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by Joseph M. Savino
Lewis Research Center
Cleveland, Ohio 44135

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by Joseph M. Savino

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

Interest in developing large wind-electric generating systems in the United States was stimulated primarily by one man, Palmer C. Putnam. He was responsible for the construction of the largest wind-power system ever built - the 1250 kilowatt Smith-Putnam wind-electric plant. The existence of this system prompted the U.S. Federal Power Commission to investigate the potential of using the winds as a source energy. Also, in 1933 prior to Putnam's effort, there was an abortive attempt by J. D. Madaras to develop a wind system based on the Magnus effect. These three projects comprise the only serious efforts in America to develop large wind driven plants. In this paper the history of each project is briefly described. Also discussed are some of the reasons why wind energy was not seriously considered as a major source of energy for the U.S.

INTRODUCTION

To those of us who are newcomers to the field of windpower, the problem has been one of learning about the past developments so as to build upon the work of the earlier pioneers. This has not been easy, primarily because much of the good engineering, operating, and test data, and experience that has been developed was not always published in the more readily available scientific and engineering journals. Sometimes the results were not published at all. Fortunately, many excellent results are available, but there are great gaps in our knowledge at the present time which hopefully will be filled in the future.

In 1973, the National Science Foundation and NASA's Lewis Research Center sponsored and hosted the first conference on wind energy (ref. 1) in more than a decade. One of the objectives of that conference was to bring together as many persons as possible who were knowledgeable about the work that has gone on in the past. It appears that all serious efforts to develop cost competitive wind energy systems ceased early in the 1960's except for the 200 kW Gedser mill project in Denmark and the Hütter 100 kW project in Germany. Many of the early pioneers have long since passed away or have gone off into other activities, and could not be located. As a result, there still exists large gaps in our knowledge about important past efforts. But the situation is changing.

In recent years there has been a growing awareness everywhere that the future energy needs are not going to be met only by fossil and nuclear fuels and hydropower. Growing with this awareness is the interest in developing alternative energy sources such as several forms of solar energy, the wind being one of them. Much publicity has been given to the various efforts that are being devoted to developing these alternative energy sources.

One result of the oil shortages and the growing concern for the future energy sources has been the coming together of persons from many nations to share information and to seek solutions. The 1974 meeting in Stockholm is one such gathering, and hopefully one outcome will be a clearer and better understanding of past developments in wind power.

One session in the Stockholm meeting is devoted to the review of past work in the developments of wind energy conversion systems with a representative from each of several nations giving a brief summary of the activities that have taken place in his country. I was asked to make a presentation on the important work that had gone on in the United States and this paper is the resulting summary of the attempts to develop large wind-electric systems in the U.S. Fortunately, most of the wind power activities in the U.S. have been well documented. As a result, there is nothing new in this paper that has not been better presented elsewhere, and if it helps guide some interested persons to the original works, which may not be easy to get, then it will have been useful.

MAJOR WIND-ELECTRIC PROJECTS IN THE U.S.A.

Whatever has been accomplished in the U.S. in an effort to develop the wind as an important source of power can be credited largely to the imagination and talents of one man - Palmer C. Putnam. It was due to his enthusiasm and drive that the largest wind-generator in the world was ever built, and then under some of the most difficult conditions possible, namely World War II.

Up until Palmer Putnam came on the scene, the main efforts to develop wind power machines had taken place in the small size (under 5 kW) machines. These were generally three bladed propeller types for generating electricity or multibladed (up to 20 blades) for pumping water. Through the decades of the 1920's, 30's, and 40's thousands of wind-power machines were used to pump water and generate electric power on U.S. farms. There were a number of companies that were manufacturing small wind plants (the Wind-Electric Co. of Minneapolis, Minn. and the Wind Charger Co. of Sioux City, Iowa are two of the better known companies), whereas only a few exist today. The creation of the Rural Electrification Administration (REA) in 1936 was the beginning of the end of the use of the wind as a source of energy.

One objective of the REA was to bring electrical power from large dams and fossil fuel plants to the American farmers, thereby undercutting the interest in developing wind-driven power systems so that today only a few small companies remain that still manufacture wind-generators or wind-water pumpers.

