Brazilian Journal of Biosystems Engineering v. 8(1): 84-96, 2014

CHARACTERISTICS OF HYBRID SYSTEMS FOR ELECTRICITY GENERATION AND APPLICATIONS IN WIND-PHOTOVOLTAIC SYSTEMS

Jair A. C. Siqueira[1*], **Luís R. A. Gabriel Filho**[2], **Fernando L. Caneppele**[3], **Odivaldo J. Seraphim**[4]

[1] UNIOESTE - Univ Estadual do Oeste do Paraná, Campus de Cascavel, PR, Brasil
[2] UNESP - Univ Estadual Paulista, Campus de Tupã, SP, Brasil
[3] Faculdade de Zootecnia e Engenharia de Alimentos, USP - Univ de São Paulo, Campus de Pirassununga, SP, Brasil
[4]Faculdade de Ciências Agronômicas, UNESP - Univ Estadual Paulista, Campus de Botucatu, SP, Brasil

ABSTRACT

A hybrid system uses jointly more than one source of energy for the generation of electricity in which one source complements the eventual failure of the other. The system may be a combination of one or more forms of generation, employing wind power, solar photovoltaic systems, diesel, water, or others, even though energy storage system is not mandatory. Solar and wind power system may be underscored among the energy sources used by hybrid systems since they feature renewable characteristics. The success of their implementation depends directly on the reliability of the operation to the power supply and to the cost of the energy produced. Current study introduces several systems´ characteristics for the generation of electricity. Regarding system design, it is important to analyze costs and usages of the system coupled to electrical system factors, such as charge loss and battery life. A photovoltaic-wind system was built at the Faculty of Agronomic Sciences of Botucatu (UNESP) to disseminate and specify the components of a hybrid system for the generation of electric power. Several research works were performed at the Center for Alternative and Renewable Energies of the Laboratory for Rural Energy of the Agricultural Engineering Department in Botucatu SP Brazil.

Keywords: renewable energy, reliable operation, system sizing, components of a hybrid system.

CARACTERÍSTICAS DE SISTEMAS HÍBRIDOS DE GERAÇÃO DE ENERGIA ELÉTRICA E APLICAÇÕES EM SISTEMAS EÓLICOS FOTOVOLTAICOS

RESUMO

Um sistema híbrido é aquele que utiliza conjuntamente mais de uma fonte de energia para geração de energia elétrica, sendo que tal opção é feita de modo que uma fonte complemente a eventual falta da outra. Tais sistemas podem ser combinações de uma ou mais formas de geração, podendo ser usados sistemas eólicos, fotovoltaicos, diesel, hídricos, ou outros, sendo a opção do armazenamento energético não obrigatória. Dentre as fontes energéticas utilizadas pelos sistemas híbridos, as que mais se sobressaem são a solar e a eólica, ambas de caráter renovável. O sucesso de sua implantação depende diretamente da confiabilidade da operação ao fornecimento de energia e do custo da energia gerada. O objetivo deste trabalho foi apresentar diversas

---

[*] jair.siqueira@unioeste.br

características de tais sistemas de geração de energia elétrica. Em relação ao dimensionamento do sistema, mostrou-se que é importante a análise de custos e formas de utilização do sistema, bem como fatores elétricos do sistema, tais como perda de carga e vida útil da bateria. Como forma de divulgação e especificação dos componentes de um sistema híbrido de geração de energia elétrica, foi eleito um sistema eólico fotovoltaico localizado na Faculdade de Ciências Agronômicas de Botucatu, o qual possibilitou diversas pesquisas junto ao Núcleo de Energias Alternativas e Renováveis do Laboratório de Energização Rural do Departamento de Engenharia Rural da UNESP, Faculdade Ciências Agronômicas, Campus de Botucatu.

Palavras-chave: energias renováveis, confiabilidade da operação, dimensionamento do sistema, componentes de um sistema híbrido.

INTRODUCTION

A hybrid system uses jointly more than one energy source and depends on the availability of local energy resources for the production of electricity (BARBOSA et al., 2004). A hybrid system is feasible so that one source would complement another if failure occurs.

