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WIND ENERGY DEVELOPMENTS IN THE 20th CENTURY

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HISTORICALLY, WIND DRIVEN ENERGY CONVERSION DEVICES CAN BE CONSIDERED AS ONE OF MAN'S TRULY BASIC MACHINES. SIMPLE VERTICAL AXIS WIND MACHINES WERE PROBABLY IN EXISTANCE IN PERSIA SEVERAL HUNDRED YEARS BEFORE THE TIME OF CHRIST (REF. 1 & 2). THESE PRIMITIVE WIND MACHINES STAYED THE SAME UNTIL THE 12TH CENTURY WHEN ALMOST SIMULTANEOUSLY IN FRANCE AND ENGLAND THE HORIZONTAL-AXIS OR DUTCH-TYPE WINDMILL MADE ITS APPEARANCE (FIG. 1). DUTCH SETTLERS BROUGHT THIS TYPE OF WINDMILL TO AMERICA IN THE MID-1700'S (REF. 3). THESE WINDMILLS TYPICALLY GROUND GRAIN AND PUMPED WATER. THROUGH THE YEARS, THE DESIGN OF THESE WINDMILLS CHANGED ONLY SUPERFICIALLY. IN 1890, THE FIRST OF THE MODERN WINDMILLS FOR PRODUCING ELECTRICITY WAS DESIGNED, BUILT AND PUT INTO SERVICE IN DENMARK (REF. 1 & 4). THEY MUST HAVE LIKED WHAT THEY HAD BECAUSE BY 1908 SEVERAL HUNDRED WIND POWER STATIONS PRODUCING FROM 5-25 KW DOTTED THE DANISH LANDSCAPE. WIND MACHINES ALSO PLAYED A SIGNIFICANT ROLE IN RURAL AMERICA UP UNTIL THE 1930'S WHEN THE RURAL ELECTRIFICATION ACT (REA) PROVIDED CHEAP ELECTRICITY TO THE FARMERS. THE REMNANTS OF MANY OF THESE EARLY WIND MACHINES ARE STILL VISIBLE IN VARIOUS PARTS OF THE COUNTRY. ALL OF THESE MACHINES WERE RELATIVELY SMALL AND DID NOT PRODUCE MUCH POWER.

IN THE 20TH CENTURY, THE SEARCH FOR POWER LED MANY COUNTRIES TO FURTHER CONSIDER THE WIND. THE POWER DENSITY OF THE WIND VERSUS WIND SPEED IS PRESENTED IN FIG. 2. AS AN ILLUSTRATIVE EXAMPLE, NOTE THAT AT A WIND SPEED OF 13 MPH, APPROXIMATELY

10 WATTS OF POWER IS CONTAINED IN EACH SQUARE FOOT OF WIND AREA (WHERE AREA IS TAKEN PERPENDICULAR TO THE WIND DIRECTION). THIS REPRESENTS THE IDEAL POWER AVAILABLE. THE LAWS OF NATURE LIMIT IDEAL PROPELLORS TO 59,3% OF THIS POWER. IF THE LOSSES OF A REAL PROPELLOR, GEARING AND GENERATOR ARE CONSIDERED, REALISTICALLY 3 TO 3,5 WATTS OF POWER COULD BE OBTAINED FROM ONE SQUARE FOOT OF THIS 13 MPH WIND. IN AN EFFORT TO TAP THIS WIDESPREAD SOURCE OF "FREE" ENERGY, SEVERAL COUNTRIES DESIGNED, CONSTRUCTED AND TESTED COMPARATIVELY LARGE WIND MACHINES.

ONE OF THE FIRST LARGE EXPERIMENTAL MACHINES WAS THIS 100 Kw (FIG. 3) WIND TURBINE WHICH WAS BUILT IN 1931 BY THE RUSSIANS. IT WAS LOCATED AT BALACLAVA NEAR YALTA ON THE BLACK SEA (REF. 5, 6 & 7). THE ROTOR IS 100 FEET IN DIAMETER AND THE TOWER IS 100 FEET HIGH. MAXIMUM RATED POWER, 100 Kw, WAS OBTAINED AT WIND SPEEDS IN EXCESS OF 24,6 MPH. THE AVERAGE WIND SPEED AT THIS SITE WAS 15 MPH. THE ROTOR DROVE A 100 Kw, 200 VOLT INDUCTION GENERATOR WHICH WAS CONNECTED BY A 6300 VOLT LINE TO A 20 MEGAWATT STEAM POWER STATION LOCATED IN SEVASTOPOL SOME 20 MILES AWAY. ALTHOUGH THIS WIND MACHINE WAS VERY PRIMITIVE; I.E., THE BLADE SURFACE WAS ROOFING METAL AND THE MAIN GEARS WERE MADE OF WOOD, THE PLANT DID ONE YEAR ACHIEVE AN OUTPUT OF 279,000 KILOWATT HOURS. THIS GAVE A POWER UTILIZATION YIELD; THAT IS, THE ACTUAL POWER OUTPUT DIVIDED BY TOTAL POSSIBLE POWER OUTPUT, OF 32%. THE GENERATOR AND CONTROLS ARE LOCATED IN THE

HOUSING ON TOP OF THE TOWER. REGULATION WAS ACCOMPLISHED BY PITCH CONTROL OF THE BLADE. THE WIND THRUST WAS ABSORBED BY THE INCLINED STRUT. THE GROUND PORTION OF THIS STRUT RESTS ON A CARRIAGE WHICH SITS ON A CIRCULAR TRACK. THE CARRIAGE WAS AUTOMATICALLY DRIVEN TO KEEP THE ROTOR FACING INTO THE WIND. IN ADDITION TO THIS MACHINE, THERE HAVE BEEN MANY SMALLER MACHINES INSTALLED IN RUSSIA TO SUPPLY POWER TO AGRICULTURAL COMMUNITIES.

THE LARGEST (1250 KW_E) (REF. 5, 8, 9 & 10) WIND MACHINE TO DATE STARTED IN 1934 WHEN AN ENGINEER, PALMER C. PUTNAM, BEGAN TO LOOK AT WIND DRIVEN GENERATORS TO REDUCE THE COST OF ELECTRICITY TO HIS CAPE COD HOME. IN 1939, PUTNAM PRESENTED HIS IDEAS AND THE RESULTS OF HIS PRELIMINARY WORK TO THE S. MORGAN SMITH COMPANY OF YORK, PENNSYLVANIA. THE S. MORGAN SMITH COMPANY AGREED TO FUND A WIND ENERGY PROJECT AND THE SMITH-PUTNAM WIND TURBINE EXPERIMENT WAS BORN. THE WIND MACHINE WAS TO BE CONNECTED INTO THE CENTRAL VERMONT PUBLIC SERVICE CORPORATION'S EXISTING SYSTEM. OUT OF SOME 50 VERMONT SITES CONSIDERED, A 2000 FOOT HILL, GRANDPA'S KNOB, LOCATED IN RUTLAND, VERMONT, WAS SELECTED. A NUMBER OF ENGINEERS FROM SEVERAL UNIVERSITIES PARTICIPATED IN THE PROJECT. ON AUGUST 29, 1941, LESS THAN TWO YEARS AFTER THE ORIGINAL MEETING, THE BLADES WERE ROTATED FOR THE FIRST TIME.