THE J. D. MADARAS PROJECT

There does not seem to have been any interest in developing large size wind plants until the early 1930's when J. D. Madaras (ref. 2) tried to develop a wind-powered machine that utilized the Magnus effect (fig. 1(a)). The Magnus effect is the thrust that is created by a spinning cylinder (or sphere) in an air stream. The most familiar manifestation of the Magnus effect is the "curve ball" that is thrown by a pitcher in a baseball game. Madaras proposed a system consisting of a train of flat cars on a circular railroad track 3000 feet in diameter (fig. 1(b)). On each flat car would be a spinning cylinder, 28 feet in diameter, 90 feet high, and weighing 15 to 40 tons. Each cylinder was to be driven by an electric motor. A component of the Magnus thrust would be parallel to the track and would propel each flat car along the track. Electrical generators were to be connected to the axles of the flat cars and the power generated was to be taken off by an overhead trolley wire. For such a system, it is necessary to reverse the rotation of the spinning cylinders twice per trip around the track to keep the thrust driving the cars in the same direction.

This system was never built. However, an experimental full-size rotor was built at West Burlington, N.J., on a stationary concrete base and tested in October 1933. Under favorable wind conditions and at tangential speeds of 50 mph of the cylinder surface, a translation force of 8000 pounds at right angles to the wind was produced (ref. 3). This experiment is as far as the Madaras concept was ever developed. In fact, there does not seem to have been developed any other nonpropeller type concept in the U.S.

THE SMITH-PUTNAM PROJECT

The next serious attempt to develop large scale wind plants in the U.S. was that of Palmer C. Putnam. (His book, ref. 4, is one of the best documented efforts to develop large wind plants available. In light of the renewed interest in wind power, the book, long out of print, has been reprinted.) The account that follows is largely that given in his book.

Putnam traces the beginning of his interest in wind power to 1934 on Cape Cod where he found that both the electricity rates and the winds were high. It seemed to him that the wind's energy ought to be usable as a source of electrical energy that would be less expensive than the energy he was getting from the power company. He envisioned a wind-generator system that would supply his home on Cape Cod with electrical energy when the wind was blowing with the utility company supplying back-up power when the wind stopped blowing. When Putnam calculated what size wind-generator plant he would need for his all-electric home, he found that it would have to be much larger than any of the systems that were commercially available. This caused him to delve deeper into the problem of how to extract electrical energy from the wind using the most efficient method for the least cost per kilowatt-hour. A study of the various methods and designs that were available (all European) led Putnam to the conclusion that a solution, if it existed, to the problem was in a very large two-bladed propeller type wind-generator that would supply alternating current into the network of an existing hydro system or fossil-steam generating system. The existing hydro or fossil system would function as a back-up system when the wind stopped blowing.

Having concluded that the most promising concept was a large two-bladed propeller type rotor that powered an a.c. generator, Putnam proceeded to develop a preliminary design and made some cost calculations. He showed his design and costs to the Dean of Engineering at MIT, Dr. V. Bush, who reacted quite favorably; this was in 1937. Bush introduced Putnam to a vice president of General Electric Company, Mr. T. Knight, who likewise was favorably impressed. From this point on Putnam was able to enlist the services of some very talented people which included Theodore von Karman, a world famous authority on aerodynamics, to assist in the design, parametric studies, cost analyses, site selection, and determination of wind characteristics.

Putnam, with the help of influential persons, was able to interest the S. Morgan Smith Company of York, Pennsylvania to fund the project and to become the prime contractor in the manufacture of the first experimental wind-generator system. The Smith Company was a manufacturer of hydraulic turbines for use in hydroelectric plants and was interested in diversifying its product line because the number of sites on which hydroelectric plants could be built was decreasing. Hence, the S. Morgan Smith Co. agreed to take on the project.