The systems may be wind-generated systems combined with photovoltaic, diesel or water systems in which energy storage may or may not be used (ROSAS; ESTANQUEIRO, 2003). Moreover, according to the above authors, the systems are employed for small isolated networks or for specific applications, such as water pumping, battery charges, supply to small communities and desalinization. The systems´ size may vary between 10 kW and 200 kW. Sizes, however, are tailored according to the case involved which justifies their high costs. However, solar and wind-based energy sources are underscored due to their renewable features (BARBOSA et al., 2004).

These systems aim at producing maximum energy from renewable sources with energy quality and reliability for each project (ROSAS; ESTANQUEIRO, 2003).

According to Hansen (1998), the successful implantation of a hybrid energy system depends on two factors, or rather, the reliability of the operation to produce energy and the costs of generated energy.

According to Rosas & Estanqueiro (2003), the wind-diesel hybrid systems are mostly employed. The main components of the systems comprise wind turbine and diesel-run generator. Other components such as energy storage, devices for energy dissipation and controlled charges may be included so that the system´s efficiency and reliability may be increased.

It should be highlighted that the wind-diesel hybrid system was one of the first systems used. It was installed in New Mexico, USA, in 1977, with a capacity of 200 kW for wind-based electric power and a diesel generated system of 7.85 MW (QUINLAN, 1996).

In the case of Brazil, Cunha (1998) performed several studies to measure wind power potential and demand in Algodoal Island in the state of Pará, Brazil, coupled to simulation for the wind-diesel hybrid system for the production of electricity, whilst Vale (2000) monitored a wind-diesel system for the generation of electricity.

Choi and Larkin (1995) assessed that the wind-diesel hybrid system did not necessarily need a battery bank since most applications had alternate current and most aerogenerators provided this type of current. However, the diesel generator should function continually to avoid fluctuations in the power provided by the aerogenerator (due to oscillations in the speed of wind). The maintenance period must not decrease.

Bhatti et al. (1997) report that in some applications a set of diesel generators of different capacities is employed. It allows that only the generator with the power amount close to the demanded charge should function. It may be necessary that more than one generator may be required in this case. Different methods were employed to reduce the de-locking between the production and the demand. Storage of energy in battery banks is the most employed.

According to Beyer et al. (1995), when energy is stored in battery banks, the system absorbs the surplus energy when wind availability is high and guarantees the storage of the energy demanded to complement or supplement the energy produced by the aerogenerator when wind availability is insufficient. The result consists of an adequate control of electric tension and frequency, a considerable decrease in fuel and a reduction in the on-off cycle frequency, even for short storage periods.

Advanced renewable technology and the expansion of systems involving solar and wind energy favor a decrease in the price of components and new controls may permit the elimination or a greater reduction of the battery bank size (BHATTI et al., 1997).

Ashari & Nayar (1999) report that, in either case, fuel decrease and the lowest price for installation have priority. Control strategies have been developed that would permit the most adequate functioning of diesel generators and which may be employed in applications under different conditions

According to Uhlen and Toftevaag (1996), the use of hybrid systems may decrease the period of functioning and the on-off cycle frequency of the diesel generators by making them work within the curve bands where they are most efficient.

The success of the photovoltaic systems and wind-diesel hybrid and photovoltaic-diesel systems has triggered migration towards the wind-photovoltaic-diesel hybrid systems in the 1990s.

The greatest contributions of the wind-photovoltaic hybrid systems come from research institutes and other institutions interested in the use of renewable energy. They have funded the installation and the monitoring of several installations and have disseminated their experiences in diverse ways (MCGOWAN; MANWELL, 1999).

Several authors (LADAKAKOS et al., 1996; MANWELL; MCGOWAN, 1994; KARINIOTAKIS et al., 1993; INFIELD et al., 1993) developed procedures and models for the whole system and the evaluation of wind-photovoltaic-diesel hybrid systems, even though most of the systems installed are almost exclusively of the wind-diesel type.

ASSESSMENT OF THE HYBRID SYSTEMS

Assessment methods of hybrid systems are generally of the energy type and are foregrounded on the condition that energy produced by different generators may satisfy demand, with evaluation of costs in some cases (CASTEDO et al., 1996).

