SEISMIC RISK ASSESSMENT OF ELECTRIC POWER SYSTEMS IN UTAH AND RECOMMENDATIONS FOR RISK REDUCTION

SEISMIC SAFETY ADVISORY COUNCIL

STATE OF UTAH

807 EAST SOUTH TEMPLE STREET
SUITE 103
SALT LAKE CITY, UTAH 84102

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Prepared By

Dr. Craig E. Taylor
Research Analyst

Under State Contract Number 80-5006

and

Delbert B. Ward
Executive Director
Seismic Safety Advisory Council

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FOREWORD

The Utah Seismic Safety Advisory Council, established in 1977, is charged to prepare assessments of earthquake hazards and associated risks to life and property in the State of Utah, and to make recommendations for mitigating hazards that may be found.

This report presents an assessment of earthquake risk for electric power supply systems in Utah. The report includes recommendations for reducing risks that are deemed reasonably manageable within available resources. The recommendations are set forth as judgements of the Seismic Safety Advisory Council in terms of effectiveness of the suggested action for reducing risk to life, health, and property.

This report is divided into a summary of findings, a discussion of earthquake effects upon electric power systems in general, an assessment of earthquake risks to Utah electric power systems with emphasis upon population centers, and recommendations for earthquake risk reduction that deal primarily with policies and procedures rather than technical solutions.

The report presents an overview of earthquake risk to electric power systems and treats particular elements of one system primarily to highlight important systematic relationships that affect public service. The vulnerabilities of particular types of components to earthquake effects are discussed, and guidance is provided by which system operators may undertake detailed evaluations to establish priorities for mitigation efforts in accordance with aspects or components of greatest vulnerability or of greatest importance to the continuing operation of the systems. As well, the importance of network analysis is stressed as a means to determine areawide effects of localized component failures that might be caused by earthquakes.

This report, like several others of similar nature dealing with various types of utilities, reveals the complexity of large systems serving entire communities, counties, and even larger regions. Such systems are made up of innumerable small and not so small components that must work together for effective and reliable distribution of the utility product. To achieve areawide service, some components and some lines in the system are more important than others in the sense that more of the service population can be affected by unplanned failures. The perspective sought from the reader, then, is of a system which is reliant upon individual components. Such a perspective helps significantly to understand how earthquakes can cause inconvenience and economic loss to populations and businesses remote from the epicenters of the events. Such a perspective also helps one to realize that unnecessary earthquake risk to electric power systems is, indeed, a matter in which the general public has a direct and proper interest.

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SECTION 1

INTRODUCTION

This report commences, in Section 2, with a summary of findings resulting from a seismic risk assessment of electric power systems in Utah. In Sections 3 and 4, earthquake effects upon electric power systems in general and earthquake risks to Utah electric power systems are treated in greater detail. Section 5 follows with recommendations for earthquake risk reduction to electric power systems applicable to Utah. Technical information describing Utah's earthquake environment and methods used for estimating potential risks to utility systems as a result of earthquakes are found in other reports prepared by the Utah Seismic Safety Advisory Council and are not repeated here. The study reported herein utilizes current seismicity data in Utah and state-of-the-art methods for earthquake damage and risk assessments. The reader must bear in mind that earthquake risk assessment is an inexact science built upon limited understanding of earthquake phenomena and effects. Thus, the technical results presented herein are largely probabilistic in nature and carry all of the imperfections implied by the term.

Earthquake damage and risk assessments commonly tend to emphasize building losses and other relatively visible effects. Earthquake safety of utility systems, that are essential elements of each community's functional fabric, often receives little or no attention in post-earthquake reports and often is relegated to a less important status by the more spectacular and visible types of damage. Yet, the loss of a community's electric power supply has significant ramifications for social, business, and economic functions. Widespread inconvenience is one of the problems, but life safety and health hazards also can arise when electric power loss occurs that affects health-care facilities, food storage, and water supply services. These and other problems are serious enough to merit attention in earthquake preparedness studies and programs of State and local governments.

This earthquake risk assessment of public electric power supply systems in Utah is the first such study that specifically addresses the seismic vulnerability of the State's electric power systems in a comprehensive way, although there are numerous general studies available of earthquake risks to electric power systems. Some of the information from these studies has been incorporated into earthquake safety programs by electric utilities conducting business in Utah. However, none of these uses has resulted in studies or efforts to provide a broad earthquake risk perspective for Utah's electric power systems. This report seeks to fill that void. Although we have not attempted to evaluate the earthquake risk of every electric system and all of their components in every detail, we believe that the report treats each type of risk condition in sufficient detail to allow application of some obvious principles of safer design by electric power utility operators.

Recommendations made herein for earthquake risk reduction to electric systems generally are of a policy type rather than technically specific. Such technical details are left to the separate owners and operators of electric power systems in the State.

The more general goal of safeguarding public health and welfare cannot be left just to the operators of electric power systems, because there exists an overriding public interest in the continuing and safe operation of these systems. In this regard, the Seismic Safety Advisory Council has observed that there are in Utah different levels of attention and consideration given to earthquake safety of electric power systems, or the lack of both. These variations seem to result from the absence of a general overall policy to guide the design and construction of the systems. Indifference to earthquake safety, when present, likely is not a deliberate action in which the interested public has participated with respect to electric power systems.

Because there are particular considerations for earthquake safety that are applicable to all electric power supply systems in Utah, because there are certain situations involving public health and welfare in which the State has chosen to regulate the operation of electric power systems, and because State regulatory authorities presently seem to include the power to oversee construction activities that directly affect earthquake safety of electric power systems, the Seismic Safety Advisory Council has recommended that aspects of governmental involvements and authorities be strengthened to provide a more specific statement of policy. Other recommendations that are made are intended primarily for consideration and implementation by the local electric power utilities companies.

The Seismic Safety Advisory Council urges adoption and implementation of the recommendations contained herein.

SECTION 2

SUMMARY OF FINDINGS

Principal findings resulting from the seismic risk assessment of electric power systems in Utah reported herein are presented in this section without elaboration or extensive discussion. More detail about the study is provided in Sections 3 and 4. Section 3 provides a general discussion of earthquake effects upon electric power systems, using information drawn primarily from damage assessments of systems in other parts of the world that have been subjected to earthquakes. In Section 4, general information regarding damage is applied more directly to electric power systems in Utah. Particular attention is given to primary electric power systems along the Wasatch Front, the most populated region of the State. Recommendations for earthquake risk reduction to electric power systems are furnished in Section 5.

Emphasis in this report is given to the systematic characteristics of electric power systems. Unlike buildings, which may be treated as isolated facilities in an earthquake environment, electric power systems must be viewed in their totality in any assessment, for when something happens in one segment of the system, other portions of the system may be detrimentally affected. In a sense, electric power systems are conduits for transporting energy. Various components are used along the routes to control the flow of energy. At some points, the components may be housed in buildings, such as are generating plants, and in other instances the components may be attached to other types of structures that are unique for the industry. Thus, two general types of possible earthquake failures may be identified for the systems. One type is a failure of the buildings or structures that house or hold the components. If the structure fails, the electric power system likely will be affected. The second type of failure is directly to components of the electric system in which case disruption of the energy flow also may occur. Both types of failures are treated in this report, although more detailed information on building vulnerability is to be found in other reports prepared by the Seismic Safety Advisory Council.

Principal findings of this study are listed below. Importance of the topic was not a basis for the list sequence, and readers will note that the findings are listed more or less in order of their appearance in the discussion sections of the report. Electric power systems have been viewed here mainly in terms of function. Economic losses, due either to social impacts of power loss or to damaged componenets as might be caused by earthquakes, are not included in the study.

Earthquake Response Of Electric Power Systems

Surveys of past earthquake damage to electric power systems indicate that failures of the following types are possible.

- Temporary power outages can be expected if earthquakes of Richter magnitude above 6.0 impact directly upon power systems.

- Damage to electric power generating facilities has been limited largely to those plants that are unreinforced or poorly reinforced structures of masonry or to those affected by landslides or floods caused by earthquakes. Penstock rupture is a possible cause of damage to hydro-electric plants, and those plants using oil or natural gas for fuel may have the source of supply interrupted.

- Damage to transmission towers of electric power systems has been caused primarily by landslides, fire, and liquefaction, rather than by ground vibrations. In rare cases, transmission lines have slapped against each other, causing burnout of other components of the system.

- Distribution systems have suffered extensive damage in past earthquakes. Wooden poles have burned, lines have slapped against each other causing burnout, and transformers on poles or other structures have shifted position, causing damage.

- There have been many failures in transmission substations. Failure of porcelain insulators has occurred even for those substations designed to meet more recent earthquake design criteria.

Evidence thus indicates that electric power systems are vulnerable to extensive earthquake damage. Damage thresholds appear to be in Intensity VII and Intensity VIII regions, with the damage becoming more severe as the earthquake intensities increase.

Seismicity In Utah

Seismicity is common in most of the State of Utah with the possible exception of the easternmost portion. The most severe and frequent earthquakes historically have occurred along a central region extending from the north central border to the southwest border. This seismic region is a part of an area that has become known as the Intermountain Seismic Belt. Geologic evidence suggests that severe seismicity in the future most likely will occur within this same region, with the Wastach Fault zone being the zone of greatest risk. Although the probable frequency of strong earthquakes is expected to be very low, the Wasatach Fault is said to be capable of producing earthquakes in the 7.3 Richter magnitude range. Earthquakes in the 6+ Richter magnitude range not only have occurred in historic time in the state, but Utah can expect to experience more such events in the future. Earthquakes of these strengths may be translated roughly to Intensity VIII or greater.

From the above general summary of seismicity in Utah, it may be concluded that earthquake strengths in the range potentially capable of causing damage to electric power systems are possible within that portion of the State coincident more or less with the Wastach Front region. Critical components of primary electric power transmission systems are located within this region, although electric power generation for the most part occurs outside the region.

Generating And Transmission System Vulnerability

Major generating facilities for electric power serving most of Utah are located outside the zone of highest seismic risk in the State. Transmission lines from the generating plants necessarily flow into the region of highest seismicity, since most of the population served is coincident with that same zone. These main transmission lines connect to bulk substations also located within the seismic zones of highest risk.

Power transmission into the zone of highest seismic risk occurs both from the north (Wyoming, and intertie lines to the Pacific Northwest) and from the south (primarily from generating facilities in the general region of Emery County). From the standpoint of system redundancy (capability to provide energy from more than one source or direction), the Utah Power and Light generating system serving principal portions of the State appears to be well sited to provide power even though interruption may occur at some point along the transmission system.

Ample evidence of bulk substation failures resulting from past earthquakes in other regions of the country and world suggest that transmission substations should be considered especially vulnerable to earthquake damage. As a consequence, and after evaluation of the systematic relationships of critical substations in the transmission system of the Utah Power and Light Company, it is concluded that at least two such substations, one at Camp Williams and the other at Ben Lomond, could, if failure were to occur, constrain effective operation of the system and might make it impossible to furnish electric power to the general Wasatch Front region, at least for a short period of time.

Component Vulnerability

Components of electric power systems appear to be most vulnerable to the effects of ground vibration among all of the various effects of earthquakes. Soil problems, although occasionally present, and fault crossings do not appear to be crucial to the performance of electric power systems during earthquake events. On the other hand and as already noted, substations appear to be especially vulnerable to ground vibrations. Substations comprise a variety of components that are intricately related both physically and systematically. Transformers, a maze of wiring, porcelain supports, lightning arrestors, and other such components have failed frequently in past earthquakes. Such failures can put a substation out of operation. If such a substation is critical to the operation of the distribution or transmission system, failure can result in power outages over fairly large areas, ranging from neighborhoods to entire regions. Past evidence of power failures show also that it is possible for critical substation failures to overload other parts of the system and cause complete system wide shutdown.

Minimal attention was given in this study to distribution networks of the electric power system. Distribution networks are here taken to mean those portions of the systems that supply specific neighborhoods and communities. In contrast, transmission is here taken to mean those portions of the system through which the power flows from generating plant to the local points where the distribution network takes over. Although extensive distribution network failures are expected as a result of earthquakes, these will be localized in nature and limited to the regions impacted by the earthquake. In contrast transmission system failures have the potential of affecting other portions of the electric power system throughout an entire region, and hence are taken to be more critical and so more important from the point of view of system performance.

Mitigation Of Earthquake Damage

Much potential earthquake damage to electric power systems can be avoided through proper design and construction methods. For the most part, damage reduction actions for electric power systems serving Utah can be best directed toward improvements in detail and construction practices, anchorage of transformers and other heavy equipment to resist lateral forces, and greater attention to selection of materials that are non-brittle. Alternatives to porcelain for power line isolators could help significantly in reducing the possibility of power outages on an areawide or regionwide basis.

The location and siting of bulk substations generally do not appear to pose earthquake safety problems for electric power systems in Utah, although note should be made of the imprudence of locating such substations in close proximity to known active fault regions, as is found for the Cottonwood and McClelland substations. Since these substations must be located near population centers, it is not possible to avoid locations susceptible to ground shaking, but there is no need to subject these apparently vulnerable components of an electric power system to other earthquake effects.

System redundancy of the Utah Power and Light system in the Wasatch Front region generally appears to be capable of providing for alternative energy flow paths, even if damage should occur to some substation along the route of energy flow, with the possible exceptions of the Camp Williams and Ben Lomond substations.

SECTION 3

EARTHQUAKE EFFECTS UPON ELECTRIC POWER SYSTEMS

In order to estimate the expected impacts of earthquakes upon Utah electric power systems, it is first necessary to review the vulnerabilities of electric power system components to earthquakes generally. In this section, following a brief description of the main components of electric power systems, an assessment is made of data on earthquake damage to such components. Since there are numerous electric power system components, such an assessment will allow the ensuing discussion to concentrate upon those components that are both vulnerable to earthquakes and central within the power system.

COMPONENTS OF ELECTRIC POWER SYSTEMS

Following Anshel J. Schiff and James T.P. Yao (Cf. [1] pp. 6-10; also [2], chapter 2) one may divide an electric power system into the following parts.

(1) Power sources, which consist of generating units, whether hydroelectric, thermo-electric, or nuclear.

(2) Very high voltage and extra high voltage (HVDC or EHVAC) transmission lines, which transmit electric power at voltages above 230 KV over long distances.

(3) High voltage AC transmission lines, which transmit high voltage alternating current between power sources, transmission substations, and interconnect switching stations.

(4) Other high voltage transmission lines, such as HVDC buried cables.

(5) Switching stations, which interconnect high voltage transmission lines and serve to sectionalize the system either to deal with short-circuits or for maintenance and construction.

(6) DC converter stations, which convert high voltage AC power from AC transmission lines to high voltage DC power, and vice versa.

(7) Transmission substations (high-voltage, major, receiving, or bulk power substations), which convert HVAC power from transmission lines (generally at 115 KV and above) to a lower voltage until the distribution system voltage is finally reached (voltages below 115 KV).

(8) Distribution substations, which are facilities to convert AC power from the subtransmission network to the distribution voltage.

(9) Tie lines, which are lines at distribution voltages and that interconnect distribution stations or provide an alternative power path to critical load users.

(10) Transformer installations, that convert power obtained from the distribution station to the voltage used by the consumer. (Transformers are defined as static devices for transferring electric energy from one circuit to another magnetically (or by induction rather than conduction) [2], 8-3).

