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Mobile wind energy plant for a low-pressure irrigation system at the Northwest coast of Egypt

Mobile Windkraftanlage für ein Niederdruck-Bewässerungssystem an der Nordwestküste Ägyptens

A. I. Omara, H. Irps, H. Sourell, F. Tack and C. Sommer

Stichworte
Windenergie, Mobile Windkraftanlage, MoWEC, Bewässerungsverfahren, Niedrigdruck-Bubbler-Bewässerungssystem, N.W.-Küste von Ägypten
Keywords
Wind energy, mobile wind energy plant, MoWEC, irrigation techniques, low-head bubbler irrigation system, N.W. coast of Egypt

Zusammenfassung
Eine neue mobile Windkraftanlage, genannt MoWEC, ist mit zwei Dreiblatt-Rotoren ausgerüstet, die in entgegengesetzte Richtungen laufen. Jeder der beiden Dreiblatt-Rotoren hatte einen Durchmesser von 7,10 m. Die erste Leistungskurve des MoWEC-Prototyps wurde im Feldversuch gemessen. Benutzt wurden ein 10-poliger Permanentmagnet-Synchrongenerator, Messeinrichtungen für Spannung und Strom, Heizelemente als Last und ein Dreischalen-Anemometer für die Windgeschwindigkeit. Die Messwerte ergaben einen Gesamtleistungsbeiwert C_{Pt} von 0,32.

Das Niederdruck-Bubbler-Bewässerungssystem kann gut zur Bewässerung von Obstbaumplantagen eingesetzt werden. Das Bewässerungssystem ermöglicht einen ökonomischen Einsatz des Wassers bedingt durch den niedrigen Betriebsdruck. Daher ist auch eine gute Kombination mit erneuerbaren Energien - wie der Windenergie - gegeben. Die Auslegung dieses Bewässerungssystems ist sehr wichtig; deshalb wurde das Computerprogramm LHBIS verwendet, um Niedrigdruck – Bubbler - Bewässerungssysteme einfacher und schneller als auf traditionelle Weise entwerfen und berechnen zu können. Mit Hilfe des Programms wurde zusätzlich ein Niederdruck-Bubbler-Bewässerungssystem für 10 ha an der Nordwestküste von Ägypten berechnet. Der maximale durchschnittliche Monatswasserbedarf für 10 ha Obstbäume beträgt an der N.W. Küste von Ägypten im Juli 19.508 m³. Das durchschnittlich im Monat durch MoWEC gepumpte Wasser an der N.W.-Küste von Ägypten beträgt 21.111 m³. Bei einer Druckhöhe von 24 m wurde ein Wasserpreis von durchschnittlich 3,4 •-Cent/m³ aus den MoWEC-Daten berechnet.

Abstract
A special kind of wind energy plant, named MoWEC, was designed with two three-blade rotors running in opposite directions. Each rotor has had a diameter of 7.10 meters. The first power curve of the MoWEC was measured in a field test with a 10-pole permanent-magnet synchronous

generator, measuring facilities for current and voltage, heating elements as a load and a digital three-cup anemometer for the wind velocity. The MoWEC total average power coefficient was determined at 0.32.

The low-head bubbler irrigation system enabled the economical use of water, and its low operating pressure makes it particularly well-suited for combination with wind energy water pumping systems. The design of this irrigation system is very important, so the computer program LHBIS was used to make low-head bubbler irrigation design simpler and faster than using charts and calculators. This program was used to design the low-head bubbler irrigation system for 10 ha at N.W. coast of Egypt. In July, the maximum mean monthly irrigation requirements for 10 ha orchards trees on the N.W. coast of Egypt were 19,508 m^3 and the average mean monthly quantity of water pumped by MoWEC was calculated to be 21,111 m^3/month. If only MoWEC is used to pump the water and total dynamic head of 24 m, the average cost per m^3 of water would be •-Cents 3.4 per m^3.