THE SMITH-PUTNAM MACHINE (FIG. 4) IS PHYSICALLY THE LARGEST WIND MACHINE EVER BUILT AND TESTED. THE TOWER WAS 110 FEET

HIGH WHILE THE ROTOR WAS 175 FEET IN DIAMETER AND HAD AN 11 FOOT 4 INCH CHORD. EACH OF THESE BLADES WEIGHED 8 TONS AND WAS MADE WITH STAINLESS STEEL RIBS COVERED BY A STAINLESS STEEL SKIN. THE BLADE PITCH WAS ADJUSTABLE TO MAINTAIN A CONSTANT ROTOR SPEED OF 28.7 RPM. THIS ROTATIONAL SPEED WAS MAINTAINED IN WIND SPEEDS AS HIGH AS 70-75 MPH. AT HIGHER WIND SPEEDS, THE BLADES WERE FEATHERED AND THE MACHINE WAS BROUGHT TO A STOP. THE ROTOR TURNED AN AC SYNCHRONOUS GENERATOR THAT PRODUCED 1250 KILOWATTS OF POWER AT WIND SPEEDS GREATER THAN 30 MPH. THIS POWER WAS FED INTO THE POWER COMPANY NETWORK. SHORTLY AFTER THE SYSTEM HAD GONE THROUGH ITS INITIAL CHECKOUT AND WAS BROUGHT ON LINE, A MAIN BEARING FAILED. SINCE IT WAS WAR TIME AND THIS WAS A LOW PRIORITY PROJECT, IT TOOK SEVERAL YEARS BEFORE A NEW MAIN BEARING WAS OBTAINED. THE NEW BEARING WAS INSTALLED EARLY IN 1945. FOLLOWING THE INSTALLATION, THE MACHINE WAS OPERATED ONLY A FEW MONTHS WHEN AN OVERSTRESSED BLADE FAILED. TOTAL INTERMITTANT RUNNING TIME ACHIEVED WAS 1100 HOURS. THE PROJECT WAS REVIEWED AND ALTHOUGH CONSIDERED TO BE A TECHNICAL SUCCESS, WAS NOT CONSIDERED TO HAVE DEMONSTRATED FAVORABLE ECONOMICS. USING THE ORIGINAL INSTALLATION COST DATA, ADDITIONAL MACHINES IN SMALL QUANTITIES WOULD HAVE COST APPROXIMATELY \$190/INSTALLED Kw. THE TARGET PRICE IN 1945 WAS \$125/INSTALLED Kw. THE PROJECT WAS STOPPED AND THE WIND MACHINE WAS DISMANTLED.

THE TECHNICAL RESULTS OF THE SMITH-PUTNAM WIND TURBINE CAUSED PERCY H. THOMAS, AN ENGINEER WITH THE FEDERAL POWER COMMISSION, TO SPEND APPROXIMATELY 10 YEARS IN A DETAILED ANALYSIS OF WIND POWER ELECTRIC GENERATION (REF. 10 & 11). MR. THOMAS, USING LARGELY THE ECONOMIC DATA FROM THE GRANDPA'S KNOB OPERATION, INITIALLY CONCLUDED THAT A 5000-10,000 Kw WIND-DRIVEN MACHINE WAS NECESSARY FOR ECONOMIC FEASIBILITY. BASED ON THESE RESULTS, HE DESIGNED TWO LARGE MACHINES; ONE OF 6500 Kw AND THE OTHER OF 7500 Kw.

THE 6500 Kw MACHINE IS SHOWN IN FIG. 5. THE FEDERAL POWER COMMISSION IN 1951 TRIED TO GET CONGRESS INTERESTED IN FUNDING A PROTOTYPE OF THIS MACHINE. BECAUSE IT WAS KOREAN WAR TIME, THE PROJECT WAS NOT FUNDED AND WAS SUBSEQUENTLY CANCELLED. TO GIVE YOU SOME DETAILS OF THE SYSTEM, THE TOWER HEIGHT WAS 475 FEET AND EACH OF THE ROTORS WAS 200 FEET IN DIAMETER. THE ROTORS DROVE DC GENERATORS WHICH PRODUCED 6500 Kw AT WIND SPEEDS GREATER THAN 28 MPH. THE DC POWER FED A DC TO AC SYNCHRONOUS CONVERTER WHICH WAS TO SUPPLY THE ELECTRICAL NETWORK. ALL GENERATING EQUIPMENT WAS TO BE HOUSED ATOP THE TOWER. MR. THOMAS ESTIMATED THE CAPITAL COSTS FOR THIS MACHINE AT \$75/INSTALLED Kw.

THE ENGLISH ALSO HAD A FAIRLY EXTENSIVE WIND ENERGY PROGRAM FROM 1945 TO 1960 (REF. 7). ONE MACHINE SHOWN IN FIG. 6 IS THE ENFIELD-ANDREAU WIND TURBINE. THIS MACHINE WAS BUILT

IN ENGLAND AND SET UP AT ST. ALBANS IN THE EARLY 1950'S. IT WAS DESIGNED TO PUT OUT 100 Kw OF AC POWER IN A 30 MPH WIND. THE TOWER WAS 100 FEET HIGH WHILE THE ROTOR MEASURED 79 FEET FROM TIP TO TIP. THIS MACHINE IS PARTICULARLY INTERESTING IN THAT UNLIKE CONVENTIONAL WIND TURBINES, IT USED AIR RATHER THAN GEARS TO TRANSMIT THE PROPELLOR POWER TO THE GENERATOR. THE PROPELLOR BLADES WERE HOLLOW AND WHEN THEY ROTATED, THEY ACTED AS CENTRIFUGAL AIR PUMPS. THE AIR ENTERED PORTS IN THE LOWER PART OF THE TOWER, PASSED THROUGH AN AIR TURBINE WHICH TURNED THE ELECTRICAL GENERATOR, WENT UP THROUGH THE TOWER AND OUT THE HOLLOW TIPS OF THE BLADES. UNFORTUNATELY, THE INTERNAL AIR DUCT FRICTION LOSSES OF THE MACHINE WERE LARGE ENOUGH TO MINIMIZE ANY ADVANTAGES ACHIEVED BY ELIMINATION OF MECHANICAL COUPLING.

THE DANISH ALSO HAD AN EFFORT DURING THE 1950'S. THE RESULT OF SOME OF THIS WORK, THE DANISH GEDSER WIND TURBINE, IS SHOWN IN FIG. 7. THIS MACHINE, BUILT IN 1957, PRODUCED 200 Kw IN A 33.6 MPH WIND. IT WAS CONNECTED TO THE DANISH PUBLIC POWER SYSTEM AND PRODUCED APPROXIMATELY 400,000 Kw HOURS PER YEAR. THE TOWER WAS 85 FEET HIGH AND THE ROTOR 79 FEET IN DIAMETER. THE GENERATOR WAS LOCATED IN THE HOUSING ON THE TOP OF THE TOWER. THE INSTALLATION COST OF THIS SYSTEM WAS APPROXIMATELY \$205/Kw. THIS WIND TURBINE RAN UNTIL 1968 WHEN IT WAS STOPPED.

