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Coordinated active power control of Wind, Solar and Diesel Generator in a Microgrid

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Abstract: In this paper, a microgrid consisting of a fixed speed diesel generator and renewable energy sources (Photo Voltaic and PMSG based variable speed Wind Energy Conversion Systems) have been considered. The photo voltaic source is operated in a derating mode and the wind generator in inertia control mode in order to mitigate the active power imbalance in the microgrid. An advanced photo voltaic derating algorithm is introduced based on the rate of change of PV power with respect to the voltage. This coordinated control limits the ramp rate of the diesel generator and operates it in the economical operating zone. The control scheme is tested for change in solar irradiation and load demand.

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1. INTRODUCTION

With the increase in the percentage of penetration of wind and solar generation in the micro grids, there has been a growing concern about the low inertia and the mitigation of active power imbalances in the system. One can handle this situation by placing fossil fuel generators with high ramp rate so as to have a better frequency response. But generating power with high ramp rates will come at a cost of the reduced life of the generators. For instance, K. R. Hoopingarner et al. (1989) describes that a quick start of a diesel generator (DG) can reduce its life. So instead we can use the wind turbine inertia and the reserve power of the derated photo voltaic (PV) source in order to provide primary frequency response.

Z.-S Zhang et al. (2012) discuss the problems of high wind penetration. Due to the wind uncertainties, the high wind power penetration has resulted in the curtailment of wind power due to the problem of frequency instability. In order to avoid such problems and to improve frequency regulation, it is a high priority to use the wind turbine inertia for the frequency control. Moreover, as the wind turbines can have inertia values up to six times that of its generator, as given by G. Ramtharan et al. (2007), it is highly advantageous to use kinetic energy of the wind turbine for frequency regulation. In this paper, an inertia control technique in a PMSG type variable speed wind generator has been introduced to reduce the active power imbalances in the microgrid due to varying wind speeds, load and insolation. In the proposed control, an auxiliary control that pertains to the change of microgrid frequency is being used in addition to the conventional power point tracking controller for generating the power order for the wind generator.

In the literature there has been frequent use of wind turbine inertia for the frequency control. The use of proportional

differential controller has been presented by Zhiheng Zhang et al. (2013) for a DFIG based wind conversion system. There has also been schemes where the Optimal Power Point Tracking (OPPT) of the turbine has been manipulated for the frequency regulation, described by Zhiheng Zhang et al. (2013). Moreover, high K_p and K_d values of a PD controller will bring in a significant contribution of wind turbine in frequency control but will bring in a significant wear and tear in the mechanical components, especially in the gear box (in case of a DFIG based wind generator). Though the optimal values of K_p and K_d have been calculated based on wind turbine stability by Z.-S Zhang et al. (2012), but it is done without taking into consideration the mechanical stresses that will be induced and will reduce the life of the mechanical couplings.

In this paper by using a proportional controller the demand for frequency support from the wind is restrained and the solar power is used instead to provide additional frequency regulation, so that the combined contribution of the solar and the wind power in the frequency support will bring better frequency regulation even in systems with high renewable energy penetration.

In the PV array a derating algorithm has been employed that is based on the rate of change of power with respect to the voltage. The derating is based on the values stored in a lookup table of the rate of change of power with respect to the voltage, corresponding to desired reserve, which is computed based on the power output. Hence through this mechanism a constant percentage derating can be obtained irrespective of the solar irradiation.

To validate the proposed control scheme, a microgrid with high penetration of wind and solar power is considered as a test system.

2. MICROGRID DETAILS

The system considered in this paper comprises of a fixed speed DG, PMSG based variable speed wind generator and PV array having ratings of 2 MVA, 1MW and 1.1 MW respectively. The complete system under study is shown in Fig. 1.

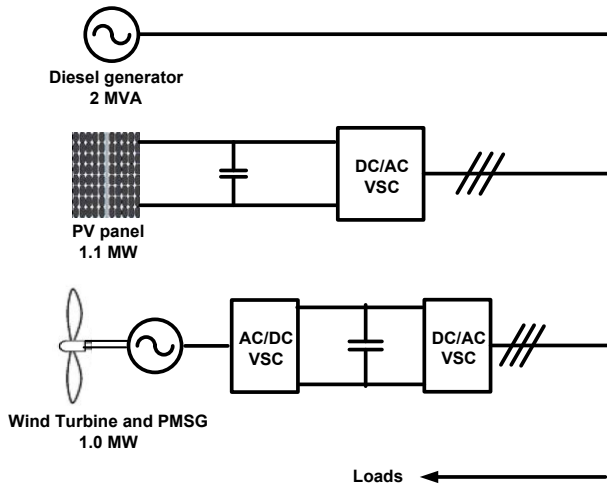


Fig. 1. Microgrid consisting of DG, PV array and wind turbine.