The Central Vermont Public Service Company of Rutland, Vermont agreed to participate in the project by supplying the site, and allowing the wind-generator to be tied into its network. Central Vermont had no peaking capacity and had to buy power from other sources to meet its peak loads. Central Vermont agreed to participate because it was interested in the potential use of wind-electric plants as supplementary power to its hydroelectric power system and to save water so that the system could meet the peak load demand. In October 1939, the decision was made to proceed with the project, and two years later on October 19, 1941 the 1250 kW Smith-Putnam wind-generator for the first time supplied electric power into the electrical network of Central Vermont Public Service Co. It should be pointed out to those who have not read Putnam's book that a great deal of time and manpower was spent in a study to determine the cost optimum system concept, and size. The result of all the study efforts was the now famous Smith-Putnam wind-generator system, which is shown and described in figure 2. Some photos never before published of the system during various stages of construction are also included in figure 3 as a matter of interest, courtesy of Dr. John B. Wilbur, Chief engineer on the project.

The Smith-Putnam machine ran and was tested off and on during the period from October 1941 to March 1945 for a total of 1100 hours. It experienced the usual problems that are inherent in any large first-of-a-kind experimental system. Wartime conditions added to the problems because it was very difficult to get replacement parts and many of the members of the project group were busy in the war effort and were scattered all over the country. As a result, the wind-generator was idled during most of the test period.

The idle periods were fruitfully used to make changes and refinements on the system that were a direct result of the tests. In addition work continued on costing studies and on plans for a follow-on simplified machine and a preliminary design of a preproduction model.

It is not the purpose of this paper to go into the details of the operating and test experience. These are covered in detail in Putnam's book. Rather, the purpose is to briefly trace the history. As is well known, the wind-generator experienced a serious malfunction. One of the rotor blades broke off in March 1945 at a place where the blade root structure was known to be overstressed. In fact, according to Dr. John Wilbur, the chief engineer on the project, it had been planned to terminate the tests shortly thereafter (ref. 5) simply because there was a great apprehension about how much longer the blade would stay on.

The blade failure itself was not the reason the project was eventually abandoned - it was the economics that ended it. A complete review of the project was planned to take place in 1945. Enough data and experience had been gained to permit the engineers to design a better, simplified version of the original test unit and to make more accurate cost estimates. The results of the review showed that a block of six simplified units would have cost \$190/kW whereas the worth of those six units to the Central Vermont Public Service Co. was about \$125/kW. There were a number of suggestions that could be tried to reduce the costs. It would have cost the S. Morgan Smith Co. several hundred thousand dollars more to test these cost reducing suggestions, and there was no guarantee that they would have succeeded. The company had already spent over a million and a quarter dollars and its directors decided it would not be wise to spend any more. Thus in November 1945, the decision was made to abandon the project.

It is generally agreed that the Smith-Putnam wind-generator system was a technical success. Palmer Putnam proved that systems as large as his could be built and operated and for the want of a few hundred thousand dollars more, he might also have proved that such large systems could be economically successful.

THE PERCY H. THOMAS PROJECT*

Percy H. Thomas was an engineer who was employed by the U.S. Federal Power Commission (FPC) until his retirement in 1949. He was responsible for what are probably the only efforts made, prior to 1972, by the U.S. Government to develop large wind-electric plants as an important source of power. The project went as far as the preliminary design stage, but did not continue to the fabrication and testing stage for the want of funding.

The Central Vermont Public Service Co. included in its annual report to the FPC, probably in 1942, the use of the Smith-Putnam wind-electric plant as a part of its system of operation. The FPC then under a mandate from its charter The Federal Power Act undertook a study to determine the potential of the wind as a source of energy. This study was conducted by Percy H. Thomas and the results were published in four FPC monographs (refs. 6 to 9). Thomas' objectives in this study were to determine the character of the wind as a source of energy, and to determine the feasibility of using wind power in connection with existing power systems - namely hydro and steam electric plants.

To meet his objectives, Thomas:

(1) Studied carefully existing wind data on record with the U.S. Weather Bureau

(2) Developed a preliminary design of a workable wind-electric plant that would be suitable for use in existing electrical networks to determine the plant performance and costs, and thereby determine the economic and operating feasibility of wind-electric systems

(3) Examined in some detail how wind-electric plants could be practically utilized in existing network of hydroelectric and steam-electric plants.

