

INITIAL UTILITY EXPERIENCE WITH CLUSTER OF THREE MOD-2 WIND TURBINE SYSTEMS

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ABSTRACT

This paper describes the initial utility experiences of operating three MOD-2s during the Engineering Acceptance Testing. Electrical quantities of bus voltage, phase currents and power are initially being recorded to evaluate impacts to customers on the 69-kV subtransmission line during synchronization and operation of one or more WTSs. To date, effects on the system have been essentially undetectable.

Measurements of television signal strengths were taken at an existing television remote pickup and relay station at the WTS site. Potential TV signal interference problems from the WTSs have been avoided by replacing the remote pickups with microwave repeater links for the four TV channels received from Portland, Oregon.

Preliminary measurements of audible and sub-audible noise levels indicate that the upwind rotor, tubular tower design of the MOD-2 does not have the pulsing high intensity infrasound problems experienced by the MOD-1 machine at Boone, North Carolina.

Some preliminary assessments have been made on the MOD-2 WTSs in regard to adequacy of emergency shutdown systems and operation and maintenance support activities. Wind Turbine Systems operating on a utility system can experience loss of connection or load and must be able to reliably shut themselves down.

INTRODUCTION

The cluster of three MOD-2 Wind Turbine Systems (WTSs) installed and placed into service at Goodnoe Hills in the Federal Columbia River Power System is the first multiunit wind turbine generator installation which has operated with all generators simultaneously supplying power to a utility electrical power system. Goodnoe Hills is located in Klickitat County in southwestern Washington. The site, at an elevation of 2600 feet, is situated on a ridge north the Columbia River, 7 miles east of John Day Dam and about 13 miles east-southeast of Goldendale, Washington. The MOD-2 units are connected to a nearby 69-kV line owned and maintained by Klickitat County PUD, a customer of the Bonneville Power Administration.

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**NPA's participation in the MOD-2 Research, Development, and Demonstration project provides for the following:**

- 1. Developed site - land, access roads, 69-kV/12.5-kV substation, 3 miles of 69-kV line, microwave radio station, underground 12.5-kV cables, underground telephone cables for protective relaying, control, telephone, data transmission, 198-foot meteorological tower, and Data Acquisition System.**
- 2. Operation and Maintenance.**
- 3. Administrative, Engineering, and Technical Support.**
- 4. Visitors' Center.. .**
- 5. Mitigation of potential television interference.**

**BPA started developing the site early in 1980 and Boeing Engineering and Construction Company working to a tight schedule completed construction of the first MOD-2 WTS by December 1980. The other two WTSs were completed within intervals of 3 months.**

**Initial synchronization of the three MOD-2 WTSs was accomplished on the following dates:**

<b>WTS-1</b>	<b>December 22, 1980</b>
<b>WTS-2</b>	<b>April 7, 1981</b>
<b>WTS-3</b>	<b>May 19, 1981</b>

**Test activities conducted by BPA since construction of the three MOD-2 WTSs have been primarily concerned with initial efforts to monitor and record the quality of power.**

**On Tuesday, April 28, 1981, WTS-1 was monitored for 24 hours by BPA power dispatchers via a remote CRT Control Terminal installed at the BPA Dittmer Control Center in Vancouver, Washington, approximately 160 km west of the site.**

**All three units were operated simultaneously for a brief period on May 27 just before the dedication which was held on Friday, May 29, 1981.**

**On June 8, WTS #1 failed during a staged emergency shutdown test and details of that incident were covered in other sessions of the workshop. At the time**

of failure the three units had accumulated running times and generation as follows:

<u>WTS</u>	<u>Operating Time</u> <u>HRS</u>	<u>Sync Time</u> <u>HRS</u>	<u>Energy</u> <u>MW hr</u>
1	107	84	99.4
2	122	113.5	138
3	19	18.5	23.7

This report covers the following areas of concern to utilities contemplating the use of wind energy on its system. They are:

1. BPA integration facilities
2. Operation and maintenance aspects of large wind turbine complex
3. Utility perspective on the June 8, 1981, failure of WTS #1 at Goodnoe Hills
4. TV signal field measurements and new microwave radio equipment and antennas provided by BPA to avoid potential TV interference problems to the existing Western Telecommunications, Inc. (WTCI) TV facilities.
5. Noise survey conducted by the Solar Energy Research Institute
6. The quality of power

BPA believes that the Goodnoe Hills MOD-2 project will provide an excellent opportunity to obtain valuable utility experience on a cluster of large WTSs as well as essential wind turbine development and demonstration type data.

