

Voltage Drop Simulation at Southern Sulawesi Power System Considering Composite Load Model

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Abstract—Voltage instability has becoming one of the major concern for power systems utilities nowadays. It is believed as one of the major drives of the blackouts. Moreover, nowadays, many loads are single-phase small air conditioning motors which are prone to stall when the voltage falls because of short circuits in transmission lines. Excessive motor stalling may cause the system to experience voltage collapse or cascaded generator tripping, especially with inadequate reactive power compensation. This paper assesses and compares dynamic voltage stability of Southern Sulawesi power system considering static and dynamic load modelling.

Keywords- *dynamic load modelling, voltage collapse, voltage stability*

I. INTRODUCTION

In the late 20th century, voltage instability has become one of the major drives of the blackouts and it is believed as the root cause of the blackout in Northeast U.S. and Canada at 14 August 2003 [1]. A mainstream scenario for occasion of voltage instability is excessive system loading because of intense power transfers across the network, followed by incidents (such as a fault, line overloaded, congested lines or generator reaching its excitation limit) where these events may activate relay actions [2-7]. As results, progressive voltage drop or rise may evolve in some buses as result of shortfall of load, or loss of transmission lines and other elements by their protective systems that may instigate cascading failures.

When a sequence of voltage instability events result in a blackout (total or partial), or significant low voltage which are below acceptable limits in most parts of the system, it is said to be voltage collapse. Voltage collapse is instability of heavily loaded electric power systems which can result in declining voltages, cascading failure and blackouts [8]. It may occur quickly or even slowly depending on the dynamics of the system and is caused by single or multiple contingencies (these can be the sudden removal of generation, transformer or transmission line, increase of load without sufficient increase of reactive power, or the slow clearing of the system fault) [9-12].

Voltage instability can cause the entire grid to experience significant voltage drop, therefore mitigation action is demanded. During planning and operation of power systems, voltage problems have become a main concern, because of significant amount of failures caused by voltage instability. Several methods to mitigate voltage instability are application

of reactive power-compensating devices; control of network voltage and generator reactive output; coordination of protections/controls; control of transformer tap changers and under voltage load shedding [18, 19]. Under voltage load shedding (UVLS) plays a vital part in power system control when the system is subjected to large disturbances. Research has validated that UVLS is an effectual counter-measure deed against voltage collapse. In the literature, various techniques have been developed to formulate efficient UVLS schemes [13-26].

Voltage collapse is more likely on deficit of reactive power [27, 28]. Voltage stability depends heavily upon the amount, location and type of reactive power sources available. Large voltage may decline if the reactive power supply is too far away, of inadequate amount, or too dependent on shunt capacitors, such as the usual contingency. Another major factor that causes a rapid voltage collapse is the characteristic of loads being served by the utilities [29]. Nowadays, many loads are single-phase small air conditioning motors which are prone to stall when the voltage falls because of short circuits in transmission lines, especially during hot weather, since these motors comprise a high percentage of loads. Excessive motor stalling may cause the system to experience voltage collapse or cascaded generator tripping, especially with inadequate reactive power compensation. Therefore, it is essential to consider static and dynamic load modelling especially induction motor driven loads for voltage stability analysis.

This paper assesses and compares dynamic voltage stability of Southern Sulawesi power system considering static and dynamic load modelling. This paper is organized as follow. Section II provides a brief overview on power systems modelling, including static and dynamic load modelling. Section III describes the test system, Section IV elaborates case study and analysis whereas Section V concludes the main findings of the research.

II. POWER SYSTEM MODELING

A. Synchronous Generator Modeling

In this study, the detailed 6th order synchronous machine model is employed. The detailed explanations of the 6th order synchronous machine modeling and the differential equations can be found in [30].

B. Load Modeling

Load modeling is one of the most significant components in dynamic voltage stability simulation including under voltage load shedding. In this work, the load at each bus is represented as composite load which is a combination of static load and dynamic load. Further detail of the load configuration is explained in Section V.

