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Power flow and small signal stability analysis on the interconnected Philippine power grid☆

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Summary The Philippines, as one of the developing nations in south-east Asia, has isolated power system networks which bring forth challenges in its operational systems, especially when subjected to a deregulated environment. This paper presents an analysis on the power flow and small signal stability of the interconnected three isolated Philippine Power Grid. To achieve this, eigenvalue analysis is employed to probe the small signal stability of the main power grids. The free software, Power Systems Analysis Toolbox (PSAT), is used to develop the model using MATLAB®/Simulink®. There have been no publicly available studies regarding stability of the proposed link between the major grid and the Mindanao (south island) grid. Participation factors were further studied to determine which states contributes most with the variety of modes. The lowest oscillatory damping modes are also assessed to better understand the systems characteristics.

Introduction

Many processes and activities especially in the course of industrialization have been possible due to dependable power systems. As the power requirements around the world grow, the stability of power grid became one of the issues for the power industry. Due to the large and complex systems, much attention is needed on the potential power oscillation problems that have direct impact on the stability of the system (Lin, 2014). In a relatively enormous system, disturbances in certain places may affect certain system components which will then create instability. Small signal stability is the ability of a system to remain in synchronism when subjected to small disturbances (Kundur, 1994). The Philippine power grid has been subjected to restructuring and the establishment of Wholesale Electricity Spot Market (WESM) is one of the big steps in its course towards

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open access retail of power and competition. WESM has been posted in the two out of three major power grids (Luzon and Visayas) in the country (Cano and Shaikh, 2013). The Mindanao grid is isolated from the main grid, and suffers from inadequate supply to its growing demands as the Department of Energy reports (Cano and Shaikh, 2013). The interconnection of the Mindanao grid to the Visayas is expected in the year 2018 (Transmission Development Plan, 2011). The stability of the system will be one of which that has significant effects when all isolated power networks are interconnected as it is planned in the development of the country's power grid. This poses challenges in the existing power grids. Some similar studies were made examining the stability of the Myanmar (Lin, 2014), Ecuador, Colombia and Panama (Montaño et al., 2006), and Nordic (Chompoobutrgool et al., 2012) power systems. This paper presents a small signal stability analysis on the impending connection between the already-connected Luzon—Visayas grid to the isolated Mindanao power grid in free and open-source software. There have been no publicly available studies regarding this interconnection. This will be of significant contribution to better understand the behavior of the system when the international interconnection, ASEAN (Association of South East Asian Nations) Power Grid, will be realized.

Methodology

The Philippine power grid models were created and modified in Power Systems Analysis Toolbox (PSAT) in Simulink ® Matlab environment. This is a free, open source educational software used to study power systems (Milano et al., 2008). Small signal stability analysis, power flow and eigenvalue analysis are some of the routines in a power system analysis that the toolbox can do.

Dynamic modeling

PSAT has documented all the dynamic models used in this study. This includes the models of generators, turbine governors and automatic voltage regulators (AVR). Simple versions (classical) of synchronous generators were modeled where transient voltage in q-axis is constant. All generators have no mechanical damping and saturation effects are neglected. The same model (Model 3) of AVR is used for all generators but with diverse parameters. The turbine governors in PSAT are represented by two models, namely: thermal generator model and a simplified model. Model 2 momentarily represents hydro generator whilst Model 1 represents that of thermal. However, in this study, Model 3 (Chompoobutrgool et al., 2012) is utilized. In this model, some properties of the system were considered such as the inelastic penstock where the inertia of water is taken into consideration, and also the ideal turbine. For simplicity of analysis, static load models were also used.