#### BPA INTEGRATION FACILITIES

As shown in Figure 1, the three MOD-2 units are connected to an existing Klickitat County PUD 69-kV transmission line located 3 miles north of the Goodnoe Hills site. BPA constructed a 10 MVA 69-kV/12.5-kV substation at Goodnoe Hills and the 69-kV tap line. Each WTS is connected to the Goodnoe Hills Substation by three single phase cables, each shielded with an outer armour ground, and a 4/0 ground mat tie conductor at the bottom of a sand-filled trench. The generator terminal voltage is 4160 volts. The 4160 volt bus tie contactor, step-up 4.16-kV/12.5-kV transformer and metering are located in a metal enclosure on a concrete pad next to each tower. At the Goodnoe Hills substation, fuses and disconnects are provided on the 69-kV side and one circuit switcher on the 12.5-kV side.

Underground telephone cables have been installed between the Goodnoe Hills Substation and each WTS and the microwave radio station. Communication circuits have been provided for the following services and systems:

1. Dial Automatic Telephone System (DATS) over the BPA Microwave Radio Communication System. A 6-button telephone set has been installed in each WTS Substation, Data Building, and Radio Station. The telephone system provides connection to the local central office telephone line and intercom service.
2. Remote control of WTSs is from BPA's Dittmer Control Center located in Vancouver, Washington. Three CRT remote computer control terminals are installed at the Dittmer Control Center. The three control channels are submultiplexed on one microwave radio communication channel.
3. Data Channel. The data from the minicomputer PDP-11/34A in the data building located near the base of WTS-2 will send data by microwave radio to an existing Data Acquisition System located in Portland.
4. Power Circuit Breaker (12.5-kV PCB) disabling circuit. Synchronizing of the WTS to the power system is done with the Bus Tie Contactor (BTC) at the base of the tower. The 12.5-kV PCB at Goodnoe Hills Substation cannot be closed unless all of the BTCs are open.

The addition of WTSs on the 69-kV Feeder required modifications to be made at the BPA Chenoweth and Klickitat County PUD Goldendale Substations. The modifications included:

1. Install "hot line" check relays and modify PCB automatic reclosure. The WTS must be disconnected from the power system before any of the 69-kV or 115-kV PCB can be reclosed.

#### OPERATION & MAINTENANCE ASPECTS OF A LARGE WIND TURBINE COMPLEX

Early experience with the MOD-2 complex at Goodnoe Hills indicate that wind turbine system designers should pay close attention to the operation and maintenance support aspects of the complex, particularly from a utility standpoint. In regard to the Goodnoe Hills complex, the nearest BPA maintenance personnel are located at BPA John Day Substation approximately 40 miles away (1 hour driving time). The complex has limited storage space, so the bulk of warehousing of turbine spares, etc., is maintained off-site at The Dalles, Oregon, approximately 50 miles away. The logistics of supporting necessary operation and maintenance activities with the transit times involved can well be imagined. BPA is working with NASA and Boeing in developing plans to provide necessary O&M support in an efficient manner. Monitoring systems that permit off-site diagnosis of wind turbine problems prior to dispatch of maintenance personnel is one area which should be addressed by wind turbine designers in laying out future remotely operated complexes.

The WTSs (and other customers) are protected from abnormal operating conditions by use of suitable relaying equipment.

An alarm should be provided for each remote CRT control terminal to alert the operator when the communication or control circuit becomes disabled.

#### UTILITY PERSPECTIVE ON THE JUNE 8, 1981, FAILURE OF WTS #1 AT GOODNOE HILLS

The failure of WTS #1 on June 8 (details of which were covered in more depth in earlier sessions) pointed out the need of having reliable, redundant emergency shutdown systems on large wind turbines. From a utility perspective, BPA is concerned that the MOD-2 units (or any large wind turbine employed on our system) be provided with "in-depth" redundant protective failsafe shutdown systems similar in philosophy to those developed by the utility industry for other prime mover systems.

Specifically, BPA has recommended to the NASA and Boeing investigative teams analyzing the WTS #1 failure the following:

1. Installation of "in-depth," maintainable, emergency shutdown systems on all MOD-2 wind turbines. The systems should be independent, redundant systems designed such that any common-mode failure of the electrical-hydraulic systems will not prevent safe shutdown of the wind turbine system.
2. General refurbishment and/or upgrading of electrical control system components.
3. Redesign of O&M procedures in regard to emergency shutdown systems.

These recommendations are being evaluated by the investigative teams. Hopefully, the modifications that are implemented on the units as a result of the incident will reflect the utility philosophical approach to prime mover protection.

#### TV FIELD MEASUREMENTS AND NEW MICROWAVE RADIO FACILITIES

Possible TV interference to the Western Telecommunications, Inc.(WTCI) , existing CATV facilities at Goodnoe Hills was recognized by BPA.