Manolakos et al. (2001) explain that a method employed by several researchers consists in selecting the size of components and determining the size of the others, aiming at the reduction of the system´s costs and maintenance, and maximizing fuel saving.

According to Elhadidy & Shaahid (2000), an aerogenerator may be chosen that would meet most requirements of demand to decrease the photovoltaic participation due to its relative high price.

García (2004) reports that a more advanced procedure based on the same principle of complementarity is employed for systems without the diesel generator, or rather, a simple wind-photovoltaic system.

The procedure takes into account the production of wind and photovoltaic components and changes in a complementary manner the size of the two types of components so that demand may be complied with.

For the selection of a combined system, Protogeropoulos et al. (1993) suggest the probability of the loss of the system´s charge which decreases in proportion to the increase of the size of the storage subsystem for the same dimension.

Habib et al. (1999) take into account the system´s cost and select the device with the lowest cost. In other words, a constant demand of 5 kW requires a combination of 59% and 41% respectively of wind and photovoltaic participation.

It is highly common for conducting an analysis by the true characteristics of a battery, a photovoltaic module and/or an aerogenerator. The selection process will determine the number of items in each subsystem. For instance, the method by Protogeropoulos et al. (1993) shows the number of modules and aerogenerators required for the probability of the loss of charge and the predetermined capacity of a battery bank.

The method by Habib et al. (1999) requires that the combination is defined by the solar/wind relationship that provides the lowest cost.

So that the energy performance of hybrid systems could be simulated, research groups and institutes have developed computer programs from the modeling of each component of the system (MORGAN et al., 1997; WICHERT, 1997; LADAKAKOS et al., 1996; INFIELD et al., 1993; MACÊDO, 2002; GIACOMINI, 2002).

Childs et al. (1996) studied the impact of an increase in the wind component on the behavior of the network in two isolated communities in the state of Alaska. They tried to establish models that would anticipate instability during transition and also provide the strategies to correct it.

Likewise, Choi and Larkin (1995) determined that the wind-based participation should not exceed 45% of demand; otherwise, the projected control system would not be able to maintain the quality of the network tension in the wake of variations in the wind speed.

Elhadidy and Shaahid (2000) showed that with two aerogenerators featuring 10 kW and 3 kWp of the photovoltaic panel, the diesel generator of the hybrid system produces 48% of the demand which decreases to 23% when a three-battery bank with three storage days is incorporated.

McGowan et al. (1996) tested 11 devices for Brazilian adapted telecommunication systems. The highest power-saving device was that which combined merely the wind and photovoltaic components (with battery bank).

According to Copetti et al. (1993), the battery or battery bank is one of the components of a complex model since its functioning comprises charge and discharge chemical processes, each one responds differently to several factors such as current, temperature and charge status.

García (2004) registers that models determine the capacity of the battery to administer the amount of stored energy or capable of storing. The autonomy of the system and its reliability may thus be estimated.

On the other hand, Ashari and Nayar (1999) established several working strategies to optimize the photovoltaic-diesel hybrid systems. They decreased energy cost in their application from $ 1.16/kWh with the diesel system to $ 0.6-0.8/kWh with the hybrid one. The system´s initial capital for solar and wind energy, hybrid or otherwise, is several times that necessary to acquire a diesel generator of an equivalent capacity. However, the life span of aerogenerators and photovoltaic modules is close to 20 – 30 years (life span of batteries ranges between 2 and 5 years) and, different from diesel generators, require minimum maintenance.

COMPONENTS OF A WIND-PHOTOVOLTAIC HYBRID SYSTEM

A wind-photovoltaic system is described to illustrate the hybrid system. It was installed at the Nucleus of Alternative and Renewable Energies (NEAR) of the Laboratory of Rural Energy Provision of the Department of Rural Engineering of UNESP, Faculty of Agronomy Sciences, Lageado Experimental Farm (Figure 1) in Botucatu SP Brazil, at 22° 51' S and 48° 26' W, mean altitude 786 m. Monthly mean wind speed at a height of 10 m is 3.1 ms^{-1} and mean daily global solar energy is 4772.13 Whm^{-2} (SILVA, 2000).