At face value, those components within the transmission system (115 KV and above) are more critical to the system than are those in the distribution system, although an analysis of a specific system is needed to determine how central a specific component is to the entire power system. In general, the presence of system redundancy makes any abstract claim about the importance of a specific component very provisional.

EARTHQUAKE RESPONSE OF ELECTRIC POWER SYSTEMS

Data available about the effects of earthquakes upon power systems indicate that moderate to large earthquakes (say, 6.0 Richter magnitude and above) have disrupted power systems at least temporarily. Why power systems are so vulnerable to earthquake damage and what social consequences can be expected from power failure are matters still not clearly defined. A review of past damage data and a sketch of some possible social consequences of power system failures are furnished in this study to help define such matters to a greater degree. Much of the data about earthquake effects upon power systems come from studies of the San Fernando Valley earthquake of 1971. Other data come largely from a historical survey made by Otto W. Steinhardt ([3]).

In the San Fernando Valley earthquake, for example, two electrical companies were affected. In the Southern California Edison Company system, damage occurred principally in the Saugus, Sylmar, and Vincent areas. There, 60 percent of the customer load was restored in one-half minute and 90 percent within 6 hours. Prolonged outages were chiefly a result of damaged transformers and distribution line poles. In the Los Angeles Department of Water and Power system, large portions of Los Angeles suffered a blackout for as much as 6 hours to over 1 1/2 days ([4], p. 1). Hence, the most studied earthquake, the San Fernando Valley earthquake, illustrates the possible extent of power failures.

Outages have occurred in numerous other earthquakes, including the recent 1979 earthquake near El Centro, California.

Generating Facilites

Generating facilites have been damaged in earthquakes generally only when the structures are of either unreinforced or poorly reinforced masonry construction, or else they were damaged as a result of slides or floods.

In the San Fernando Valley earthquake, the only direct damage occurred to two 3-MW hydroelectric units at the San Fernando Power Plant, which was located in an Intensity X area. The plant, constructed in 1921, contained little reinforcing steel, and so was severely damaged by the shaking. In addition, flooding resulted from a break in the penstock, which had no flexible joint at the conncention to the powerhouse ([4], p. 10).

In the 1923 Kanto (Japan) earthquake (Richter magnitude 8.2), 23 of 91 hydroelectric plants and all 11 steam-electric plants were damaged as a result of failure of unreinforced masonry structures, or were damaged due to washouts and landslides. Soil settlement was the only cause of generator failure.

In the 1952 Kern County (California) earthquake, failing rocks and soil damaged a hydroelectric plant, which nonetheless continued operating at reduced capacity.

In the 1964 Niigata (Japan) earthquake, 11 of 230 hydroelectric stations were put out of service. One steam power station suffered damage to the condensor and cooling lines.

In the 1964 Anchorage (Alaska) earthquake (Richter magnitude 8.4), an intensely shaken hydroelectric plant was able to be placed back on line within 20 minutes, although rock and snow slides made plant operation difficult for six weeks. Rupture of gas lines and loss of oil supply meant that other facilities with gas turbines and diesel generators couldn't operate.

In the 1976 Guatemala earthquake (Richter magnitude 7.5), a 42.5-MW electric power plant tripped out for 40 minutes but was undamaged ([3]).

The most illustrative structural damage occurred to a 70-MW Managua (Nicaragua) plant in the 1972 Managua earthquake (Richter magnitude 6.5). The plant was designed for 0.1 g lateral force by a static load method. A 40-MW turbine was put out of service for 4 months. It and two 15-MW turbine generator units were damaged as a result of hammering of turbine pedestals against the surrounding concrete floor. Rail-mounted transformers derailed and some bushings broke ([3]).

As data from the Guatemala earthquake indicate, structural failure is not the only cause of generation failure, since units can be tripped off line by other causes. In the San Fernando Valley earthquake, five units were tripped off line. Of eighteen units in the City of Los Angeles, two were permanently tripped. The two permanently tripped units were those structurally damaged. Three other units were tripped as a result of the operation of sudden-pressure relays ([4], p. 10).

In summary, damage to generating facilities can result from:

(i) Failure of unreinforced-concrete structures to withstand ground-shaking, or, in rare cases, failure of structures with some seismic resistance to withstand forces larger than those for which they were designed.

(ii) Landsliding or flooding, possibly due to rupturing of penstocks or siting problems.

In addition, generation can be halted owing to the operation of transformer sudden-pressure relays, or by virtue of a loss of generating fuel, such as occurred in Anchorage.

Tripping Of Relays

The operation of transformer sudden-pressure relays occurs not only in connection with generation but also in connection with transmission and distribution. At generating stations, transformers step up voltages so that bulk power can be efficiently transmitted. Voltage levels must be stepped down as they approach the distribution system. Large transformers contain "fast-acting, pressure-sensitive, sudden-pressure relays which are also sensitive to pressure fluctuations caused by earthquake vibrations" ([1], p. 15).

According to H.L. Holland, there were numerous cases of the "incorrect operation" of transformer bank sudden-pressure relays, so that the resulting tripping led to widespread power blackouts in the San Fernando Valley earthquake ([5], pp, 2,3). According to Patrick Wong, it is not known whether or not such relays mitigated the extent of damage by deenergizing the distribution system and eliminating wire burn down ([4], p. 25). According to Anshel J. Schiff and James T.P. Yao, the immediate response of the Western States Power Network to the San Fernando Valley earthquake was very good, as measured by the extent and duration of power outages. As the earthquake occurred, a large percentage of the sudden-pressure relays in the transformers throughout northern Los Angeles were triggered, dropping the loads which they were carrying. Sudden-pressure relays at 9 receiving stations in one system also were triggered, dropping 418 megawatts of load ([1], pp. 18-21).

It appears that the triggering of sudden-pressure relays can be expected to cause temporary and possibly widespread power outages. Yet, whether or not such relays operated incorrectly in the San Fernando Valley earthquake, it appears that their triggering, apart from other factors such as damaged transformers, is only a temporary problem. According to Schiff and Yao, yard facilities usually are inspected for damage before reclosing the relays, so that delays from 1 to 107 minutes were required before all units were reclosed ([1], p. 20).

Transmission Facilites

Transmission towers and lines apparently have performed well in past earthquakes. Since towers are designed to resist heavy loads resulting from ice, wind, and broken wires, earthquake loads may not have much influence on their design. Towers, though, can be damaged by landslides, rolling boulders, or liquefaction of the supporting soil, any of which might be a secondary effect of an earthquake. Power lines also can swing so wildly when shaken that they slap against each other and burn down or trip the circuit ([3], p. 225). Broken or burned-out conductors occur much more frequently in the distribution system ([6], p. 178). Cables on pole lines can oscillate owing to pole movements and earthquake "pulse" motions, and so lead to damage of heavy splice cases and amplifier equipment on suspended cable spans ([7], p. 206).

According to Otto Steinhardt, underground transmission lines are only rarely subject to fault-related or ground-shaking damage, except where the line is buried in earth masses that fail or where manholes from the conduits in which the cables are laid are displaced. Where failure occurs, overhead lines can be rigged as a temporary bypass ([3], p. 225). J.W. Foss has stressed possible axial elongations of buried cable as a result of ground ruptures and shears caused by seismic compression waves along the cable length ([7], p. 205).

In the San Fernando Valley earthquake, the only extensive repairs to transmission towers and lines were for the Gould-Sylmar line in the Southern California Edison system ([4]). In several locations, water pipe breaks led to flooding of utility tunnels which, in turn, led to small cracks in the cable sheath and subsequent loss of underground high voltage transmission lines ([1], p. 36).

In the Kanto (Japan) earthquake, much damage occurred to wood pole transmission lines, mainly owing to fire. About 10 percent of the 2,400 transmission towers were damaged, with very few structural failures and with most failures due to landsliding. In the Kern County (California) earthquake, landslides or foundation failures damaged some towers. Also, some conductors slapped against each other and burned ([3]). In the Niigata (Japan) earthquake, buried lines were damaged as a result of breakage of their buried pipe conduits ([8], p. 518). In the distribution system, 26.6 percent of all affected lines were interrupted, with 46.7 percent interrupted in Niigata proper. Moreover, 12.1 percent of the electric poles were damaged ([8], p. 521).

After the San Fernando Valley earthquake, 30 wood poles, 2,500 circuit feet of 5 KV cable, 240 instances of 4.8 KV wires, 6,000 circuit feet of 34.5 KV cable, 6 manholes, and 200 feet of underground conduit needed replacement in the Los Angeles Department of Water and Power system. Nine poles were replaced. Conductors slapped, causing outages, chiefly in the San Fernando-Newhall area of the Southern California Edison system ([4]).

In summary, transmission towers, normally designed to resist high lateral forces, are damaged chiefly as a result of site-related factors, such as soil settlement, landslides, or liquefaction. Overhead transmission lines may be damaged when conductors slap, although infrequently. Buried lines can be damaged on occasion by shear forces, or as a result of flooding of utility tunnels. From data that exist, damage to poles and lines in the distribution system appears to be more likely than damage to towers and lines in the transmission system.

Substations

According to Keizaburo Kubo and Tseuneo Katayama, transmission substations have suffered the most important and expensive earthquake damage of all power system components ([6], p. 178).

Transmission substations generally deal with voltages of 115 KV and above. Roughly speaking, there are two sorts of such stations:

(1) Switching stations, which sectionalize the system owing to short-circuits or maintenance and construction.

(2) Primary substations (high-voltage, major, receiving, or bulk power substations), which step down voltage until the power finally reaches the distribution station.

Chief failure modes in substations are porcelain failures. Equipment that is not allowed to slip and slide, or that depends upon brittle porcelain devices for support has been especially subject to earthquake-induced damage. Porcelain is used in connection with columns serving as lightning arrestors, post insulators, disconnect-switch insulators, insulator strings, and platforms holding capacitors or circuit breakers ([1], pp. 30-35). According to one source, many earthquake disasters in the electric power industry have been caused by failure of porcelain insulators ([12]). In a report of the 1978 Miyagiken-Oki (Japan) earthquake, Tseuneo Katayama claims that most of the equipment damage at two key bulk substations resulted from porcelain failures (inadequate anchorage was a rare cause of damage) ([21], p. 606).

In the San Fernando Valley earthquake, as in other earthquakes, extensive damage occurred to transmission substations ([1], [3], [4], [5], [9], [10]). Some of the other types of damage to these substations are noted.

Air-blast circuit breakers (ABB's) protect transformers from power surges. Circuit breakers also are essential equipment at switching stations, where circuits are switched in and out of service. In the San Fernando Valley earthquake, damage to ABB's was extensive at two switching stations. At the Olive Switching Station, three ABB's were severely damaged. At the Sylmar Switching Station, all eleven 230-KV ABB's were totally destroyed. Large displacements of 2,200 lb. ABB interrupter heads led to considerable secondary damage. Displacements ruptured porcelain columns and caused pretensioned wood support rods to fail. Failing interrupter heads damaged ABB control cabinets and 26 adjacent disconnecting switches. At the Rinaldi station, two ABB's also were damaged, repaired, and damaged again by an aftershock. ABB's were also damaged at the Vincent 500/220 KV substation. One bus 500-KV PCB was out of service for forty days. Its failure caused a 22-minute separation of the Southern California Edison system from an intertie as five porcelain columns were broken or cracked.

Some records exist of circuit breaker damage in other earthquakes. In the 1923 Kanto (Japan) earthquake, circuit breakers were undamaged if they had flexible connections to the busses. In the 1960 Chile earthquake (Richter magnitude 8.5), circuit breakers were damaged in great numbers ([3]).

Lightning arrestors allow transient peaks of overvoltage to go into the ground and so protect the electric power system against voltage spikes. In the San Fernando Valley earthquake, several lightning arrestors were damaged, sometimes leading to secondary damage. At the Sylmar station, several lightning arrestors fell over and chipped transformer bushings. One 500-KV lightning arrestor was damaged at the Vincent 500/220 KV substation, and DC lightning arrestors were severely damaged at the Sylmar HVDC station. At the Saugus substation, one arrestor fell and caused secondary damage. Seven other lightning arrestors were damaged in other earthquakes. It is noteworthy that the Vincent substation appears to be in an Intensity VII region, and the Saugus substation in an Intensity VIII region.

Other porcelain failures occurred at the Sylmar HVDC station, where insulated support structures failed for all four DC filter capacitors, and for power correction capacitors. At the Saugus substation, a 220-kv post insulator fell and caused secondary damage. At the Vincent substation, two 500-kv. buss insulators and one disconnect switch insulator were damaged.

Hence, much damage in the San Fernando Valley earthquake occurred as a result of porcelain failures that led not only to direct damage to equipment vital to operations, such as circuit breakers, but also to secondary damage to such vital equipment as buss structures, disconnect switches, and possibly transformers.

Transformers, which serve to step down voltages at substations, have been damaged severely in past earthquakes, chiefly as a result of failures at mountings or anchorages.

In the San Fernando Valley earthquake, at the Olive station, seven single-phase transformers toppled from elevated track mountings. At the Sylmar station, 10 of 12 230-KV bus potential transformers suffered major damage, as seven broke from post-support pedestals and fell. Others suffered damage to oil seals, terminal taps, and base connections. At the Saugus substation, transformers shifted. Two other transformers moved at other substations. Within the distribution system, transformer damage was extensive. Sixty three distribution transformers were damaged in the Southern California Edison system, 285 overhead distribution transformers were damaged in the Los Angeles system, and some underground transformers were damaged by earthquake ground faulting.

In the 1933 Long Beach (California) earthquake, transformers shifted, bushings broke, and oil spilled from transformers and switches. In the 1952 Kern County (California) earthquake, transformers not strongly anchored rolled off their platforms. In the 1960 Chile earthquake, transformers were severely damaged. And, in the 1972 Managua earthquake, transformers were damaged.

Capacitors are used in transmission to control voltages. In the San Fernando Valley earthquake, at the Sylmar HVDC station, power factor correction capacitors (VAR banks) suffered failures owing to weld failures, bolt failures, and porcelain failures. Capacitor banks were also severely damaged in the 1960 Chile earthquake.

Extensive damage also has occurred at distribution substations owing to porcelain failures or to mounting or anchorage failures. In the San Fernando Valley earthquake, an additional five distribution substations were severely damaged, and another 24 were damaged. Trippings occurred at 82 of 134 distribution substations in the Los Angeles system.

COMPARATIVE COMPONENT VULNERABILITY

In order to keep power flowing, the following electric power system components are essential.

Generating stations
Transmission lines

Transformers
Circuit breakers
Switches
Buss structures

It appears that those components of transmisssion and distribution stations that have been heavily damaged in past earthquakes are also central to the flow of power.

As a partial explanation of electric power system equipment response, A.J. Schiff, et. al., divide equipment into two types.

(i) Rigid--with a fundamental natural frequency higher than a certain value (15 or 20 Hz).

(ii) Resonant--with one or more natural frequencies in the range of seismic excitations.

As a further complication, equipment may be on the ground or on rigid supports, or else it may be mounted on a resonant structure. Resonant structures require a dynamic analysis based upon the peak velocity experienced during their response ([14], p. 453; [1], p. 44).

According to Philip Barkan, much high voltage equipment is subject to very large resonance effects (up to 6 times), because inherent damping of many electrical structures tends to be very small (<1%). Pendulous equipment tends to experience large motions relative to the ground when subject to lateral earthquake forces ([10], pp, 3, 4). H.L. Holland has also warned that high voltage and extra high voltage equipment tends to be resonant, and specially refers to the vulnerability of high voltage air-blast breakers ([5], p. 4).