THE FRENCH ALSO DID SOME WORK DURING THE 1950's (REF. 7 & 12). IT IS KNOWN THAT THEY BUILT AT LEAST TWO LARGE MACHINES. ONE OF 130 Kw (FIG. 8) HAD A BLADE DIAMETER OF APPROXIMATELY 70 FEET; THE OTHER (FIG. 9), A 300 Kw MACHINE, HAD A BLADE DIAMETER OF APPROXIMATELY 100 FEET AND WAS LOCATED AT NOGENT LEROI, IN FRANCE.

THE GERMANS, UNDER THE DIRECTION OF DR. ULRICH HUTTER, DID SOME VERY FINE WORK IN THE 1950's AND 1960's (REF. 7). THE FIRST MACHINE SHOWN IN FIG. 10 PRODUCED 100 Kw OF POWER IN AN 18 MPH WIND. PREVIOUS MACHINES REQUIRED MUCH HIGHER WIND SPEEDS. THIS MACHINE USED LIGHTWEIGHT, 115 FOOT DIAMETER FIBERGLASS BLADES WITH A SIMPLE HOLLOW PIPE GUY WIRE SUPPORTED TOWER. THIS MACHINE CHANGED BLADE PITCH AT HIGHER WIND SPEEDS TO KEEP THE PROPELLOR ROTATION CONSTANT. DR. HUTTER'S MACHINES RAN FROM SEPTEMBER 1957 TO AUGUST 1968. DURING THIS PERIOD, HE OBTAINED MORE THAN 4000 HOURS OF FULL RATED POWER OPERATION. HE ALSO MADE SUBSTANTIAL CONTRIBUTIONS TO THE DESIGN OF HIGH SPEED WIND TURBINE ROTORS. THE GERMAN EFFORT REPRESENTS ADVANCED WORK ON LARGE WIND MACHINES.

CONSIDERING THE ONES REVIEWED ABOVE AND OTHERS, IT IS CLEAR THAT WIND TURBINE SYSTEMS HAVE BEEN BUILT AND TESTED IN MANY COUNTRIES AROUND THE WORLD. HOWEVER, AFTER RUNNING FOR A WHILE, THESE SYSTEMS WERE DISMANTLED. THE PROBLEM IS THAT THE INSTALLATION COST PER KILOWATT OF CAPACITY OF THE WIND

TURBINES HAS BEEN TOO HIGH COMPARED TO OTHER METHODS OF PRODUCING ELECTRIC POWER. IN ADDITION, BECAUSE OF WIND VARIABILITY, IT IS USUALLY NOT SUFFICIENT TO HAVE A WIND TURBINE ALONE, ONE MUST ALSO CONSIDER FORMS OF ENERGY STORAGE.

TODAY'S INCREASING COST OF FUEL COUPLED WITH POTENTIAL FUEL SCARCITIES HAS CAUSED THE RE-EXAMINATION OF WIND ENERGY AS A FUTURE SOURCE OF POWER. IN THIS REGARD, THE NATIONAL SCIENCE FOUNDATION (NSF) HAS BEEN MADE RESPONSIBLE BY THE EXECUTIVE AND CONGRESS FOR CARRYING OUT THE NATION'S SOLAR ENERGY PROGRAM, A PART OF WHICH IS WIND ENERGY.

WIND ENERGY IS BEING CONSIDERED BECAUSE IT IS:

NONDEPLETING;

NONPOLLUTING;

FREE FUEL SOURCE.

THESE ADVANTAGES MUST BE WEIGHED AGAINST THE DISADVANTAGES:

THE WIND IS A VARIABLE SOURCE;

SYSTEM COSTS HAVE BEEN HIGH.

THE NATIONAL WIND ENERGY PART OF THE SOLAR PROGRAM (REF. 5) CALLS FOR:

(1) STUDIES, CONSTRUCTION, AND TESTING OF WIND ENERGY CONVERSION SYSTEMS WITH AND WITHOUT STORAGE;

(2) STUDIES, CONSTRUCTION, AND TESTING OF ENERGY STORAGE SYSTEMS;

(3) METEOROLOGICAL STUDIES TO ESTIMATE THE WIND ENERGY IN THE NATION AND TO DETERMINE FAVORABLE REGIONS AND SITES FOR WIND-DRIVEN ENERGY SYSTEMS; AND

(4) STUDIES AND IDENTIFICATION OF SUITABLE APPLICATIONS FOR WIND ENERGY DEMONSTRATION TESTS.

THE PLANNED ACCOMPLISHMENTS OF THIS FIVE-YEAR PROGRAM ARE:

(1) IDENTIFICATION OF COST EFFECTIVE WIND ENERGY CONVERSION SYSTEMS;

(2) CONSTRUCTION AND OPERATION OF WIND CONVERSION PROTOTYPES;

(3) DEVELOPED AND PROVEN WIND CONVERSION COMPONENTS AND SUBSYSTEMS;

(4) PROVEN COST EFFECTIVE ENERGY STORAGE SYSTEMS;

(5) AVAILABLE DEMONSTRATION SYSTEMS WITH STORAGE FOR SELECTED APPLICATIONS;

(6) AN ACCURATE ESTIMATE OF THE NATION'S WIND ENERGY POTENTIAL; AND

(7) DEVELOPED TECHNIQUES FOR SELECTING SITES FOR WIND CONVERSION SYSTEMS.

NASA-LERC IS MANAGING THE LARGE SCALE EXPERIMENTS PROJECT; I.E., THE 100 KW AND MW SIZE CONVERSION SYSTEMS. LEWIS' PARTICIPATION IS A DIRECT RESULT OF OUR AERONAUTICAL AND AEROSPACE BACKGROUND. MANY YEARS OF EXPERIENCE IN AERONAUTICS, PROPULSION AND SPACE POWER SYSTEMS RESEARCH AND DEVELOPMENT AND PROJECT MANAGEMENT GIVE US A BROAD CAPABILITY IN ALL THE REQUIRED TECHNOLOGIES.

WE ALSO HAVE FROM OUR LARGE SPACE PROJECTS THE NECESSARY SYSTEMS EXPERIENCE.

THE OVERALL GOAL OF THE WIND ENERGY PROGRAM IS TO EXPEDITE THE DEVELOPMENT OF RELIABLE AND COST COMPETITIVE WIND ENERGY CONVERSION SYSTEMS -- SYSTEMS WHICH ARE CAPABLE OF RAPID COMMERCIAL EXPANSION TO PRODUCE SIGNIFICANT QUANTITIES OF ELECTRICAL ENERGY AS AN ALTERNATIVE ENERGY SOURCE. THIS LEWIS FIVE-YEAR WIND ENERGY PROJECT IS A COMBINED IN-HOUSE/CONTRACTOR EFFORT CONSISTING OF:

- (1) THE SMALL SYSTEMS PROJECT;
- (2) THE MW SIZE SYSTEMS PROJECT;
- (3) SUPPORTING RESEARCH AND TECHNOLOGY; AND
- (4) ENERGY STORAGE.