As with the discussion above of the Smith-Putnam project, it is not the purpose of this paper to present in detail what is already well covered in the monographs. Rather, it is the purpose to touch lightly on some, but not all, of the important and interesting results of Thomas' work.

Thomas first took on the task of determining the nature of the wind.

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*In tracing the history of the Thomas effort to develop practical wind-electric systems, I had to rely exclusively on the four FPC monographs (refs. 6 to 9) and on the Hearing before The U.S. House of Representatives' Committee on Interior and Insular Affairs, Sept. 19, 1951 (ref. 10). No other documents, memoranda, or knowledgeable persons could be found to provide a more complete and accurate account. Perhaps this paper will somehow result in more information being uncovered, so that the complete story will be known.

He wanted to learn how much reliance could be placed on the winds, which winds were the most useful, where the useful winds could be found, and how the winds might be used to derive an adequate amount of power. The U.S. Weather Bureau had on record hourly averages of wind speed for hundreds of locations for periods over 30 years, and also instantaneous readings taken four times each day at six hour intervals. He selected the data from 50 of the most representative stations in the country for a period of 31 years.

A study of this large amount of data revealed a number of important facts about the behavior of the wind as related to the use of wind energy. First, Thomas learned that over long periods of time the wind is surprisingly consistent and dependable even though it is quite variable on an hourly and daily time scale. For example, the monthly average wind speed at a location rarely drops below 50 percent of the yearly average and that in a great majority of the cases the monthly averages were within 10 or 1 percent of the yearly average. The yearly average wind speed seldom drops below 10 or 15 percent of the long time average.

Thomas was also interested in whether the diversity in the winds from location to location over a large geographical area would result in a minimum amount of power in an interconnected grid covering the area. He analyzed 5000 pieces of data for 20 stations in 1945 (and 25,000 data points in the 1950's) spread over a large part of the eastern half of the U.S., and tentatively concluded from this limited study that a certain minimum firm capacity, called "diversity capacity," may always be available because of the variations in the wind over a large geographical area.

To determine the economic and operating feasibility of using wind energy in an existing utility, Thomas felt it was essential to develop a design of a workable wind-electric plant using the existing technology of the time. In figure 4 is shown the 6500 kW concept and a short description of the essential features including the capital costs. A similar 7500 kW unit was also designed by Thomas. A complete description of the two designs is given in references 6 and 7. It is interesting to note the difference between Thomas' cost figures and those of the S. Morgan Smith Co. mentioned above. Thomas' figures of $68/kW for the 6500 kW unit and $75/kW for the 7500 kW unit are considerably lower than the $191/kW the Smith Co. calculated. The $191/kW cost was based on actual experiences with the 1250 kW machine and the $68 and $75/kW were not. It would have been most useful if the Thomas plant had been built to check the accuracy of his figures.

When Thomas studied the ways wind derived electricity could best be used, he concluded that connecting the wind-electric plants onto existing networks to be the most practical method for utilizing wind energy. He explains in the monograph (refs. 6 and 9) how an existing hydroelectric (or steam-electric) system would be used to firm up the wind-electric plants. It was envisioned that the hydro plant would supply the difference between the load demand and the power supplied by the wind-electric plants. He did not anticipate any unusual problems in operating a combination of wind and hydro or steam plants. Because the wind-electric plants alone could not supply power on demand, the wind was only considered to be a secondary power source, but a valuable secondary source. In effect, the wind and hydro together would provide a system with a higher base-load possible than from the hydro alone. Also, because the periods of low wind are only days in length, sites that normally would not be used for hydroelectric plants could possibly be used as hydro storage plants to firm up a system of wind plants.

Thus, as a result of this study, using wind-energy in conjunction with hydro and steam electric plants and utilizing the "diversity capacity" of the wind, Thomas was convinced that the wind could be used to supply up to 20 percent of the country's electric power if all the grids were interconnected. He strongly recommended in 1945 that a program be undertaken to demonstrate the use of wind-electric systems.