Hence, evidence indicates that power systems are vulnerable to extensive earthquake damage. Not only may generating facilities be damaged, and transformer sudden-pressure relays be triggered to cause temporary outages, but much of the equipment in both transmission and distribution substations is susceptible to severe damage, partly as a result of amplification of the ground motion.

In the next section, the applicability of such earthquake vulnerabilities will be discussed in conjunction with the expected seismicity in Utah as well as policies for designing Utah electric power systems.

SECTION 4

EARTHQUAKE RISKS TO UTAH ELECTRIC POWER SYSTEMS

In this section, general characteristics of Utah electric power systems are discussed along with the general seismicity in the State so that, on the basis of findings in Section 3, some preliminary results can be derived concerning possible future effects of earthquakes upon these systems.

UTAH'S SEISMIC ENVIRONMENT

Locations in Utah vary considerably in terms of expected seismicity. The seismic zonation map which appears in the most recent edition of the Uniform Building Code indicates, for instance, that a large portion of Utah lies in an area of high seismic activity, a zone 3 region, whereas other portions of Utah lie in zones of lesser activity (See Figure 1). More recent research has indicated that a slightly different group of macrozones is warranted, and that, in locations close to the Wasatch fault, even more seismic activity is expected in the future than has been recorded in the limited historical past. The new zones are outlined in Figure 2 and a technical discussion of their basis is found in Reference [27].

In Figure 2, the zone of highest expected seismicity is Zone U-4, followed by Zone U-3, Zone U-2, and then Zone U-1. A portion of eastern Utah lies in no macrozone owing to the negligible seismicity expected in such locations.

The most appropriate measurement of seismicity for a given site might seem to be the return interval for a given maximum expected acceleration value (g-value). However, not only is such a measurement difficult to develop from other data, but some evidence has been reported that peak g-values may not accurately indicate dynamic structural response. In this study, in place of g-values, we employ intensity values as an indicator of expected seismicity.

Intensity values, given in Roman numerals, are indicators of earthquake effects upon human works. At Intensity VI, some buildings have failed. As intensities increase, damage to various structures also increase. Intensity VIII corresponds roughly to 0.15 g acceleration, and 0.5 g may be exceeded at Intensity IX or X.[1]

In Zone U-1, the maximum expected earthquake, based upon the historical record, has a near-field value of Intensity VI ([14], p. 17). Such an earthquake could damage some equipment, but most power system structures, including equipment, should be undamaged. Hence, not much direct earthquake damage to electric power systems is expected in Zone U-1.

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[1] For a more complete account of the Modified Mercalli Intensity Scale, see Appendix A and also [25], pp. 202-205. For attempts to correlate intensity and maximum effective peak acceleration values, see [24].

So, the only seismic zones where much expected direct damage to electric power systems should occur are Zones U-2, U-3, and U-4.

In Zone U-4, the maximum expected earthquake, based upon geological evidence, has an epicentral value of Intensity X. Such an earthquake could causes considerable damage to electric power systems.

In Zone U-3, the maximum expected earthquake has a value of Intensity IX, based upon historical records. Here, again, such an earthquake could damage electric power system structures and equipment.

In Zone U-2, the historical record indicates the maximum epicentral value is Intensity VII ([14), p. 17). Such an earthquake could damage unanchored transformers and even some older, more vulnerable structures.

Another way to compare seismic zones is to examine recurrence intervals for expected earthquakes. However, estimated recurrence intervals for the different zones may be misleading unless one takes into account the diverse sizes of the zones. Zone U-1 is about 261,000 sq. km.; Zone U-4 is only about 14,000 sq. km.; Zone U-3 is about 29,200 sq. km.; and Zone U-2 is about 76,400 sq. km.

Table 1 indicates the expected recurrence intervals of earthquake epicentral intensities equalling or exceeding the given intensity somewhere within the zone. If one recognizes that recurrence intervals for given intensities being located in the zone are a result of either having epicentral intensities in the zone or attenuation from earthquakes lying outside the zone, then one can bear in mind that the recurrence intervals in Table 1 do not take into account attenuation from outside the zone.

Readers are cautioned to note that recurrence intervals given in Table 1 are merely estimates of average return periods for earthquakes of different strengths in the various seismic zones. The return periods should be considered more in terms of their relative values rather than as firm numbers owing to the uncertainty of the initial numbers used as input for the mathematical model. Although better input data for the model might result in changes in the numbers shown in the table, any such changes would not alter relationships of recurrence in the seismic zones nor for the various earthquake strengths. One other note of caution is made. Exponential factors in the mathematical model mean that tabulated data are not proportionally (linearly) related, so any changes that might be made later in input data would not result in proportional change in the tabulated data, though relative ordering of recurrence would not change.

The value of such information as is contained in Table 1 is that earthquake occurrences may be viewed in their totality. One often thinks of earthquake risk in terms of the strongest expected earthquake for an area; yet, as is shown in this and other technical reports, more frequent earthquakes of less than expected maximum strength also can damage facilities and cause loss. Thus, Table 1 allows one to examine the range of possible damage that earthquakes might cause to electric power systems.

Not all earthquake epicenters are expected to lie close to electric power system facilities or structures. But, Table 1 indicates that large earthquakes are expected which could damage vulnerable facilities.

Given the wide differences in area among the various zones, a more direct measure of the vulnerability of a given facility or piece of equipment comes from estimates of recurrence intervals for intensities equalled or exceeded at sites randomly chosen within a given zone. Table 2 summarizes such recurrence intervals for Utah's seismic zones.

Table 2 indicates clearly that sites in Zone U-4 are considerably more susceptible to levels of ground-shaking that cause earthquake damage. At the same time, structures and equipment that are designed to resist the effects of lower earthquake intensities are much less likely to suffer damage.

In summary, not only does Utah have considerable seismicity, but certain portions of the State have much more expected seismicity than others. When recent geological evidence is added to historical records, only California clearly has a higher expected seismicity among the contigious United States. The seismicity in Zone U-4 compares in seismicity to portions of Nevada and other high risk portions of the United States (Cf. [14], pp. 17, 18, plus adjustments in the methodology).

ELECTRIC POWER SERVICE IN UTAH

Utah electric utility companies are members of the Western Systems Coordinating Council (WSCC), which covers 14 western and far western states and which attempts to assure reliability of the interconnected bulk electric power system. Formed in 1967 as a result of the 1965 Northeast power failure, WSCC attempts to improve coordination among the member electric power systems, and so studies network performance to evaluate additions and make proposed changes ([1], p. 22; [15]).

Most cities in Utah are served by Utah Power and Light Company (UP&L). Other cities and areas are served by surpluses from the hydropower system run by the Water and Power Resources Service (the former Bureau of Reclamation). Still others are served by the Intermountain Power Consumer Association (ICPA) or by the California Pacific Utilities system. Logan, for instance, has its own small hydro-plant, which at peak produces 1.5 MW, or 16-18 percent of its needs, and purchases power primarily from the Water and Power Resources Service but also from the ICPA and from UP&L. ICPA has 28 members, including 26 municipalities. At least 18 municipalities purchase power from the Water and Power Resources Service. And, all but 18 or fewer main municipalities purchase some power from, or are served primarily by, UP&L ([1]).

The majority of large generating facilities in Utah lie outside the high risk seismic zones. A study of large hydro-plants, such as the U.S. Water and Power Resources Service Flaming Gorge Plant, lie outside the scope of this report, as does study of several smaller, perhaps somewhat vulnerable, hydro-plants owned and operated by UP&L or by separate municipalities and occasionally located in high risk seismic zones. As indicated in Section 3, smaller hydro-plants may be vulnerable to penstock rupture and subsequent flooding, as well as to direct structural failure. In the UP&L system, hydro-plants can generate 120 MW, or only about 3 percent of the power used. Many of these hydro-plants are apparently old.

The main units in the UP&L system are indicated in Figure 3. The major facilities, at Naughton (Wyoming), at Huntington, and at Castle Dale, as well as the facilities at Helper, are in a zone of low seismicity. According to Chad A. Peterson, Associate Engineer at UP&L, the Naughton facility consists of three units with maximum net 177 MW, 235 MW, and 350 MW capacities and which were constructed in 1963, 1968, and 1971, respectively. The Helper facility at Soldier Summit consists of two generating units with 70 MW and 106 MW maximum net capacities and which were constructed in 1954 and 1957, respectively. The Huntington Station facility in Huntington Canyon consists of two 460 MW maximum net capacities that were constructed in 1974 and 1977. The Castle Dale-Hunter Station near Fairview consists of 4 planned 400-MW units, one of which was constructed in 1978.

Two of the smaller main UP&L generating facilities are located in the Utah's seismic zone of highest risk. The Gadsby plant consists of three units that have 70, 80, and 106 MW capacities and that were built in about 1951, 1952, and 1955, respectively. The Hale Plant, east of Provo, built perhaps 50 years ago, has only 46 MW capacity.

Further information about the Gadsby Plant indicates that it was constructed by Bechtel Engineering Corporation in accordance with the seismic standards of its day, at which time Zone 2 (*Uniform Building Code*) requirements applied. Preliminary calculations suggest that Zone 2 requirements at that time are roughly equivalent to Zone 1 requirements today. The Gadsby Plant, though, did not suffer damage from the 1962 Magna earthquake (Richter Magnitude 5.2).[2]

All major UP&L generating facilities are coal-fired, although natural gas can be used at Gadsby. Hence, the problem of a fuel shortage, such as occurred as a result of the Anchorage earthquake, is improbable. So, without further detailed research, the major points of vulnerability within the generating system serving most of Utah appear to be the two smaller facilities in the highest risk seismic zone.

Figure 4 indicates that transmission lines owned by companies other than UP&L by and large lie outside Utah's highest risk seismic zone. Only short lines near Brigham City and near Springville lie in the zone of highest seismicity.

Figure 5 indicates that the transmission lines in the UP&L system, in contrast, are much more likely to be located in the highest risk seismic zones.

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[2] In a study of the general vicinity of the Gadsby Plant and done for a newer office tower, Dames & Moore, engineering geology consultants, concluded that the bedrock acceleration value with a 90-percent probability of not being exceeded in 50 years is 0.23 g. Moreover, the response spectra appropriate was for a deep alluvial soil sequence ([26], p. 21).

This is a direct result of the distribution of population in the State served by UP&L. Figures 6, 7, and 8 analyze the transmission lines by their kilovolt capacity.

EARTHQUAKE CONSIDERATIONS IN THE DESIGN OF ELECTRIC POWER STATIONS

Design criteria used by UP&L for electric power systems come from the National Electrical Safety Code ([17]). General ice and wind loading requirements are found in section 25 of the National Electric Safety Code. The porcelain used in transmission towers, as with post insulators, has not proved so far to be a known problem in past earthquakes.

According to Gayle Porter, engineer at UP&L, design for whipping and ice unloading makes transmission towers resistant to earthquakes. As suggested in Section 3, earthquake forces do not seem to present major problems for the transmission system, although problems of conductors slapping and other seismic damage may occur more frequently in the distribution system.

Siting of electric power facilities on land owned by the federal government involves the development of an Environmental Impact Statement, often with the Bureau of Land Management (BLM) serving as the lead agency. On State-owned lands, an environmental analysis report is developed in conjunction with such agencies as the Forest Service or BLM, which may serve as liaisons for the State, or with the State Division of Wildlife Resources or other agencies. No State siting requirement exists for transmission lines or structures, although the Utah Geological and Mineral Survey (UGMS) presently is authorized to aid with such siting investigations upon request.

Transmission lines do exist on occasion as buried conduits in cities. Generally, ouside cities, they are overhead.

Transmission lines in Utah sometimes must cross various faults, such as when the Wasatch fault is crossed by lines from Naughton to Ben Lomond or by lines from Wellington in Carbon County to Spanish Fork. However, as long as care is taken, no special geoseismic problems need apparently exist for overhead lines. Buried conduits that cross faults, though, may be subject to special risks resulting from ground ruptures or fault offsets.

Several smaller power plants and penstocks are found within the zones of deformation associated with faults, such as plants in the mouth of Little Cottonwood Canyon, Provo Canyon, Battle Creek, Box Elder Canyon, and Payson Canyon [18].

For larger generating units, such as those proposed for the Intermountain Power Project (IPP), the Governor's Energy Council reviews such projects and may require initial reviews of geoseismic hazards. Proposals for facilities on land owned by the federal government require Environmental Impact Statements. Those on State-owned lands, once again, only involve review by a State Environmental Committee if they are proposed by a State agency.

In general, no special siting problems for electric power generating facilities have been uncovered in this study, except for those connected with smaller plants. As regards problems in the generation system and system of transmission lines, then, the only known earthquake risk problems are those possible at the Gadsby and Hale plants.

As indicated in Section 3, transmission substations may be the most seismically vulnerable critical facilities in an electric power system. The Water and Power Resources Service apparently applies Uniform Building Code standards in the design of its facilities. Although it is not known if the Water and Power Resources Service has constructed many facilites within Utah's highest risk Seismic zone, it is implied in Section 3 that standards for substations may need to be higher than the 0.2 g horizontal loading factor suggested in the Uniform Building Code.

Logan City Power, as an example of one local power system, also appears to use Uniform Building Code standards for its facilities, which are in the highest risk seismic zone.

According to George Morris, engineer for the Provo City Power system, Rural Electrication Association (REA) guidelines are used in the design of that community's substations and other facilities. Such guidlelines may be exceeded where appropriate or also may be augmented by means of information from outside sources, such as engineers from other power systems.

Rural Electrification Association guidelines also are used by the Intermountain Consumers Power Association (ICPA) which on occasion can provide design criteria for facilities and lines to the point of consumption.

An examination of a 1978 edition of the REA guidelines for substations indicates that such guidelines are developed from pre-1970 Uniform Building Code standards ([22], pp. II-11, VII-9, VII-10). Hence, if in areas of high seismicity, such as Zone U-4, REA standards for substations are used, then such standards are too low, given findings from the San Fernando Valley earthquake.

According to Maurice Wixon, engineer at UP&L, design criteria for substations within the UP & L system were raised in late 1971 as a consequence of findings from the San Fernando Valley earthquake. As a result, most UP&L expansions and revisions of transmission substations have been designed in accordance with the 0.5 g lateral load requirements suggested by the San Fernando Valley earthquake findings.

Figure 9 indicates the location of transmission substations in the UP&L system in relation to Utah's seismic zones. Because the population within Utah is predominantly located in high seismic risk zones, substations also tend to be concentrated in high risk zones. Table 3 provides a list of UP&L transmission substations by location, seismic zone, and original construction date.

Since the original construction dates, alterations, and expansions have been made to most, if not all, of the substations, some of which affect the seismic performances of the substations. For instance, a 345-KV yard was added to the 90th South (Salt Lake County) substation in 1977, and a capacitor bank was added in 1976. For other instances, a transformer was revised at the

Pavant station in 1973, and a transformer was added to the McClelland station in 1975. Moreover, as Table 3 indicates, later developments generally have been in the direction of higher voltage, making them more critical facilities.