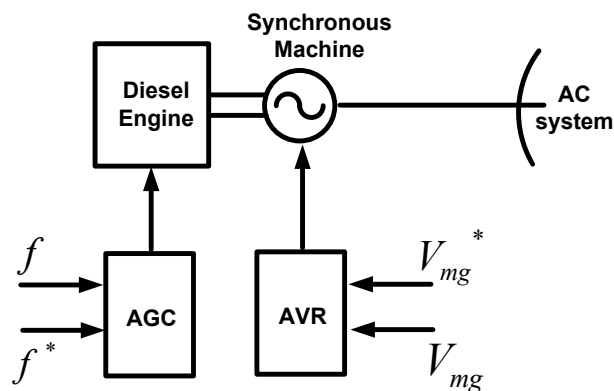


Fig. 2. Control of DG.

The DG control is done by using conventional automatic generation control for frequency regulation and automatic voltage regulator for its terminal voltage regulation; as shown in Fig. 2. The wind generator is controlled using its inertia while the PV array is operated in derating mode.

The secondary frequency control lies with the DG while the renewable energy sources help in the primary frequency regulation; thus helping in reducing the ramping of DG.

3. PMSG CONTROL

PMSG based wind energy conversion system is used in this paper for being more popular these days. Moreover, their LVRT capabilities, gearless transmission and better controllability as compared to DFIG based systems gives them an upper hand when compared with DFIG based wind energy conversion systems.

In the Maximum power tracking of the wind generator the power command is set based on the rotor speed. This power control is translated into torque command and subsequently to current command. So whenever there is an increase in the wind speed, the rotor speed increases and hence the power command. But if by some means we increase the power command on a fixed wind speed scenario, then in order to obey the power command, the extra amount of power is drawn from the rotor inertia. This results in the overall reduction in the rotor speed. Hence, by adding an auxiliary signal that pertains to the change in frequency, in the power command obtained by the MPPT algorithm, we can manipulate the power output of the wind generator. This will also result in better frequency regulation of the microgrid by regulating the power output at the wind generator terminals based on the frequency of the microgrid.

The power output at the terminals of a generator could be written as:

$$P_{ele} = P_{input} - J \frac{d\omega}{dt} \tag{1}$$

The term $J \frac{d\omega}{dt}$ constitutes the inertial power that is either consumed in or dissipated from the generator, when the generator accelerates or decelerates respectively. In a wind generator, unlike a conventional synchronous generator we can control the rotor speed or the inertial power irrespective of the grid frequency. Now the key to the participation of wind generators in the frequency response lies in using this inertial power. The control scheme using the inertial power is shown in Fig. 3.

4. PV CONTROL

A PV source operating in derating mode can be treated as a reserve power which can be used for better frequency regulation as shown by P.P. Zarina et al. (2014). Maximum Power Point Tracking (MPPT) Algorithm provides the reference voltage to operate the PV at its maximum power. Various MPPT algorithms are available in literature; most of these discussed by Trishan Efram et al. (2007). To keep a reserve power the PV is operated in derating mode and such operation is achieved by modulating the reference voltage to operate the system at the voltage greater than the MPP voltage. However, the change in reference voltage needs to be decided as per the reserve required.