Generally, load are reliant of the bus voltage [31]. The static load's voltage dependence can be expressed through a polynomial or exponential formulation. Static ZIP load modeling is usually stated as a function of voltage magnitude at a specific bus to which the load is connected as [32, 33],

$$P_{Li}(V_i) = P_{Li}^0 \left[\alpha_P \left(\frac{V_i}{V_0} \right)^2 + \beta_P \left(\frac{V_i}{V_0} \right) + \gamma_P \right] \quad (1)$$

$$Q_{Li}(V_i) = Q_{Li}^0 \left[\alpha_Q \left(\frac{V_i}{V_0} \right)^2 + \beta_Q \left(\frac{V_i}{V_0} \right) + \gamma_Q \right] \quad (2)$$

Dynamic load model is important for dynamic voltage stability analysis [34], because induction motors will decelerate substantially if their terminal voltage falls as a result of short circuits [35]. The generic load dynamic models are [36-39],

$$T_p \frac{dP_d}{dt} + V^{\alpha_t} P_d = V^{\alpha_t} P_s(V) + \alpha_t T_p \frac{P_d}{V} \frac{dV}{dt} \quad (3)$$

$$T_q \frac{dQ_d}{dt} + V^{\beta_t} Q_d = V^{\beta_t} Q_s(V) + \beta_t T_q \frac{Q_d}{V} \frac{dV}{dt} \quad (4)$$

III. THE TEST SYSTEM: THE SOUTHERN SULAWESI SYSTEM

A. Description of the Study System [40]

The Southern Sulawesi interconnected system in Indonesia consists of many different power generations which are connected by some transmission lines of 150 kV, 70 kV and 30 kV. The Southern Sulawesi system has a distinctive characteristic where the main economic power generation centers are located in the northern part of the system, whilst the main load center is located in the southern part.

Loads in Southern Sulawesi system are dominated by household load. However in Makassar city, as the capital of the South Sulawesi province (represented by buses Tello, Panakukang, Tallo Lama and Tanjung Bunga substations), the dynamic loads are mostly air conditioning and water pump loads. Makassar is the center of business for eastern part of Indonesia.

B. Load Composition

In this works, the load is assumed to be peak load. In the main city, Makassar, the load is exemplified as 50% static and 50% dynamic motor, since Makassar is the center of province governance, offices, business and the residents are mainly in the middle and upper economic levels. Fig. 3 shows the load representation in Makassar zone. In the other small towns, the load is represented as 80% static and 20% dynamic. Detail of the load composition is presented in Table 1 whereas detailed parameters of induction motors can be found in [41].

TABLE I LOAD COMPOSITION

Substation (Bus No)	Load type (%)				
	Static	Dynamic motor			
		I	II	III	IV
Bakaru (1), Polmas (2), Majene (3), Pinrang (4), Pare-Pare (5), Barru (7), Pangkep (8), Bosowa (9), Sungguminasa (14), Talasalapang (15), Jeneponto (16), Bulukumba (17), Sinjai (18), Bone (19), Soppeng (20), Sidrap (21), Makale (22), Palopo (23), Sengkang (24)	80	20	-	-	-
Tello (10), Panakukang (11), Tallo Lama (12) Tanjung Bunga (13)	50	20	25	5	-

IV. CASE STUDY AND ANALYSIS

In this study, the system is assumed under a stressed condition at the peak load. Voltage drop analysis is performing by comparing the voltage drop with static load modelling only and static – dynamic load modelling.

A. Static load modelling only

Fig. 1 shows the voltage collapse after fault occurs causing the loss of transmission line between buses Pangkep and Tello when loads are modelled with static load modelling only. For this simulation, buses Tello, Panakukang, Tanjung Bunga, Tallo Lama, Pangkep and Bosowa become unstable. The lowest voltage is 0.83 pu.

