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# Dynamic Response of Different Wind Generator Topologies Connected to Medium Size Power Grid

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*Abstract*--**The research in this paper focuses on the system-wide impacts on a medium size power system network with wind turbines during disturbances. The first part of this study is to construct a simplified medium size electricity supply grid of Malaysian perspective using a public domain Matlab toolbox for electric power system analysis and simulation. There are two common types of wind turbines, which are the Constant Speed Wind Turbine with Squirrel-Cage Induction Generator (CSWT) and Variable Speed Wind Turbine with Doubly Fed Induction Generator (DFIG), connected to the medium size grid at a suitable location. The main focus of this paper is to evaluate and compare the dynamic interactions and responses of both types of wind turbine when connected to the grid and subjected to typical electrical system disturbances. The disturbances are introduced by means of faults, generator tripping, line and load disconnections on different network configurations. The impact on the dynamics and stability of a power system is mainly caused by the fact that the wind turbines generating systems deployed are not based on conventional synchronous generator type.**

*Index Terms*—**Constant Speed Wind Turbine, Doubly Fed Induction Generator, Power System Stability, Transient Stability, Fault Response, Line Disconnection, Generator Tripping, Load Disconnection.**

## I. Introduction

Malaysia is a fast growing, modern and progressive nation. It is one of the most developed economies in South East Asia and enjoys strong socio-economic and political stability. The Federation of Malaysia comprises Peninsular Malaysia and the states of Sabah and Sarawak on the island of Borneo. Malaysia comprises of 11 states in Peninsular Malaysia and the states of Sabah and Sarawak on the island of Borneo [1].

The potential for wind energy generation in Malaysia depends on the availability of the wind resource that varies with location. The first wind turbine installed in Malaysia was in Terumbu Layang Layang, Sabah with a generating capacity of 150kW. Maintained by Tenaga Nasional Berhad (TNB), it harnesses power from wind speed of up to 50 knots per hour to provide additional electricity supply to the Royal Malaysian Navy base [2].

Wind resource at a geographic location is highly variable. Power generated from wind turbine depends on the wind speed, which fluctuates randomly with time. Wind power studies, therefore, require accurate models to forecast wind speed variation for wind farm locations of interest [3]. When erecting wind turbines, it is best to choose a site where the wind can blow freely over the turbines from all directions. In this study [3], Weibull distribution was used. Based on the statistical analysis, the average wind speed is around 7m/s.

Wind speeds in most of the world can be modeled using the Weibull distribution. This statistical tool tells us how often winds of different speeds will be seen at a location with a certain average wind speed. Knowing this helps us to choose a wind turbine with the optimal cut-in speed (wind speed at which the turbine starts to generate usable power), and the cut-out speed (wind speed at which the turbine hits the limit of its alternator and can no longer put out increased power output with further increases in wind speed) [4].

This paper investigates the system wide impact of wind power on the medium size power grid. The dynamic of power system normally referred to the stability of the power system such as voltage stability, rotor angle or rotor speed stability and frequency stability. The purpose of this research is to:

i. To understand the working principals of wind power generation with different wind turbine topologies which are the Constant Speed Wind Turbine with Squirrel-Cage Induction Generator (CSWT) and Variable Speed Wind Turbine with Doubly Fed Induction Generator (DFIG).
ii. To evaluate and compare the dynamic interactions and responses of both topologies of wind turbine when connected to the grid and subjected to typical electrical system disturbances. The disturbances are introduced by means of faults, generator tripping, line and load disconnections on different network configurations.

## II. Practical System Preparation

The practical system used in this investigation consists of simplified Malaysian power grid model. According to Malaysian Meteorological Department data, the best location to install wind turbine is at Bus 4083. Some of the characteristics of the simplified Malaysian power grid system

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are given in Table 1. The practical system is depicted in Fig. 1.