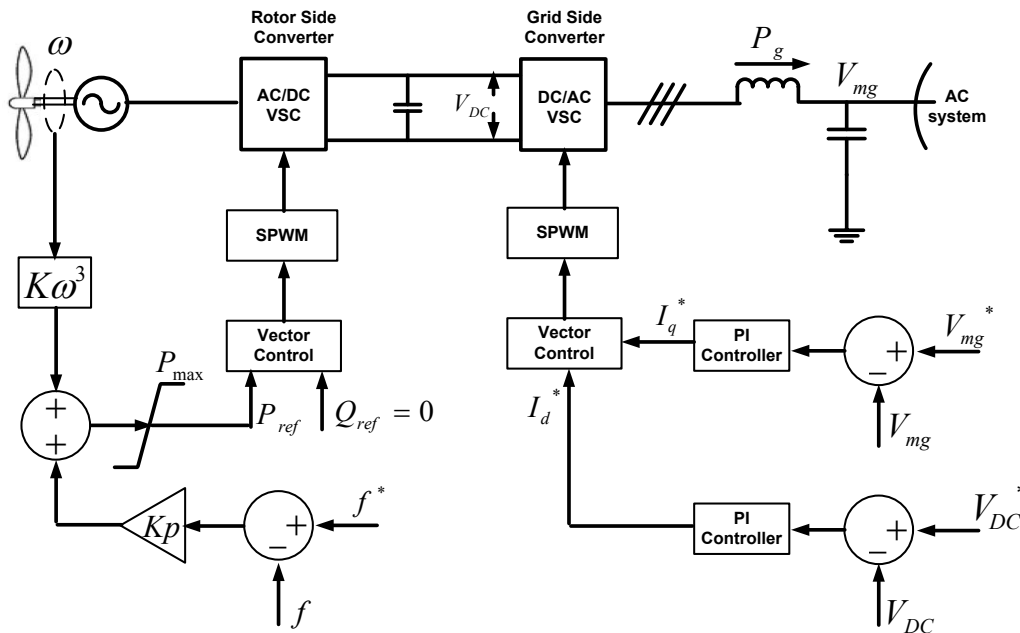


Fig. 3. Control of wind energy conversion system with primary frequency regulation.

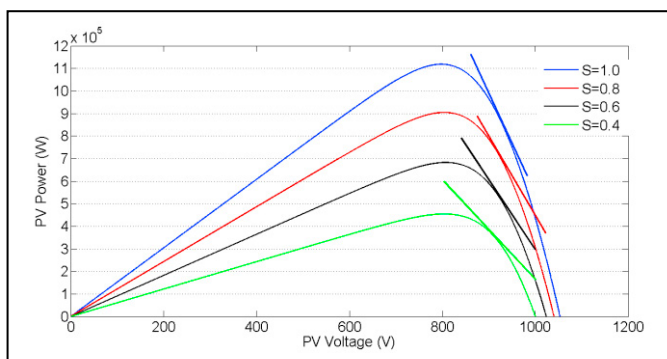


Fig. 4. Variation of slope at 80% of the maximum power at different solar irradiation.

Under low solar irradiancies, PV maximum power reduces; accordingly the reserve available should also reduce. Thus a control strategy should be designed to operate the PV at fixed percentage derating depending of the maximum power it can deliver. In this paper, 80% derating (i.e. 20% reserve) has been considered. To achieve this, a $\frac{dP}{dV}$ slope based derating

approach has been used in this study; which is motivated from the traditional Incremental Inductance MPPT algorithm; described by Trishan Esum et al. (2007) and Perumalla Chandra Sekhar et al. (2014). It can be observed from PV characteristics, shown in Fig. 4, the $\frac{dP}{dV}$ slope at a certain

percentage derating (80% in the Fig.) of the maximum power varies with solar irradiation. Higher is the insolation; higher is the magnitude of rate of change of power with respect to the change in voltage.

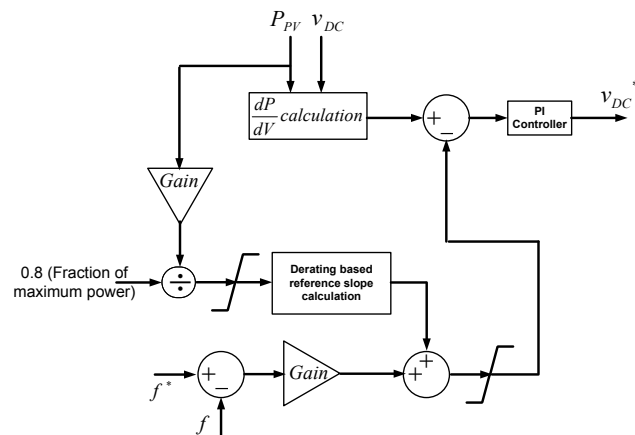


Fig. 5. PV DC reference voltage calculation as per required derating and primary frequency control.