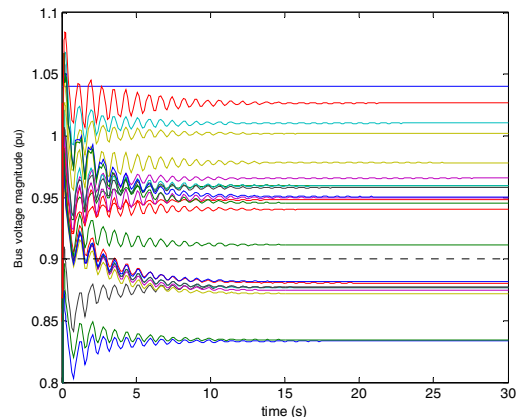


Fig. 1 Voltage drop after outage with static load modeling only

B. Static and dynamic load modelling

Fig. 2 shows the voltage collapse after fault occurs causing the loss of transmission line between buses Pangkep and Tello. From this outage, there are 3 critical zones identified: zone Makassar City, Pangkep and Palopo. Fig. 3 shows voltage decline drop at Makassar City zone and it clearly show significant voltages decline at substations in Makassar zone that drop to 0.66 – 0.69 pu at $t=30$ s. This is because Makassar as the load center in the system has substantial large amount of induction motor loads. Since motors have difficulties to reaccelerate after large disturbances then they stall and distressing the voltage at Makassar zone.

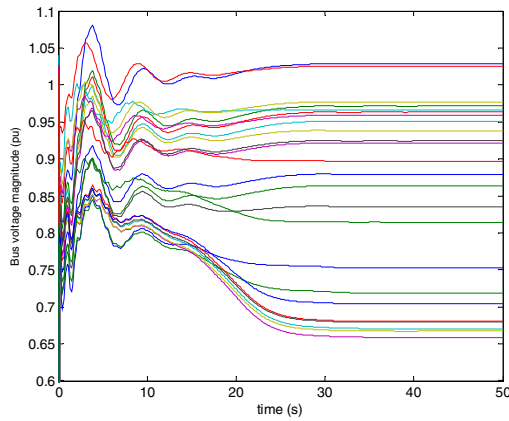


Fig. 2 Voltage drop after outage between bus Pangkep and Tello

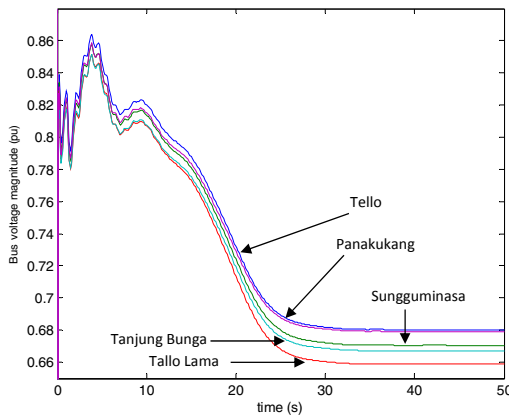


Fig. 3 Voltage drop after fault in the critical affected zone: Makassar City

Table 2 presents the comparison of the voltage drop with static load modelling only and static-dynamic load modelling. By using static load modelling, the lowest voltage is 0.83 pu with 6 buses with voltage below stability limit. However, when consider the dynamic load modelling, bus Tallo Lama has the lowest voltage of 0.66 pu with 8 unstable buses.

TABLE 2 COMPARISON OF VOLTAGE DROP BETWEEN STATIC AND STATIC-DYNAMIC LOAD MODELLING

	Load modelling	
	Static	Static and dynamic
Lowest voltage	0.83 pu	0.65 pu
Unstable buses	Tello Panakukang Tanjung Bunga Tallo Lama Pangkep Bosowa	Tello Panakukang Tanjung Bunga Tallo Lama Pangkep Bosowa Makale Palopo

V. CONCLUSIONS

This paper presents dynamic voltage stability of Southern Sulawesi power system considering static and dynamic load modelling. This paper compares the voltage drop with the same

amount of total load and same fault location. The results are significantly different, where with static load modelling only, the lowest voltage is 0.83 pu with 6 buses with voltage below stability limit. However, when consider the dynamic load modelling, bus Tallo Lama has the lowest voltage of 0.66 pu with 8 unstable buses.

Dynamic load modelling is important for dynamic voltage stability assessment, since excessive motor stalling may bring the system to experience voltage collapse. Furthermore, it can provide better assessment for under voltage load shedding design.

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