1. Introduction

The world energy demand is continually increasing due to the increase in the world's population, economic growth, and energy usage. But the world supply of oil is projected to last approximately 50 years at current production rates (CAMPBELL, 1997 and DUNCAN, 1998). Worldwide, the natural gas supply is adequate for about 50 years and coal for about 100 years (BARTLETT, 1995). These projections, however, are based on current consumption rates and current population numbers.

Renewable energy resources can be defined as energy that is replaced rapidly by natural processes. Renewable energy is beginning to grow out of its initial status and has experienced exponential growth in usage over recent years (HASSAN, 2003). Wind energy is one of the most flexible of all renewable energy resources. It can be used for different purposes such as irrigation, generation of electricity, crop drying, grain grinding and also many other purposes through a wind energy converter system.

Mobile **w**ind **e**nergy **c**onverter **(MoWEC)** is the prototype of a special kind of wind energy plant which allows the installation of more than one rotor and which has a chassis for transportation. The latter makes it possible to use this machine seasonally at different locations. The rotational energy of the prototype, which is produced by the two three-bladed rotors, leads on to two positions to a shaft for power take off (PTO) use. A three point fastening, similar to the three point hydraulic hitch on modern tractors is used to connect the desired energy transformer to the PTO, like, e.g., a mechanical water pump, a permanent magnet generator for stand alone use or with grid connection, an air-compressor for energy storage or other suitable equipment. There are lots of different designs in terms of heights, see Figure 1 and Figure 2. The wings tip heights amounts in the present MoWEC prototype to 10 meters. The total rotor swept area is 80 m^2, because each of the two rotors has a

diameter of 7.10 meters [IRPS and OMARA (2003)]. This first MoWEC has been used for testing and development at the Institute of Production Engineering and Building Research of the German Federal Agricultural Research Center (FAL) in Braunschweig since the beginning of the year 2002.

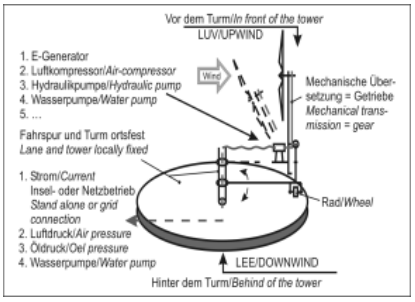


Figure 1:
Construction details of MoWEC (IRPS, 2002)

Figure 2:
MoWEC field test (OMARA, 2003)

Energy costs are more significant than water costs in most countries. Today most irrigation techniques are developed for conditions under which fossil energy plants deliver pump energy every time as needed. In contrast, a wind energy plant in stand alone use converts use energy only according to the present wind velocity. So it requires a wind energy driven irrigation system which has an energy store, here a water tank. It is also necessary to choose an irrigation system based on the energy source availability and reliability.

An electrical wind energy system like MoWEC, working mainly in an adapted irrigation system, can also be used to supply remote regions with electricity for other processes.

Every irrigation system requires a special energy supply. To chose a water and energy saving irrigation technique suitable for a MoWEC application on small orchard farms. According to the comparison of the irrigation methods and the characteristic data the "Low-Head Bubbler Irrigation System" enables the economical use of water, and its low operating pressure makes it particularly well-suited for combination with alternative energy such as wind energy water pumping systems. This irrigation system is particularly well suited for orchard crops and requires very low-pressure heads to distribute irrigation water to the trees. It is based on gravity flow and has large orifice opening to deliver water directly to the root zone, thus eliminating the elaborate filtration systems and pumps required by other micro irrigation systems. Despite these advantages, bubbler systems have not been widely used (OMARA, 2004).

