A Review of Wind Energy Based Decentralized Power Generation Systems with New Developments in India

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Abstract

Wind energy based decentralized power generation implies power generation at islands, remote villages or hilly regions either by stand alone wind energy systems or by wind-diesel-solar etc hybrid systems that are not connected to common grid. There is an imperative need to review the past and discuss the present situation in this upcoming field. This paper reviews the research and development in decentralized power generation using wind energy over the last 20 years. Such a review helps the researchers, public, industries and governments to realize the tremendous potential of wind energy based decentralized power generation that reduces transmission and distribution losses and restricts grid expansion. The International status and developments in India are discussed.

Introduction

The most potential application of wind energy is in remote, windy places which have weak Decentralized Power Generation System (DPGS). DPGS means production of electricity near the location of use irrespective of size or technology. Wind energy based DPGS contains either a stand alone wind energy system or wind-diesel-solar etc hybrid systems that are not connected to common grid. The main advantage of a diesel system is good reliability. The disadvantages are high cost and maintenance. Integration of wind energy conversion system (WECS) into the existing DPGS saves cost and improves reliability of power supply. So the wind-diesel-solar etc hybrid system has been recommended in literature in which diesel set forms the back up. The size of WECS in DPGS ranges from a few KW to 5 MW [1]. According to World Alliance for Decentralized Energy (WADE) the total annual global generation based on DPGS has increased to 7.2% up from 7% in 2002. The International Energy Agency and World Bank are realizing the role of DPGS in reducing electricity prices [2].

In this international context this review attempts to explore the developments that have taken place globally and the new trends in India. The selection of wind turbine, electrical generators and power electronic converters with respect to wind energy based DPGS are explained in this paper. The energy storage methods such as long term storage and short term storage are also described. The long term energy storage in the form of hydrogen is stressed. The load control and source control techniques that provide frequency stability in such systems are illustrated.

Decentralized Wind Energy Conversion System (DWECS)

Selection of wind turbine

In the DWECS either horizontal axis (HAWT) or vertical axis (VAWT) wind turbine can be used. In the DWECS operated in parallel with diesel system the turbine size depends upon the size of the diesel set and load. To get high penetration (50% or more) of wind power the wind turbine rating should be twice the diesel rating. However, in low power isolated wind energy conversion system a typical HAWT is preferred [3]. In HAWT as the direction of wind changes, the horizontal axis is turned out by some means to keep blades facing wind. In smaller wind machines, the tail vane serves the purpose without human support. Recently computer simulations are performed to design a wind turbine suitable for a given wind profile to turn out maximum electric power [4].

Choice of electrical generators

D.C. generators are relatively abnormal in WECS because of high cost and maintenance. Nowadays the electrical generators used for WECS are either an alternator or an induction generator. It is normal for a DWECS to have an alternator. The major advantage of an alternator is that its reactive power characteristic can be controlled. It requires flexible coupling in the drive train, or to mount the gearbox assembly on springs or dampers to absorb wind turbulence. It needs frequent regulation of speed or suitable power converters to keep the voltage and frequency at desired level. The alternator that is used in DWECS must be of permanent magnet type in order to avoid excitation requirements. Induction generator is known for its brush less and rugged construction, low cost, simplicity in maintenance and operation, self-protection against faults, good dynamic response, and ability to generate power at varying speed. To operate induction generator in isolated mode external capacitors are employed. Though, it suffered from the frequency drop and poor voltage regulation. Series capacitors were used to improve the voltage regulation. The induction generator can also be operated in parallel with synchronous generator to meet the increased local power demand. The configuration may possibly exploit the advantages of both the machines, i.e. improved power factor of synchronous generator and low power generation cost of induction generator as noted by G.K. Singh [5]. The axial flux permanent magnet generator suggested by B. J. Charlmers [6] gives a relief from the use of gear boxes in wind based DPGS.

Choice of power electronic converters

The effect of wind system on the whole DPGS operation should be considered in designing power electronic interface as the intermittence of wind plays a significant role. A power electronic interface should have the following features: (i) Optimize energy conversion and transmission, (ii) Control reactive power, (iii) Minimize harmonic distortion, (iv) Have high reliability, (v) Have high efficiency and (v) Be low cost. The output power from the DWECS is first converted into dc by using controlled rectifiers. The dc output of the rectifier has to be converted into ac at required level of voltage and frequency. An advanced IGBT inverter was used that increases efficiency, reduces harmonic distortion in the output with an added advantage of control over the active and reactive power [7]. A boost dc–dc converter used in [8] increases the operating range of wind turbine over a wide range of wind speeds. The converter uses a predetermined relationship between generator electrical frequency and dc-link voltage to obtain a high efficiency.