What events had transpired between 1945 and 1951 when the Hearing (ref. 10) was held is unknown at this time. It is conjectured from the reading of the transcript of the Hearing that the FPC and the Department of the Interior agreed to work together in the construction, testing, and operation of an experimental 7500 kW wind-electric plant in connection with a hydroelectric grid. The purpose of the experiment was to determine the engineering and economic feasibility, and to conduct research and development studies to determine the best plant sites, designs, and operating conditions. The proposed experiment was enthusiastically promoted by the FPC and the Department of the Interior and received enthusiastic support of many of the committee members. But, that is where it ended. It appears that no action was taken by the committee or the House of Representatives. Thomas' 1954 monograph (ref. 9) makes no mention of the proposed experiment or the attempts to get it going. Until more research is done to find records, the detailed history of the 7500 kW project will remain unknown. It has been conjectured by some people that the outbreak of the Korean War in 1951 probably was the indirect reason why the request for authorization and funds for the experiment was never fulfilled. And so, with the end of the Thomas efforts, also ended an era of America's interest in developing large wind-electric systems for more than about 15 years.

WAR BOARD REPORT

One other contribution should be mentioned as an outcome of the efforts in the 1940's, and that is the War Board Report (ref. 11). This document which is not readily available contains detailed technical material on many aspects of wind-generator design. For example, it is one of the few references available that contains the results of systematic wind tunnel tests of different rotor designs. As a result, the War Board Report is a valuable reference to anyone who is actively working to develop reliable and cost-effective wind-electric plants.

REASONS FOR DISCONTINUING MAJOR U.S. WIND-ELECTRIC PROJECTS

The reason the development of the wind as an important source of energy in the U.S. was not seriously pursued any further was probably due to several factors. First, the wind was of itself an undependable energy source that needed some other system such as hydroelectric or fossil fuel plant as a backup, because there existed no suitable energy storage method. In such a case, the wind-electric plant would be a fuel saver and as such would be competing with the cost of fossil fuel (namely coal) which was very low, and coal was abundant. Thus, the abundance of low cost fossil fuel and the absence of environment restrictions which exist today made it possible to build large steam-electric plants for low capital costs.

Secondly, atomic power was being developed and in the 1950's and 1960's, it appeared that atomic power plants would be the ultimate clean and inexhaustible source of energy.

Hence, the incentives to develop wind-power were very low when such attractive options were available, and all efforts to develop wind energy ended until the 1970's when renewed interest developed.

CONCLUDING REMARKS

America's interest in large wind-electric systems was comparatively brief, narrow in scope, but highly productive. Its contributions to wind-power technology were significant, and of the many contributions, probably the most valuable was the demonstration that large size units could be successfully built and operated, and for costs which were less than a factor of two too high on the first generation production machines. These cost figures, even though high, are never the less impressive.

What has been missing in the past efforts to develop cost effective large wind-electric plants has been the sustained effort that is needed to carry on the research and development to the point where enough was learned about the systems performance and costs to determine accurately the economic feasibility of wind-power.

In 1973, the National Science Foundation was given the responsibility for planning and executing a sustained program whose objective is to develop the technology that is needed to build reliable and cost effective wind energy conversion systems that have the potential for early and rapid commercial implementation. The NASA Lewis Research Center and other government agencies are assisting the National Science Foundation in the planning and execution of this program.

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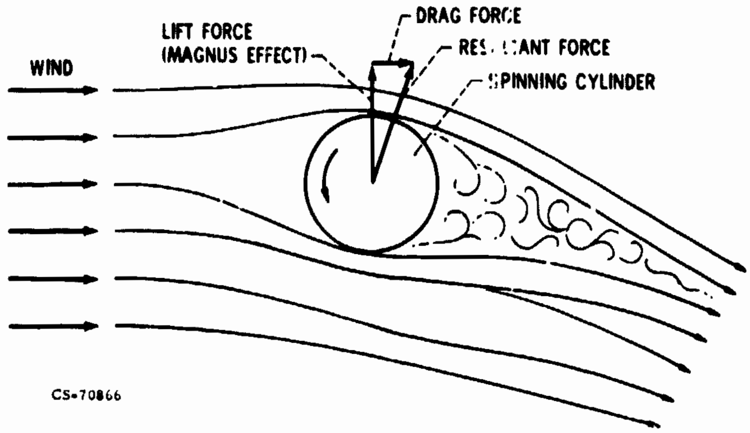

Figure 1(a). - The Magnus effect.

