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Electrical Hybrid Braking Technique in Wind Turbine Uncontrolled Speed Overcoming

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Abstract: Wind energy can operate big turbines and hence, helps to produce of electrical power. It is a green energy and far less expensive than traditional sources of energy. Wind turbines are encountered with several issues due to their deployment in harsh environments where they are highly susceptible to wind storm and other environmental fluctuation. The windmills are designed to work under particular conditions and it need to be isolated in otherwise. Braking system is vital to windmills life and hence, it need to be selected carefully. This study discusses the technical norms of selecting the brake system that halt wind turbine during uncontrolled conditions such as high speed of wind. Furthermore, the effects of speed on the power quality is also discussed.

Key words: Windmills, EMF, PWM, VAWT, HAWT, clamping force

INTRODUCTION

Todays world is witnessing greet advancement in technology where energy is mostly demanded to run the infrastructure of technology revolution. In order to turn the machinery that associate the success of technology, construction, medical sectors, etc., electrical power is undoubtedly demanded. It is obvious that main source of energy in the world is the hydrocarbons that populated in forms of diesel, petrol, etc. which is being used to operate machinery used in human daily life (Santos *et al*., 2015). The current researches have diverted the focus of hydrocarbons dependents to other source of energy since the fact of hydrocarbons vanishing within several decadesis been validated (Devis *et al*., 2013). So-to-say, human starts to search for hydrocarbon alternatives. Furthermore, in some parts of the world, hydrocarbon ignition within large machines has caused environmental crises and that made some governments to bansome motors and factories that producing harsh out ages for efforts of saving the environment, taking in account the pollution level of geographical areas has been noticeably increased due to hydrocarbons burning (Fan and Wang, 2016). As a result of those incidents, energy companies begin to search new alternatives to substitute the traditional energy sources. The green energy has come into image and shown a good performance in elimination of harmful outputs and reduction of cost. Wind energy is promising substitution of the classical source of energy, it outperformed in open yards such as marine's areas, rural areas and forests where the capacity of air is more. Wind energy can be exploited to turn a wind turbine on and hence, generating electrical power (Uadiale *et al*., 2014). Wind turbine share the same concept of electrical generator as a machine rotating inside a magnetic field and hence, producing Electromotor Force (EMF). The only difference between the wind and normal electric generator is that rotor part of wind generator is connected with big blades operates with air. There are two categories of wind turbines, the most popular kind of wind turbine is the Horizontal Access Wind Turbine (HAWT) as well as the Vertical Access Wind Turbine (VAWT). Generally, the power produced at the wind turbine is directly proportional to the speed of turbine in other word, it proportional to the speed of air in windmills vicinity. Researches shown that two fold of wind speed cause eightfold of turbine productivity of electrical power (Uadiale *et al*., 2014). However, the problem raised when the speed goes higher than usual and above turbine capacity which can cause turbine windings hearing, fusion and ultimately ignition. Furthermore, the mechanical structure of turbine may not sustain in high speed. It is worth to mention that blades have specific tolerance before it gets deconstruction as wind speeds up. The need of speed braking is associated with two concern of the turbine operations such that, turbine structure maintenance and power quality maintenance. This study is concerned to discuss the available techniques of braking and the relation between the speed and power quality in wind turbines.

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Turbine subsystems: Windmills are witnessing set of operations considered as malfunctioning such as faults of turbine as whole or faults occurred at the controlling unites. In order to keep track of every operation taking place in wind turbine, a wind turbine management system is designed and involved monitoring of turbine speed, status of windmills, analyzing of windmills farm that includes many windmills (Datta ana Ranganathan, 2003). Furthermore, breaking system is invented to control the turbine speed and limited the performance of the turbine to the boundaries that permitted bynorms of safety and efficiency. One of the most essential subsystems that integrated with windmills are the breaking devices. These devices are usually termed as emergency subsystem, the main tasks of such devices are prevention the undesired occurrences such as uncontrolled circumstances happened when turbine speed goes higher. Another undesired events that required the action of speed braking device are: system entire failure or partial failure (fault of part of the system). In the next sections, the most popular types of braking devices are discussed for identifying the performance and working norms of them (Hansen *et al*., 2006).