WTCI operates a marginal system installed in 1963 which consists of "off the air" antenna reception of television channels 2, 6, 8, and 12 from Portland, Oregon. The TV channels are retransmitted by microwave radio to some seven eastern Oregon communities.

TV field measurements were made on February 12 and 13, 1980. The received signal strength at the time of the test, on all channels, was less than the ideal 500 microvolts (field intensity measurement) desired at the receiving antenna site with reference to a high-gain yagi antenna. At the time of the test, measurements of 140 to 190 uV were obtained at the channels 2, 8, and 12 antenna location and 350 uV at the channel 6 antenna location. The channel 8 video information was receiving some TV channel 7 audio interference from a station of unknown location. This may explain the periodic channel 8 interference noted during video tape recording in the WTCI station. Channels 6 and 12 in the WTCI station have some periodic ghosting problems as can be observed on the video tape recording.

Because of ghosts the best location for "off the air" antenna reception of Channel 6 found by WTCI was in a ravine northwest of WTS-2 . . .

To preclude any possible TV interference from the rotors of the MOD-2 units the four TV receiving antennas have been relocated. TV channels 2 and 6 are now being picked up at Scapoose, Oregon, and relayed to Goodnoe Hills via a WTCI microwave radio repeater station at Mt. Defiance about 58 miles west southwest of the site. TV channels 8 and 12 are picked up at Mt. Defiance and relayed by microwave radio to Goodnoe Hills. BPA paid WTCI \$162,412 for the new facilities. The modified system for WTCI is operating satisfactorily.

Planned static and dynamic measurements of TV scattering from the MOD-2 blades of signals originating from Portland about 160 km away have not been completed. Tests are planned to be made to

- a) determine the TVI at the TV channel 6 location near WTS-2
- b) determine the TVI at the TV receiving antennas for channels 2, 8, and 12 located 1/2 miles south of WTS-1
- c) determine the equivalent blade scattering area of MOD-2.

BPA also made TV field measurements at the Jones residence about 3/4 mile north and 1000 feet below the WTS site, "cluster" home sites about 2 miles west of the site and at Nacelle height of WTS-1. The signals at the home sites are below FCC Grade B and considered by BPA to be "arbitrary Grade D" or less. <sup>1/</sup> TVI to the residences is not expected and no complaints have been received.

1/ IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No. 1 Jan/Feb 1980 Page 373.

#### NOISE SURVEY OF MOD-2 WTS-1 BY SERI

Personnel from the Solar Energy Research Institute (SERI) made noise measurements during February 1981 with WTS-1 operating. SERI's plans for more elaborate measurements with three MOD-2 units, previously scheduled for July 16, 1981, have been postponed indefinitely due to overspeed damage of WTS-1 on June 8, 1981.

The following are excerpts from the SERI report:

"A preliminary noise survey was made February 24, 1981, at Goodnoe Hills, Washington, using the Turbine No. 1 MOD-2 Wind Turbine Generator (WTG). The results of this highly preliminary survey show that, in the average, the acoustic output of the MOD-2 is totally broadband in nature, with no strong periodic components. . . The sound produced by the MOD-2 has been described as a "heavy whoosh." This noise does not appear to be correlated with the passage of the blade past the tower and probably is due to random turbulent eddies passing through the blade disk. . . SERI field personnel reported that the "whoosh" could be heard clearly up to about 30-45 m (100-150 ft.) away from the turbine, however, as the distance from the machine is increased further, the "whoosh" is rapidly covered by wind noise."

An assessment of the preliminary noise survey of the MOD-2 wind turbine has been completed with following results:

"The turbine noise at 1-1/2 rotor diameters downwind (450 ft.) is largely composed of incoherent, broadband rotor noise whose peak energy is confined to frequencies below 20 Hz. The sound pressure levels, as determined from this small sample, do not appear excessive and compare favorably with measurements of other turbines when impulses were not present. No strong periodic impulses were found similar to those characteristic of the MOD-1 turbine. "

It is to be noted that the "heavy whoosh" reported by SERI and heard by any others is caused largely by the unstreamlined tips. If streamlined covers were to be fabricated and installed on the tips the noise level would probably be reduced significantly.

#### QUALITY OF POWER

##### Northwest Power Pool Voltage Schedules

In order to provide voltage compensation on the Northwest Power Pool transmission system the transmission voltage levels are adjusted four times each day.

### Monitoring of Bus Voltages

Both circular and strip chart recording voltmeters have been installed and maintained to monitor bus voltages at the BPA and Klickitat County PUD substations. The recording voltmeters are located at the substations listed below and are shown in Figure 1 Utility System One-Line Diagram Goodnoe Hills.