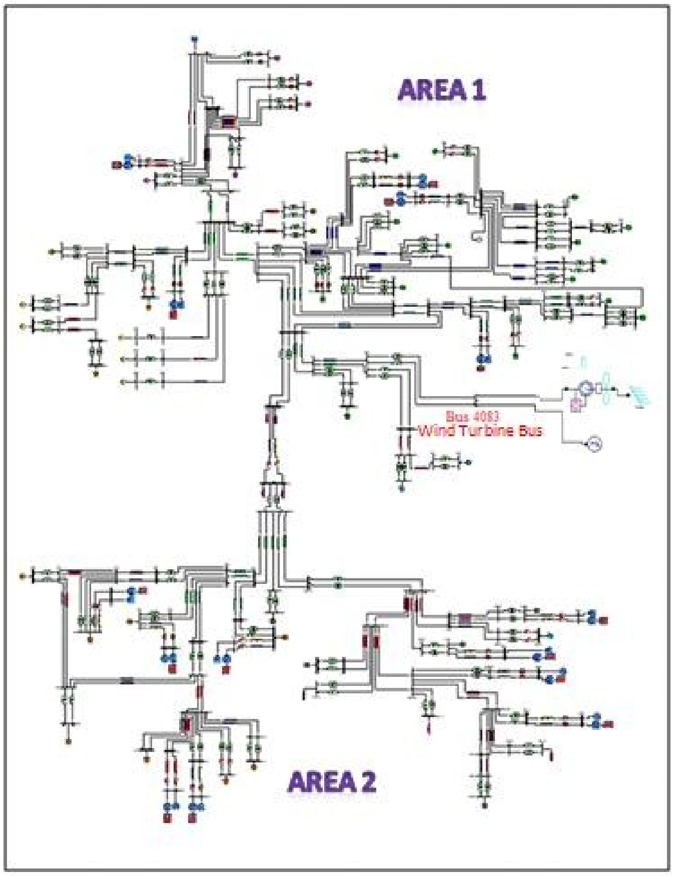



Fig. 1. Simplified Malaysian power grid system

TABLE I
NETWORK STATISTICS OF THE SIMPLIFIED MALAYSIAN POWER GRID SYSTEM

| System characteristic | Value |
|---|---|
| No. of buses | 150 |
| No. of Generators | 15 |
| No. of loads | 46 |
| No. of transformers | 144 |
| No. of transmissions | 152 |
| Total generation | 6030.6 MW / 1314.3 Mvar |
| Total load | 5997.1 MW / 1478.7 Mvar |

## III. SIMULATION RESULTS

In this investigation, the wind power was assumed to be geographically concentrated and connected to Bus 4083. This bus was connected to the simplified Malaysian power grid system with one double circuit overhead line. Although the chosen solution is not the most favorable from the perspective of reliability and the smoothing of output power fluctuations, it is the most interesting case for investigating the impact of a large amount of wind power on the power system. Hence connection to one bus can also be considered as the worst case scenario. If this does not lead to instability, the chances that the connection of the same amount of wind power to other buses leading to instability can be assumed to be very low.

### *A. Fault Response*

In the first scenario, the occurrence of a fault in the simplified Malaysian power grid network was simulated. Two cases were simulated in order to investigate the robustness of the system, which are:

- Case 1: 150 ms fault at wind turbine bus
- Case 2: 300 ms fault at wind turbine bus

The fault was cleared without disconnecting any network components. The fault occurs at t=10s. A fault clearance of 300ms is selected as the worst case scenario that can occur in a particular network. Fig. 2 and Fig. 3 shows the voltage and rotor speed at the wind turbine bus.