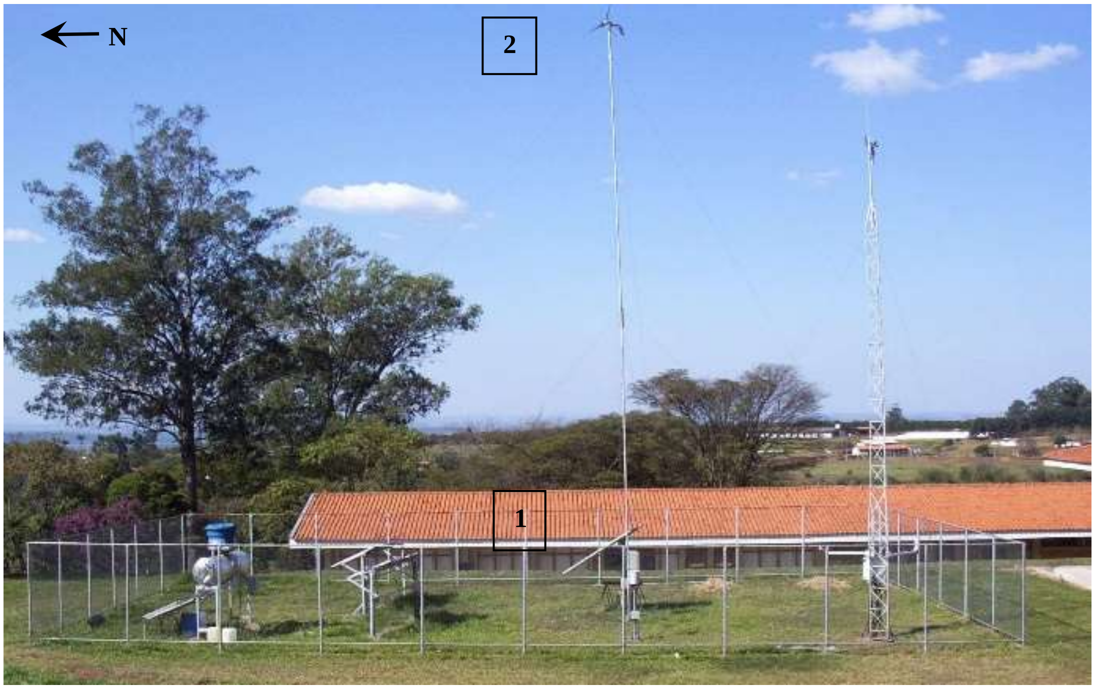

FIGURE 1 – Overview of NEAR and the Wind-photovoltaic system. 1 – The system´s photovoltaic panel; 2 – the system´s aerogenerator; N = geographic North.

Aerogenerator AIR-X rural model Southwest Windpower with a nominal potential of 400W and an internal charge controller was installed to generate electric energy from the wind power available on the spot. The aerogenerator was placed on a 14-m steel tower (Figure 2) and its technical and construction features may be verified in Table 1.

FIGURE 2 – Aerogenerator AIR-X with a 400W nominal potential installed in a hybrid system.

TABLE 1 – Technical details of the aerogenerator in a hybrid system.

AEROGENERATOR AIR-X TECHNICAL DETAILS	
Diameter of rotor	1.15m
Catchment area	$1.04m^{-2}$
Weight	5.85kg
Assembly	1.5” bar Schedule 40
Wind speed at starting point	$3.13ms^{-1}$
Tension	12 and 24VDC
Nominal potency	400 watts at $12,5ms^{-1}$
Controller of turbine charge	Regulator of internal charge based on intelligent microprocessor with probe for maximum potency.
Propeller blades (3):	Made of carbon fiber.
Material	Cast aluminum
Monthly energy generated	38kWh at $5.4ms^{-1}$
Survival at wind speed	$49.2ms^{-1}$ ($177kmh^{-1}$)

Three photovoltaic modules I-100 ISOFOTON with nominal potency of 100Wp each, totaling 300Wp, were employed to supplement the wind-photovoltaic hybrid system with regard to the generation of electric energy from local solar energy. The modules were connected in parallel for current rise, with the same tension at the exit.