	<u>Substation</u>	<u>Bus Voltage</u>
1.	Goodnoe Hills (BPA)	12.5 kV
2.	Goodnoe Hills (BPA)	69 kV
3.	Dot (KCPUD)	69 kV
4.	Goldendale (BPA)	69 kV
5.	Chenowith (BPA)	115 kV

Table I is the schedule of voltages for Big Eddy Substation 115-kV and The Dalles Dam Power House 115-kV bus.

TABLE I VOLTAGE SCHEDULE

<u>STATION</u>	<u>Bus kV</u>	<u>HI</u>	<u>MED</u>	<u>LOW</u>
The Dalles Dam	115	121	119	118
Big Eddy Sub	115	121	119	118

Figure 2 - Goodnoe Hills Substation Voltage Chart 69-kV 4/20/81 and Figure 3 - Dot Substation Voltage Chart 69-kV 4/20/81 show the changes in bus voltage when WTS-2 and WTS-1 were synchronized to the power system. The bus voltage increased about 0.9 percent when the WTS was supplying power. The generators are equipped with both voltage regulators and power factor controllers in the generator excitation system. Only the power factor controllers have been used. The generator power output has been maintained at unity power factor.

Two circular recording voltmeter charts, i.e., Figure 4- Goodnoe Hills Substation Voltage Chart 12.5 kV April 15-21, 1981, and Figure 5 Goldendale Substation Voltage Chart 69-kV April 9-21, 1981, show the scheduled voltage compensation.

Between April 16 and June 2, 1981, there were 79 operating periods varying from 1 minute to nearly 12-1/2 hours. Of these periods, 51 or 65 percent created no detectable change in voltage. Twenty-eight, or 35 percent, created changes of from 0.2 to 0.8 percent with the average change being 0.35 percent.



The effect of WTS on the Goodnoe Hills bus voltage is minimal and less than the scheduled change. At Goldendale Substation since the bus is much "stiffer" the effect of operation of the WTSs is much less perceptible. The typical variation of bus voltage due to loads coming on and going off masks any voltage transients that occur when a WTS is synchronized and operated with varying wind speeds.

The voltage disturbance at Goodnoe Hills and Dot Substation was minimal each time a WTS was synchronized or removed from service, generally less than one half of one percent (0.5%).

Neither BPA nor Klickitat County PUD has received complaints about abnormal voltage dips or service interruptions that could be associated with the MOD-2 complex operation.

The corresponding voltage changes at the Dot 69-kV Substation were essentially the same as at the Goodnoe Hills Substation on the 69-kV side.

#### Noise Spectra on the Bus

Noise spectra data of bus voltage was recorded at Goodnoe Hills Substation on June 10, 1981, without any of the WTSs in operation. Further on-site spectral data and other data will need to be obtained with the WTSs in operation. The data will be used to analyze possible interactions between the Goodnoe Hills MOD-2 WTS and the natural dynamic modes of the Western Power System which vary from 0.2 to about 1 Hz at various times of the day and year.

BPA engineers have analyzed system dynamics and report the following with respect to Goodnoe Hills. 2/

". . . Conditions at Goodnoe were inspected while the wind turbines were off-line, which gave no information about the actual degree of coupling there. Further on-site spectral analysis with some machines in operation, and additional operating records, should enable this to be estimated. . . .

The information at hand is by no means complete enough to indicate the extent to which these or related interactions are, or could become, "adverse". Some extrapolations about impact upon MOD-2 performance and security seem reasonable, however:

1. Intermittent power system oscillations at frequencies near that of the quillshaft mode might produce unnecessary tripping of the MOD-2 unit(s), but probably would not be of sufficient magnitude or duration to degrade shaft longevity. Such tripping, if it occurs, would probably be too infrequent to justify revision of unit protection or reclosure schemes.

2. Coupling of the persistent 0.35 Hz power system activity into the MOD-2 machine controls (e.g., for blade angle) may produce appreciable wear and fatigue to mechanical elements. If this is found to be the case then revisions of the machine control logic may be in order."

2/ Ref: Memo by J. F. Hauer to E. J. Warchol dated June 23, 1981, Subj: Possible Interactions between the Goodnoe Hills MOD-2 WTS and Natural Dynamic Modes of the Western Power System.

#### SUMMARY

No adverse power transients were observed during synchronization of the WTSs. During operation from no load to full load the changes in bus voltages were minimal and well below the scheduled voltage adjustments. The WTS generator is equipped with both voltage regulator and power factor controller. The power factor controller was used during the Engineering Acceptance Tests to maintain the generator power output at unity power factor.