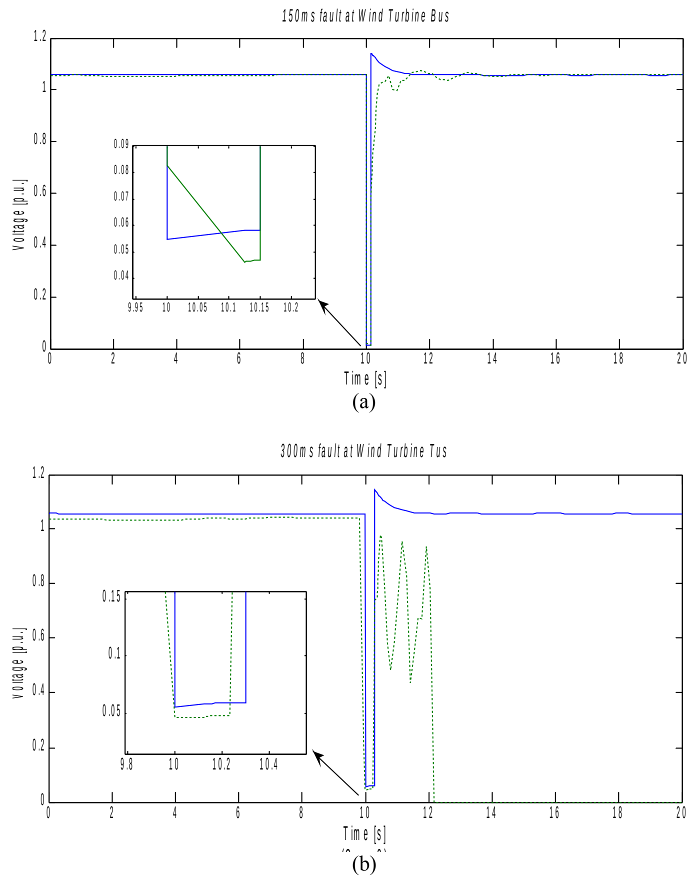
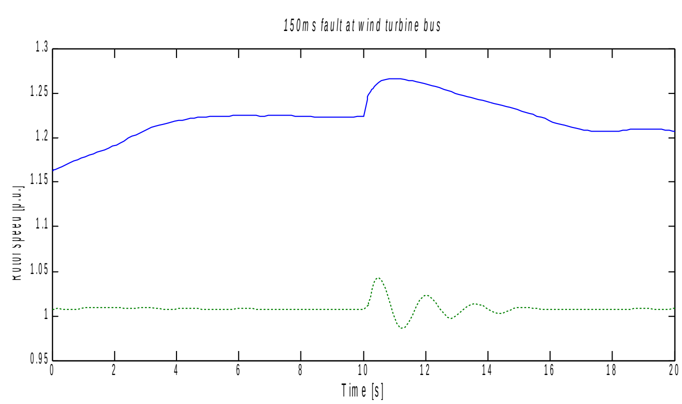
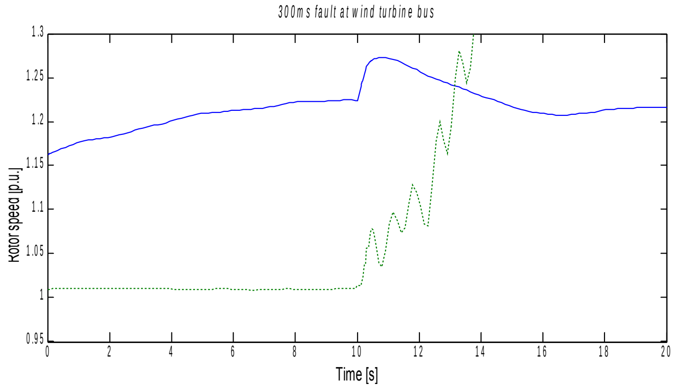



Fig. 2. *Voltage at the wind turbine bus connected with constant speed wind turbine (dotted) and with variable speed wind turbine (solid) for both cases. (a) Case 1: Subjected to 150ms fault at wind turbine bus. (b) Case 2: Subjected to 300ms fault at wind turbine bus.*



(a)




(b)

Fig. 3. *Rotor speed at the wind turbine bus connected with constant speed wind turbine (dotted) and with variable speed wind turbine (solid) for both cases. (a) Case 1: Subjected to 150ms fault at wind turbine bus. (b) Case 2: Subjected to 300ms fault at wind turbine bus.*

From the simulation results, it can be concluded that the power system remains stable in Case 1 but not for Case 2. The fact that the behavior of a variable speed wind turbine is fundamentally different from that of a constant speed wind turbine is clearly illustrated by these simulations. In Case 1, a 150ms fault was introduced at the wind turbine bus and it was found that the voltage remains stable for both wind turbine topologies.