The Philippine power grid

The Philippines, as a developing country, the availability of test systems to which the grid may be utilized in academic research is not at hand. Commercial and security concerns have compounded this unobtainability. However, (Cano and Shaikh, 2013) has developed reduced and approximate

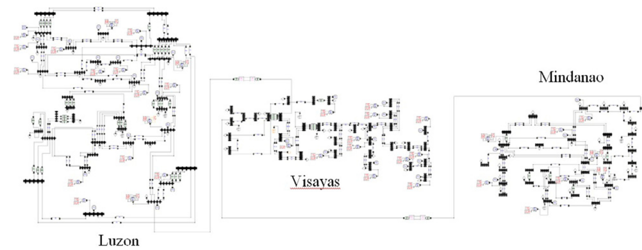

Figure 1 The Philippine power grid model in PSAT.

models, and these were utilized in the study. Luzon and Visayas are presently connected with a 230 kV High Voltage Direct Current link, with an impending connection of the Mindanao (south) grid.

A 900-ckt-km 500 kV line passing from the north to the south serves as the backbone of the power system with a meshed 230 kV network from the center portion. Luzon has 7829 MW generation capacity. Visayas predominantly has 138 kV voltage level for its power transmission system with some 230 kV connections. A mixture of coal, diesel and geothermal power plants comprises the main generation profile of the grid peaking to 1400 MW. Recent developments the southern grid of the Philippines added a 230 kV network in its existing 138 kV and 69 kV lines which originally has a total of 3100 ck-km. Mindanao experiences lesser capacity together with its growing electricty demands. All in all, the model is composed of 103 buses with a total number of lines is 161 with 43 units of transformers and 73 load representations.

System studies

Test system data

The model is composed of components divided in three areas as shown in Fig. 1. The areas namely: Luzon (North), Visayas (Central) and Mindanao (South) are connected by two HVDC lines. A 440 MW at 350 kV direct voltage and 230 kV alternating voltage is already existing while a proposed 500 MVA 250 kV two pole HVDC link was also included in the model.

For conventional thermal generating units, Model 1 turbine governors (TG) were employed while the hydroelectric units use Model 3 TG. There are 103 buses and 36 lumped generating units in total.

Results and discussion

A base case was investigated by ensuring that the working models without the new interconnection (Luzon—Visayas and isolated Mindanao) are properly working. Though not shown, load flow results, e.g. voltage levels, were observed to be within the limit as expected.

The load flow analysis of the connected Philippine power grid was also conducted. The bus no. 42 (Kadampat) was chosen as the slack bus while the others are voltage controlled. Fig. 2 shows the voltage profile of all the buses which are within the voltage level as stipulated by the Energy Regulatory Commission in N-0 condition (0.95—1.05 p.u.). Small signal stability analysis was then employed in the system both interconnected and not connected power grids for comparison. Fig. 3 only shows the critical eigenvalues of the system which are near the Y axis (stability threshold) since

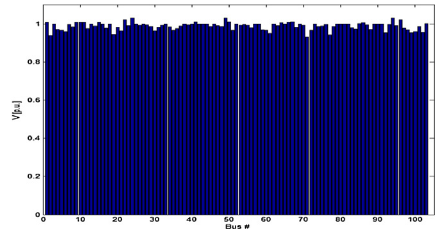

Figure 2 Philippine PSAT model voltage levels.

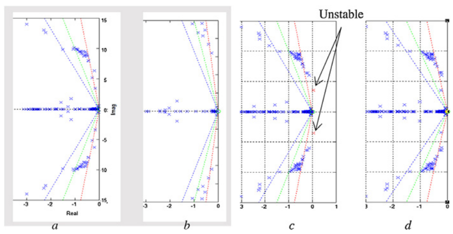

Figure 3 Philippine PSAT model eigenvalues (a) isolated Luzon—Visayas, (b) isolated Mindanao, (c) whole country without PSS and (d) whole country with PSS connected to unstable synchronous generator.