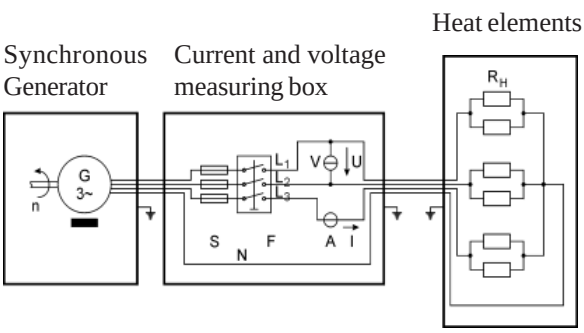
The computer program LHBIS was written and tested by OMARA 2004 to make low-head bubbler irrigation design simpler and faster than the traditional way of using charts and calculators. It allows a user to determine the distributor hose's outlet elevation or distributor hose's length, and required head at constant head device for a given discharge per tree and field condition.

The following chapters present the first measured MoWEC power curve, the MoWEC actual mean monthly energy production and water pumping for bubbler irrigation system on N.W. coast of Egypt

2. Measurement of the MoWEC power curve

The power curve for a wind energy conversion system (WECS) indicates the power output from WECS as a function of the wind velocity at hub height. The power curve of a WECS is an important parameter in the wind plant energy yield prediction. More often the power curve measurements are included in the proposed warranty assessment procedures as part of the wind plant commissioning. The power characteristics therefore need to be determined in a proper way.

First power measurements with MoWEC were made under stand-alone conditions with a permanent-magnet synchronous generator. The generator current is converted with heating elements into air heat, Figure 3.



G = three-phase generator;
F = main switch;
L_1, L_2, L_3 = three-phase current lines;
N = neutral conductor;
S = fuses;
V = Voltmeter;
A = ammeter;
n_g = generator rotation speed;
R_H = six heating elements

Figure 3:
Electric circuit diagram (Generator and electrical consumer in star-connection)

The generator fulfills the international safety class system IP 55 (dust and water protected). It is a 10-pole (5 pairs of poles) generator, which achieves a frequency of 50 Hz at the rotational speed of 600 rpm. During the calibration of this generator, the generator rotational speed, current, voltage, torque and power were measured. The

following equations illustrate the generator characteristics. The generator rotational speed as function of the current is:

$n_g = 43.5\ I_g$ [rpm]

n_g = generator rotational speed in revolution per minute; I_g = generator output current in Ampere

The output generator power and torque as a function of the rotational speed are determined with:

$P_g = 2 \times 10^{-5}\ n_g^2 + 0.0034\ n_g$ [kW] and $T_g = -9 \times 10^{-5}\ n_g^2 + 0.367\ n_g$ [Nm]

P_g = generator output power in kW; T_g = generator torque in Nm.

The heating elements are arranged in three parallel phases according to Figure 3. Their technical data are R = 35.2 Ù and 1500 W. The current I on L_1 L_2 or L_3 was measured with a calibrated current clamp. The wind speeds are measured using a digital three-cup anemometer. This anemometer was fixed on a vertical shaft at the MoWEC hub height.

MoWEC was installed in the field at the FAL experimental station in Braunschweig, Germany, and tested to determine the power curve and the total power coefficient C_{pt}. The wind speed was measured every five seconds. And at each wind speed time, the electric current output from the generator was also measured. Data are taken when winds are available, so a test may be a few minutes long or extend more than an hour. These tests were performed on a day-to-day basis; the end result was a large amount of data taken for a wide range of wind conditions over many days. These data for a given generator output current can be combined with the generator performance equations and so the performance of the MoWEC-prototype could be computed.

3. Results and discussion

3.1 MoWEC power curve

The first MoWEC-prototype power curve was measured in a field test with a permanent-magnet synchronous generator, which reaches 10.6 kW/50 Hz by 600 rpm. A speed of 600 rpm has had a power output of 13.66 kW. So that we could measure the power curve only until the rated power of the installed generator which was chosen for further tests with a second prototype of MoWEC. Figure 4 shows three power curves in relation to the wind velocity. First the wind power, second the extrapolated MoWEC power with the total average power coefficient of C_{pt} = 0.32, and third the measured power curve. The stall rotor diameter was 7.10 m each and the hub heights 6.45 m.