Energy Storage

The advantages of using energy storage in DPGS are stability improvement, economic operation of WECS and reliable electric power. A long term storage battery of 100 KWh connected with two way 120 KW inverter was used in a DPGS that included a 72 KW diesel electric set and two 30 KW wind turbines. This was built by Gunther and Thomas on Irish Island of Cape Clear two decades ago. In short term storage two methods were used: (i) Hydraulic pneumatic storage and (ii) flywheel storage. The hydraulic pneumatic storage was practiced by Bullock and Musgrove. The advantages were acceptable cost, well proven technology, suitability to small systems and helpful to avoid peak lopping. The disadvantages were difficult maintenance and standing losses. In the flywheel storage system, the flywheel and generator are rotating all of the time. The advantages were simplicity, robustness, well proven technology, affordable cost, wide variety of sizes, helps to avoid peak lopping, low standing losses and high efficiency. The disadvantages were KWh of storage not well proven and maintenance problem [3]. In the isolated power system of Israel the use 30 MW battery storage shows that significant reduction in frequency variation due to demand side changes has been achieved [9]. The optimum size of a battery storage unit depends upon the relative size of the subsystems present in DPGS and profit can be achieved using suitable battery [10-11]. The recent technology for long term storage is in the form of hydrogen. The hydrogen stored in the electrolyzer (Fig. 1) is fed to fuel cell to produce electric power [12-13].

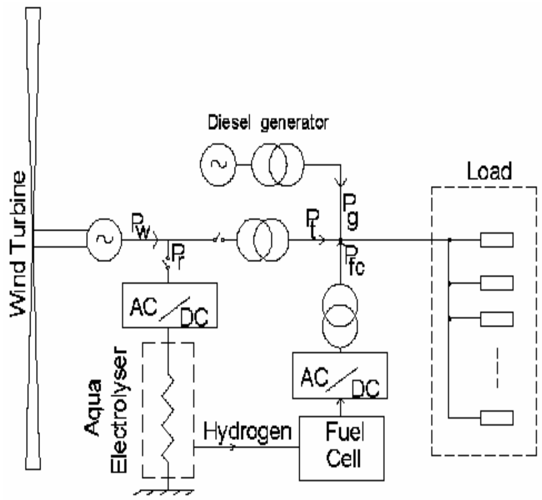

Fig. 1 Typical energy storage by hydrogen

Control System

Load control schemes

Load control minimize the frequency variations by shutting down non-essential loads momentarily to allow DPGS to pass the lulls in wind speed. In the wind diesel system (Fig. 2) of Fair Isle in U.K. the control technique was load switching by frequency sensing switches. The frequency sensing switches in every house will bring the loads in/out rapidly according to the availability of wind [3].The recent techniques in load control are distributed intelligent controllers, distributed fuzzy controllers, robust controllers and adaptive fuzzy logic controllers that are detailed in [14-17].

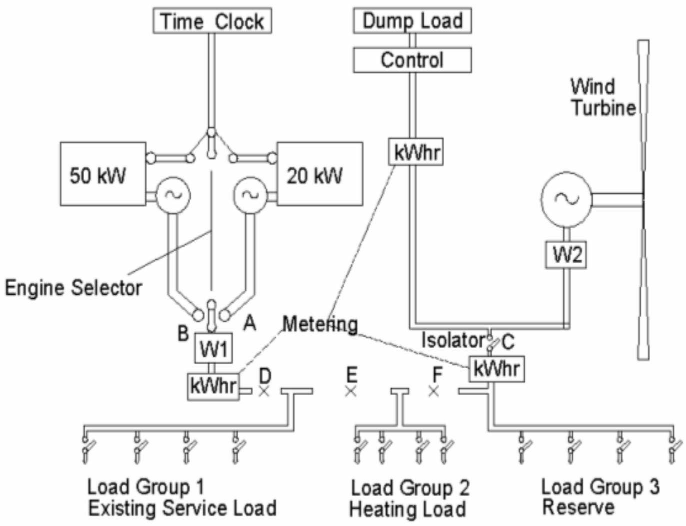

Fig. 2 Typical load control of wind-diesel hybrid system

Source control

The control of power supply units present in DPGS provide frequency stability. The control is made depending upon the availability of source and to achieve maximum utility of the wind energy source available at any time. The Table 1 indicates the four modes of source control. The passivity/sliding mode controller in [18] explains the method of controlling the power generated by the wind subsystem so as to assure the total power demand. A supervisor control provides a flexible decision framework to determine the operation mode of each electrical subsystem [19].