In the proposed control structure, the power is measured and the reference voltage from MPPT algorithm is modified in such a way that the PV array always operate at a constant percentage derated power irrespective of the solar irradiation depending on a look up table having $\frac{dP}{dV}$ slope corresponding to different output power from the solar PV for operation at 80% of maximum power.

To operate the PV in frequency regulation mode; the $\frac{dP}{dV}$ slope defining the amount of relating is modified as per frequency deviation; thus varying the PV power during frequency deviations. The derating approach with primary

frequency regulation is shown in Fig. 5. The actual $\frac{dP}{dV}$ slope is compared with the reference slope and a PI controller is used to match the actual slope with the reference by varying the DC reference voltage.

The PV inverter is controlled by Vector control as shown in Fig. 6.

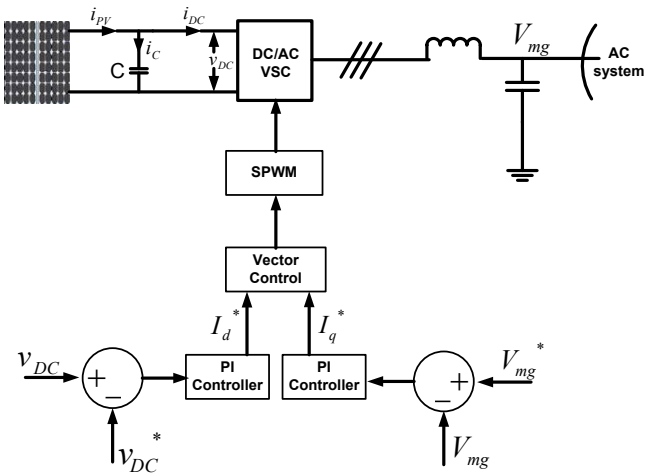


Fig. 6. PV control.

5. RESULTS AND ANALYSIS

5.1 Under constant wind speed and solar irradiation

The system, initially operating at nominal 50 Hz, is subjected to a load change of 0.25 p.u. (at a base power of 2MW) at 0.5 s. The DG participates in the secondary frequency regulation. The frequency response is compared for various control schemes in Fig 7. The results are compared for four different operating schemes i.e. when frequency is controlled only by DG; when wind generator also participates in primary frequency control along with the DG; when PV and DG participate and when all the 3 sources participate in primary frequency control.

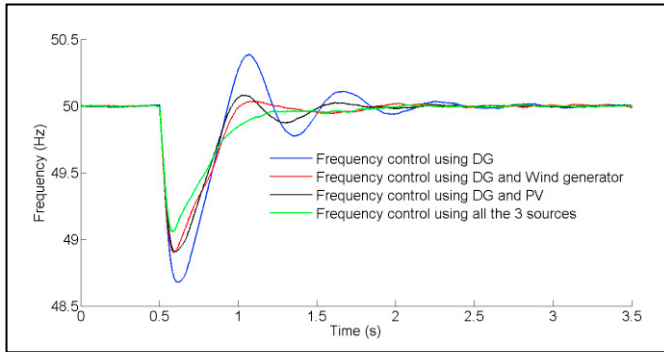


Fig. 7. Frequency response following a load change.

The peak deviation in frequency and settling time for the four cases are tabulated in Table 1. It can be seen from the results that best system dynamic response are obtained by using all

the sources in frequency control using the proposed control scheme.

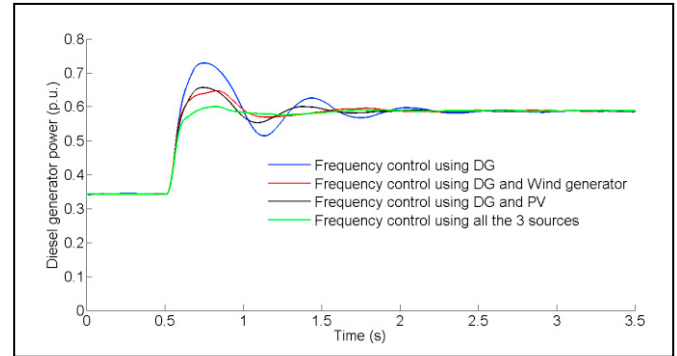


Fig. 8. DG power.