3.2. MoWEC actual mean monthly energy production on N.W. coast of Egypt

MoWEC power curve measurements are used as input for wind plant energy yield predictions in order to compute the MoWEC energy production on the N.W. coast of Egypt. Egypt is located in the north-eastern corner of the African continent. The Northwest coast of Egypt extends about 550 km from Alexandria to Al-Salloum, and about 10-20 km south of the Mediterranean coast.

The daily average wind speed and duration at the N.W. coast of Egypt (stations Alexandria and Mersa Matruh), in the years 1984 to 2002, with wind speeds between 3.5 and 20 m/s were taken to calculate the mean wind speed and duration, see Table 1 (according NWSTOC, 2002).

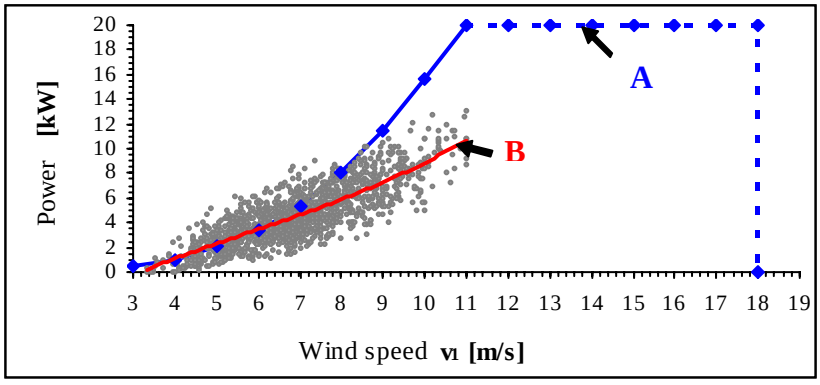


Figure 4:
MoWEC power curve: A = Extrapolated MoWEC power curve with 2 rotors and total C_{pt} = 0.32; B = Measured MoWEC power curve

MoWEC's actual mean monthly energy production was calculated by using the mean monthly wind speed and duration on the N.W. coast of Egypt, MoWEC rotors swept area 80 m², air density 1.225 kg/m³, the MoWEC total power coefficient of 0.32 and the Energy Pattern Factor of 2 [PETER (1993)]. Table 1 shows the actual mean monthly energy production (AMEP) from MoWEC. Where MWS is the mean monthly wind speed in m/s, MWD is the mean monthly wind speed duration in h/month. Table 1 also contains the actual mean annual energy production (AMAEP) by MoWEC in total 27,005 kWh/year.

The total initial investment of the MoWEC-prototype was 26,000 •, with an additional 4,000 • for the generator and water pump. A payback period of 10 years was selected with an annual rate of interest of 8 %, which results in a fixed charged rate of 14 %. Annual operation and maintenance was assumed to be 2 % of the initial

cost, which is 600 •. An actual mean annual energy production of 27,005 kWh/year on the N.W. coast of Egypt was taken for the calculation. The cost of energy with the preceding data was calculated based on the RAMLER-Equation (1979) with 17.77 •-Cent/kWh.

Table 1:
Mean monthly MoWEC energy production on the N.W. coast of Egypt

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
MWS [m/s]	5.62	5.56	5.82	5.61	5.41	5.51	5.32	5.32	5.19	5.10	5.26	5.75	-
MWD [h/month]	384	388	470	451	469	475	504	496	429	429	383	411	5286
AMAEP [kWh/month]	3132	2091	2906	2494	2326	2485	2377	2340	1879	1779	1748	2447	27005

3.1. MoWEC water pumping for bubbler irrigation system at N.W. coast of Egypt
The low-head bubbler irrigation system with different distributor hose outlet elevation is well-suited for the irrigation of fruit trees and orchard crops. In addition, this irrigation system enabled the economical use of water, and its low operating pressure makes it particularly well-suited for combination with alternative energy such as wind energy.

Ground water is adequate and accessible along most parts of the N.W. coast of Egypt at a depth ranging from 5 to 50 m (BALBA, 1981) and EL-MALLAH, 1991). A report by UNDP/FAO (1970) indicated that an area of 137,460 ha in this region is suitable for fruit trees.