TV interference and noise from the MOD-2 WTSs are not expected to present problems at Goodnoe Hills.

WTS-1 which was damaged on June 8, 1981, during a brief overspeed incident is being repaired and will be ready for more tests in March 1982. Units 2 and 3 are expected to be back in operation in late September 1981. A careful and thorough examination of the emergency shutdown philosophy and associated systems by NASA, Boeing, and BPA is currently under way. BPA will recommend that several load rejection tests under different wind conditions should be included in the Engineering Acceptance Tests to demonstrate the reliability of the normal and backup emergency shutdown systems.

Operation and maintenance aspects of wind turbine complexes will be thoroughly analyzed so the complex can be supported in an efficient manner.

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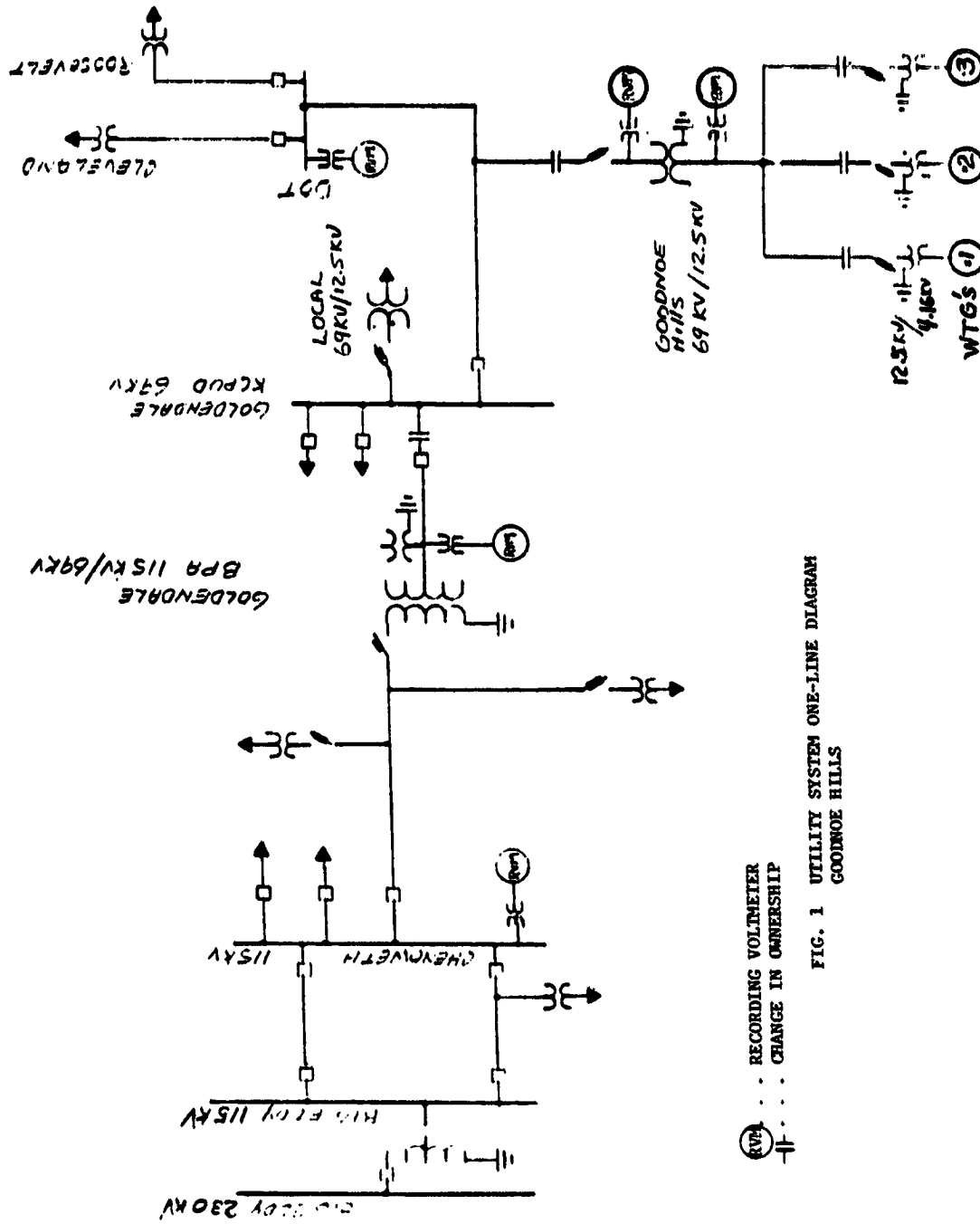
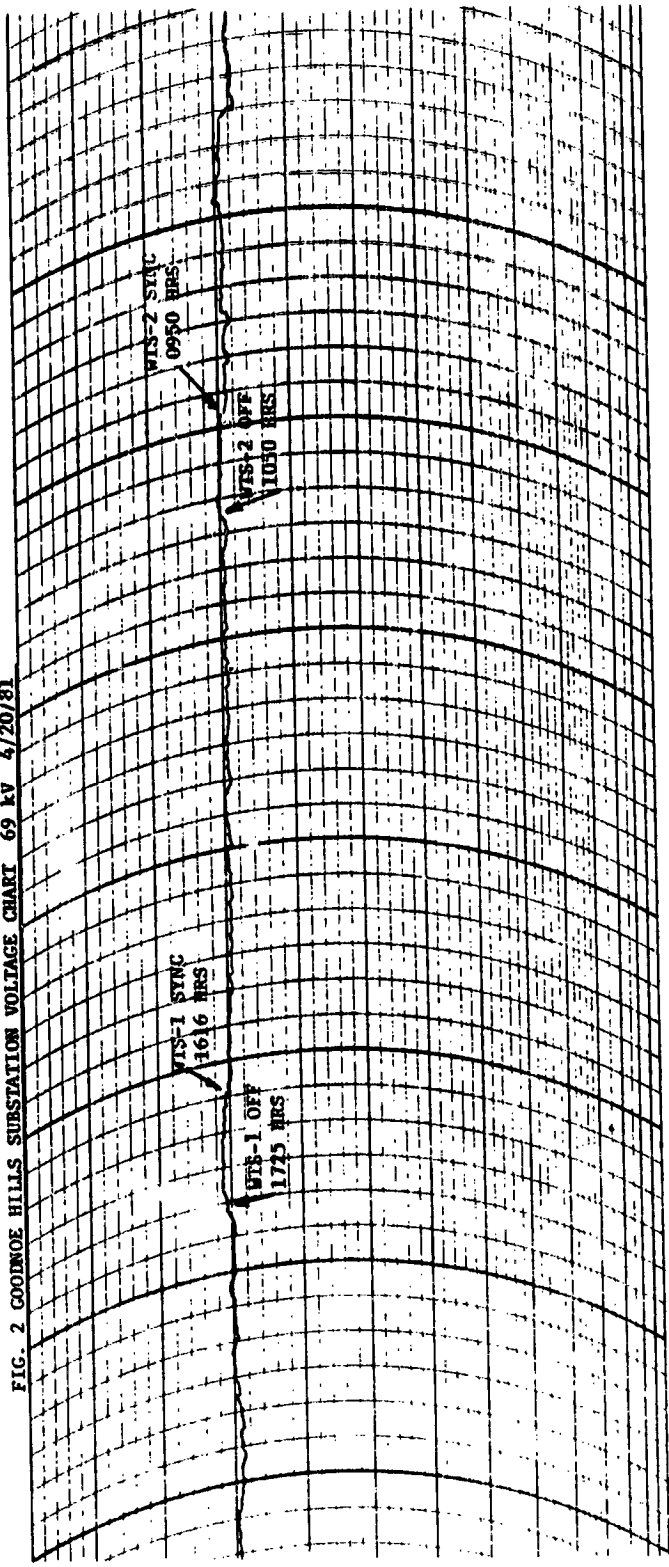