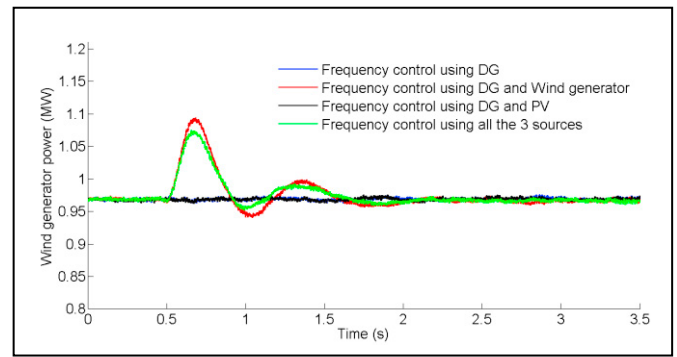


Fig. 9. Wind generator power.

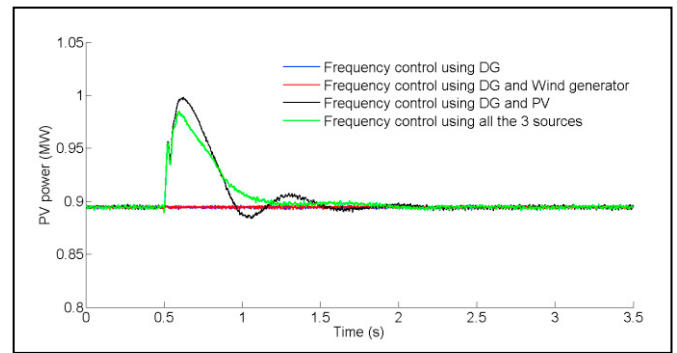


Fig. 10. PV power.

It is also seen from Fig. 8 that the ramp rate of DG is reduced when renewables are used in controlling the system frequency. The DG, initially operating at 0.34 p.u. increases its power to 0.59 p.u. following the load change. When only the DG is controlling the frequency; it ramps at a very high rate and goes as high as 0.73 p.u. while the DG power is properly controlled when other sources are used and there is negligible power overshoot. The power delivered by the wind and the PV source for these four cases are shown in Fig. 9 and Fig. 10 respectively. From Figs. 9 and 10; it can be observed that the power from the two renewable energy sources varies only if they participate in frequency regulation. As discussed in the introduction, the combined effect of solar and wind gives better response when penetration of

renewable energy sources is high. The maximum power change for both wind and PV when both contribute to primary frequency control is less than the power change when each of these sources individually contribute along with the DG.

Table 1. Comparison of frequency response

Frequency Control	Maximum Change in Frequency (Hz)	Settling Time (s)
Using only DG	-1.35	2.5
Using DG and Wind generator	-1.15	2
Using DG and PV	-1.15	2
Using all the 3 sources	-0.95	1.8

The above shown results are obtained at high solar irradiation. The system has been tested under very low solar irradiation as well. Fig. 11 shows the system frequency when solar irradiation is only 200 W/m² and Fig. 12 shows the power generated by the three sources when all the sources are participating in primary frequency regulation and the load variation is same as earlier. Following the load change, the system comes to steady state and operates at desired frequency i.e. 50 Hz.

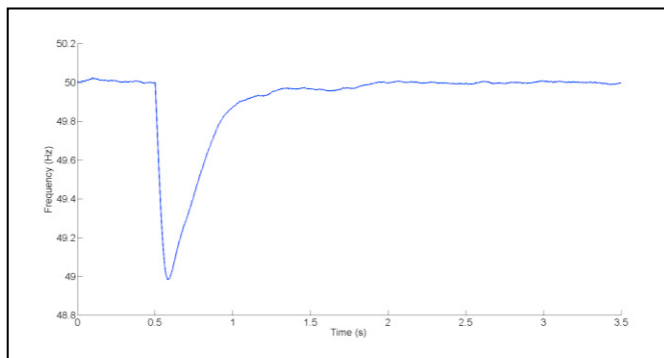


Fig. 11. Frequency response following a load change at low solar irradiation.