If the total orchard field area is approximately 10 ha, the field shall be divided into four large plots; each plot has an area of 100 x 250 m², see Figure 5. The water storage tank will be constructed individually for each plot at the middle of area. In a wind-energy water storage tank system, water is pumped year-around into a storage tank by an electric or mechanical wind-powered water pumping system. The tank and the wind plant are sized so that the crop's water needs are met throughout the year. In this paper it is assumed that the water source is shallow groundwater with a sum of well-depth and draw down of about 12 m, and the total required dynamic head for the pump was calculated to be 24 m by the computer programme, which wrote and presented by OMARA 2004 , see Figure 6. The water level in the tank may be not constant at all operation times, in this case a constant head device must be used to obtain the manifold constant design pressure head at all operation times.

The amount of water needed by the crop depends on the rate of water transpired by the plant and the evaporation rate from the soil surface. The maximum monthly irrigation requirements for 10 ha orchards, olives or citrus trees at the N.W. coast of Egypt were in July; which are 16648, 18093 or 23784 m³/(10 ha $_*$ month) respectively. Figure 7 shows the mean monthly irrigation requirement (MIR) for orchards, olives or citrus trees and water (Q_M) pumped from MoWEC on the N.W. coast of Egypt.

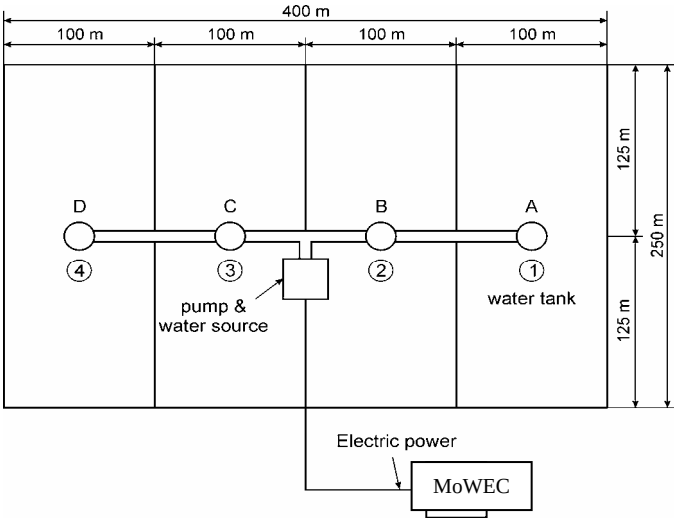


Figure 5:
Layout of the irrigation fields

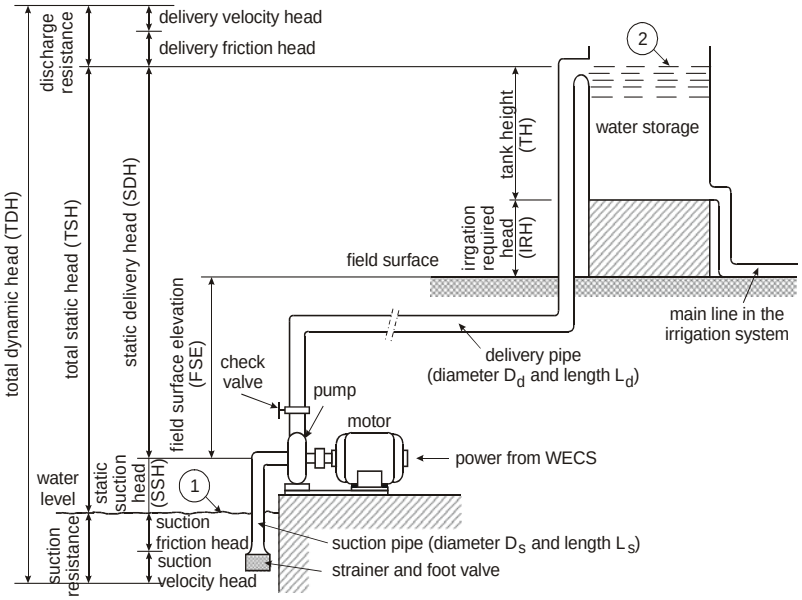


Figure 6:
Typical motor pump unit and water storage installation

The average mean monthly MoWEC water pumped at the N.W. coast of Egypt is 21,111 m³/month when the total dynamic head is 24 m. If MoWEC is used only for pumping the water to irrigate 10 ha of orchards, olives or citrus trees at the N.W. coast of Egypt, the cost per each one m³ of the water with 24 m total dynamic head would be 2.77, 3.92 or 3.5 •-Cent/m³ of water for orchards, olives or citrus respectively based on the economics of the MoWEC-prototype.

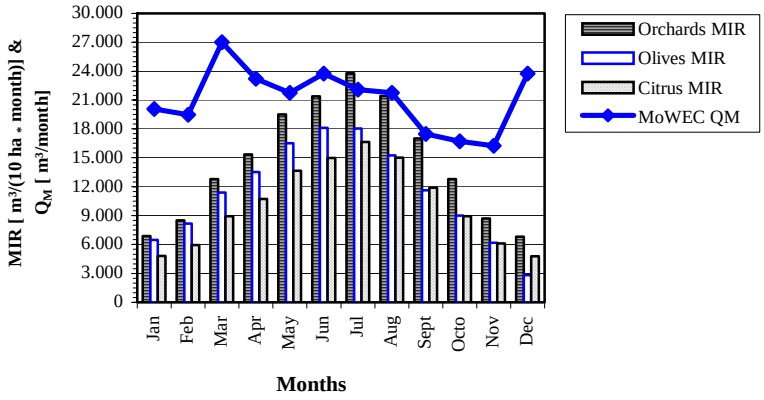


Figure 7:
Mean monthly irrigation requirement (MIR) and pumped MoWEC water (Q_M) at the N.W. coast of Egypt