In view of the facts that unadjusted estimates of expected g-values are difficult to make and that more extensive knowledge of each substation would be required in order to determine design criteria implemented for main components, it is possible here only to state very general conclusions concerning the vulnerabilities of various substations.[3]

Two of four 345 KV substations of the UP&L system appear to be designed in accordance with higher standards suggested by San Fernando Valley earthquake studies. However, porcelain failure and possible adverse resonance effects could still occur at such substations. Insofar as lower voltage areas at the same substations may have been designed in accordance with lower standards, failure is more likely at lower voltages.

Many of the lower voltage substations originally were designed with lower standards for lateral load resistance. As a result, those designed before 1971 and in the State's worst seismic zone may be regarded as being vulnerable possibly at Intensity VII, or perhaps above. As Table 2 indicates, the return interval of such an earthquake is about 180 years for a site randomly chosen in Zone U-4.

Inasmuch as two switching stations were almost completely damaged in the San Fernando Valley earthquake, the most vulnerable substation of all in the UP&L system may be the Hale substation. Since it is reported that high voltage equipment is more vulnerable to potential resonance effects, the oldest very high voltage substation, at Camp Williams, also may be regarded as a critical facility, perhaps somewhat vulnerable to earth-shaking. Since, in contrast, smaller voltage substations generally are developed in accordance with older, lower seismic design standards, vulnerability in terms of design criteria increases as one moves closer to the distribution system.

ANALYSIS TO ASSESS SYSTEM RESPONSE

For reasons already mentioned, it is difficult to estimate very precisely the point at which direct failure of a substation is likely. However, preliminary estimates can be made if one takes Intensity VIII to be the threshold for damage to pre-1971 substations.

Figure 10 indicates the location of major substations in the Salt Lake County area. An earthquake having an epicentral Intensity of VIII or above is expected to affect the designated area approximately every 160 years. If the epicentral region is modelled as 3.2 miles in radius, then even the smallest

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[3] In a study of suggested relationships between peak ground acceleration and Modified Mercalli Intensity, M.D. Trifunac and A.G. Brady find that past estimates for Intensity VIII have ranged from 0.10 g to 0.35 g. The two authors estimate Intensity VIII to have 0.26 g horizonal acceleration ([24], p. 143).

such earthquake could damage 2 or even 3 substations. The largest earthquake, expected every 2,500 years or less, could damage all but perhaps one or two of the substations. Hence, where substations are heavily concentrated, as they are in Salt Lake City, Ogden, and Provo, the chances of simultaneous failure of serveral essential substation components exist, especially for older substations or for older portions of substations.

The only known previous attempt at such system analysis comes from the USGS report, A Study of Earthquake Losses in the Salt Lake City, Utah Area [19]. The study included field inspections of two large terminal substations, one intermediate distribution substation, and two small distribution substations, and implied that there are numerous points of vulnerability within such substations ([19], pp. 286, 287). The study thus concluded that numerous substations would be rendered non-functional in the event of a 7.5 Richter magnitude earthquake, and that 2,690 distribution transformers would be damaged ([19], pp. 288-294).

Such an evaluation as described above indicates numerous points of vulnerability within the electric power system serving major portions of Utah and provides a model for estimating what may occur in an earthquake expected every 2,000-3,000 years. Earthquakes of less magnitude, expected more frequently, also can be modelled in order to estimate damage likely to occur over shorter periods of time.

The need for a systematic analysis is a result primarily of the complicated way in which electric power failure at one point can be transmitted hundreds of miles to cause problems at another point. Systematic effects occur within the distribution system as well as within the transmission system, but it is here presupposed that the major problems in the distribution system described above pertain to damaged lines or facilities that can be repaired more readily than can components in the transmission system.

The systematic character of electric power failure is indicated by various reports of past outages. On July 4, 1976, about one million people in Utah were affected by a power outage that began at 5:50 p.m. and lasted two hours for the majority of customers and until midnight for some. The widespread outage was the result of a malfunctioning relay that tripped two 230 KV lines that were carrying 675 MW to the Ben Lomond substation. The control circuitry for protective relaying at the Naughton switchyard had failed ([20]).

Some of the variables concerning system performance further indicate the need for a systems analysis. Peak load hours are generally 6 p.m. and 10 a.m. Peak load months are generally December and July. The spinning reserve, that is, the reserve immediately available, is close to zero during these times, although estimates of the overall reserve, including off-line reserve, reach 20 percent. UP&L, according to Chin Mo Lee, economist at UP&L, is a net importer of power. In the event of a loss of load, demand might need to be cutback. First, the intertie system would be employed to receive power from other electric power systems outside Utah. If such exchanges were to prove inadequate or impossible, interruptible customers (large customers having cheaper rates) would be cut back. If problems still resulted, voltage reductions could be made, and, at last resort, public appeals for cutbacks would be possible.

According to Bob Dintelman of the Western Systems Coordinating Council, an examination of possible earthquake damage and its systematic effects would have two problems of analysis. First, there are limits on the state-of-the-art in regard to estimating how loads would perform as voltages dip. Second, apart from past earthquakes, there are no control situations to test the results of any findings.

According to James S. Hooper, manager of power operation at UP&L, extensive first contingency and even second contingency operation plans exist for events such as conductor breakage, tower failure, insulator failure, or failure on the terminus as a result of malfunction from a variety of causes including moisture, shock, design, and electromagnetic fields.

In developing a model systems analysis, it is necessary to remember that a moderate earthquake (say, of Richter magnitude 6.0 or above) is likely to cause a temporary outage due to the rapid action of sudden-pressure relays or for a variety of other reasons. In the El Centro (California) earthquake (6.4 Richter magnitude) of October, 1979, for instance, minor outages resulted from slapping wires, pole-top transformer fires, damaged circuit breakers, and damaged lightning arrestors in spite of the fact that the earthquake epicenter was located about 6 miles outside the city ([23]).

A major goal of a systems analysis, then, is to determine not whether outages will occur but whether or not power can be supplied, by one means or another, at some time after a temporary outage has occurred.

In cooperation with this study, James D. Tucker, Supervisor of Transmission Planning, UP&L, consented to perform a systems analysis based upon postulated damage to two proximate (about 9 miles apart) bulk substations, the 90th South substation and the Camp Williams substation. Mr. Tucker's statement of results is to be found in Appendix B.

Before a review of the detailed findings of this study is made, several general conclusions may be stated. Among the components of the UP&L system that are vulnerable to earthquake damage, the Camp Williams substation appears to be the most important major system component at present, with the Ben Lomond substation, the Terminal substation, and the Gadsby Plant also having some degree of importance, although slightly less than that of the Camp Williams substation. Hence, an analysis of the overall response of the UP&L system to extensive damage is a good indicator of the potential of the system to respond to severe earthquakes. As the UP&L system evolves, and as consumer demands change, individual components or particular elements can take on increasing or decreasing degrees of importance. For instance, if further generating capacity were to be added at Naughton, and if higher voltage lines were to be deployed between Naughton and the Ben Lomond substation, then the importance of the Ben Lomond facility would presumably increase in terms of systems response to earthquakes. The importance of the Ben Lomond facility already is indicated by its role in the outage of July 4, 1976. Nonetheless, an updated analysis would be needed in order to determine the current importance of the Ben Lomond facility or any other facility in terms of the functioning of the entire system.

A SELECTED ANALYSIS OF THE UP&L SYSTEM IN SALT LAKE VALLEY

The fact that the UP&L system can respond as well as Mr. Tucker's analysis indicates (see Appendix B), given extensive postulated damage to the Camp Williams substation, appears to suggest that loss of power owing to earthquakes is not likely to become a long-term problem in the UP&L system. Of course, if one were to postulate the maximum credible earthquake in the Salt Lake Valley, with a very low probability of occurrence, the UP&L system could be severely disrupted, with possible damage both to almost all bulk substations and also to the Gadsby Plant. Although preparations should be made for maximum credible earthquakes, it is here presumed that costs would be prohibitive to design for an earthquake with such a low probability of occurrence and that such money could be spent more beneficially in providing for system redundancy and in other measures that also bear upon life-safety hazards. How present system redundancy bears indirectly upon long-term power recovery is ilustrated in the more detailed following analysis of Mr. Tucker's study in which an earthquake of Intensity IX is assumed to occur in a location that impacts both the Camp Williams substation and the 90th South substation.

Figure 11 provides a diagram of the postulated earthquake. Of course, a larger earthquake could occur that damgages more substations, but probabilities of occurrence decrease as one presumes that more of the Salt Lake Valley is affected at very high intensities. In addition, it is also presupposed that an outage would occur for some indefinite period of time. The issue addressed was not the likelihood of an outage. Rather, the issue was whether power could be restored to all or most of the system within two to four hours after the main shock.

Other assumptions limit the study results. It is assumed that both the Naughton plant and the Gadsby plant can be brought up to full generating capacity, e.g., that none of the units at the two plants have been shut down for maintenance work. It is also assumed that within the two to four-hour time period, dispatchers can optimize the line capacity from the northern and eastern lines into the Ben Lomond facility. Furthermore, import capacity from other systems into the Ben Lomond facility also is presupposed. Hence, if units at either the Naughton or Gadsby plants had previously suffered a forced outage, if dispatchers cannot optimize relevant line capacities, or if import capacity from other systems is either unavailable or less than supposed, further non-interruptible or firm load would need to be shed than is stated in the results of the study done by UP&L (Appendix B).

Figure 12 provides a diagram of relevant portions of the UP&L system so that the importance of various components may be better understood. Extensive damage to the Camp Williams facility means that roughly 1,200 MW of generating capacity cannot proceed northward, given that the Emery County units can produce 1,600 MW for the system and that about 400 MW are demanded south of Camp Williams. Loss of the 90th South facility means that something less than 150 MW cannot be moved northward (study results suggest that the figure is about 100 MW).

In the study, it is assumed that peak non-interruptible load in Salt Lake Valley is about 926 MW. In the event of an earthquake, if power users were to limit their consumption, the need to shed load would be reduced if not eliminated.

However, as the population changes, the peak load may well increase, thus altering another central factor in the study findings.

According to the study findings, if both the 90th South and Camp Williams stations are completely disabled, 86 percent of the Salt Lake Valley peak load could be restored within two to four hours. To restore all but 14 percent of such peak load, it would be necessary to shed load in the southern portion of the Salt Lake Valley. If demand were reduced, a higher percent of demand could be supplied.

If one of the transformers is functional at the 90th South facility, then another 50 MW, or 6 percent of the firm peak load in Salt Lake Valley, could be restored within two to four hours. Again, load would be shed in the southern portion of Salt Lake Valley in order to optimize the distribution of available load.

As study findings indicate, the load shed in the transmission system would probably not be able to be delivered in the southern portion of the valley anyway, given presumed damage to the distribution system and also priorities placed upon restoring the transmission system.

Study findings thus suggest that system redundancy is great enough so that the UP&L system can be restored almost completely within two to four hours after an earthquake that disables perhaps the most important substation. Speculative findings, based upon the diagram in Figure 12, indicate similar restorative capabilities if eathquakes are postulated to disable other major components in zones of high seismicity.

For instance, if an earthquake were to disable the Gadsby Plant and the Terminal substation, but if the Camp Williams facility were fully functional, 1,200 MW would be available for the Salt Lake Valley, with its peak demand of 926 MW. So, if voltages could be maintained, more than enough power would be available.

For another instance, if the Ben Lomond substation were disabled, load might need to be shed near Ogden primarily because of its distance from generating facilities to the south (although total generating capacity may well exceed the peak demand).

Larger but less probable earthquakes could cause greater system damage. The Gadsby Plant and the Terminal substations are about 22 or 23 miles from the Camp Williams substation, and, as Figure 10 indicates, an earthquake large enough to damage major facilities in the northern portion of the Salt Lake County and also Camp Williams might also be presumed to damage several other bulk substations, such as the 30th South facility. It is here noted that such an earthquake could occur and preparations should be made for such a possibility. However, the probability of such an earthquake is low (although subject to various estimates dependent upon existing geophysical information), both because the more recently installed higher-KV portions of the Terminal substation are designed in accordance with higher seismic load factors and because the facilities are at some distance apart.

In summary, the UP&L system appears to be able to respond well to those earthquakes more likely to occur in Utah, although system damage will be great if a maximum credible earthquake does occur. Systems of other distributers of electric power in Utah, however, may be more vulnerable to substation and hence system failure if, indeed, preliminary information is correct about the lateral load factors used in substation design.

SECTION 5

RECOMMENDATIONS FOR EARTHQUAKE RISK REDUCTION TO ELECTRIC POWER SYSTEMS

The following recommendations result from a study of the expected impact of earthquakes upon electric power systems and facilities in Utah. The study, titled "Seismic Risk Assessment Of Electric Power Systems In Utah," provides information upon the extent and nature of earthquake hazards to electric power systems in general and to electric power systems in Utah's seismic environment in particular. Both existing and possible new systems are covered in the study. The recommendations that follow are based upon the findings of this study.

Electric power is one of a small group of areawide utility systems whose importance to the functions of any community is truly recognized only when power supply is disrupted for some reason. Public reliance upon electric power is so widespread and so pervasive that its importance and its extensive use are realized primarily when blackouts occur, when traffic control semaphores fail to work, when air conditioning and heating systems will not operate, when refrigerators cannot be used, when elevators will not work, and when businesses must close down because personnel cannot work, etc. Public dependency upon electric power cannot be overestimated, and the public therefore has an overriding interest in the continuing availability of that energy even though that public may not be directly involved in the business of generating, distributing and operating the electric power systems. This overriding public interest has been long recognized, as is manifested by the presence of public service commissions or equivalent governmental agencies created to represent that public interest. Although it appears to be the case that regulatory agencies in the past have focused their attention mostly upon another element of public interest, i.e., upon rate structures, it can be argued that there is an equal public interest in safeguarding utility systems to insure their continuing serviceability.

The following recommendations regarding earthquake safety of electric power systems, then, are designed to balance the special interests of the public in these facilities with the interests of the industries who own and operate the systems and whose own resources are at risk in such investments.

The recommendations which follow are intended to deal with identified problems that earthquakes pose for electric power systems in two ways. The first problem is the past absence of public participation in policies establishing performance standards of electric power systems, including safeguards from earthquake hazards. The second problem addressed in the recommendations is of a technical nature concerning particular vulnerabilities of electric power systems and the means to mitigate those vulnerabilities.

1. It is recommended that the Utah Public Service Commission, through existing statutory authority, assert its role in

matters pertaining to the construction of safe, reliable utilities systems, including representing the public interest in policies relating to these matters.

Standards of construction for electric power systems in Utah historically have been established by the separate owners of the systems. Although the principal supplier of electric energy in the State in recent years (Utah Power and Light Company) has followed practices that consider earthquake safety of the systems, it is observed that other smaller systems operators follow different earthquake safety standards, some of which are lower than ought to be the case. There is no systematic procedure or policy within the State for public participation in deciding an appropriate level of safety from earthquakes for the systems or which provide a means for identifying the vulnerabilities caused by possible underdesign.

The Public Service Commission has been singled out as the most appropriate agency to meet this suggested overview responsibility for several reasons. First, the Public Service Commission presently is the only agency of the State having any general regulatory authority over most, if not all, electic power system operators. Second, present statutory authority of the Public Service Commission appears to allow for oversight of electric utilities that goes beyond the traditional role of rate evaluations and approvals, though this extended authority apparently has been exercised very little. Third, the Public Service Commission employs engineers knowledgeable about electric power systems in general, so the additional responsibilities concerning earthquake safety considerations would appear to be a logical extension of current capabilities of the agency.