For constant speed wind turbine, a disturbance of the terminal voltage affects the active and reactive power and rotor speed, whereas mechanical oscillations after the fault are reflected in the active and reactive power and thus in the terminal voltage [5]. In Case 2, the voltage and the rotor speed is unstable for the constant speed wind turbine. This is because, when a fault occurs close to a constant speed wind turbine, the voltage at the generator terminal of the wind turbine drops, which results in the reduction of active power. A constant speed wind turbine controller does not attempt to reduce the mechanical power input, thus the rotor accelerates during the fault. Therefore, when a constant speed wind turbine has no means of controlling its power, the critical clearing time will be very short [6].

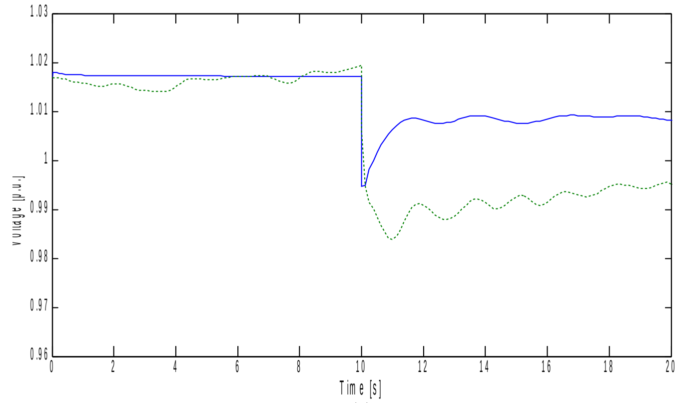
Finally, the rotor speed oscillations of the synchronous generators that occur after a fault were investigated and illustrated in Fig. 3. It was concluded that the shape of the oscillation changed due to the fault duration. For Case 1, the rotor speed remains stable while in Case 2, the rotor speed experiences a run out condition. The rotor speed of a constant speed wind turbine increases without returning to its initial condition. This is due to the reactive power drawn by the induction generator proportional to the rotor speed.

### *B. Line Disconnection*

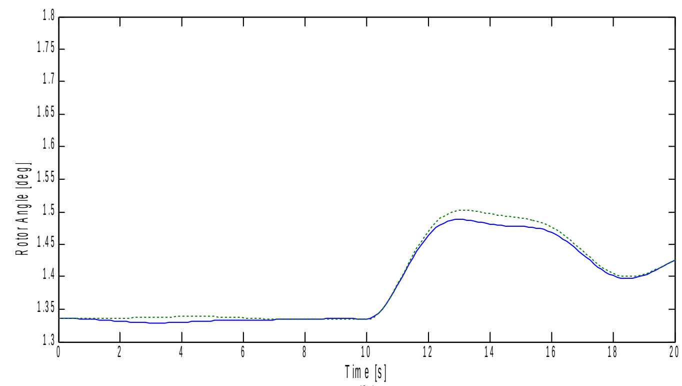
Disconnection of transmission lines is effective for reducing the short circuit current though it may worsen the voltage stability. The simplified Malaysian power grid network consists of two main areas: Area 1 and Area 2 which is connected by two 275kV three phase lines. In this section, the impact of the transient stability of both wind turbine topologies is simulated and analyzed. The two cases investigated are:

- Case 1: One of the 275kV transmission lines is disconnected.
- Case 2: Both the 275kV transmission lines are disconnected.