Figure 3 shows that the photovoltaic modules were installed on a platform directed towards the geographical north at an angle of 33^o in the same direction, corresponding to the latitude plus 10^o. Table 2 provides the physical, electrical and construction details of the photovoltaic modules.

FIGURE 3 – Photovoltaic module with 100Wp each, installed in parallel, to form the photovoltaic panel of the hybrid system.

TABLE 2 – Technical details of photovoltaic modules employed in the hybrid system.

I-100/12 **DETAILS**	
Physical	
Size	1310 x 654 x 39.5mm
Weight	11.5kg
Number of cells in series	36
Number of cells in parallel	2
Area of the module´s cells	$0.72m^{-2}$
TONC (800 Wm^{-2}, 20 ºC, AM1.5, $1ms^{-1}$)	47 ºC
Electrical (1000 W/m^2, 25 ºC cell, AM 1.5)	
Nominal tension	12V
Maximum potency	$100W_P$ ± 10 %
Short circuit current	6.54A
Open circuit tension	21.6V
Maximum potency current	5.74A
Maximum potency tension	17.4V
Construction	
Cells	Textured, monocrystalline silicone with anti-reflection layer
Contacts	Redundant, multiple contacts in each cell
Laminated	EVA (ethylene-vinyl acetate)
Front segment	Tempered glass resistant to impacts, with high transmittance
Back segment	Protected by multi-layer Tedlar

A 20A ISOLER charge controller by the manufacturer of the photovoltaic modules was installed to protect the battery bank from eventual overloads produced by the photovoltaic panel or high energy consumption by loads, respectively, by excessive production of energy by the photovoltaic panel or by load consuming a very high current.

Figure 4 shows that the controller interconnected the photovoltaic panel, battery bank and charges. When the controller indicates full battery and energy is generated by the panel, energy is directly transferred to the load. When the battery is full but the panel is not generating energy, the battery´s energy is transferred to the load by the controller. Further, when no energy is generated by the photovoltaic panel and the battery has reached maximum charge, charges are electronically disconnected. Table 3 shows the physical, electrical and construction details of the charge controller.

FIGURE 4 – Charge controller ISOLER connected to the photovoltaic panel, battery and charges.

TABLE 3 – Technical details of charge controller connected to the hybrid system panel

ISOLER 20 - DETAILS	
Nominal tension	Automatic selection 12/24V
Equal charge band	15-14.7V
Deep charge tension	14.7V
Flow charge band	14.40 – 13.80V
Deep recharge tension	12.60V
Consumption disconnection tension	11.1V
Consumption reconnection tension	13V
Maximum intensity of generation	20ª
Maximum intensity of consumption	20ª
Permitted overcharge	25%
Auto-consumption	<20mA
Maximum generation/consumption loss	<2W/2W

A 300W PORTAWATTZ inverter model PWZ 300 was employed to transform continuous current tension into alternate current tension (Figure 9).

The inverter supplied energy to alternate current charge. Nominal tension supplied by the inverter was 115VAC +/- 5%. The inverter´s alternate wave was of a modified senoidal form, with features ranging between the senoid and the square wave. Table 4 provides more details on the inverter´s electric characteristics.

FIGURE 9 – Modified senoid tension inverter PWZ 300 installed in the system.

TABLE 4 – Technical details of tension inverter installed in the system.

PWZ 300 Technical details	
Continuous use exit potency	300W
Peak potency	500W
Mean yield	90%
Consumption without any charge	0,1A
Wave form	modified senoid
Entrance tension	10 - 15VDC
Exit tension	115 VCA RMS ±5%
Low tension alarm	10,6VDC
Low tension auto-disconnection	10VDC

An automatic acid lead battery TUDOR 46MVD, 150Ah and 12VDC, was provided to supply energy needs of charges during windless periods or without any solar irradiation.

The battery was connected to the charge controller of the photovoltaic panel and the aerogenerator was directly locked, in parallel, to the battery. The latter has an internal charge controller following recommendations for the installation of wind-photovoltaic hybrid systems manufactured by SOUTHWEST WINDPOWER (2002). Table 5 provides technical details of the battery and Figure 10 demonstrates the battery installed in the system.