the ones portrayed in the far left plane are considered as very stable. Fig. 3a shows the eigenvalues of the connected Luzon—Visayas grid. All the eigenvalues are located in the left plane, indicating that the system is stable. Fig. 3b also shows the stable eigenvalues of the Mindanao power grid which is relatively less in number than that of the former since it is composed of lesser generating units. Fig. 3a and b further shows that the system is working in stable condition even without interconnection and even with the absence of control devices. The interconnected whole country test model was then analyzed. A total of 422 states with 67 complex pairs are initialized and observed. Two positive eigenvalues (Fig. 3c) were observed in the impending interconnection of the Mindanao grid to the main grid. This is due to the absence of FACTS devices integrated in the model. The eigenvalues of the system with which, the synchronous machine no. 10 became unstable. The model, being approximate and reduced, became a factor in this instability. For the purpose of analysis, the participation factors were used to determine which bus is weakly damped and most exposed to instability. Table 1 enumerates the weakly damped states during the linking of the third grid. This includes the rotor angular velocity and rotor angle of generating units nos. 10, 19, 1, 25 and 16 as the most associated states. It can be observed that most of the weakly damped states in the system are the rotor's speed and angle of the synchronous machine. This is true to most generating units, these states have lower than 10% damping ratios both in connected and isolated grids. Aside from the positive eigenvalues, the least damped are in local modes. As the results show, the generators with highest participation factors are optimal places where power oscillation dampers (POD), e.g. power systems stabilizers (PSS) should be placed to improve the stability and this should be considered.

When PSS is installed in the unstable generator, Syn_10, the eigenvalues (Fig. 3d) come to be stable. From −1.12%, it improved to 6.4% damping ratio. With the correct parameters of PSS, the real part of eigenvalue nos. 195—196 became negative (−0.22186).

Table 1 Linear value analysis of the system.

Eig. #	Most associated states	Real part	Imaginary part	Frequency	Damping ratio
195—196	delta_Syn_10, omega_Syn_10	−0.03881	3.46512	0.551490	−0.011200
159—160	omega_Syn_19, delta_Syn_19	−0.14261	5.97981	0.951714	0.023842
155—156	delta_Syn_1, omega_Syn_1	−0.19740	6.34482	1.009807	0.031097
157—158	omega_Syn_25, delta_Syn_25	−0.26188	6.38263	1.015825	0.040996
132—133	omega_Syn_16, delta_Syn_16	−0.40075	8.01357	1.275396	0.049947

Conclusions

The paper describes power flow and small signal stability analysis of the Philippine power grid modeled in PSAT, free and open software. The developed Model 3 was utilized in the hydro power plants in this model which differentiates it with the conventional thermal units. The eigenvalues, frequencies and participation factors were closely examined in the course of the study. Connecting Mindanao shows instability in one of the existing weakly damped buses which can be attributed to the parameters of the dynamic elements and the innate banes of reduced and approximate networks with the absence of FACTS devices and control devices. In order to stabilize the network, PODs and control devices are installed in the observed optimal spots making the system stable significantly. Further studies can use a more practical data of the Philippine power grid incorporating renewable resources in the system. Further studies in the interconnection to nearby countries can be investigated as well.

Conflict of interest statement

The author does not have any competing interests.

References

Cano, E.B., Shaikh, F.A., 2013. Reduced and Approximate Models of Philippine Major Island Power Grids, ICPEC 978-1-4673-6030-2/13.

Chompoobutrgool, Y., Li, W., Vanfretti, L., 2012. Development and Implementation of a Nordic Grid Model for Power System Small-Signal and Transient Stability Studies in a Free and Open Source Software., pp. 1—8, IEEE978-1-4673-2727-5.

Kundur, P., 1994. Power System Stability and Control. McGraw-Hill, Inc., pp. 699.

Lin, M.K., 2014. Small signal stability assessment of mepe test system in free and open source software. Int. J. Elect. Comput. Electron. Commun. Eng. 8 (11.).

Milano, F., Vanfretti, L., Morataya, J.C., 2008. An open source power system virtual laboratory: the PSAT case and experience. IEEE Trans. Educ. 51 (1).

Montaño, A.M., Ruiz, E.Y., Morataya, J.C., Castillo, J.A., 2006. Stability analysis for the electrical integration of Ecuador, Colombia and Panama. In: IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela 1-4244-0288-3/06.

Transmission Development Plan, 2011. Volume 2, Part I, Final Report, January 2012. National Grid Corporation of the Philippines.