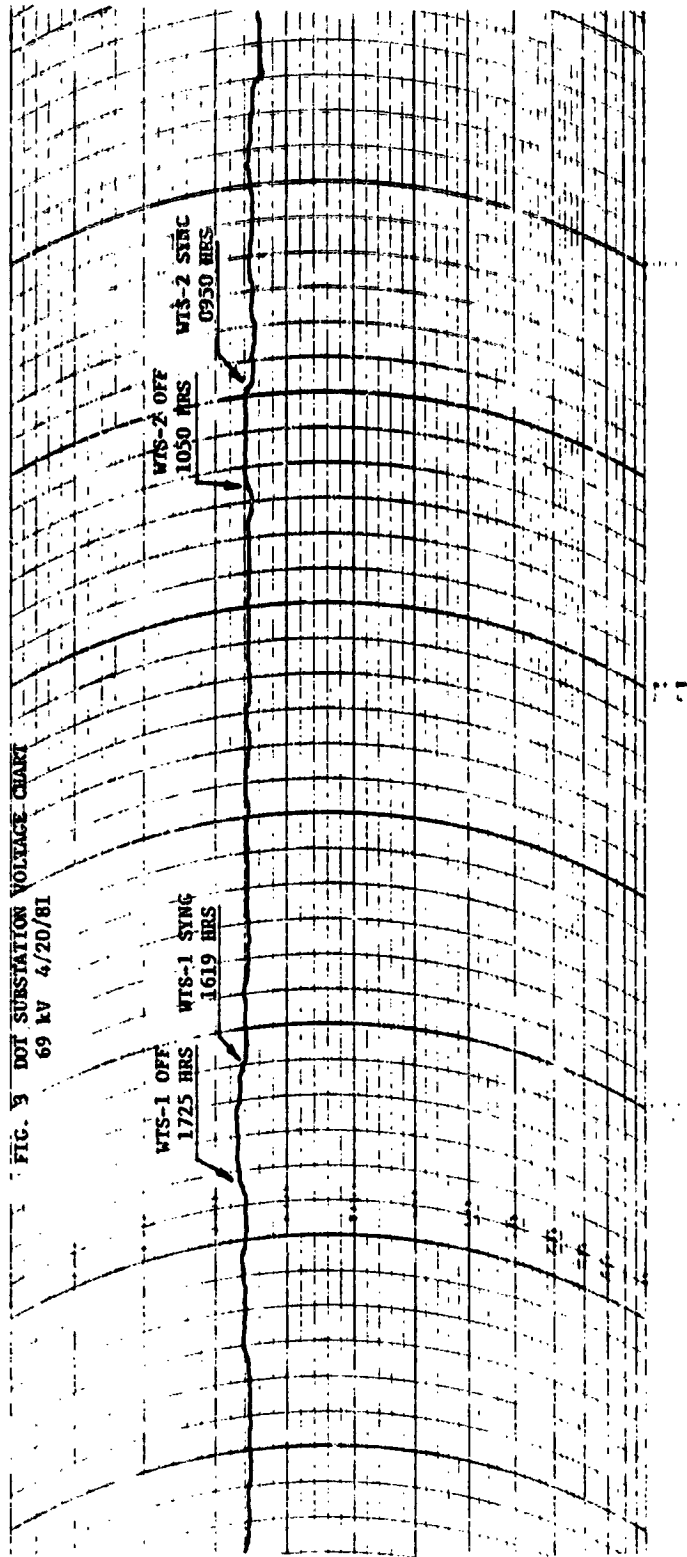
FIG. 1 UTILITY SYSTEM ONE-LINE DIAGRAM  
GOODNOE HILLS