The line is disconnected at t =10s. Fig. 4 and Fig. 5 show the simulation results of the voltage and rotor angle for both cases.

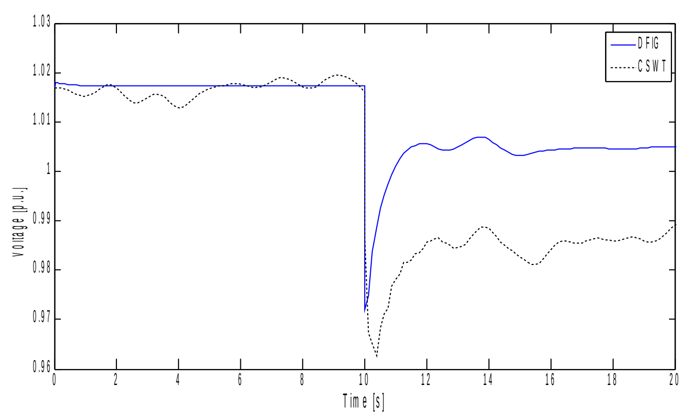



(a)

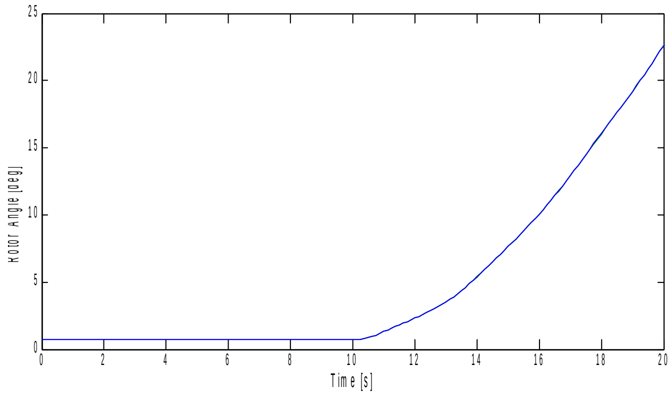



(b)

Fig. 4. *(a) Voltage at wind turbine bus and (b) Rotor angle at wind turbine bus for Case 1: One of the 275kV transmission lines is disconnected with constant speed wind turbine (dotted) and with variable speed wind turbine (solid).*




(a)




(b)

Fig. 5. *(a) Voltage at wind turbine bus and (b) Rotor angle at wind turbine bus for Case 2: Both the 275kV transmission line are disconnected with constant speed wind turbine (dotted) and with variable speed wind turbine (solid).*

From the simulation results, it can be observed that the voltage drop is greater for Case 2 as compared to Case 1. The rotor angle goes unstable when both the 275kV line is disconnected. When both the lines were disconnected, the network is islanded into two main areas, which are Area 1 and Area 2. This unbalance phenomenon between the generation and load initiates a transient that causes the rotor of the induction machine to swing to a run-out condition [7].

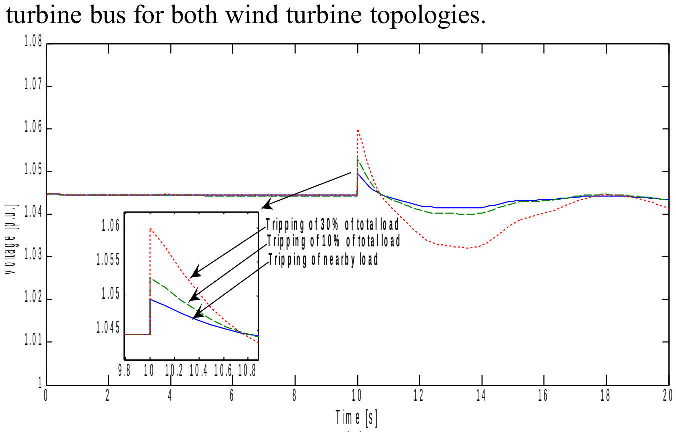
From the results, it can be deduced that as the rotor speed increases, the reactive power consumption will be higher after the disturbances. At the same time, it will make the voltage to recover slowly hence leading to transient stability. For the constant speed wind turbine, the reactive power shows transient changes while for the variable speed wind turbine, the reactive power increases due to the electronic controller restoring the voltage.