2. It is recommended that there be established in the State minimum standards for the design and construction of electric power systems pertaining to earthquake forces and effects, and that such recommendations be based upon the effects of ground acceleration time histories rather than upon general seismic zones contained in the Uniform Building Code.

Study findings indicate that there are at least two, and possibly more, different standards for earthquake-resistant design for electric power systems in use in the State even though the earthquake environments in which the electric systems are located are virtually the same. It also is observed that earthquake-resistant design for electric power systems commonly is based upon ground accelerations derived from seismic zone information contained in the *Uniform*

Building Code. It must be borne in mind, however, that the ground accelerations derivable from the Uniform Building Code were developed to fit the dynamic response characteristics of buildings, and that the corresponding real ground accelerations have been modified (downward) to accommodate variations in building response as the ground motion occurs. In fact, the ground accelerations in Utah's most severe seismic regions are estimated to have maximum values in the range of 0.4 to 0.5 g, whereas similar data derived from the Uniform Building Code would suggest that 0.2 g acceleration is an adequate design-basis force. While such design values may hold for buildings, there is no data that supports the use of building seismic response information in the design of components and structures for electric power systems, and there is good evidence which suggests that the dynamic response is different for the two types of facilities. This information suggests that seismic factors from the Uniform Building Code are not always transferable to other types of structures besides buildings and that the seismic standards for electric power systems should be developed uniquely to fit those systems. Although the data base is far from complete, there is ample information available today to allow the development of or the adoption of appropriate earthquake standards for electric power systems.

3. It is recommended that earthquake safety standards be developed and adopted for the design of electric substations, and that these regulations apply to the installation of all new substations constructed in the State in the future and to major modifications or expansions of existing substations.

   There is ample evidence from failures of electric power systems in past earthquakes to allow one to conclude that electric substations are one of the most, if not the most, seismically vulnerable elements of an electric transmission and distribution system. Components that are especially vulnerable, such as ceramic insulators, have been identified in numerous studies with enough frequency to suggest that improvements in design standards should be made.

4. It is recommended that an information and educational program be commenced by the State to broaden general awareness of electric systems owners and operators regarding earthquake hazards, and that available guidelines for improved earthquake-resistant practices in the design and construction of electric power systems be distributed.

   Useful guidelines for improved earthquake-resistant design practices in electric power systems have been developed as a result of severe damage and losses to electric power systems in relatively recent earthquakes. Although the major power supplier in the State of Utah has kept abreast of such recent developments, it must be recognized that there are other smaller electric power suppliers in the State that are less familiar or are not at all familiar with these guidelines. Increased attention should be given to improving the knowledge and awareness of all electric power owners and operators in the State regarding appropriate earthquake-resistant design of systems.

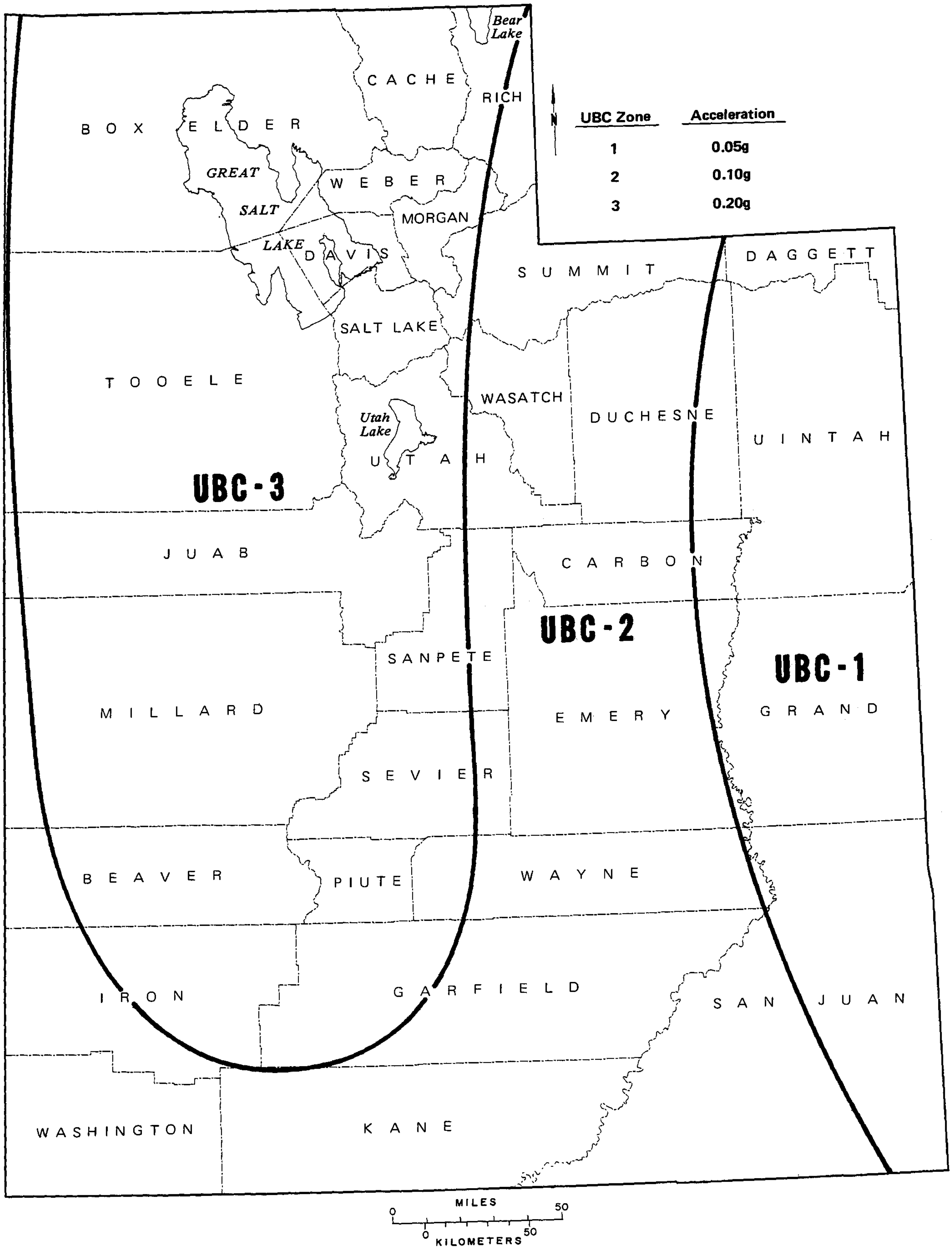

Figure 1

SEISMIC ZONES—1976 UNIFORM BUILDING CODE
STATE OF UTAH

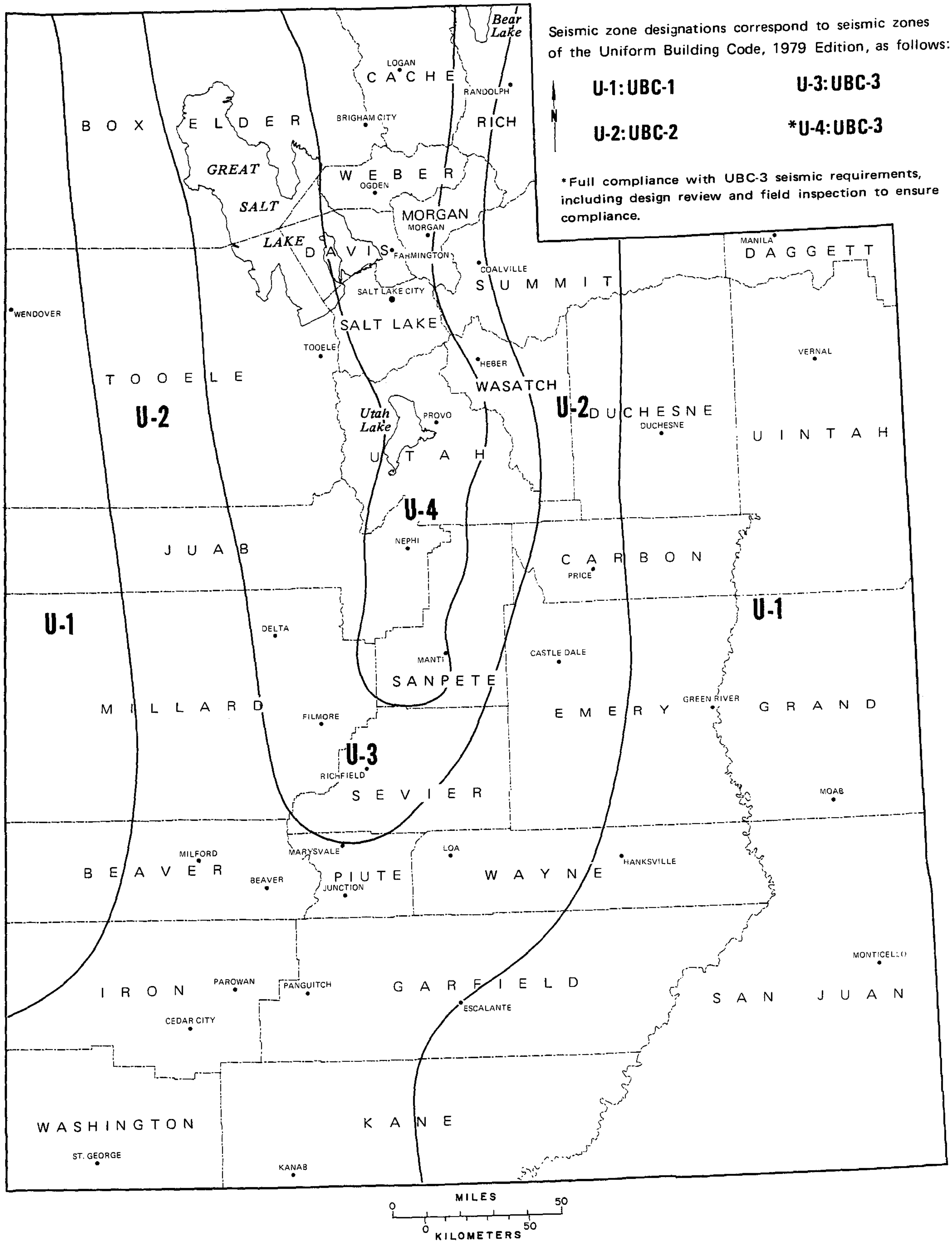

Figure 2

SEISMIC ZONES

January 1980

(Recommended by the Utah Seismic Safety Advisory Council)