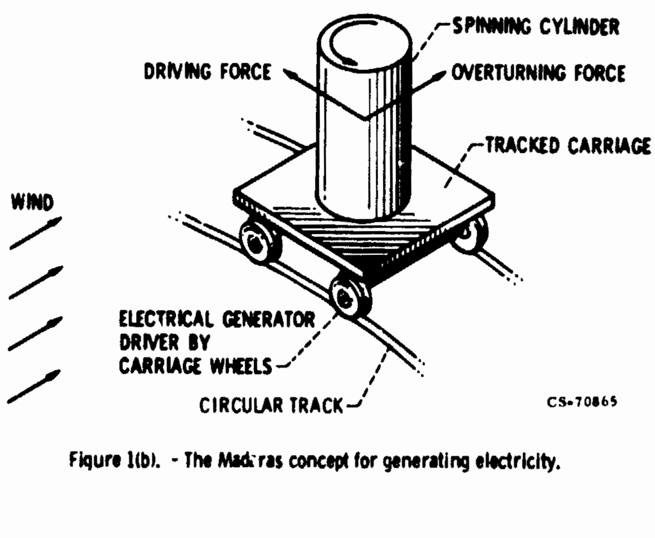

Figure 1(b). - The Madaras concept for generating electricity.

Figure 2. - American Smith-Putnam wind turbine, 1941-1945.

1. The largest wind turbine ever built - tower height, 110 feet; rotor size - 175 feet tip to tip.
2. Was situated on a 2000-foot hill near Rutland, Vermont.
3. Produced a maximum of 1250 kW ac power in winds 30 mph or higher.
4. Rotor drove an ac synchronous generator.
5. The power was fed into the electrical network of the Central Vermont Power Company.
6. It ran intermittently for 1100 hours.
7. An overstressed blade broke off in 1945.
8. Production models of the prototype would have cost $286 673 each ($191/rated kW) in 1945. To be competitive the cost should have been $125/kW, hence the project was terminated.
9. Project was conceived by Palmer C. Putnam and was funded by the S. Morgan Smith Company of York, Pa.

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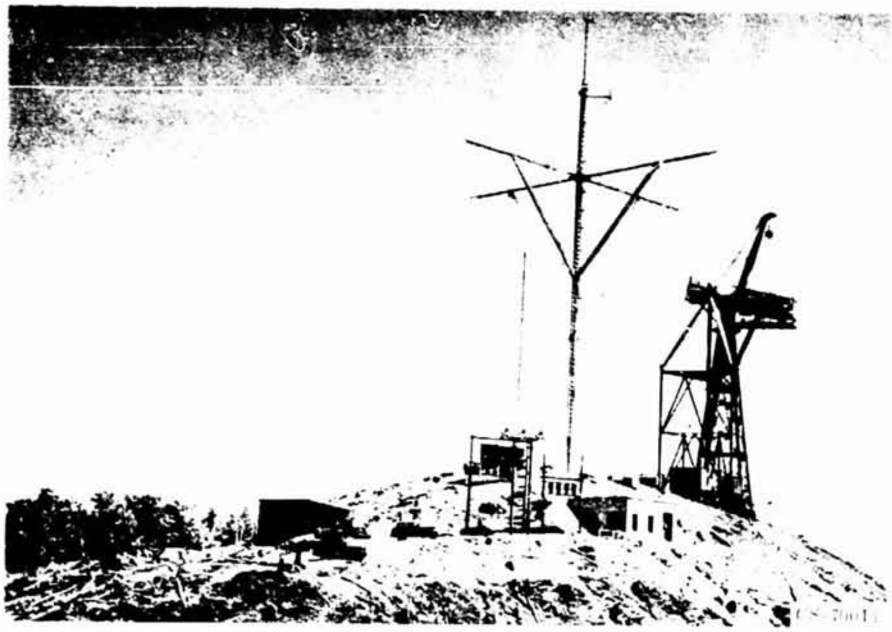

(a) A view of the Summit of Grandpa's Knob showing the wind measurement tower and the Smith-Putnam wind-electric plant being erected in the background.