TABLE 5 – Technical details of battery installed in the system.

BATTERY TUDOR 46MVD 150Ah **Details**	
Density of electrolyte	1.225gcm^{-3}
Capacity reserve	300 minutes at a discharge of 25A – final tension 10.5VDC
Current at start (27º C)	500A
Current at start, cold (-18°C SAE):	950ª
Nominal capacity	150Ah
Nominal tension	12VDC
Number of plates per element	23
Number of elements	6

FIGURE 10 – Battery TUDOR 46MVD, 150Ah, installed in the system.

FINAL CONSIDERATIONS

Current research essay provided several characteristics of electric energy generation hybrid systems locked to photovoltaic, wind and diesel systems.

Discussions revealed the relevance of cost analysis and usage of the system coupled to the electric factors of the system such as charge loss and battery life span.

A wind-photovoltaic system was installed at the Faculty of Agronomy Science of Botucatu and Nucleus of Alternative and Renewable Energies (NEAR) of the Laboratory of Rural Energy Provision of the Department of Rural Engineering of UNESP, Faculty of Agronomy Sciences, in Botucatu SP Brazil, to disseminate and specify the components of a hybrid system of electric energy generation. The above institutes conducted several researches with photovoltaic (FIORENTINO et al., 2005; SERAPHIM et al., 2011; MOREIRA et al., 2012; GABRIEL FILHO et al., 2010, 2012), wind (GABRIEL FILHO et al., 2008, 2011;) and wind-solar hybrid systems (CANEPPELE et al., 2013; SIQUEIRA et al., 2007).

REFERENCES

ASHARI, M., NAYAR, C.V., An optimal dispatch strategy using set points for a photovoltaic (PV)-diesel-battery hybrid power system. *Solar Energy*, v.1, n. 66, p.1-9, 1999.

BARBOSA, C. F. O.; PINHO, J. T.; SILVA, E. J. P.; GALHARDO, M. A. B.; VALE, S. B.; MARANHÃO, W. M. A. *Situação da geração elétrica através de sistemas híbridos no estado do Pará e perspectivas frente à universalização da energia elétrica*. In: AGRENER 2004 - ENCONTRO DE ENERGIA NO MEIO RURAL, 5, 2004, Campinas. Anais...Campinas: NIPE/UNICAMP, 2004. 10p. CD-ROM.

BEYER, H. G., DEGNER, T., GABLER, H., Operational behaviour of wind diesel systems incorporating short-term storage: an analysis via simulation calculations. *Solar Energy*, v.6, n.54, 429-39, 1995.

BHATTI, T. S., AL-ADEMI, A. A. F., BANSAL, N. K., Load frequency control of isolated wind diesel hybrid power systems. *Energy Conversion and Management*. v.9, n.38, p.829-837, 1997.

CANEPPELE, F. L.; SERAPHIM, O. J.; GABRIEL FILHO, L. R. A.; CREMASCO, C. P.; SAVI, A. F. Gains obtained in hybrid systems of energy generation solar photovoltaic and wind power for rural electrification with the use of fuzzy logic controllers based. *Scientific Journal Agricultural Engineering*, v. 2, p. 35-44, 2013.

CASTEDO, S.; CORBUS, D.; FLOWERS, L.; HOLZ, R.; LEW, D.; MCALLISTER, A. *Wind hybrid systems applications for rural electrification: the case study of Chile*. In: 1996 EUWEC - EUROPEAN UNION WIND ENERGY CONFERENCE, 1996, Goteborg. Proceedings...Bedford: H.S. Stephens & Associates, 1996. 4p.

CHILDS, S. E.; SHERWIN, R. W.; REEVE, B.; *Dynamic modeling of the Kotzebue wind diesel grid*. In: 1996 EUWEC - EUROPEAN UNION WIND ENERGY CONFERENCE, 1996, Goteborg. Proceedings...Bedford: H.S. Stephens & Associates, 1996. 4p.

CHOI, S.S, LARKIN, R., Performance of an autonomous diesel-wind turbine power system. *Electric Power System Research*, n.33, p.87-99, 1995.