SMALL SYSTEMS PROJECT. THE SMALL SYSTEMS PROJECT IS TO DEVELOP COST-COMPETITIVE WIND ENERGY CONVERSION SYSTEMS IN THE POWER RANGE OF 50 TO 250 Kw. THE RESULTS OF OUR EARLY DESIGN AND OPERATING EXPERIENCE AND THE SUPPORTING RESEARCH AND TECHNOLOGY EFFORT WILL BE USED TO PROVIDE INPUT TO THE MORE ADVANCED DESIGNS.

THE FIRST 100 Kw MACHINE IS BEING DESIGNED BY LERC USING EXISTING TECHNOLOGY. IT WILL BE INSTALLED AT OUR PLUM BROOK FACILITY NEAR SANDUSKY, OHIO, SOME 50 MILES WEST OF CLEVELAND. THIS UNIT, SCHEDULED TO BE IN OPERATION IN 1975, WILL PROVIDE EARLY OPERATIONAL EXPERIENCE, AND ALSO SERVE AS THE TEST BED

FOR TESTING COST EFFECTIVE COMPONENTS RESULTING FROM THE SUPPORTING RESEARCH AND TECHNOLOGY PROJECT.

BASED ON STUDIES AND OPERATING EXPERIENCE, A 100 KW WIND ENERGY SYSTEM OF ADVANCED DESIGN WILL BE COMPLETED. THIS MACHINE IS TO BE COMPLETED BY CONTRACTOR EFFORT IN TWO PHASES. IN THE FIRST PHASE, CONTRACTS WILL BE AWARDED FOR CONCEPTUAL DESIGN, PARAMETRIC ANALYSIS AND PRELIMINARY DESIGN. IN THE SECOND PHASE, A CONTRACT WILL BE AWARDED FOR DETAILED DESIGN, FABRICATION, ERECTION AND OPERATION OF THE MOST PROMISING FIRST-PHASE DESIGN. IT IS PRESENTLY CONTEMPLATED THAT TWO TO FOUR UNITS WILL BE BUILT AND INSTALLED AT SELECTED SITES. THE SUCCEEDING PROGRAM DEPENDS ON RESULTS OBTAINED FROM THESE EXPERIMENTAL UNITS.

THE MEGAWATT SIZE SYSTEMS PROJECT. THE MEGAWATT SIZE SYSTEMS PROGRAM IS TO DEVELOP WIND-ENERGY CONVERSION SYSTEMS IN THE POWER RANGE OF 500 TO 3000 KW FOR TIE-IN TO EXISTING PUBLIC UTILITY POWER LINES. THIS OBJECTIVE IS TO BE ACCOMPLISHED IN THREE STEPS.

THE FIRST MEGAWATT WIND ENERGY SYSTEM IS BASED ON EXISTING TECHNOLOGY AND SHOULD HAVE GOOD INHERENT RELIABILITY. IT WILL BE DESIGNED AND FABRICATED BY CONTRACTOR EFFORT. THIS WORK, SIMILAR TO THE SMALL SYSTEMS PROJECT, WILL BE DONE IN TWO PHASES. IN THE FIRST PHASE, CONTRACTS WILL BE AWARDED FOR CONCEPTUAL DESIGN, PARAMETRIC ANALYSIS AND PRELIMINARY DESIGN OF A HIGH-

POWER SYSTEM. IN PHASE 2, A CONTRACT WILL BE AWARDED FOR THE MOST PROMISING PHASE 1 DESIGN. THE UNIT WILL BE INSTALLED AT A SELECTED SITE TO PROVIDE EARLY OPERATIONAL EXPERIENCE WITH LARGE SYSTEMS. BASED ON OPERATIONAL EXPERIENCE AND OTHER TECHNOLOGY INPUTS, EXPERIMENTAL UNITS WILL BE CONSTRUCTED FOR TEST INSTALLATION AT SELECTED SITES.

SUPPORTING RESEARCH AND TECHNOLOGY PROJECT. THE SUPPORTING RESEARCH AND TECHNOLOGY PROJECT IS DESIGNED TO DEVELOP COST-EFFECTIVE COMPONENTS AND/OR APPROACHES FOR BOTH THE SMALL AND MW ADVANCED WIND ENERGY SYSTEMS. THE MAIN WORK ELEMENTS RECOGNIZED AT THIS TIME ARE VARIOUS TECHNOLOGY PROJECTS IN BLADES, PITCH CHANGE MECHANISMS, POWER TRANSMISSION MECHANISMS, GENERATORS AND CONTROLS, ENERGY STORAGE AND STRUCTURES.

THE WINDMILL TEST SITE AT OUR PLUM BROOK FACILITY IS SHOWN IN FIG. 11. FOR THE PURPOSE OF ORIENTATION, YOU ARE UPWIND SOUTHWEST OF THE WINDMILL SITE LOOKING NORTHEAST. THIS IS THE DIRECTION OF THE SUMMER PREVAILING WIND. WE HAVE INSTALLED AT THIS SITE A 200 FOOT INSTRUMENTED WEATHER TOWER. THIS TOWER WILL BE USED TO OBTAIN BOTH STEADY FLOW AND GUST WIND MEASUREMENT. A SMALL, 4.1 KW RESEARCH MACHINE WILL BE DOWNSTREAM AND TO THE LEFT OF THIS WEATHER TOWER. THE 100 KW MACHINE WILL BE SOME 600 FEET DOWNSTREAM AND TO THE RIGHT OF THIS WEATHER TOWER.

ALTHOUGH THE 100 KW MACHINE DESIGN IS NOT FIXED, A SCALE MODEL OF THE PRESENT DESIGN IS SHOWN IN FIG. 12. IN THE REAL MACHINE, THE TRUSS TOWER WILL BE 100 FEET HIGH AND THE ROTOR 125 FEET IN DIAMETER (REF, 13). THIS MACHINE IS DESIGNED TO BEGIN TURNING IN 8 MPH WIND AND TO REACH ITS RATED OUTPUT OF 100 KW AT 18 MPH. THE BLADE PITCH CHANGES TO MAINTAIN A CONSTANT TURNING SPEED OF 40 RPM AND 100 KW AT WIND SPEEDS GREATER THAN 18 MPH.

PRESENT DESIGN THOUGHTS ARE TO SHUT THE MACHINE DOWN AT WIND SPEEDS LOWER THAN 8 MPH OR IN EXCESS OF 60 MPH. THIS WIND TURBINE FAVORS THE DESIGN OF DR. HUTTER. THE 40 RPM OF THE MAIN ROTOR GOES THROUGH A GEAR BOX TO TURN AN 1800 RPM 100 KW 480 V 3 PHASE 60 CYCLE SYNCHRONOUS TYPE GENERATOR. IN THE CHECKOUT PHASE OF THE SYSTEM, THE GENERATOR WILL BE CONNECTED INTO A LOAD BANK WHICH IS INDEPENDENT OF THE GRID. AFTER SUFFICIENT EXPERIENCE AND CONFIDENCE IN THE WIND MACHINE ARE ACHIEVED, THE GENERATOR WILL BE CONNECTED INTO THE LOCAL UTILITY GRID. THE GEAR BOX, GENERATOR, AND CONTROL SYSTEMS ARE ALL CONTAINED ATOP THE TOWER.