MATERIALS AND METHODS

Windings closure (isolation): The wind turbine generator can be shut by closing the windings in some cases, windings isolation is resulting an emergency braking of wind wheel. In order to perform winding isolation, two possible ways can be taken: the wind farm operator or control system operator can do this job (Okamura, 2017). This technique is different from the classical methods that have similar concept to regulate the speed of turbine such as Pulse Width Modulation (PWM). It is noteworthy that speed control using PWM is completely different operation than speed braking through winding isolation (Peter and Rosso, 2016). The operation of braking the wind turbine by windings isolation may last for relatively long time. The duration of braking is direct proportional to the number of windings involved in the operations.

There are several advantages noticed in this technique such as: as soon as generator windings are closed, the braking operation is taking place within very quick time which maintain the turbine in state of inhabitation. This method can be implemented by opening the windings circuit of the generator, so, it stops moving. This usually requires toggling the relay and this can happen in two ways: either in automated way or in manual way. Very less amount of energy is consumed in automatic toggling of relay to isolate the generator windings. Furthermore, the manual way of toggling can happen by any changing the switching status of the relay manually which is also not taking big time or big efforts. In other word, this method is encountered a smooth and easy operations (Rijanto *et al*., 2012).

In same regard, some drawbacks are also encountered while using this technique. This technique can deliver rapid braking of wind wheel which can cause a serious damage to the mechanical and civil objects in the windmill field vicinity. These unfortunates can be happened at the conditions when the speed of turbine is very high, more occurrences are being experienced due to the same such as blades deconstruction or turbine base damages. The rapid braking (braking over very short time) usually yields a large amount of heat energy which leads to fusion of windings slots and then to winding ignition. This method of braking is limited only for no load usage more likely, when the turbine generator windings areyet heated up. Otherwise, this method is completely incompatible when the windings of generator already encounter some level of temperature such that when generator is running since long time (Kirpichnikova *et al*., 2013).

Tread braking: This is as well folded under the emergency braking of wind turbine. However, this technique is taking place by pads compression around the disk located on the turbine wheel. The pads are located around the disk and can be compressed up to stop the rotation of the wheel (Travaglia and Lopes, 2014). This technique is the most suitable technique to tackle the heat problem that act against using other ways of braking. This kind of braking is happening with involvement of electro or hydro force (drivers) to compress the pads around disk. In case of electric driver is used, the reducer is also integrated with the braking system in order to produce the translational motion from the rotational motion (Abhang and Bhaskar, 2014). The benefits of this technique can be listed as herein: reliability which means (system is trusted by other applications) that system is outperformed for long years, since, it had deployed by automotive companies as method of auto braking before it being used in wind turbines sector, the torque resulted from this braking (disk halting) can provide a supportive shoulder for braking torque applications; lastly, this technology is fit as solution of temperature absorbing, so, it can be deployed in high temperature conditions. Some disadvantages are also experienced while using of this technology, the disadvantages can be listed herein: the challenges of space which means that area occupied by this braking device is very big due to the large dimension designed for this device, this leads to their impossibility to be deployed in small windmills and they sare limited to be used in large windmills only (Belhocine and Abdullah, 2014), the second point that also considered as major drawback of this technique is electricity consumption, the pads compression on the disk are consuming large amount of electrical energy to perform the braking, the other way of tackling the energy consumption drawback is using the hydraulic drive instead of electrical drive, this solution is required larger space than usual to accommodate the additional devices of hydraulic station. The above interpretaton of tread braking technique revealed that technique can out perform as braking solution, if either space or electricity are likely to be given up.

Hybrid braking: This is another technique of emergency braking that can be applied to wind turbine base on mechanical braking, aerodynamic braking (air is used as fluid in this braking) and electrical generator braking (which is additional that integrated for braking assistance). This technique is usually preferred by large windmills. It designed to merge multiple technique to obtain the both advantages at once.

The hybrid nature of this technique is not enough reason to make it an optimum solution of wind generator braking, it has some advantages and disadvantages as well. As a benefit, the time spent to reach steady state (zero motion) is very short as compared with other techniques of braking, this is related to using two different techniques at the same time which plays important role to minimize the consumption of time (Ochoa *et al*., 2006).

As a drawback that observed over using this kind of braking techniques, its dependency of external devices, in other word, it is depending on some elements and some tools that are already involved in wind turbine operations. So, if such tools become faulty or working improperly, it may worsen the case. The sample design of wind turbine braking illustrates the system general components is depicted in Fig. 1.