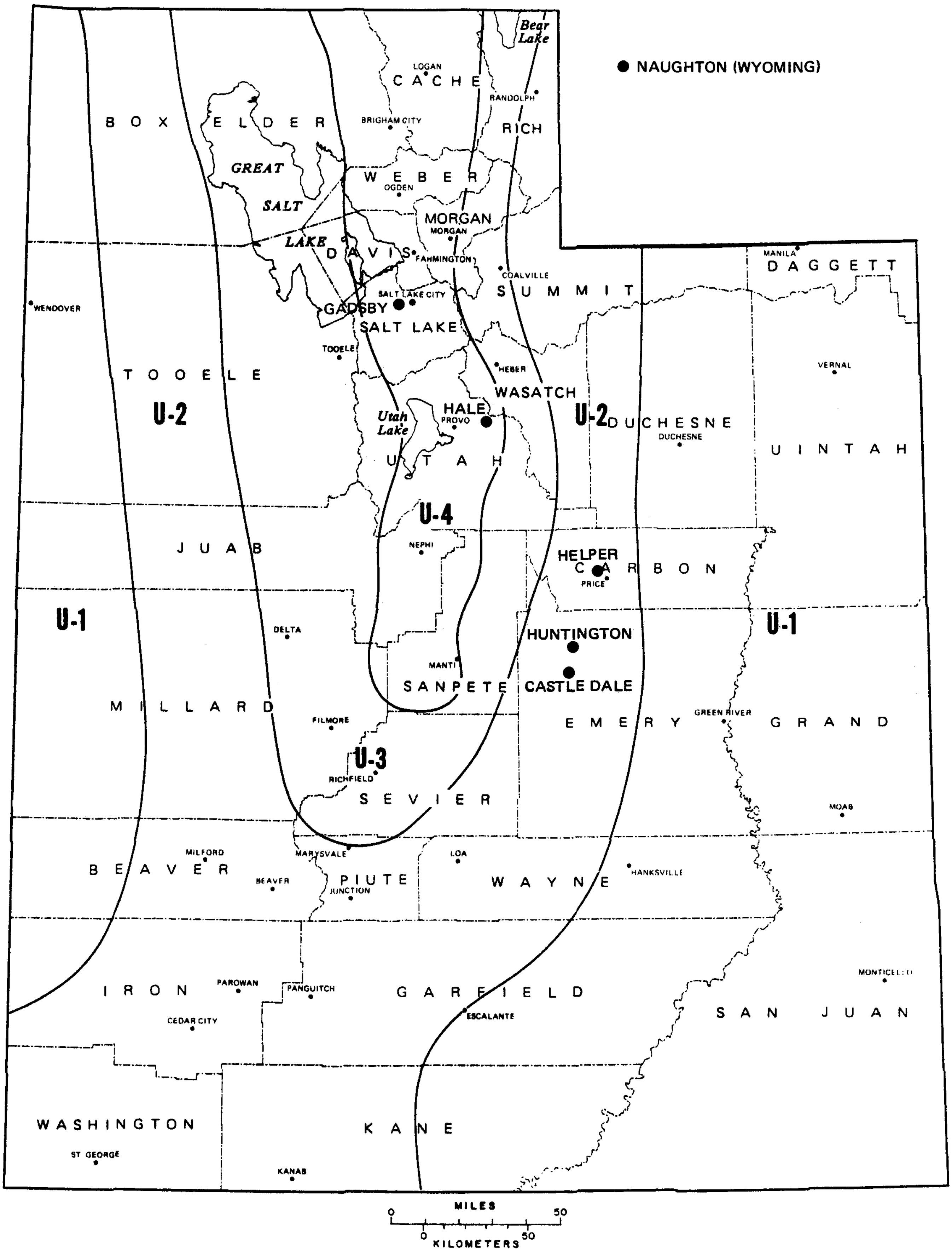

Figure 3

LOCATION OF MAJOR GENERATING FACILITIES OF THE UTAH POWER & LIGHT COMPANY SYSTEM IN RELATION TO SEISMIC ZONES

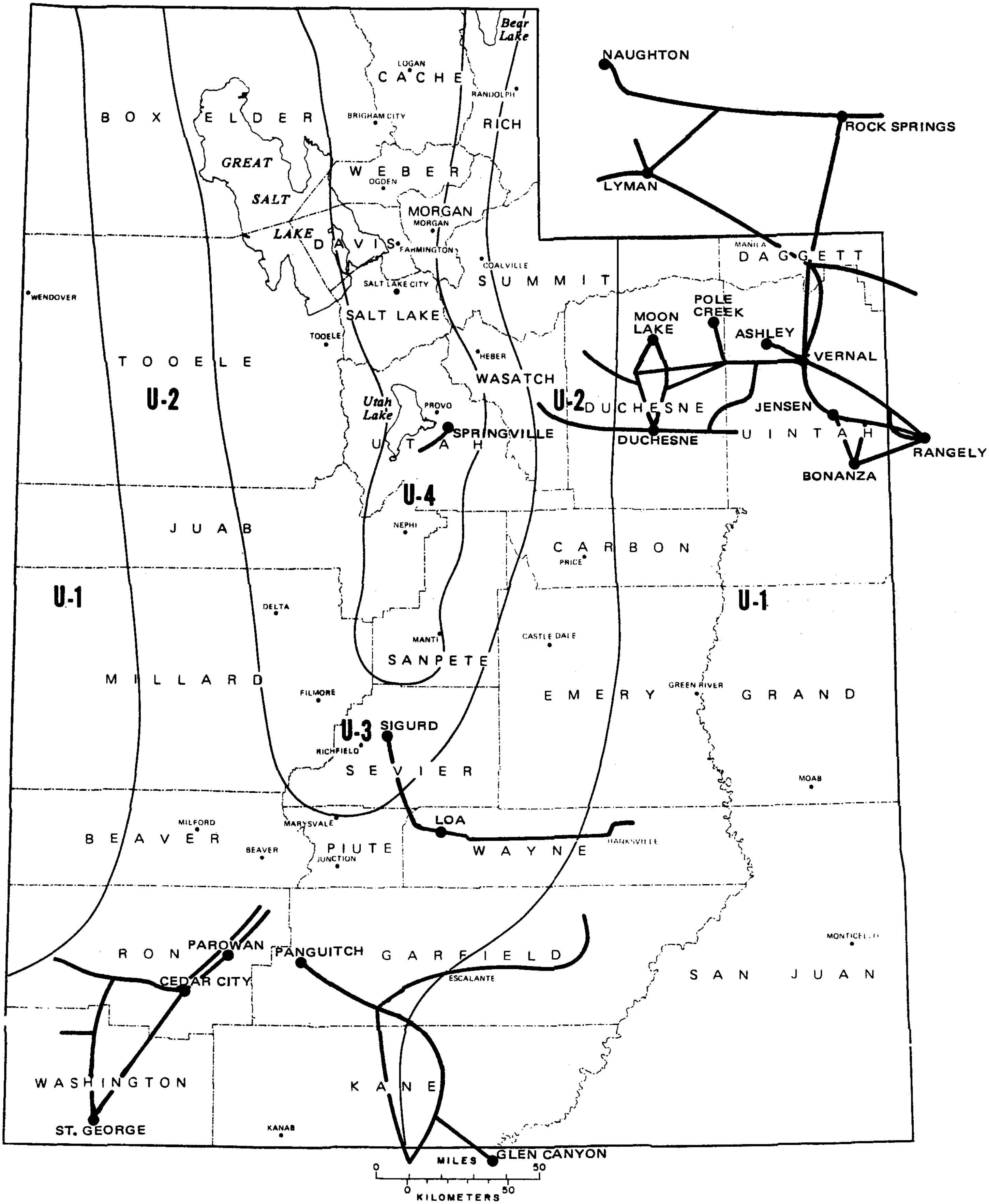

Figure 4

OUTLINE OF TRANSMISSION LINES NOT OWNED BY UTAH POWER & LIGHT COMPANY AND IN RELATION TO SEISMIC ZONES

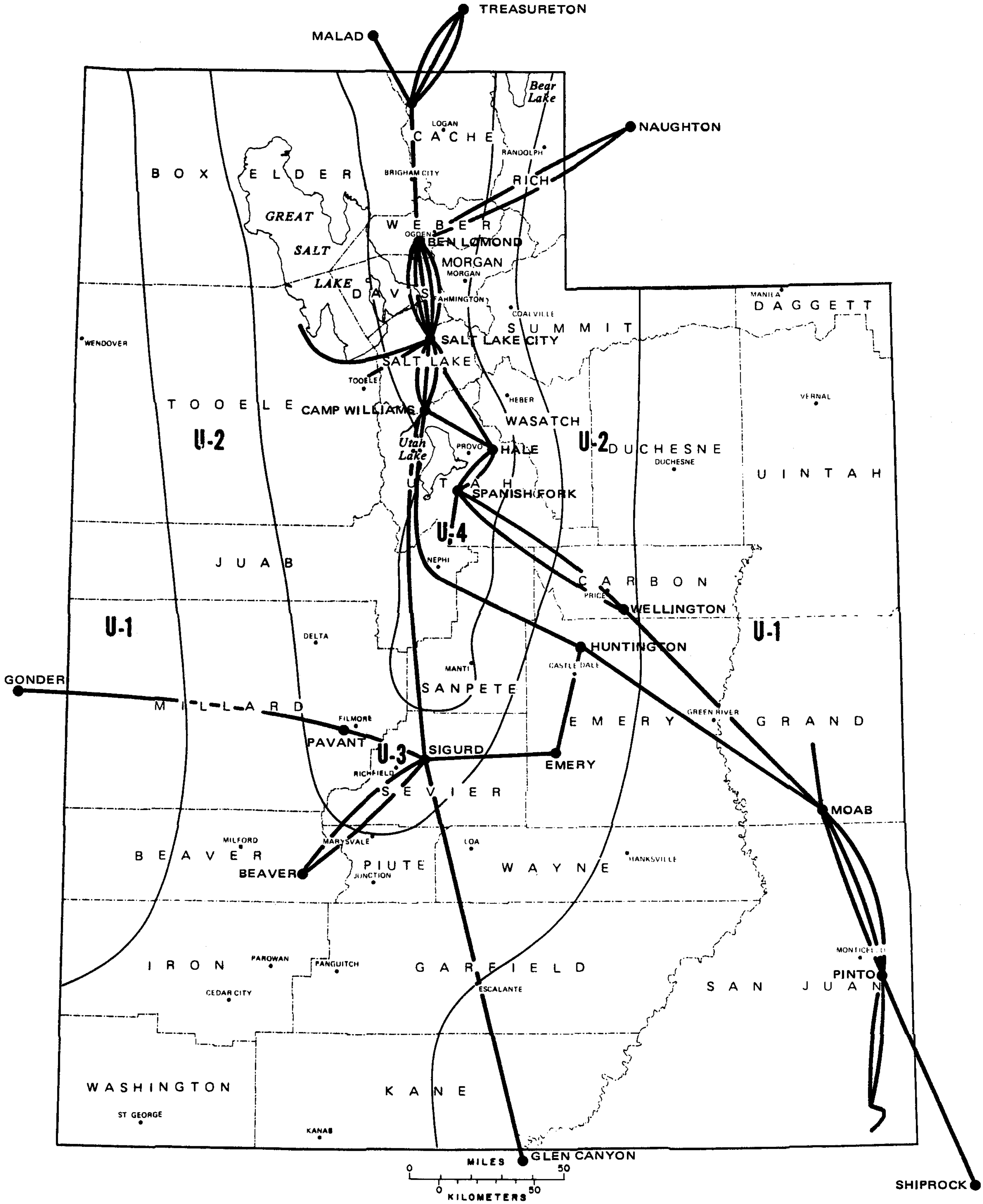

Figure 5

OUTLINE OF TRANSMISSION LINES IN THE UTAH POWER & LIGHT COMPANY SYSTEM

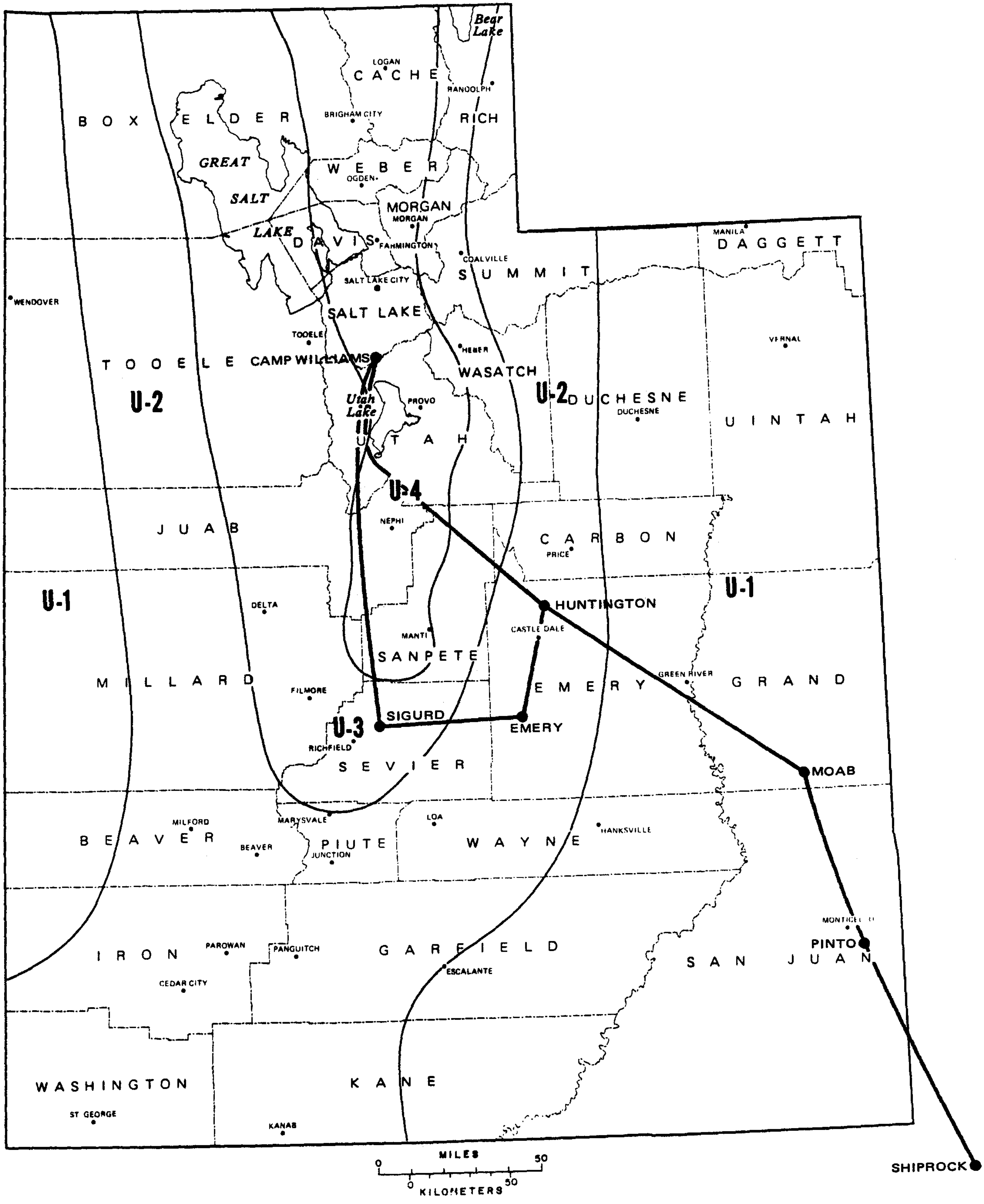

Figure 6

345-KV TRANSMISSION LINES
UTAH POWER & LIGHT COMPANY

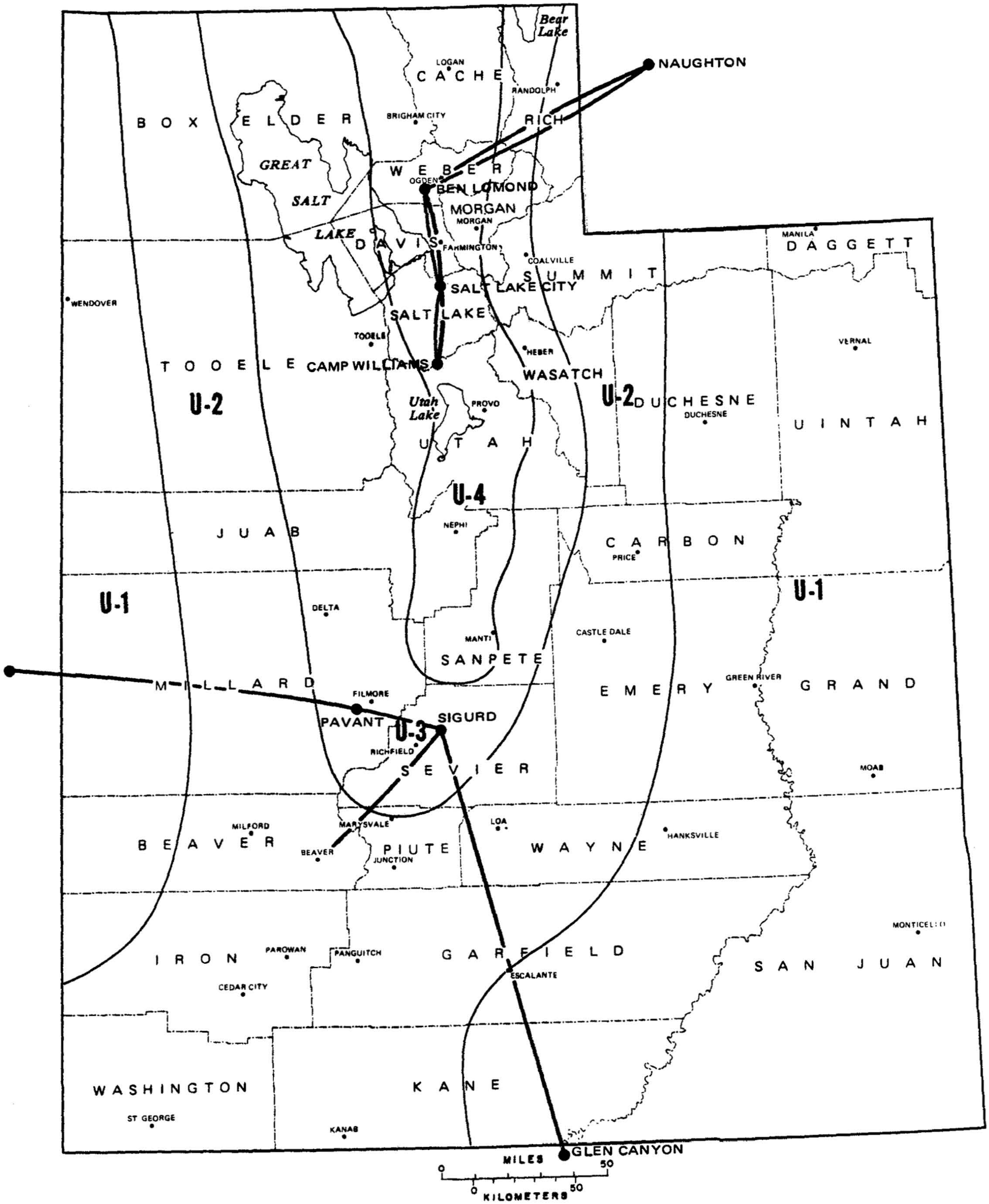

Figure 7

230-KV AND 161-KV TRANSMISSION LINES
UTAH POWER & LIGHT COMPANY

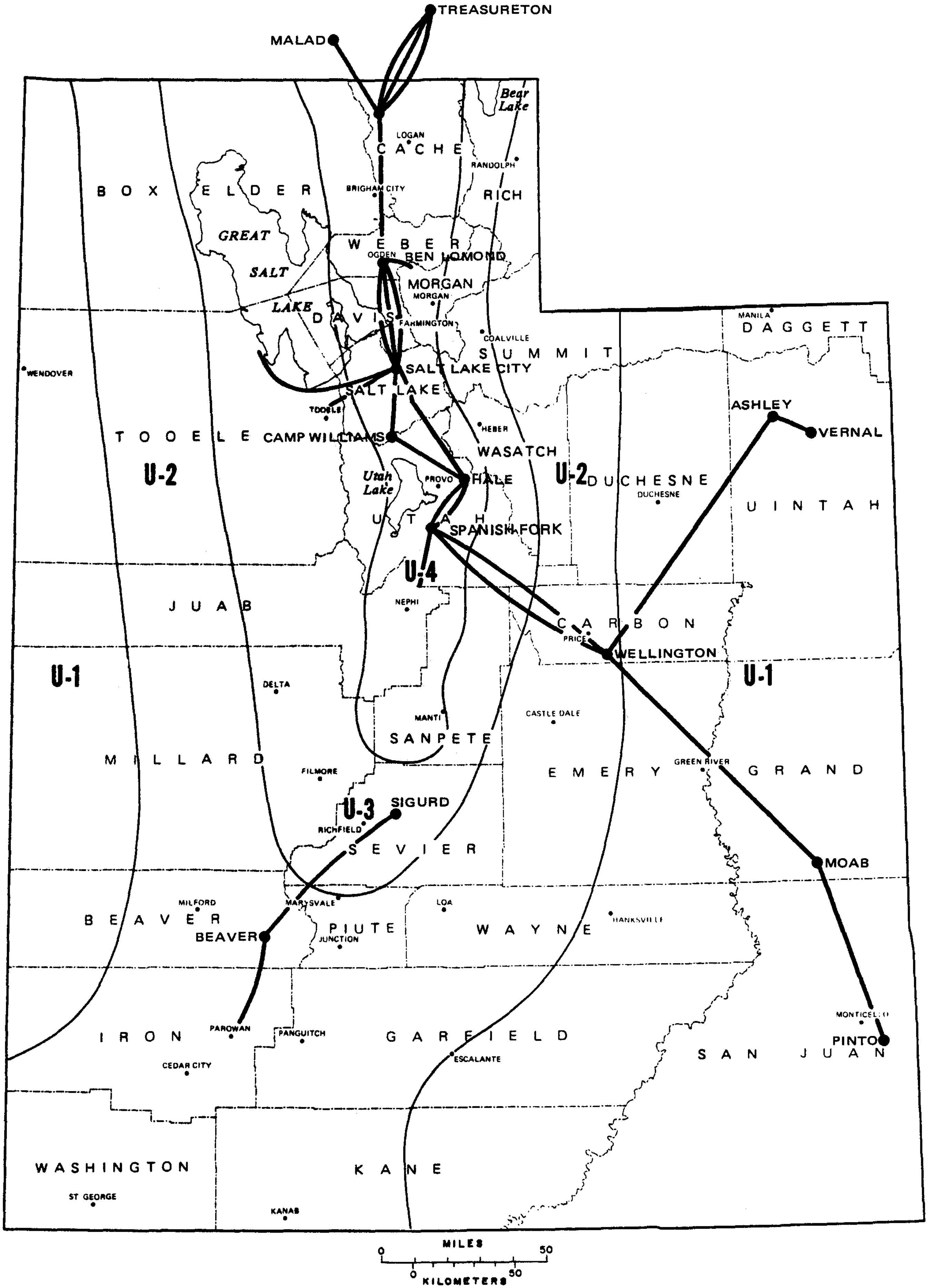

Figure 8

138-KV TRANSMISSION LINES
UTAH POWER & LIGHT COMPANY

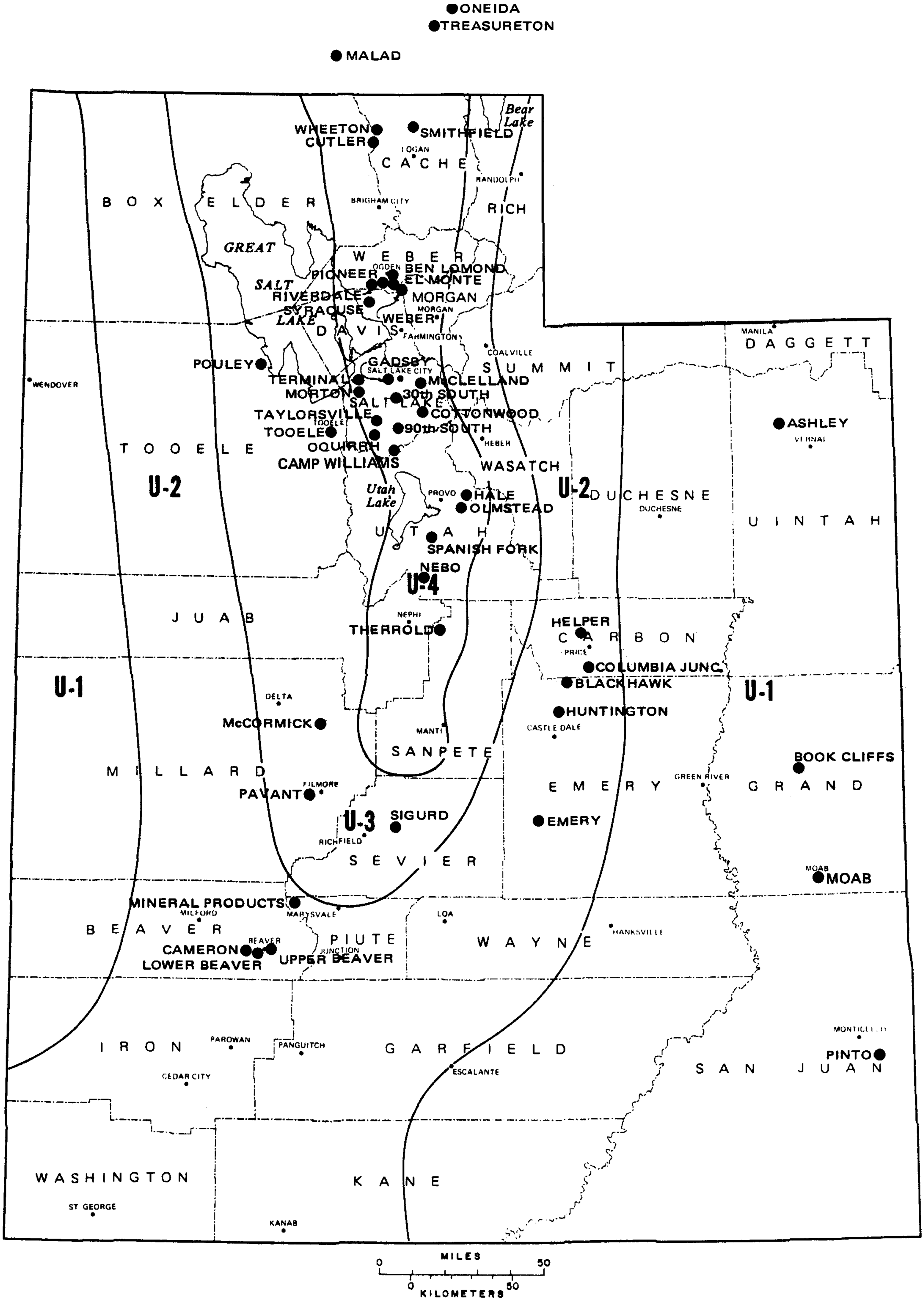

Figure 9

LOCATION OF TRANSMISSION SUBSTATIONS IN THE UTAH POWER & LIGHT COMPANY SYSTEM IN RELATION TO SEISMIC ZONES

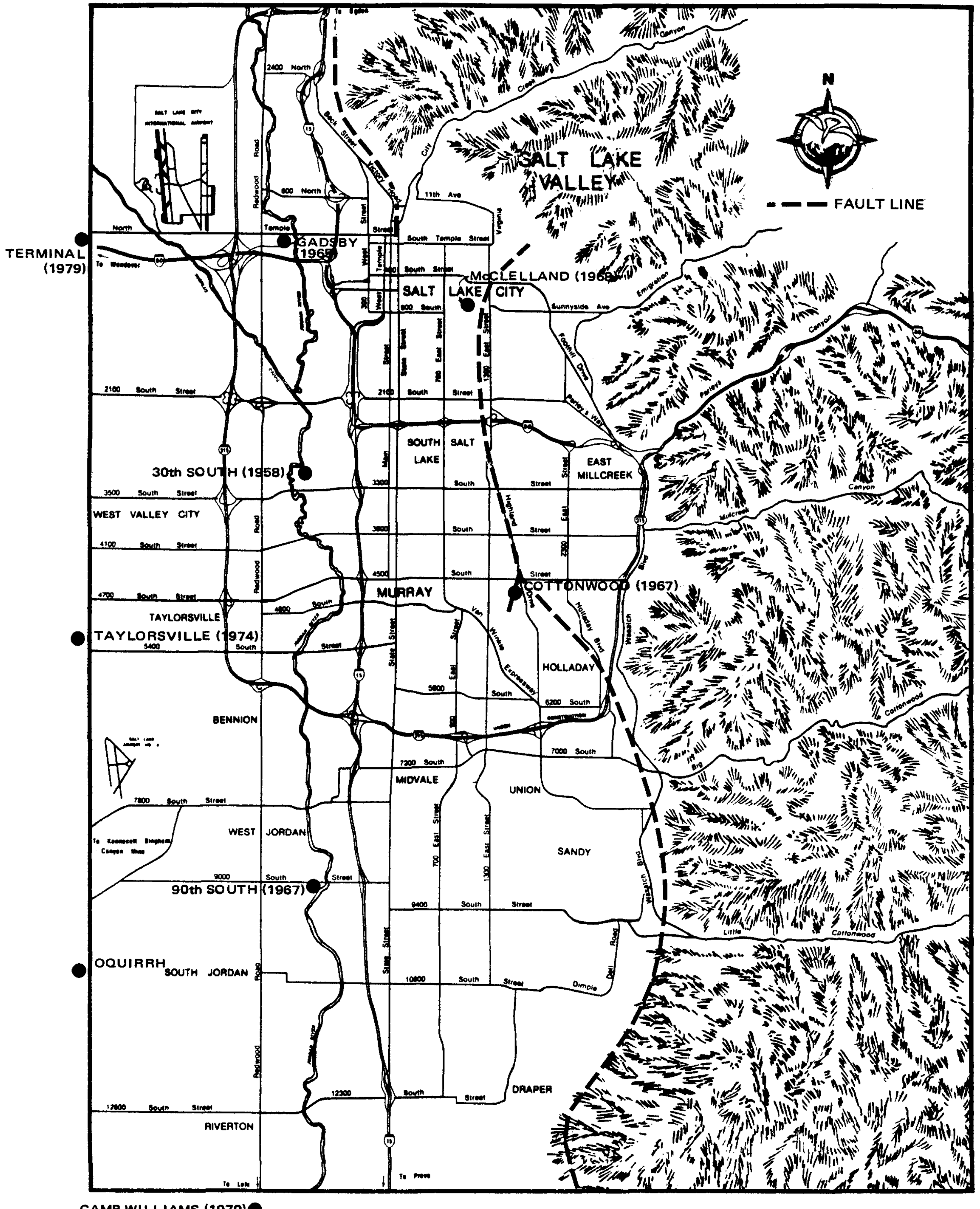

Figure 10

LOCATION OF SUBSTATIONS IN THE SALT LAKE COUNTY AREA
UTAH POWER & LIGHT COMPANY

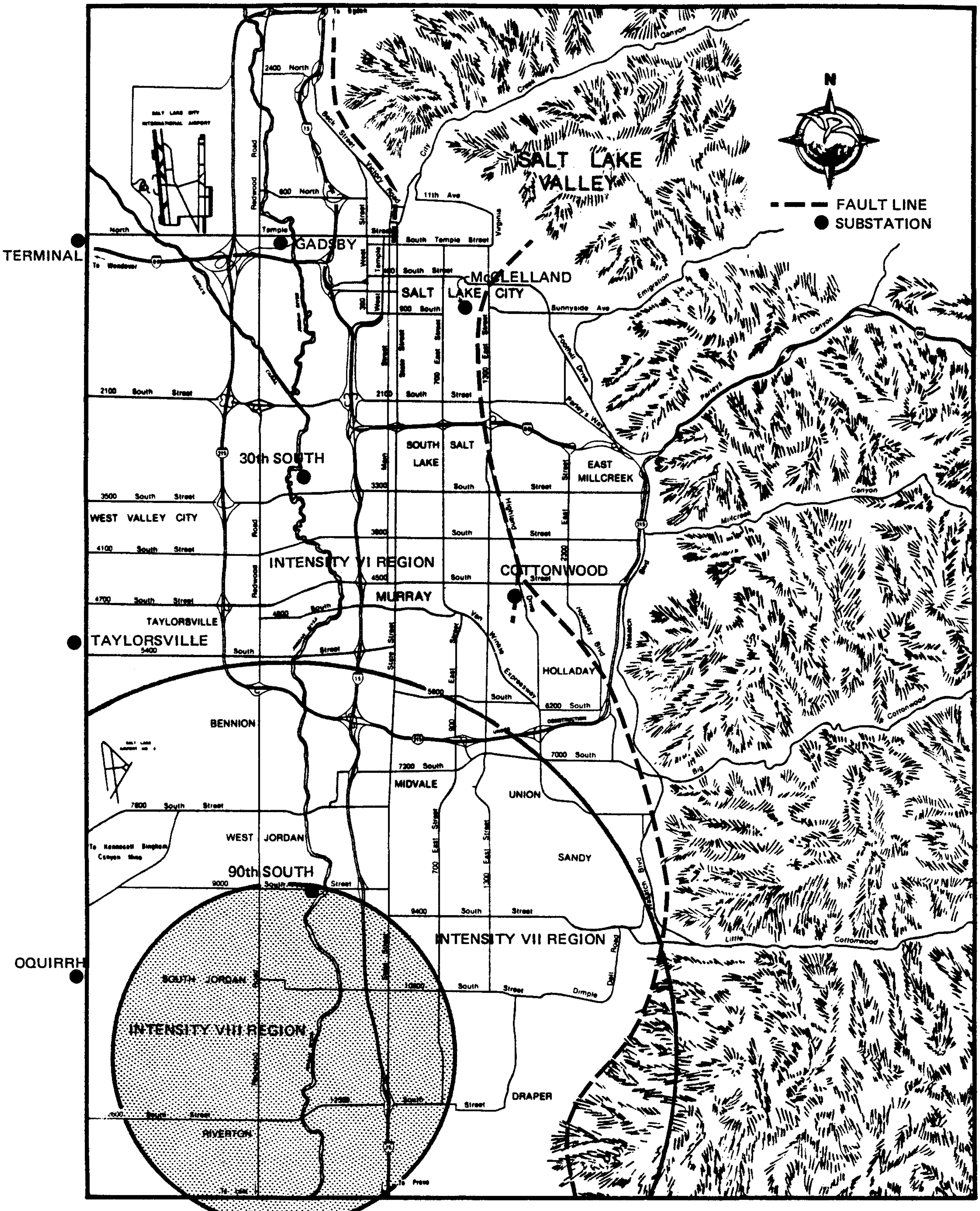

Figure 11

A POSTULATED EARTHQUAKE MODEL TO ASSESS SYSTEM RESPONSE
UTAH POWER & LIGHT COMPANY SYSTEM IN NORTHERN UTAH

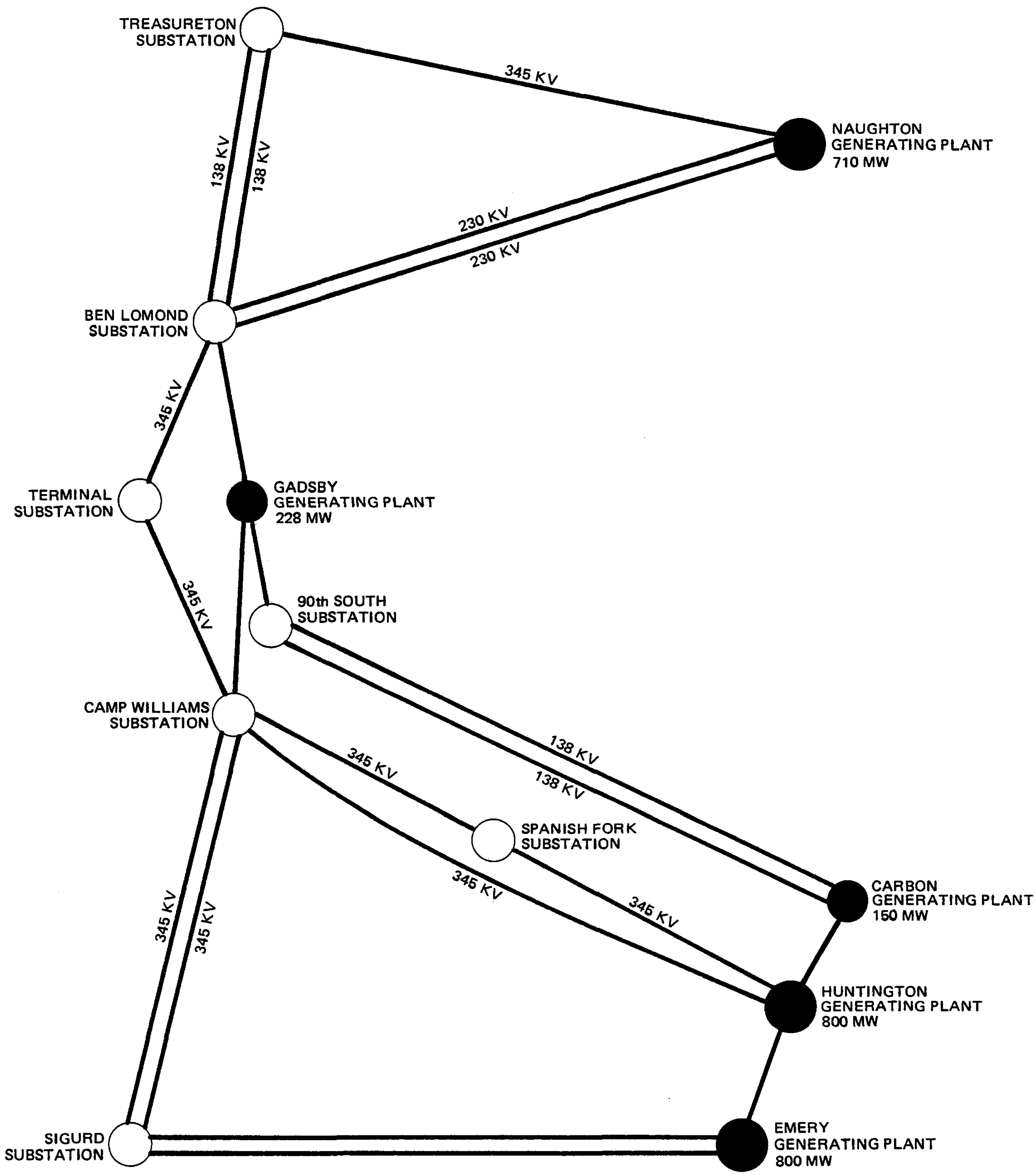

Figure 12

SCHEMATIC DIAGRAM OF THE UTAH POWER & LIGHT COMPANY TRANSMISSION SYSTEM

TABLE 1

EXPECTED RECURRENCE-INTERVALS (IN YEARS)
OF EARTHQUAKES WHOSE EPICENTER EQUALS OR EXCEEDS
THE GIVEN INTENSITY SOMEWHERE IN THE GIVEN ZONE

Seismic Zone	Intensity Equalled Or Exceeded				
	X+	IX+	VIII+	VII+	VI+
Zone U-1	3,300	770	200	56	16
Zone U-2	900	190	50	14	4
Zone U-3	1,250	260	65	11	4
Zone U-4	450	133	39	12	4
Cummulative Recurrence For All Four Zones	223	56	15	4	1

TABLE 2

RECURRENCE INTERVALS (IN YEARS)
FOR INTENSITIES EQUALLED OR EXCEEDED
AT SITES RANDOMLY CHOSEN WITHIN GIVEN SEISMIC ZONES

Seismic Zone	Intensities Equalled Or Exceeded				
	X+	IX+	VIII+	VII+	VI+
Zone U-1	--	--	1.7×10^5	29×10^3	6,300
Zone U-2	10^6	67×10^3	10×10^3	2,000	450
Zone U-3	5×10^5	90×10^3	8,200	1,300	221
Zone U-4	15×10^3	2,400	620	180	54

TABLE 3

SEISMIC ZONE AND ORIGINAL CONSTRUCTION DATE
OF UP&L TRANSMISSION SUBSTATIONS*

Identification	Seismic Zone	Original Construction Date	Type Of Substation
Camp Williams	U-4	1970	345/230/138 KV
90th So. (S.L. City)	U-4	1967 (1977)	345/138/46 KV
Sigurd	U-3	1973	345/230/138/46 KV
Terminal	U-4	1979 (345 KV)	345/230/138 KV
Pavant	U-2	Feb. 1971	230/138/46 KV
Ben Lomond	U-4	pre-1971	--
Emery	U-1	post-1971	--
Huntington	U-1	post-1971	--
Moab	U-0	--	--
Pinto	U-0	--	--
Treasureton, Idaho	U-4	1960	230/138 KV
Nebo	U-4	1967	138/46 KV
Ashley	U-0	1960	138/69 KV
Cameron	U-2	1965	138/46 KV
Taylorsville	U-4	1974	138/46/12.5 KV
Columbia Jct.	U-1	1958	138/46 KV
Syracuse	U-4	1969	138/46 KV
Smithfield	U-4	1977 and before	138/46 KV
Carbon	U-1	1956	138 KV switchrack
McClelland	U-4	1968	138/46 KV
Cottonwood	U-4	1967	138/46 KV
Tooele	U-3	1967	138/46 KV
Hale	U-4	1958	138 KV switchyard
Gadsby	U-4	1965	138/46 KV
El Monte	U-4	1964	138/46 KV
McFadden	U-1	1972	138/69/12.5 KV
Helper	U-1	1953	138/46 KV
Malad, Idaho	U-4	1966	138/69 KV
Oneida, Idaho	U-4	1960	138 KV

*(Others are outside Utah or below 138 KV level)

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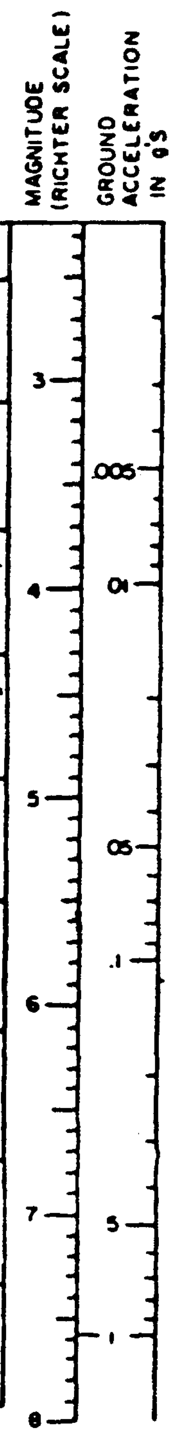
APPENDIX A

MODIFIED MERCALLI INTENSITY SCALE APPROXIMATE RELATIONSHIP WITH MAGNITUDE AND GROUND ACCELERATION

ABRIDGED MODIFIED MERCALLI INTENSITY SCALE

I	Not felt except by a very few under especially favourable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.



Modified Mercalli Intensity Scale after Wood and Neumann, 1931. (Intensities XI and XII not included).

Magnitude and acceleration values taken from Nuclear Reactors and Earthquakes, TID-7024, United States Atomic Energy Commission.

APPENDIX B

UTAH POWER & LIGHT COMPANY

1407 WEST NORTH TEMPLE STREET
P. O. BOX 899
SALT LAKE CITY, UTAH 84110

RESPONSE OF THE UP&L SYSTEM TO A POSTULATED EARTHQUAKE

(A Summary Of A Study By UP&L Furnished To Dr. Craig E. Taylor)

February 25, 1980

Mr. Craig Taylor
Utah Seismic Safety Advisory
807 E. South Temple, Suite #103
Salt Lake City, UT 84102

Dear Mr. Taylor:

As per your request, Utah Power & Light Company is pleased to provide you with the following information. We hope that it will be valuable in completing your study.