COPETTI, J.B., LORENZO, E., CHENLO, F., A general battery model for PV system simulation. *Progress in Photovoltaics: Research and Applications*, n.1, p.283-92, 1993.

CUNHA, D.J., Análise da Viabilidade Técnico-Econômica de um Sistema de Geração Híbrido Eólico-Diesel para a Ilha de Algodoal. Belém, 1998, 94p. Master´s Dissertation in Electric Engineering, Universidade Federal do Pará.

ELHADIDY, M. A.; SHAAHID, S. M. Parametric study of hybrid (wind + solar + diesel) power generating systems. *Renewable Energy*, n.21, p.129-39, 2000.

FIORENTINO, J. J.; SERAPHIM, O. J. Análise da Eficiência de Módulos Fotovoltaicos Instalados em Condições Normais de Operação. *Energia na Agricultura*, Botucatu-SP, v. 20, n.3, p. 89-112, 2005.

GABRIEL FILHO, L. R. A.; GABRIEL FILHO, L. R. A.; VIAIS NETO, D. S.; CREMASCO, C. P.; SERAPHIM, O. J.; CANEPPELE, F. L. Mathematical analysis of maximum power generated by photovoltaic systems and fitting curves for standard test conditions. *Engenharia Agrícola*, v. 32, p. 650-662, 2012.

GABRIEL FILHO, L. R. A.; CREMASCO, C. P.; SERAPHIM, O. J.; CANEPPELE, F. L. Caracterização Analítica e Geométrica da metodologia Geral de determinação de Distribuições de Weibull para o Regime Eólico e suas Aplicações. *Engenharia Agrícola*, v. 31, p. 56-66, 2011.

GABRIEL FILHO, L. R. A.; CREMASCO, C. P.; SERAPHIM, O. J.;

SERAPHIM, O. J.; CAGNON, J. A. Análise do Comportamento da Bateria Utilizada em Sistemas Fotovoltaicos de Pequeno Porte. *Energia na Agricultura*, v. 26, p. 54-70, 2011.

GABRIEL FILHO, L. R. A.; CREMASCO, C. P.; SERAPHIM, O. J. Análise Diferencial da potência Máxima Gerada por um Sistema Solar Fotovoltaico. *Energia na Agricultura*, v. 25, p. 123-138, 2010.

GABRIEL FILHO, L. R. A.; SERAPHIM, O. J.; CREMASCO, C. P.; CANEPPELE, F. L. Metodologia da Determinação dos Parâmetros Característicos de Sistemas Eólicos de Geração de Energia. *Revista Technologia*, v. 9, p. 15-27, 2008.

GARCÍA, F. H. Análise Experimental e Simulação de Sistemas Híbridos Eólico-Fotovoltaicos. Porto Alegre, 2004.185p. Doctoral Thesis in Engineering. UFRGS.

GIACOMINI, A. T., Desenvolvimento de Programa Computacional para Simulação de Sistemas Híbridos, Utilizados em Energização Rural. Botucatu, 2002. 112p. Doctoral Thesis in Agronomy). UNESP/FCA.

HABIB, M.A., SAID, S.A.M. EL-HADIDY, M. A., AL-ZAHARNA, I. Optimization procedure of a hybrid photovoltaic wind energy system. Energy, v.24, n.11, p.919-29, 1999.

HANSEN, U., Technological options for power generation. The Energy Journal. v.2, n.19, p.63-87, 1998.

INFIELD, D. G.; LUNDSAGER, P. et al., *Engineering design tools for wind diesel systems: presentation and validation of the logistic modelling package*. In: 1993 ECWEC - EUROPEAN COMMUNITY WIND ENERGY CONFERENCE, 1993, Lübeck-Travemünde. Proceedings...Bedford: H. S. Stephens & Associates, 1993. 4p.

KARINIOTAKIS, G.; STAVRAKAKIS, G.; NOGARET E; BORDIER M. *Advanced modelling and identification of autonomous wind-diesel power systems*. Application on the French Island Désirade. In: 1993 ECWEC - EUROPEAN COMMUNITY WIND ENERGY CONFERENCE, 1993, Lübeck-Travemünde. Proceedings...Bedford: H.S. Stephens & Associates, 1993. 4p.