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FIG. 2 GOODNOE HILLS SUBSTATION VOLTAGE CHART 69 KV 4/20/81



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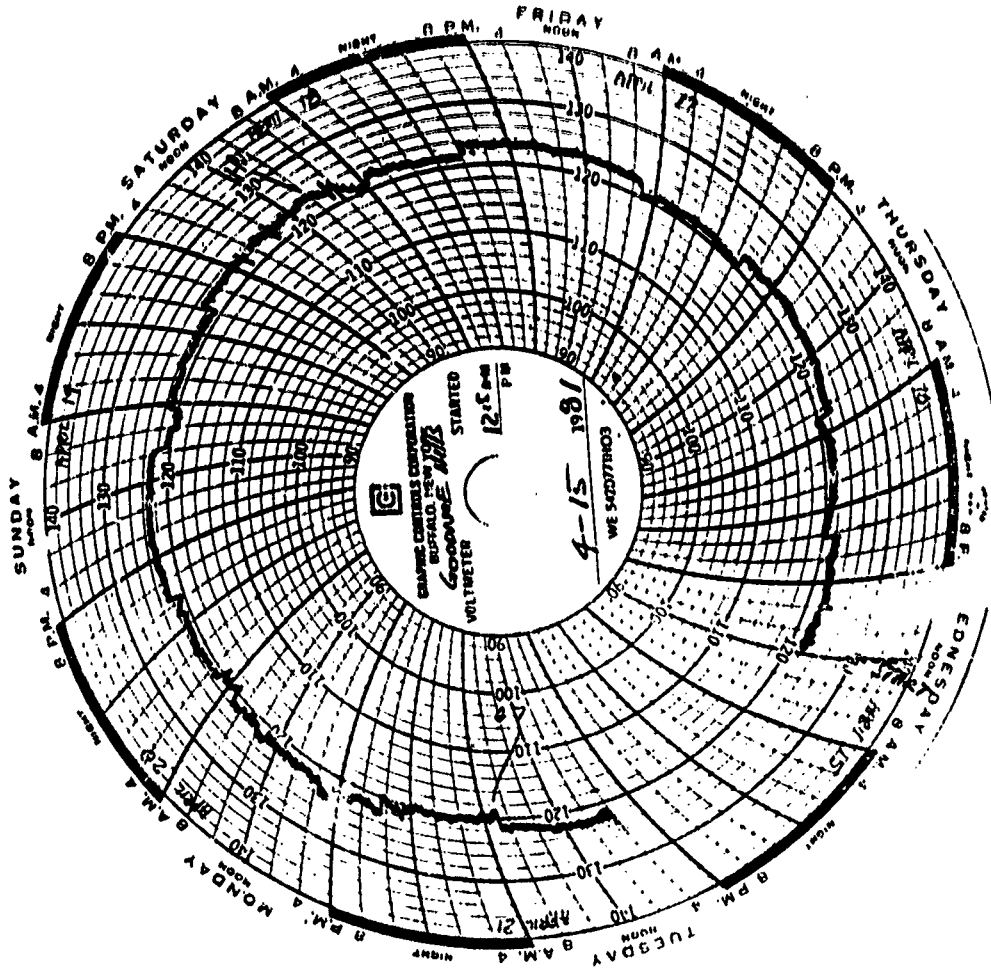