IN OPERATION, THE BLADES RUN BEHIND THE TOWER. THIS IS OPPOSITE FROM THE WAY MOST WINDMILLS HAVE OPERATED IN THE PAST. THE PROBLEM HAS BEEN THAT THE BLADE SETS UP VIBRATIONS IN THE TOWER CAUSING IT TO FATIGUE. IN OUR DESIGN, THE TOWER SETS

UP VIBRATIONS IN THE BLADE. SINCE THE BLADE IS FLEXIBLE, OUR ANALYSIS INDICATES IT CAN WITHSTAND THESE VIBRATIONS AND PROVIDE THE NECESSARY LONG LIFE.

THIS FAR I HAVE NOT IN THIS TALK ADDRESSED THE VERY IMPORTANT ISSUES OF STORAGE AND POTENTIAL APPLICATIONS OF THE ENERGY PRODUCED. SOME STORAGE MECHANISMS ARE SHOWN IN FIG. 13. ONE METHOD OF STORAGE IS TO USE BATTERIES. TYPICALLY, LEAD-ACID BATTERIES HAVE AN ENERGY DENSITY OF 10 WATT-HOURS PER POUND, ARE GOOD FOR ABOUT 1500 CHARGE-DISCHARGE CYCLES, AND COST \$80/KILOWATT HOUR. AT THE PRESENT TIME, NO OTHER CONVENTIONAL BATTERY SYSTEM APPEARS ABLE TO SUCCESSFULLY COMPETE WITH THE LEAD-ACID BATTERY FOR BULK ENERGY STORAGE (REF. 14). NASA AND OTHERS ARE LOOKING AT ADVANCED BATTERY SYSTEMS POTENTIALLY CAPABLE OF STORING SEVERAL TIMES MORE ENERGY PER POUND OF WEIGHT AT A LOWER COST THAN CAN LEAD ACID. THESE ARE SOME TIME AWAY FROM BEING COMMERCIALY AVAILABLE IN QUANTITY. THERE ARE ALSO PROGRAMS UNDERWAY EVALUATING REDOX OR REDUCTION OXIDATION CELLS (REF. 15). THESE COMPRISE ELECTRODES IMMERSSED IN SUITABLE SOLUTIONS OF ELECTROLYTES THAT ARE SEPARATED BY AN ION EXCHANGE MEMBRANE. TO EXTRACT ENERGY FROM THE CHARGED SYSTEM, THE REDUCING FLUID FLOWS ALONG ONE SIDE OF THE ION EXCHANGE MEMBRANE, WHILE THE OXIDIZING FLUID FLOWS ALONG THE OTHER SIDE. ELECTRONS FLOW FROM THE ELECTRODE IN THE OXIDIZING SOLUTION TO PRODUCE CURRENT FLOW IN THE EXTERNAL CIRCUIT, WHILE IONS

ARE EXCHANGED ACROSS THE MEMBRANE TO MAINTAIN THE ELECTRIC CURRENT AND THE CHEMICAL REACTION. THE SYSTEM CAN BE CHARGED BY FLOWING DISCHARGED FLUIDS ALONG THE MEMBRANE WHILE MAINTAINING A SUITABLE POTENTIAL DIFFERENCE AND CURRENT BETWEEN THE TWO FLUIDS. THE ADVANTAGE OF THIS PROCESS IS THAT THE ENERGY TRANSFER AND STORAGE PROCESS CAN BE VERY EFFICIENT.

THERE IS ALSO WORK GOING ON IN HIGH ENERGY DENSITY FLY WHEELS (REF. 16). RESEARCHERS IN THE FIELD FEEL THAT THEY MAY BE ABLE TO DOUBLE THE ENERGY STORAGE PER UNIT OF WEIGHT COMPARED TO PRESENT LEAD ACID BATTERIES. IF SUITABLE HIGH EFFICIENCY MECHANISMS FOR THE INSERTION AND EXTRACTION OF ENERGY FROM THESE FLY WHEELS ARE DEVELOPED, THEY MAY BECOME A COMPETITIVE METHOD OF ENERGY STORAGE.

SOME OTHER ENERGY STORAGE IDEAS SHOWN ARE TO PUMP WATER INTO A TOWER OR TO COMPRESS AIR WITH THE WIND ENERGY (REF. 17 & 18). AT SOME LATER TIME, WHEN THE ENERGY IS REQUIRED, THE WATER OR AIR COULD BE USED TO TURN TURBINES AND GENERATE POWER.

ONE WIND ENERGY STORAGE TECHNIQUE RECEIVING ATTENTION IS SHOWN IN FIG. 14 (REF. 19). THIS USES THE WIND DERIVED ELECTRICAL POWER TO DISSOCIATE WATER INTO H_2 AND O_2 BY ELECTROLYSIS. THE H_2 AND O_2 CAN BE PIPED TO A SITE WHERE ELECTRICITY COULD BE PRODUCED BY FUEL CELLS OR H_2/O_2 COMBUSTION. THE PROMISE OF THIS SCHEME LIES BASICALLY IN THE LOW COST OF TRANSMITTING THIS H_2/O_2 ENERGY VIA PIPELINES.

ONE POTENTIAL APPLICATION OF WIND ENERGY IS THE COMBINING OF A WIND MACHINE WITH AN EXISTING DIESEL ELECTRIC SYSTEM (FIG. 15) (REF. 5). PRELIMINARY ECONOMIC ANALYSES SHOW THAT WIND GENERATED ELECTRICAL POWER MAY NOW BE COMPETITIVE WITH DIESEL ELECTRIC POWER IN HIGHER AVERAGE WIND AREAS.

ANOTHER POTENTIAL APPLICATION MAY BE TO INTEGRATE A LARGE WIND ENERGY SYSTEM WITH A HYDRO ELECTRIC SYSTEM (FIG. 16). THE ARRANGEMENT SHOWN MIGHT PROVE ECONOMICAL BASED ON A NUMBER OF VARIABLES. A PROPOSAL (REF. 20) MADE BY PROFESSOR HERONEMUS FOR A NATIONWIDE GRID OF WINDMILLS IS SHOWN IN FIG. 17. THE IDEA IS THAT ALTHOUGH THE WINDS ARE VARIABLE, ON THE AVERAGE, THERE IS ALWAYS WIND BLOWING IN SOME AREAS. IF YOU HAD A LARGE NUMBER OF WINDMILLS OVER A LARGE PORTION OF OUR COUNTRY AND THEY WERE ALL INTERCONNECTED, THEN A LARGE AMOUNT OF POWER SHOULD BE PRODUCED ALL THE TIME. THE CONCEPT, OF COURSE, HAS YET TO BE VERIFIED IN A PRACTICAL SENSE.

IN CONCLUSION, WINDS CONTAIN A LARGE AMOUNT OF AVAILABLE ENERGY. RECOGNIZING THIS, SEVERAL COUNTRIES HAVE BUILT AND TESTED WIND MACHINES. THESE MACHINES HAVE SHOWN THE TECHNICAL FEASIBILITY OF WIND GENERATORS. THE PROBLEM WITH THESE MACHINES HAS BEEN THAT:

- (1) WINDS ARE VARIABLE; STORAGE IS REQUIRED;
- (2) THE COSTS HAVE BEEN HIGH WHEN COMPARED TO FOSSIL FUEL SYSTEMS; AND THUS OPERATING COSTS OVER PLANT LIFETIMES FOR WIND

MACHINES APPEAR TO EXCEED COSTS WITH FOSSIL FUEL SYSTEMS;

(3) THERE HAS BEEN NO MAJOR SUSTAINED EFFORT TO MAKE WIND MACHINES COMPETITIVE WITH OTHER ENERGY PRODUCING SYSTEMS.