As you are well aware, it is very difficult to predict the impact of a major earthquake on a complex system like the UP&L Generation and Transmission System. This makes the assumptions of the study very important in evaluating the study results, since results under different assumptions could be somewhat different. The assumptions for this study were as follows:

1. All generation capacity is available without restrictions.

2. All transmission lines are in service except for those assumed lost due to the earthquake (specified later).

3. The distribution system is not modeled in the studies.

4. The study objective is to determine the amount of load that can be restored within 2 to 4 hours after the disturbance.

The above assumptions are general to all study cases.

Study Results

Case Configuration: The Camp Williams substation is 100% disabled. Additionally, the 90th South 345 kV substation is disabled except for one line to Terminal and one of the two 345/138 kV transformers.

Analysis: The Utah Power & Light transmission system is capable of supplying all of the estimated 1980 summer peak load except for 234 MW of interruptible industrial load and 75 MW of firm customer load. In order to accomplish this, it was necessary to increase Naughton and Gadsby generation to their maximum capability and to buy moderate capacity from northern neighboring utilities. Naughton and Gadsby generation is important to give voltage support to the northern Utah transmission system. Without full generation from these plants, additional load would have to be shed. Since the backbone transmission system can supply all but 75 MW of the firm load, and since it seems likely that distribution problems may cause significant power outages, I believe that the backbone transmission system would be able to supply all of the capacity that the distribution system could accommodate. It seems that with the shedding of interruptible load, all customers without distribution system problems may be served.

Case Conditions: 100% disability of both Camp Williams and 90th South substations.

Analysis: The transmission system is capable of supplying the estimated 1980 peak load except for 234 MW of interruptible industrial load and 125 MW of firm load. Most of the firm load lost would probably be in the south Salt Lake Valley. The same importance is placed on Gadsby and Naughton generation as in the previous case.

Summary

Although an event of this nature would initially cause a major system break up, it appears that after the system is pieced back together it would be able to supply all or most of the firm electrical power that the distribution system could reasonably be expected to accommodate. During the initial 2 to 4 hours, off-line generation would be placed in service and the system would be adjusted. Nevertheless, if the Naughton or Gadsby generation were not fully available (due to mechanical problems), then the bulk supply of power would be less. This could impact significantly the ability to supply the firm load. With the loss of Camp Williams substation, our southern generation (Huntington and Hunter) would be of little value in supplying load north of Camp Williams, because of transmission constraints throughout the WSCC system and our ability to maintain voltage support in the Salt Lake Valley under extreme import conditions.

Because of the importance of the lines south of Camp Williams to supply southern generation, immediate priority would be given to installation of a temporary line to bypass the Camp Williams substation. Although this may take longer than 4 hours, it would not take more than 12 hours unless the damage is extensive.

I hope these results will provide you with some insight of the reliability of the UP&L system under extreme conditions. If I can be of further assistance, please contact me.

Sincerely,

Jim Tucker

James D. Tucker
Supervisor Transmission Planning

ss

APPENDIX C

TRANSMISSION ANALYSIS FOR SEISMIC DISTURBANCES

(Source: Dr. C.E. Taylor, based upon a systems analysis performed by UP&L)

Introduction

Seismic disturbances may severely impact the operation of an electrical power system. In order to evaluate the extent of the impact it is recommended that a computer loadflow program be used.