Figure 3. - Photos of various components during the assembling of the Smith-Putnam wind electric plant. (Courtesy of Dr. John B. Wilbur, Chief engineer.)

(b) A view showing the generator housing platform being lifted onto the top of the tower.

Figure 3. - Continued.

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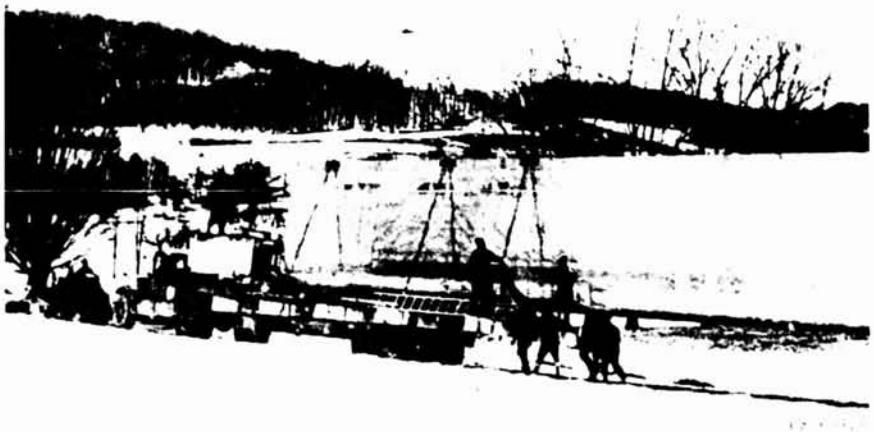
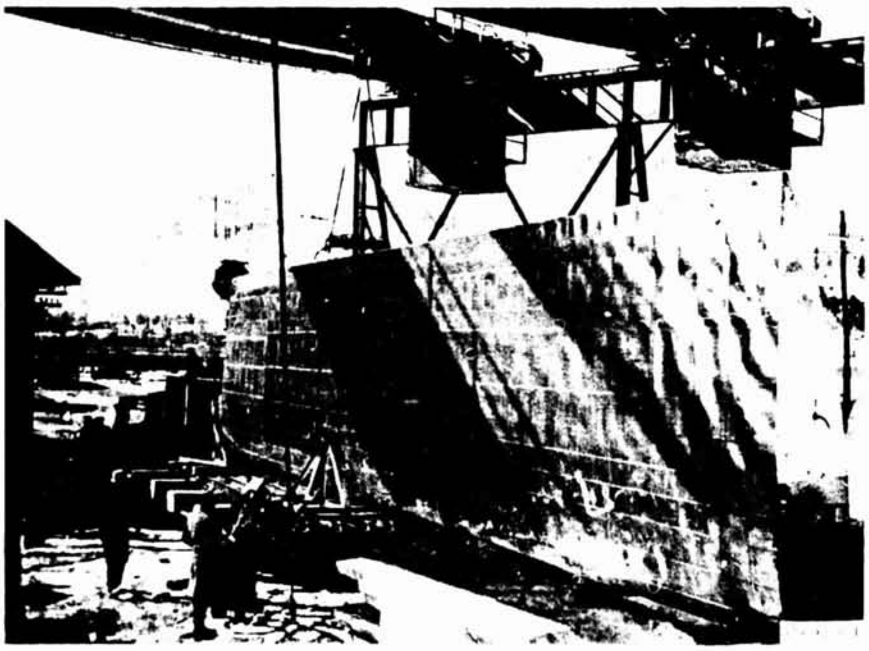


(c) A view showing one of the 8-ton rotor blades being hauled up to the summit.