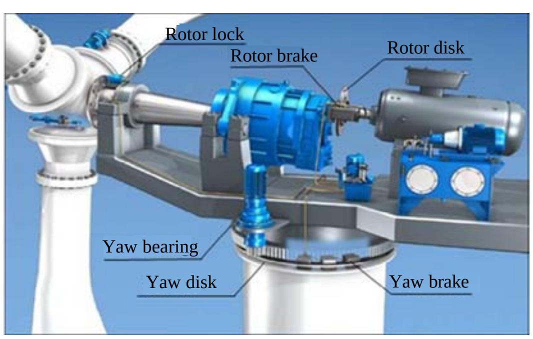

Fig. 1: The braking system of wind turbine

RESULTS AND DISCUSSION

Design of rotor braking system: Figure 1 shows that rotor braking device is located next to the gear box. This device is used for supporting the braking system. In the case that main braking system fails, this substitutional braking device slows down the blades speed and tries to overcome the case. Two more candidates are associated with this technique and helped as a supportive to the main braking system (aerodynamic braking, electrical braking, etc.) these candidates are the rotor lock, that shut the rotating of the rotor and yawing brake to manage the nacelle yawing. The design of rotor braking is to conducted in accordance with standards of IEC such as IEC6140022 (Ochoa *et al*., 2006; Chen *et al*., 2008) which is formed the regulations of designing and testing of the wind turbine rotor braking system. The brake system paramount design concern of the torque analysis and material strength analysis. As it is explained above, the rotor braking is taking place by using of pads that force the rotor to halt the wheel, if the speed of the rotor reached a specific level. This technology is borrowed from the automobile braking system. Manufacturers of automobiles are essentially, concern about heat resistance technology to combat the heat produced after compressing the pads on the disk (Ratnakumaran *et al*., 2011; Schubel and Crossley, 2012). The design of the same can be explained in hereinafter.

Figure 2 depicts the ideology of rotor braking using a hydraulic pressure, the two pads are compressed on each other for making a brake, the total force required to perform the braking is around 70 bar. The mean force of clamping can be calculated as per the following:

$$\begin{aligned} \text{Avg.FC} &= \frac{P.\pi D^2}{4} \\ \text{Avg.FC} &= \frac{7*10^6*\pi*0.12^2}{4} \\ \text{Avg.FC} &= 70178\ \text{N} \end{aligned} \tag{1}$$

The actual acting pressure on the pads can be calculated by dividing the clamping force by the cross-sectional area of the pads, so that, we can write the following Eq. 2. Table 1 is enlisting the design parameters:

$$\begin{aligned} \alpha &= \frac{\text{Avg.FC}}{A} \\ \alpha &= \frac{70178}{0.0453} = 1613287\ \text{MPa} \end{aligned} \tag{2}$$