This type of program simulates the steady state power flow on the modeled load, generation, and transmission system with mathematical equivalents. Once the generation, load, and available transmission is specified, the program calculates the power that will be carried on each transmission line and the resulting voltage at each bus. Using this, an experienced engineer can determine whether the operating condition is acceptable. By modeling various facilities that are assumed to be undamaged, the power system engineer can determine the impact of a seismic disturbance and the critical equipment that must be preserved to reduce the impact on the power system.

Limitations

In order to determine the power system's ability to respond under conditions, it is necessary to use an iterative process of assuming outage conditions, then using the loadflow program to determine how the system may be re-dispatched to restore as many customers as possible under the outage condition.

These assumptions about the electrical facilities available for service are very critical to the results, and by varying the equipment failure assumptions, the sensitivity to system outages is determined.

Utah Power and Light conducted studies to evaluate the amount of load that could be restored within two to four hours after an initial seismic disturbance affecting two major substations. The general study assumptions are as follows:

1. All generation capacity is available without restrictions.
2. All transmission lines are in service except for those assumed lost due to the earthquake (specified later).
3. The distribution system is not modeled in the studies.
4. There is no attempt to evaluate the dynamic impact of the initial disturbance.

Study Procedure

The power system with the study assumptions is modeled in the load flow. An iterative process is used to determine the best use of available system equipment. For example, in this study it was determined that the opening of some overloaded 138 kV lines is required for operation of the power system. Through successive load flow studies the generation and customer load would be dispatched to utilize the power system to its best ability.

Study Results

Study Configuration: The first major substation is 100% disabled. Additionally, a second 345 kV substation is disabled except for one line and one transformer.

Analysis: The Utah Power and Light transmission system is capable of supplying all the estimated 1980 summer peak load except for 234 MW of interruptible industrial load and 75 MW of firm customer load. In order to accomplish this, it is necessary to increase northern generation to maximum capability and to buy additional capacity from northern neighboring utilities. Local generation is important to give voltage support to the northern Utah transmission system. Without full generation from these plants, additional load would have to be shed.

Study Configuration: 100% disability of both major substations.

Analysis: The transmission system is capable of supplying the estimated 1980 peak load except for 234 MW of interruptible industrial load and 125 MW of firm load. Most of the firm load lost would probably be in the South Salt Lake Valley because of transmission and substation limitations. The same importance is placed on local generation as in the previous case.

Summary

Although an event of this nature would initially cause a major system break up, it appears that after the system is pieced back together it would be able to supply all or most of the firm electrical power that the distribution system could reasonably be expected to accommodate. During the initial two to four hours, off-line generation would be placed in service and the system would be adjusted. Nevertheless, if the local generation were not fully available (due to mechanical problems), then the bulk supply of power would be less. This could impact significantly the ability of the system to supply the firm load. With the loss of both substations, our southern generation would be of little value in supplying load in the Salt Lake Valley, because of transmission constraints and in our ability to maintain voltage support in the Salt Lake Valley under extreme import conditions.

Because of the importance of the lines south of Salt Lake, immediate priority would be given to installation of temporary lines bypassing the damaged substation. Although this may take longer than 4 hours, it shouldn't take more than 12 hours unless the damage is extensive.

Through the use of computer simulations it is possible to determine the long term impact of an earthquake or other disaster by making equipment failure assumptions and evaluating the ability of the power system to respond with the equipment failures modeled.