BECAUSE OF TODAY'S ENERGY PROBLEMS, NASA IS COOPERATING WITH NSF IN A FIVE-YEAR WIND ENERGY PROGRAM. THE OBJECTIVE OF THIS PROGRAM IS TO DEVELOP COST COMPETITIVE WIND ENERGY SYSTEMS. PRELIMINARY ANALYSES SHOW THAT IN THE HIGH AVERAGE WIND AREAS, WIND GENERATED ENERGY CAN BE COMPETITIVE WITH SOME OTHER EXISTING POWER PRODUCTION METHODS.

USING PRESENT STATE-OF-THE-ART TECHNOLOGY, A 100 KW WINDMILL IS SCHEDULED TO BE INSTALLED AND OPERATING AT THE NASA LEWIS RESEARCH CENTER'S PLUM BROOK FACILITY DURING 1975 AS A PRECURSER OF FUTURE LARGER MACHINES.

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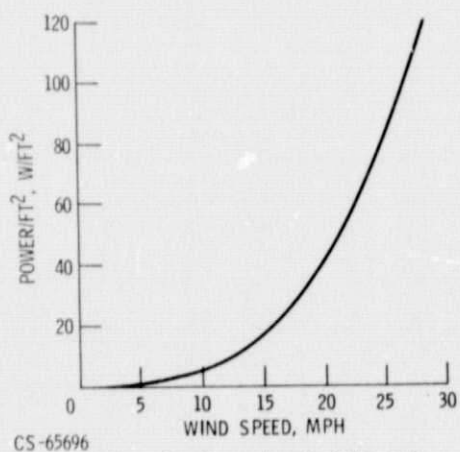
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Figure 1. - Typical Dutch type windmill.



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Figure 2. - Power density of the wind.



Figure 3. - 100 kW Russian Wind-Turbine.



Figure 4. - 1.25 mW Smith-Putnam Machine.

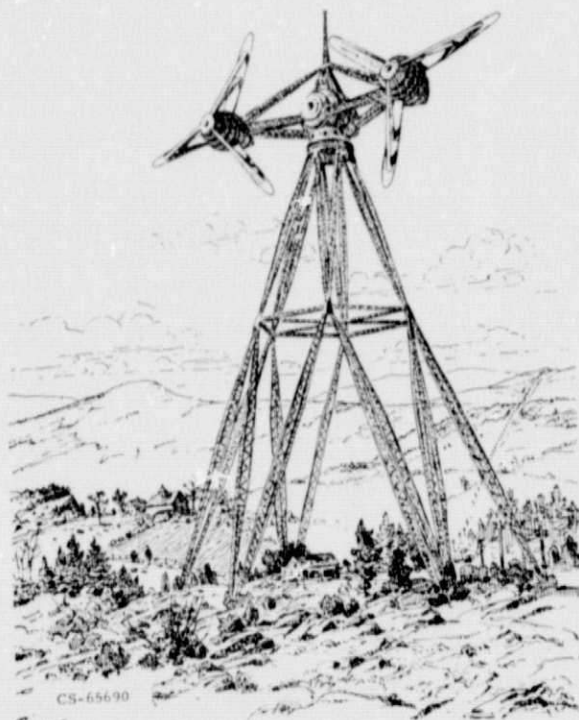


Figure 5. - Proposed 6500 kW Percy Thomas twin wheel turbine.

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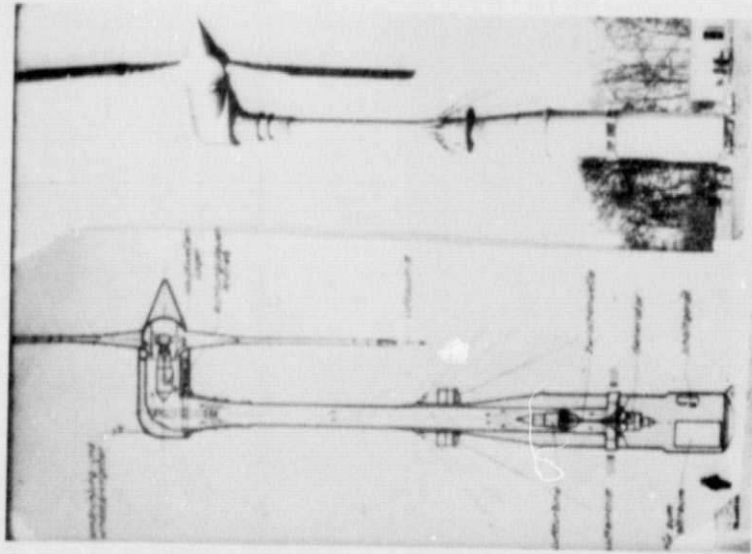


Figure 6. - 100 kW Enfield-Andreu machine.

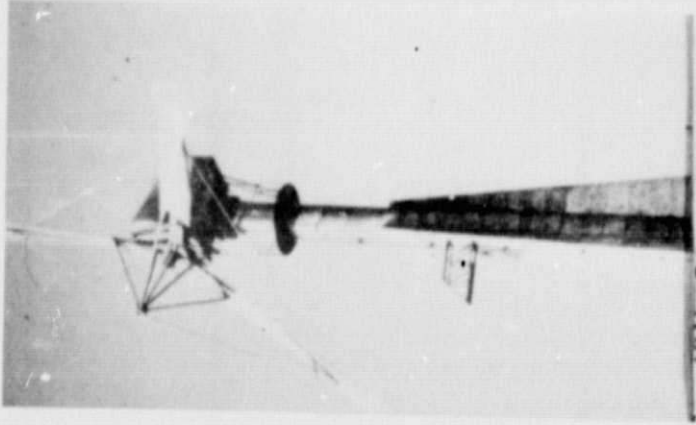


Figure 7. - 200 kW Danish-Geiser wind turbine.

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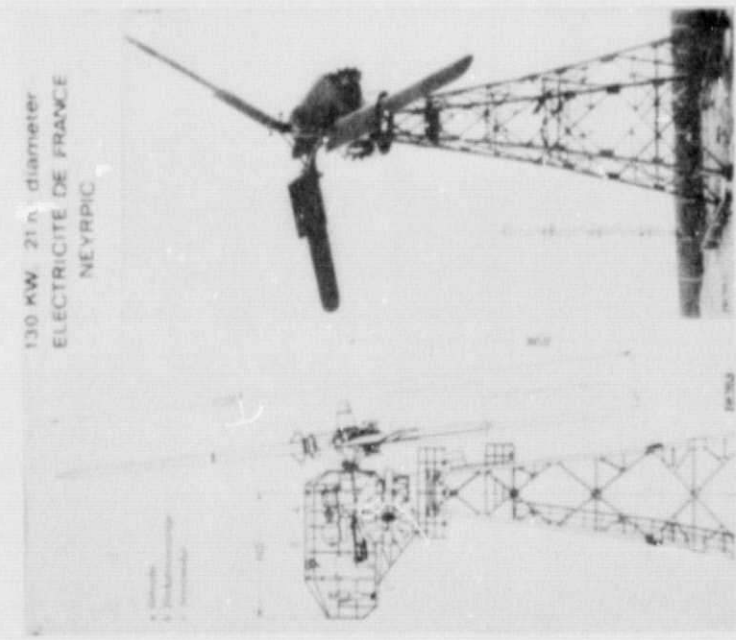


Figure 8. - 130 kW Electricite de France Neyrpic machine.