## *C. Load Disconnection*

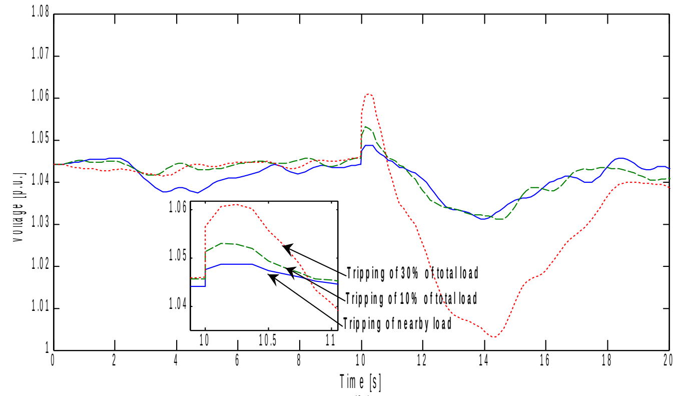
The third scenario investigates the dynamic response of different wind turbine topologies when loads were tripped. Three cases were studied:

- Case 1: Nearby load were tripped
- Case 2: 10% of the total load were trip
- Case 3: 30% of the total load were trip

Fig. 6 and Fig. 7 show the voltage and rotor speed at the wind turbine bus for both wind turbine topologies.

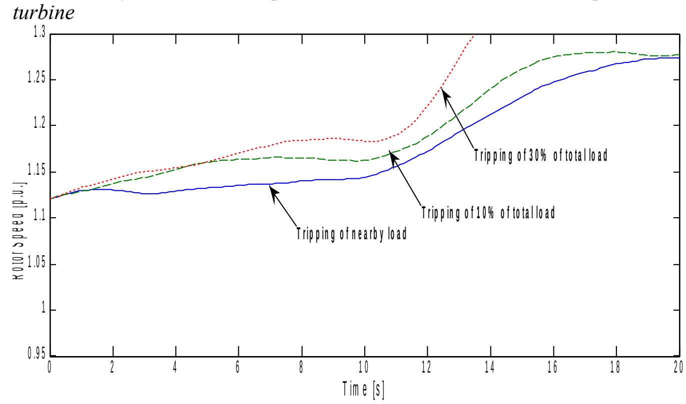



(a)

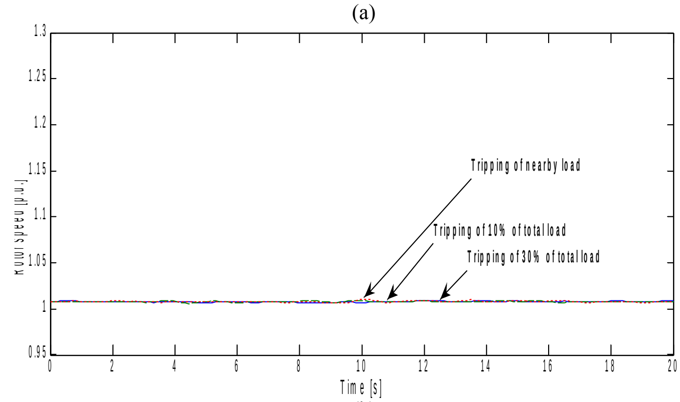



(b)

Fig. 6. *Voltage at wind turbine bus after tripping of nearby load (solid), tripping of 10% of the total load (dashed), tripping of 30% of the total load(dotted) for (a) variable speed wind turbine and (b) constant speed wind turbine*




(a)




(b)

Fig. 7. *Rotor speed at wind turbine bus after tripping of nearby load (solid), tripping of 10% of the total load (dashed), tripping of 30% of the total load (dotted) for (a) variable speed wind turbine and (b) constant speed wind turbine*

For both types of wind turbine, the voltage increases as the loads were tripped. The main difference between the constant speed wind turbine and the variable speed wind turbine is the time taken for the voltage to be restored [8]. Fig. 6 shows that, the variable speed wind turbine is able to restore the voltage faster than the constant speed wind turbine. Due to the robustness of the practical system, even after 30% of the total load is disconnected, the system is able to maintain the stability of voltage.