Figure 3. - Continued.



(d) A view of one of the rotor blades at the base of the tower being readied for hoisting into place at the top.

Figure 3. - Concluded.

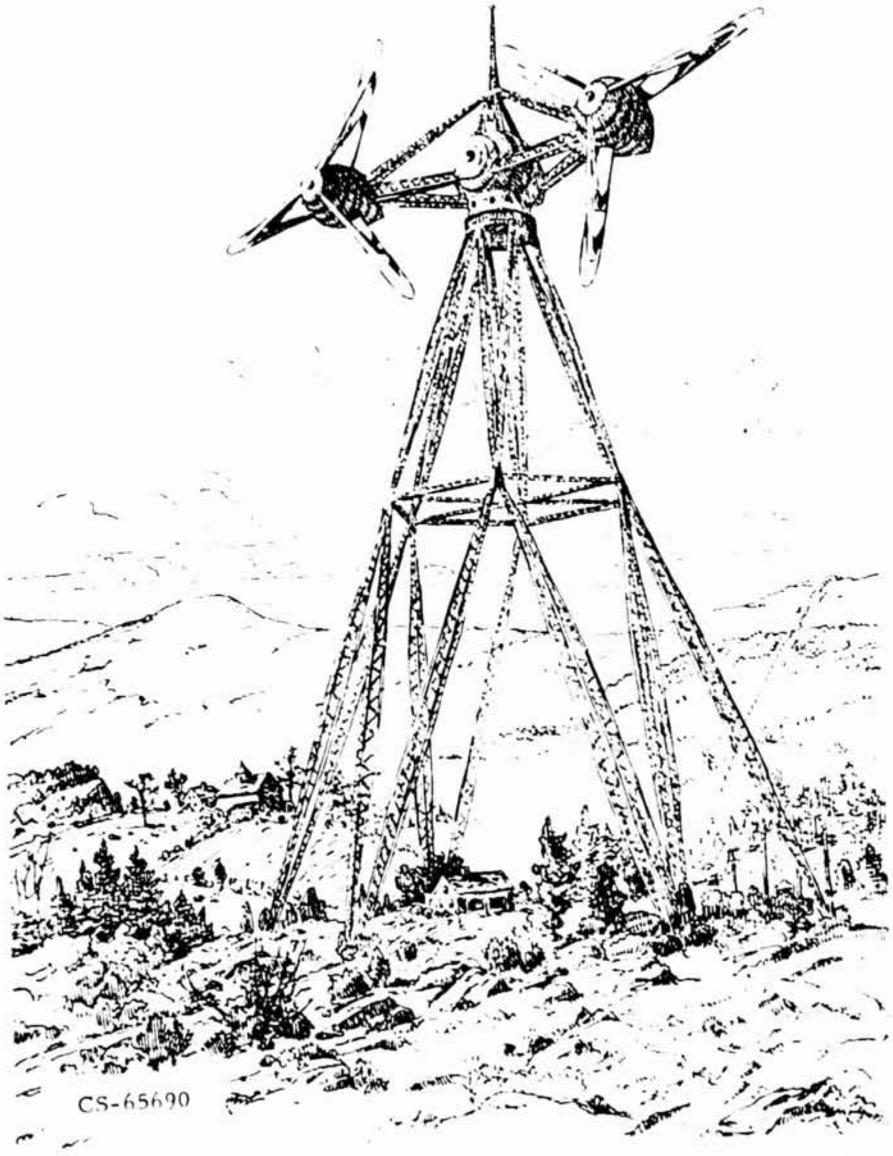


Figure 4. - Percy Thomas (of FPC) 6500 kW design, 1945-1951.

1. Swept area of each rotor - 200 feet diameter.
2. Tower height - 475 feet.
3. Maximum power output - 6500 kW in winds over 28 mph.
4. Rotors were to drive dc generators which were to feed a synchronous converter that was to supply ac power to an electrical network.
5. All generating equipment was to be housed atop the tower.
6. Estimated capital costs were \$68/rated kW.
7. In 1951 an attempt to get money from Congress to build a prototype failed.

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