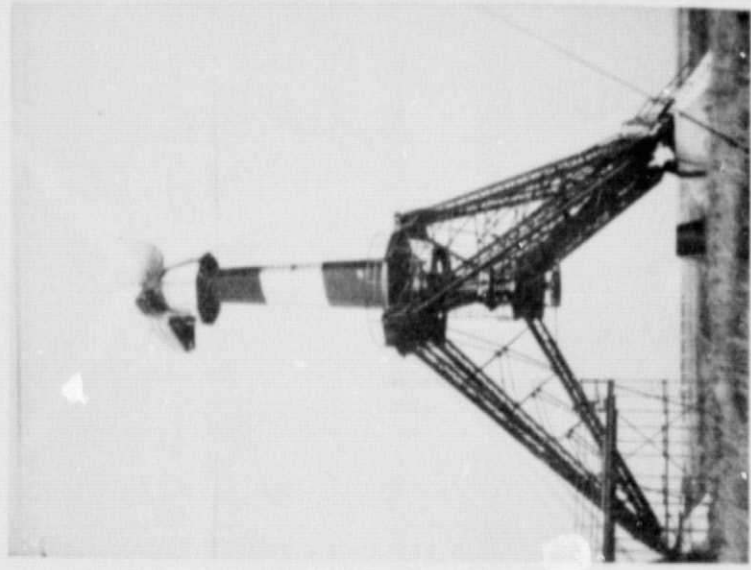


Figure 9. - 300 kW wind turbine located at Nogent Le Roi, France.

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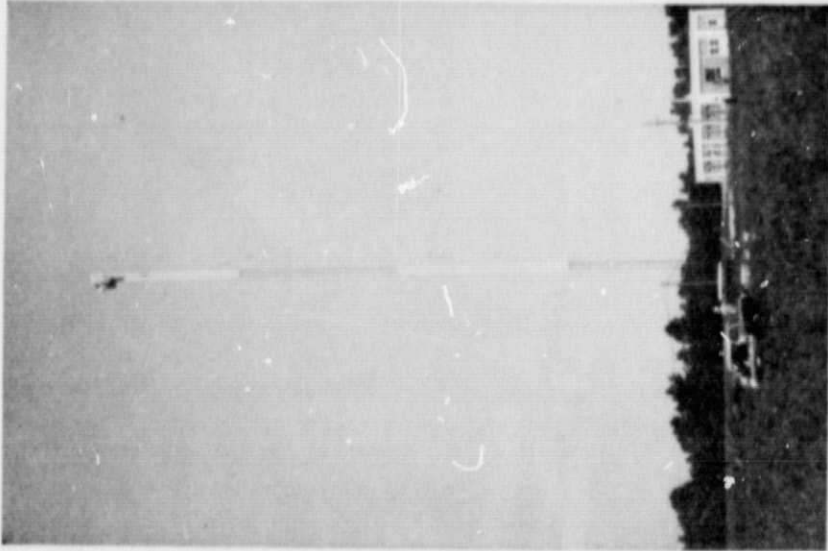


Figure 11. - Weather tower at the Plum Brook 100 kW wind machine site.

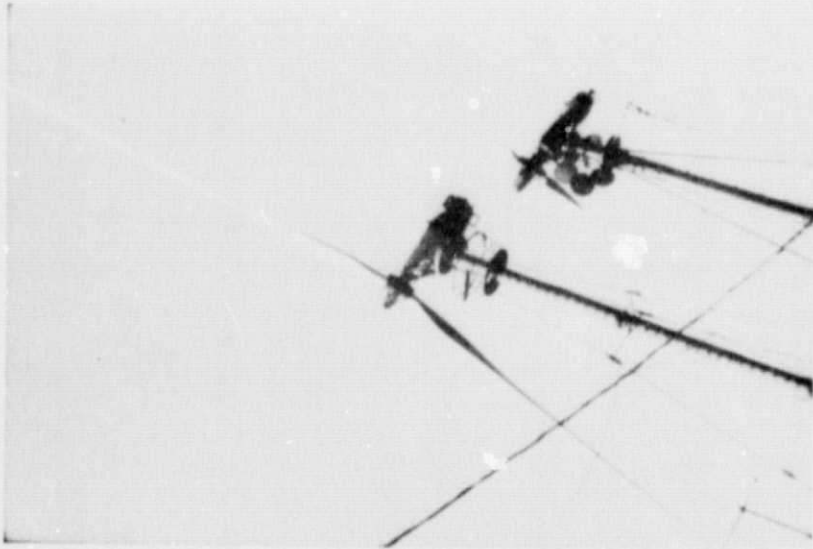


Figure 10. - 100 and 10 kW German (Ulrich Hutter) wind machines.

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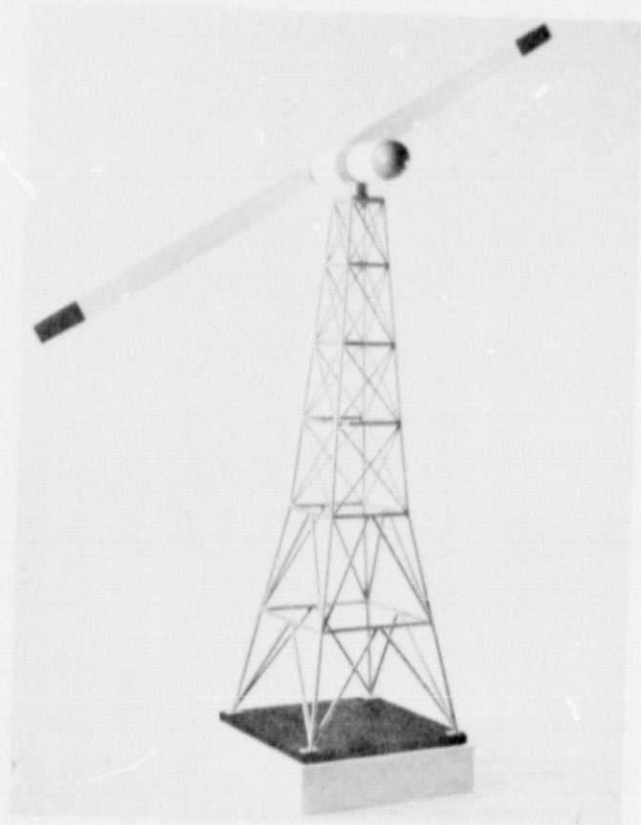
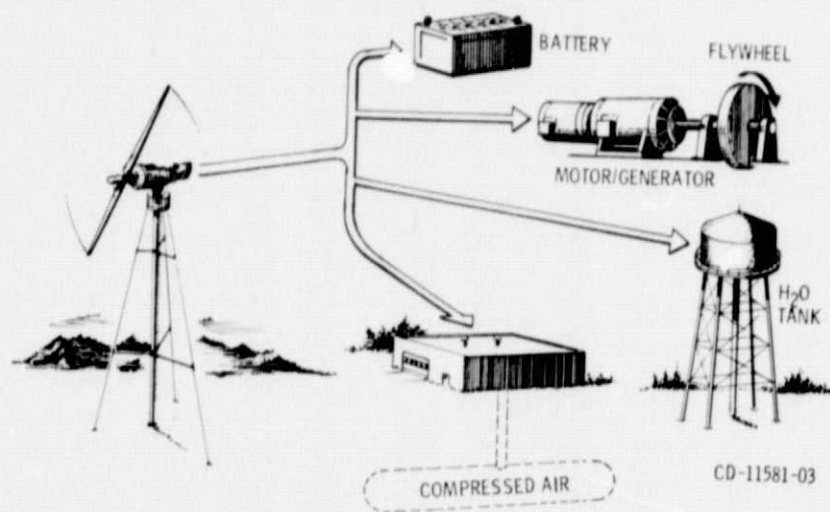