LADAKAKOS, P.D., ANDROUTSOS, A.I., PAPADOPOULOS, M.P., 1996. *A probabilistic model for evaluating the performance of wind-diesel power systems.* In: 1996 EUWEC - EUROPEAN UNION WIND ENERGY CONFERENCE, 1996, Goteborg. Proceedings...Bedford: H.S. Stephens & Associates, 1996. 4p.

MACÊDO, W. N. Estudo de sistemas de geração de eletricidade utilizando as energias solar fotovoltaica e eólica. Belém, 2002, 154p. Master´s Dissertation in Electric Engineering, Universidade Federal do Pará.

MANOLAKOS, D., PAPADAKIS, G., PAPANTONIS, D; KYRITSIS, S, A simulation-optimization programme for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas case study: The Merssini village, Donoussa island, Aegean Sea, Greece. Energy, v.26, n.7, p.679-704, 2001.

MANWELL, J.F., MCGOWAN, J.G., A combined probabilistic/time series model for wind diesel systems simulation. *Solar Energy*, n.53, v.6, p.481-90, 1994.

MCGOWAN, J.G., MANWELL, J.F., Hybrid wind/pv/diesel system experiences. *Renewable Energy*, n.16, p.928-33, 1999.

MCGOWAN, J.G., MANWELL, J.F., AVELAR, C., Hybrid wind/pv/diesel hybrid power systems modeling and South American applications. *Renewable Energy*, v.1, p.836-847, 1996.

MOREIRA, C. A. M.; SERAPHIM, O. J.; GABRIEL FILHO, L. R. A. Sistema fotovoltaico monocristalino para bombeamento de água. *Energia na Agricultura*, v. 27, p. 31-47, 2012.

MORGAN, T. R.; MARSHALL, R. H.; BRINKWORTH, B. J. ARES – A refined simulation program for the sizing and optimization of autonomous hybrid energy systems. *Solar Energy*, v.59, n.4, p205-15, 1997.

PROTOGEROPOULOS, C.; MARSHALL, R. H.; BRINKWORTH, B. J. *Sizing scenarios for stand alone hybrid photovoltaic/wind power systems and the effects on system autonomy with battery storage*. In: 1993 ISES - SOLAR WORLD CONGRESS, 1993, Budapest. Proceedings...Budapest: ISES, 1993. 6p.

QUINLAN, P. J. A. Time series of modeling hybrid wind photovoltaic diesel power systems. Master's Dissertation, University of Wisconsin, Madison, USA, 1996.

ROSAS, P. A. C.; ESTANQUEIRO, A. I., Guia de Projeto Elétrico de Centrais Eólicas. Recife: CBEE, 2003. 62p.

SILVA, C. D. Avaliação do Potencial das Energias Solar e Eólica para Acionamento de Pequenos Sistemas de Bombeamento na Fazenda Lageado. Botucatu, 2000. 98p. Dissertação (mestrado em Agronomia). UNESP/FCA.

SIQUEIRA, J. A. C.; SERAPHIM, O. J. Comportamento da energia solar e eólica em um sistema híbrido de pequeno porte para energização rural. *Energia na Agricultura*, v. 22, p. 38-50, 2007.

SOUTHWEST WINDPOWER. Air-X: The New 400 Watt Turbine! - Owner´s Manual. USA: Southwest Windpower Inc, 2002. 48p.

UHLEN, K.; TOFTVAAG, T. *Design and operating experience of a second generation wind-diesel system*. In: 1996 EUWEC - EUROPEAN UNION WIND ENERGY CONFERENCE, 1996, Goteborg. Proceedings... Bedford: H.S. Stephens & Associates, 1996. 4p.

VALE, S. B., Monitoração e análise de um sistema híbrido eólico-diesel para geração de eletricidade". Belém, 2000, 107p. Dissertação (mestrado em Engenharia Elétrica). Universidade Federal do Pará.

WICHERT, B. PV-diesel hybrid energy systems for remote area power generation – A review of current practice and future developments. *Renewable and Sustainable Energy* Reviews, v.1, n.3, p.209-228,1997.