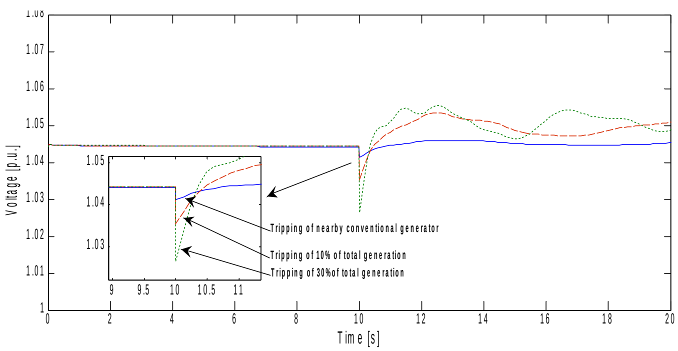
From Fig. 7, it is found that the rotor speed of a variable speed wind turbine increases during the tripping phenomenon takes places while for the constant speed; there are no significant changes for any of the cases. This is because the variable speed wind turbine have power electronic controller to stabilize the mechanical power and the electrical power to maintain its stability. As for Case 3, although the variable speed wind turbine have power electronic controller, it still cannot maintain the rotor speed which leads to a run-out condition.

### *D. Generator Tripping*

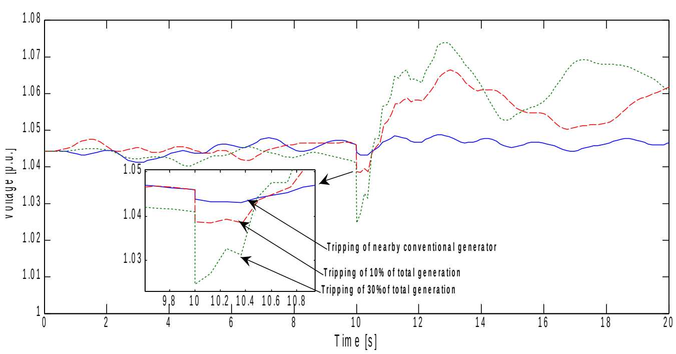
The fourth scenario investigates the dynamic response of different wind turbine topologies due to generator tripping. Three cases were investigated:

- Case 1: Tripping of nearby generator
- Case 2: Tripping of 10% of total generation
- Case 3: Tripping of 30% of total generation

Fig. 8 and Fig. 9 show the voltage and rotor speed at the wind turbine bus for both wind turbine topologies.

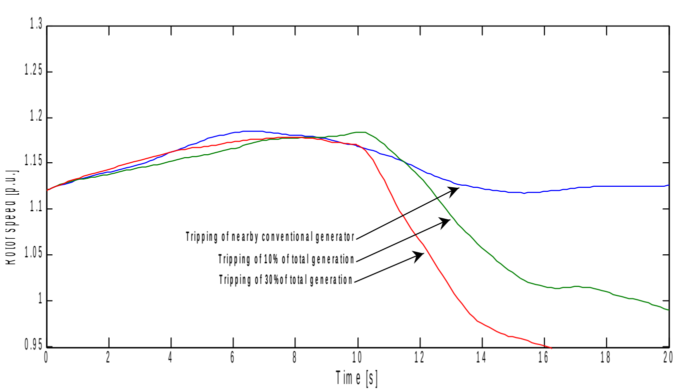



(a)