Table 1 Operating modes for frequency control

Wind Condition	Load Demand	Parallel operating sources
Low	High	Wind Energy Converter, Diesel Generator and Battery Bank
Unstable	Normal	Diesel Generator and Battery Bank.
Sufficient	Normal	Wind Energy Converter and Battery Bank.
Low	Low	Battery Bank.

Generation Cost

The profit obtained by adding WECS into a DPGS is calculated in terms of fuel saved during operation of such system. The Probabilistic method [20-23] and Monte Carlo method proved to be excellent for such calculation. In the Monte Carlo method diesel generators are more carefully considered to overcome the disadvantages present in probabilistic method [24].

International Scenario

The Global installed DPGS capacity was around 281.9GW at the end of 2004. Around 32.2GW of DPGS capacity was added worldwide during the two year period between 2002 and 2004 [2]. The Table 2 presents the DPGS survey of few countries that have significant installed capacity.

Table 2 World DPGS data

Country	TEG (TWh)	TEC (GWe)	DPGSG (TWh)	DPGSC (GWe)	DPGSC %	DPGSG %
Argentina	94.8	23.8	1.8	0.5	2.1	1.9
Brazil	350	88.7	11.5	3.5	3.9	3.3
Canada	580	117	65	14	12	11
China	2200	441	332.1	83.8	19.1	15.1
France	542.3	105.9	26.6	7	6.6	4.9
Germany	560	115	100.8	22.8	19.8	18
India	535	112	16.5	5.2	4.6	3.1
Indonesia	108	25	6	3	12	5.6
Japan	1094	268	174	36	13.4	15.9
Mexico	224.9	51.5	18.8	5.6	10.9	8.4
Nigeria	26.5	8.1	9.3	2.1	26.1	34.9
Poland	151.8	28.9	24.4	8.2	28.4	16
Russia	915	208	Nil data	65	31.3	Nil data
UK	376.8	78.5	24.4	4.9	6.2	6.4
USA	3945.6	1031.7	160.3	80	78	4.1

TEG: Total Electricity Generation, TEC: Total Electricity Capacity
DPGSG: Total DPGS Generation, DPGSC: Total DPGS Capacity

Indian Scenario

India ranks fourth in the world in producing electricity from wind. The total installed capacity of Wind Power in India is 4200 MW. State wise contribution in the order of capacity addition is as follows: TamilNadu-364.08 MW, Gujarat-14.05 MW, Maharashtra-154.55 MW, Karnataka-51.85 MW, Rajasthan-26.50 MW [25-26]. In the Indian grid, losses from the transmission and distribution system alone are 20-40%. There is a tremendous potential for DPGS in the industrial, commercial, sugar cane and renewable energy sectors. Main industrial players such as the cement, chemical, petrochemicals, refining and textile sectors have started initiatives in this direction. Moreover, India's Five Year Plan contains proposals for 10,000 MWe of new renewable installed capacity by the year 2012. In India 3.1% of total power generation is by DPGS. A DPGS capacity of 20-30,000 MW from the industrial and commercial sectors could be added by 2012 in India [2]. A DPGS comprising of wind power capacity of 500 KW and diesel generating capacity of 280 KW is supplying electricity to the surrounding villages in Sagar Island in West Bengal since March 2002. Similar projects are under operation at Gandhidham in Gujarat, Auroville near Pondicherry, Sikkim and Nubro Valley in Ladhak. Some of these projects were encouraged by government of India through the Ministry of Non-Conventional Energy Resources, India [25].

Conclusion

According to WADE 2006 DPGS generation added globally is 125 TWh in 2005 and 24.5% of total power generation is by DPGS. In India during 2004 to 2006 the DPGS generation has increased from 16.5 to 68.2 TWh and DPGS capacity increased from 5.2 to 8.7 GWe. The share of DPGS on total power generation rose from 3.1% to 12.1%. Hence major developments are taking place in India and world.

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