4. Summary and conclusion

Renewable energy is beginning to grow out of its initial status and has experienced exponential growth in usage over recent years. Wind energy is one of the most flexible of all renewable energy resources.

MoWEC is the prototype of a special kind of wind energy plant. It was designed with two three-blade rotors running in opposite directions and with a yaw drive, which has its travel path on a locally fixed portable frame. The wing tip heights amount in the MoWEC prototype to 10 meters. The total rotor swept area results in 80 m², because each of the two rotors has a diameter of 7.10 meters. The first power curve of the MoWEC was measured in a field test with a permanent-magnet synchronous generator. The MoWEC total average power coefficient was calculated from the power curve with 0.32. The actual mean annual energy production by MoWEC on the northwest coast of Egypt was calculated to 27,005 kWh/year. The total initial cost of the MoWEC-prototype was 30,000 •. The cost of energy was calculated with 17.77 •-Cent/kWh.

The low-head bubbler irrigation enables the economical use of water, and its low operating pressure makes it particularly well-suited for combination with alternative energy such as wind energy water pumping systems. The design of this irrigation system is very important, so the computer program LHBIS was written and tested by OMARA 2004 to make low-head bubbler irrigation design simpler and faster than using charts and calculators.

This computer program was used to design the low-head bubbler irrigation system for 10 ha. The maximum monthly irrigation requirements for 10 ha orchards, olives or citrus trees at the N.W. coast of Egypt were in July; which are 16648, 18093 or 23784 $m^3/(10\ ha_*\ month)$ respectively.

The average mean monthly MoWEC water pumped was calculated with 21,111 m^3/ month, when the total dynamic head is 24 m that calculated by the computer programme. If MoWEC is used only for pumping the water to irrigate 10 ha at N.W. coast of Egypt, the cost per each m^3 of the water would be 2.77, 3.92 or 3.5 •-Cent/m^3 of water for orchards, olives or citrus respectively, based on the economics of the MoWEC-prototype.

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