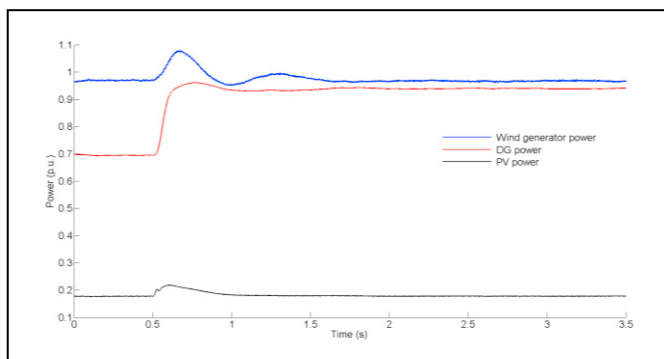


Fig. 12. Power generated by different sources.

5.2 For change in solar irradiation

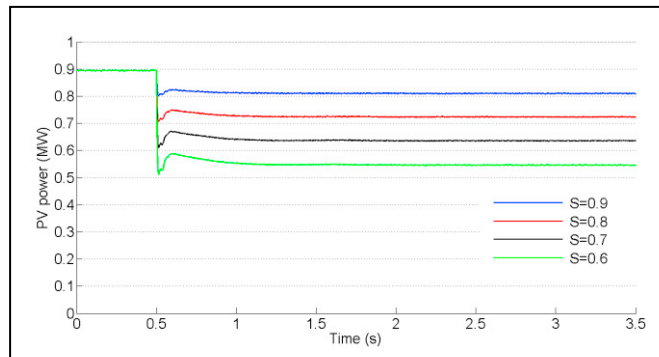


Fig. 13. PV powers at different solar irradianations.

Table 2. PV reserve available at different irradianations

Solar Irradiation (Normalized to 1000 W/m ²)	Maximum power (MW)	Operating power (MW)	Reserve (%)
1.0	1.1181	0.895	19.95
0.9	1.0125	0.81	20
0.8	0.9	0.72	20
0.7	0.7943	0.63	20.68
0.6	0.6824	0.545	20.13

The results obtained when there is a sudden drop in solar irradiation from 1.0 to 0.9, 0.8, 0.7 and 0.6 also shows the same characteristics. One of the objectives of this scheme is to operate at 80% of maximum power at all solar irradianations. The control scheme achieves proper frequency regulation. The PV power drops with drop in irradiation; shown in Fig. 13. The DG power is accordingly increased to mitigate the power imbalance in the microgrid. From the Fig. 13; it can be observed that at each solar irradiation the PV array is operated at 20% reserve as tabulated in Table 2.

6. CONCLUSIONS

With this study it can be concluded that the inertia control and slope based control of wind and PV respectively gives satisfactory response in frequency regulation. The slope based derating control ensures constant percentage derating irrespective of solar irradiation. The proposed control scheme limits the ramping of DG and provides improved frequency regulation in a microgrid.

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REFERENCES

- Esrām, T. and Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. *IEEE Transactions on Energy Conversion*, vol. 22 (2), pp. 439-449.
- Hoopingarner, K. R. and Zaloudek F. R. (1989). Aging Mitigation and Improved Programs for Nuclear Service Diesel Generators. Washington, DC: Division of Engineering, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission.
- Ramtharan, G., Ekanayake, J.B. and Jenkins, N. (2007). Frequency support from doubly fed induction generator wind turbines. *IET Renewable Power Generation*, vol. 1 (1), pp. 3-9.
- Sekhar, P.C. and Mishra, S. (2014). Takagi-Sugeno fuzzy-based incremental conductance algorithm for maximum power point tracking of a photovoltaic generating system. *IET Renewable Power Generation*, vol. 8 (8), pp. 900-914.
- Zarina, P.P., Mishra, S. and Sekhar., P.C. (2014). *Exploring frequency control capability of a PV system in a hybrid PV-rotating machine-without storage system*. International Journal of Electrical Power & Energy Systems, vol. 60, pp. 258-267.
- Zhang, Z., Wang, Y., Li, H. and Su, X. (2013). Comparison of inertia control methods for DFIG-based wind turbines. *2013 IEEE ECCE Asia Downunder (ECCE Asia)*, pp. 960-964.
- Zhang, Z.-S., Sun, Y.-Z., and Li, G.-J. (2012). Coordinated frequency regulation by doubly fed induction generator-based wind power plants. *IET Renewable Power Generation*, vol. 6 (1), pp. 38-47.