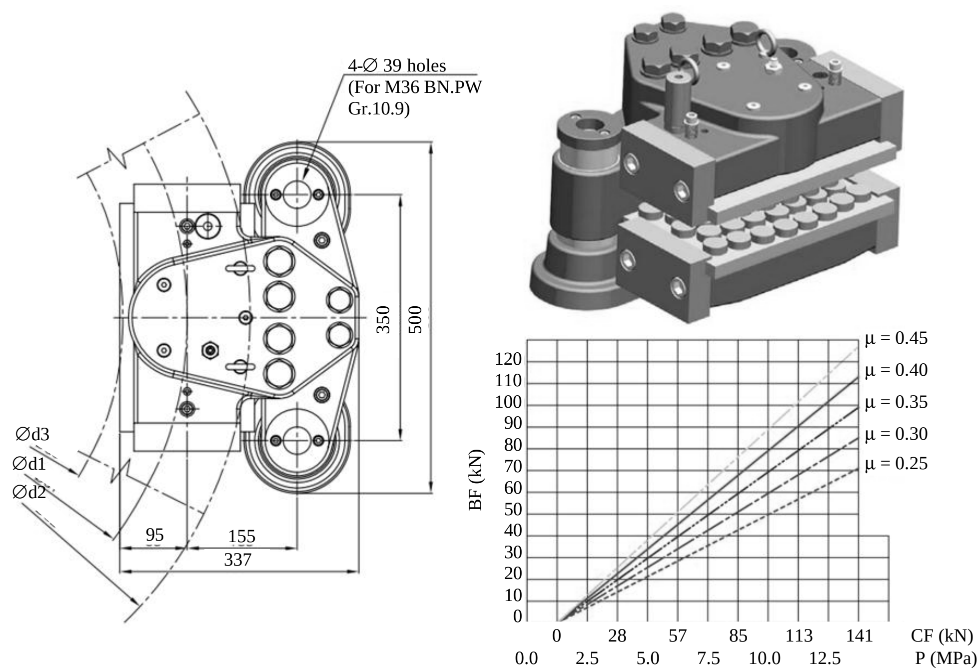

Fig. 2: Rotor braking system

Table 1: Rotor brake design parameters

Particles	Values
Disk radius of brake	485 (mm)
The functioning pressure	0.07 (kbar)
Effective radius of braking disk	365 (mm)
The friction coefficient	0.36, 0.4 for dynamic and static, respectively
Running conditions	Speed (max): 1800 rpm or 68.8 (m/sec)
	Force Clamping (FC): 79000 (N)
	Pad area, pad force: 345 (cm^2),
	2.3 (N/mm^2), respectively
	Max temperature: 200 (°C)
	Cylinder radius: 60 (mm)
	Torque breaking: 20800 (Nm)

The nominal torque of breaking can be calculated using the following Eq. 3:

$$BT = A_{effective} * \mu_{effective} * Avg.FC \qquad (3)$$
$$BT = 20800 \text{ nm}$$

Figure 2 demonstrate the design of the rotor braking system.

Electro-speed relationship: It was explained in the preceding sections that speed of wind turbine can go above the tolerance of the machine components and hence, machine may go faulty. A technique of halting the turbine as it reaches to that speed were discussed, the literature shown two methods to brake the speed. One of those methods is variation of generator windings in such way generator can stop moving. The other method is inherited from automobile companies that deploy a pads and disk and expected to brake the motion by compression the pads around that disk. The major point in designing wind turbines is the speed variation and their effects on the electrical power quality at the turbine output. In most of the cases, wind turbines are formed a network that supports bigger power grids such as (IEEE 13 nods, 132 nodes etc.) (Elnaggar *et al*., 2017) in this case wind energy can be injected into this bigger system and enhance the performance of overall network. The speed of wind turbine is variable in accordance with wind activity and the speed variation is impactingoutput of generator and hence, impacting the bus network that wind turbines are part of. Controlling the speed of the said turbine is an important key to enhance the continuity of performance while turbine is working as standalone or part of other system. The wind power is directly proportional with wind density (wind activity) Eq. 4 is deriving the relationship between the capacity of wind and the productivity of power (Wavhal *et al*., 2015):

$$EP = 0.5 * \partial * C_p * V^a * E \qquad (4)$$

Where:

∂ = The wind density calculated in particular geographical area. And measured in kg/m^3

C_p = Electrical power Coefficient
E = The area that influenced of air from wind turbine
V^a = The Velocity of air streaming

The relationship above indicates clearly that two factors are impacting the power generation from wind turbine: the wind velocity and wind (air) capacity. The braking system is vital for ensuring power continuity and efficiency (Kaldellis and Zafirakis, 2011).

CONCLUSION

The electricity demand increment, environmental limitations (pollution) and the noticeable hike of, fuel cost is motivated the use of green source of energy such as wind turbines. In countries that deploy wind energy such as US and Australia, the wind power is participating a 75% of entire power grid of the country which means that wind energy is reliable source of energy to fulfil the demand of energy. This study involves the methods of finding a suitable braking technique of wind turbine, if the operation of entire system went into wrong direction. Study is however, shown that different techniques are deployed for braking the turbine and some of those techniques are not sustainable for turbine due to high temperature or high bearing torque associating the braking process. In winding isolation braking technique, temperature may reach to 200°C which not taking much time to ignite the turbine generator. Other braking techniques can overcome temperature hike but consume large resources such as cost alike large power consumption (electric braking drive) or large space occupancy (hydraulic braking drive). Other way of braking is hybrid braking that act against temperature and power consumption (used to tackle two challenges) and this is found as the best suitable technique of wind turbine braking. The experiments shown that large windmills are hybrid braking technique is outperformed in large windmills. Wind turbine speed hike is paramount reason behind the turbine vanishing and that is causing big problem for the countries depending on wind power. in order to tackle this problem, suitable speed braking must be used. Furthermore, the location to install windmills is need to be chose with care such as monitoring the weather activity in last 10 years, so that, the design of wind machinery can happen in accordance with the same.

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