Figure 12. - Model of the NASA-Lewis 100 kW wind machine.



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Figure 13. - Some storage mechanisms for wind energy.

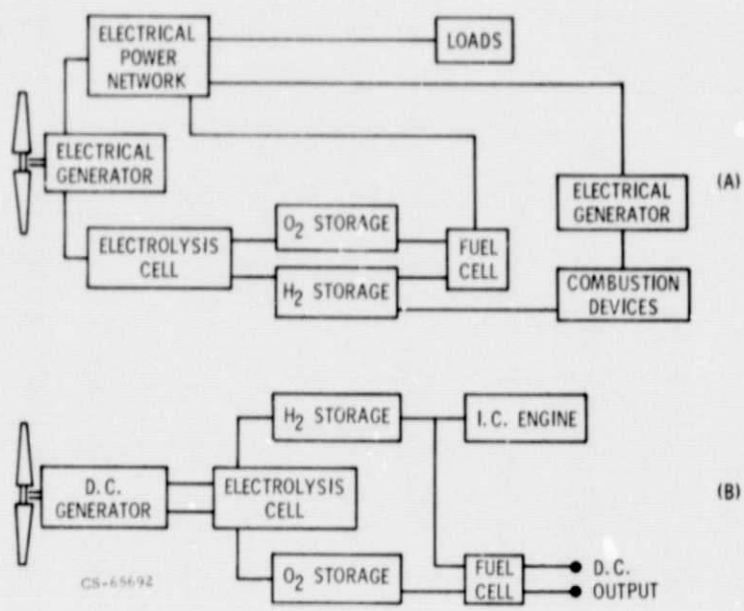


Figure 14. - Electrolysis of water as a wind energy storage mechanism.

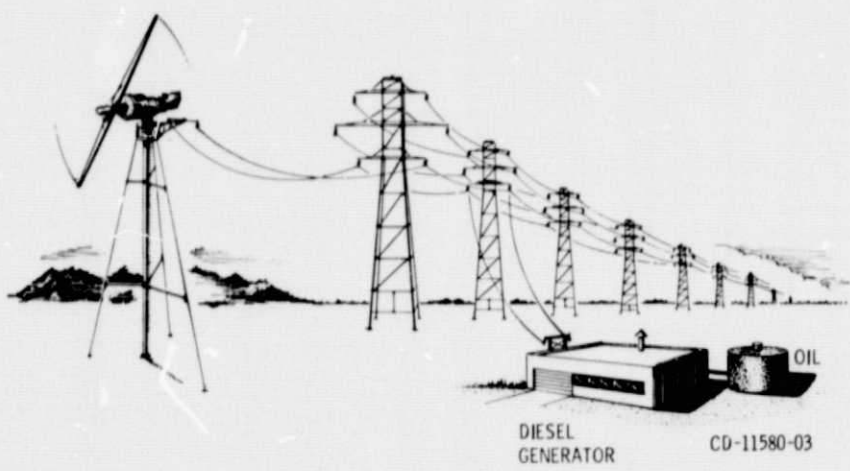
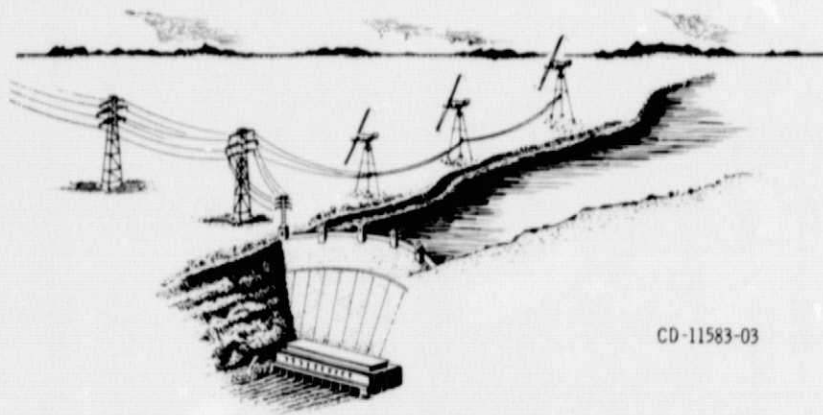


Figure 15. - Wind turbines applied to existing diesel-electric systems.

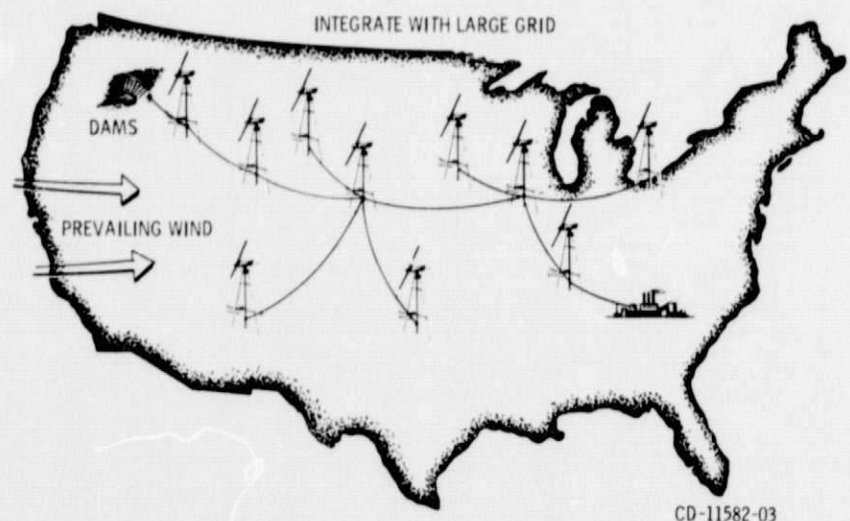
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Figure 16. - Wind turbines integrated with an existing hydroelectric system.

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Figure 17. - Wind turbines distributed to take advantage of prevailing winds.