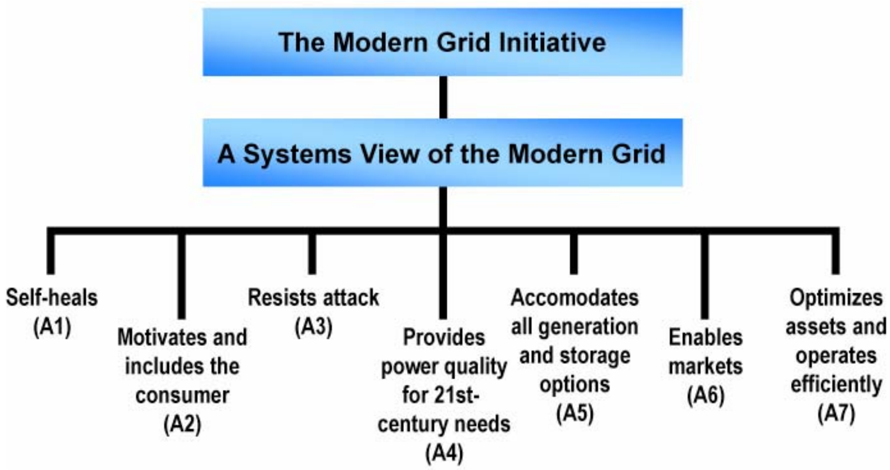
1. Integrated communications.
2. Sensing and measurement technologies.
3. Advanced components.
4. Advanced control methods.
5. Improved interfaces and decision support.

By integrating these types of current and future technology solutions for asset utilization and maintenance, information will be better gathered, better communicated, and better processed to achieve this important characteristic of the modern grid.

For more information

This document is part of a collection of documents prepared by The Modern Grid Initiative team. For a high-level overview of the modern grid, see "A Systems View of the Modern Grid." For additional background on the motivating factors for the modern grid, see "The

Modern Grid Initiative." MGI has also prepared seven papers that support and supplement these overviews by detailing more specifics on each of the principal characteristics of the modern grid. This paper describes the seventh principal characteristic: "Optimizes assets and operates efficiently."



Documents are available for free download from the Modern Grid Web site.

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