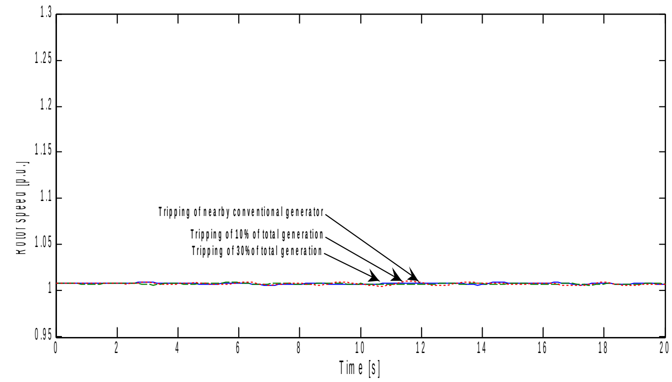



(b)

Fig. 8. *Voltage at wind turbine bus after tripping of nearby generator (solid), tripping of 10% of the total generation (dashed), tripping of 30% of the total generation (dotted) for (a) variable speed wind turbine and (b) constant speed wind turbine.*




(a)




(b)

Fig. 9. *Rotor speed at wind turbine bus after tripping of nearby generator (solid), tripping of 10% of the total generation (dashed), tripping of 30% of the total generation (dotted) for (a) variable speed wind turbine and (b) constant speed wind turbine.*

From the simulations results, it can be observed that the practical system is a stable system. Further, in all three cases, the voltage at wind turbine bus stays well within the allowable limits, when 10% and 30% of the total generation trips. This is because the simplified Malaysian power grid system is relatively compact and robust. From Fig. 9, the rotor speed of the variable speed wind turbine decreases as the generation decreases. It can be concluded that the rotor speed is inversely proportional with the generation losses. For the constant speed wind turbine, no significant change is observed.

## IV. Conclusion

In this paper, the impact of wind power on the transient dynamics and stability of power systems were investigated. From the simulation results of the Malaysian power grid system, it can be concluded that no voltage instability was observed for the variable speed wind turbine for all the scenarios. For constant speed wind turbine, the voltage was unstable for a fault clearing time of 300ms. It can be concluded that, the critical clearing time for both wind turbine topologies are different.

For rotor angle stability, both the wind turbine is not stable when both the 275kV line is disconnected. It is found that the there is no changes in the constant speed wind turbine rotor speed when the system is subjected to generator trip and load trip. It was also concluded that the frequency drop occurring after the tripping of a generator becomes higher when the wind energy penetration in the system increases. This observation can be explained in the following way:

- As the prime mover of wind turbines cannot be controlled, the power generated by the wind turbines does not increase when the frequency decreases
- In variable speed wind turbines, the mechanical rotor frequency is decoupled from the grid frequency and the energy stored in the rotating mass is not released, resulting in a frequency drop that is larger than that for constant speed wind turbines.

## V. Acknowledgment

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## VII. Biographies

**M.S.A Rapheal** was born in Pulau Pinang, Malaysia, on October 24, 1984. He received his B.Eng. degree in Electrical Power from University Tenaga Nasional, Malaysia in 2007, and the M.Eng. degree in Electrical Energy and Power System from University Malaya, Malaysia , in 2009. He is currently with Tenaga Nasional Berhad as a Project Engineer. His main research interests are in the system stability and renewable energy especially on wind power generation. He is a registered member of Board of Engineer Malaysia and IEEE student member.

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**Assoc. Prof. Dr. Ir Hew Wooi Ping** received the B.Eng degree and M.Eng degree from University Teknologi Malaysia, and the PhD degree from University Malaya, Malaysia. Dr. Hew is presently the Head of Electrical Department in University Malaya. Dr. Hew's industrial consultancy includes periods with Dunham-Bush, Malaysia, MS Elevator, Malaysia, Tenaga Nasional Berhad, Malaysia, OYL Research and Development, Malaysia, and Pusat Tenaga Malaysia, Malaysia. Dr. Hew has published numerous journals in the areas of machines and drives