FIG. 4  
GOODNOE HILLS SUBSTATION  
VOLTAGE CHART 12.5 KV  
APRIL 15-21, 1981

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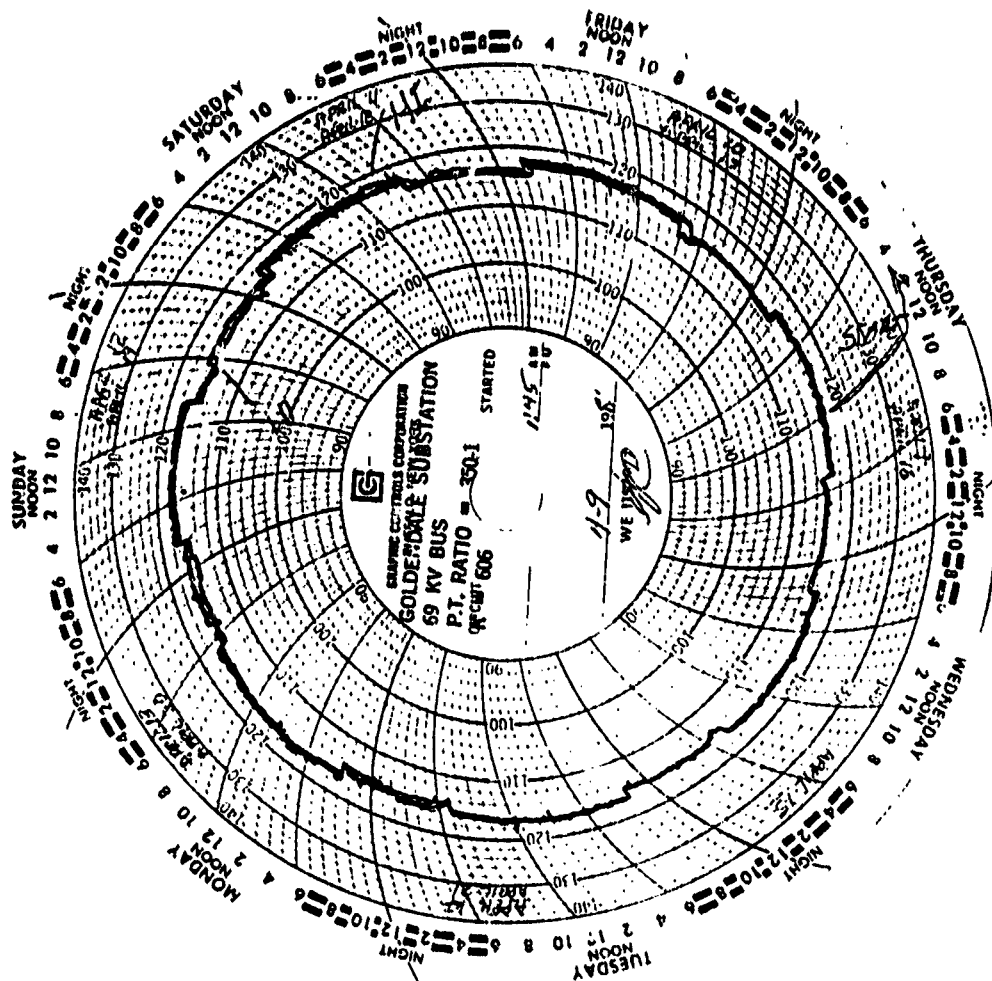


FIG. 5  
GOLDDENDALE SUBSTATION  
VOLTAGE CHART 69 KV  
APRIL 9-21, 1981