Study of Capacitor Placement to Improve the Voltage Profile in Contingency Conditions of the 150 kV Madura Electricity Power System

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ABSTRACT

The contingency is a very important issue in the electricity power system security. The contingency impact can change voltage, particularly the voltage drop on the load bus. This condition can have an impact on the quality of power supplied to the load, system reliability, and system security. The solution to overcome the voltage drop is to improve the voltage profile through the injection of reactive power sources into the system. This study focuses on improving the stress profile when a contingency occurs in the electricity power system. The stabilization profile is improved by placing the capacitor in distribution and centrally on the electricity power system. Newton Raphson method is used to determine the power flow and voltage on each bus normal and contingency conditions. The results showed that the worst undervoltage impact occurred in scenario 7 where the value of the Sumenep bus voltage decreased to 132.4 kV and the value of the bus voltage of Pamekasan was 131.8 kV. The centralized capacitor placement method is carried out on the Sumenep bus with an injection of a negative power of 24.93 MVAR. the centralized capacitor placement method can increase the bus voltage profile above the standard minimum value used. the distributed capacitor placement method is carried out by measuring the reactive power on each bus Sumenep 24.93 MVAR, Sampang 29.78 MVAR, Bangkalan 50.85 MVAR, Gilitimur 67.41 MVAR. The results of the voltage profile show that the voltages of all load buses are above the standard. The voltage standard used is the Regulation of the Minister of Energy and Mineral Resources CC2.0: 2007 with a minimum voltage limit of -10%.

Keywords: Contigency Analysis, Voltage Profile, The Centralized Capacitor Placement Method, The Distributed Capacitor Placement Method

1. INTRODUCTION

The problem of voltage stability is very important issue in terms of planning and operation in the power system [1]. Voltage instability will result in the system's inability to supply the power required by the load. Voltage instability in the power system can make a voltage drop.

A voltage drop in the electric power system is a continuation of the voltage instability when the voltage drops rapidly and uncontrollably. The issue of voltage drop can happen by inappropriate reactive power sources, unexpected increases in load levels due to unusual conditions in the power system, or due to the influence of disturbances in the power system such as contingency disturbances for disconnection of the transmission lines, transformers, or generator [2]. the best system performance voltage stability is based on SPLN No. 1: 1995 Article 4 regarding the provision of service voltage variations where the allowable voltage drop is only -10% to +5% [3].

One of the anticipations of these disturbances can be done by using a contingency analysis to maintain service continuity, and the system can survive when a disturbance occurs [4] - [6]. Contingency analysis is an analysis used to predict power flow and bus voltage conditions in the event of disturbances which include: transmission line outage, transformer outage, load outage, generator unit outage, capacitor/reactor outage, etc. [7] - [11]. Efforts to reduce the damages that occur due to these disturbances can be done by using a contingency analysis, because contingency analysis is an analysis to determine changes of power flow and changes of voltage for each bus when the transmission...
line is disconnected [12]. Indication of system instability is the occurrence of voltage drop and undervoltage. The solution to prevent undervoltage is by injecting a reactive power source for the capacitor to improve the voltage profile [13] - [21].

This study discusses of capacitor placement to improve the voltage profile when the contingency of Madura 150 kV electricity power system happened. Contingency analysis in Madura 150 kV electricity power system carried out with 8 contingency scenarios. Each scenario consists of an outage transmission line on Madura 150 kV electricity power system. The Newton Raphson method is used to calculate the power flow in Madura 150 kV electricity power system. This function is to determine the voltage drop that results in undervoltage when an element of the power system outages. The worst impact of undervoltage then calculate to voltage profile which is then followed by placing the capacitor to inject the reactive power bus. The capacitor placement method in this study to optimal capacitor placement is a centralized capacitor placement method and distributed capacitor placement method. Where the centralized placement method focuses on placing capacitors on the worst bus, while the distributed placement method places capacitors on each of the other buses.

2. MATERIAL AND METHOD

2.1. Newton Raphson Methods

The solution to select a release case or contingency condition scenario is to use the newton raphson power flow method. The electricity power system not only consists of two buses but consists of several buses that are interconnected with each other. The electricity injected from the generator to the bus is not only absorbed by the load bus but also absorbed by other buses that are also connected or interconnected. A Diagram of one line of several buses from a power system is shown in figure 1:

![Figure 1 One Line Diagram of n-bus in an Electricity Power System](image1)

The current on bus i is a multiplication admittance y and V voltage, and there can be written in the form of the following equations:

\[ I_i = V_i \sum_{j=1}^{n} y_{ij} V_j - \sum_{j=1}^{n} y_{ij} V_j \]  
\[ I_i = y_{i0} V_i + y_{1i} (V_1 - V_2) + \ldots + y_{in} (V_i - V_n) \]  
\[ I_i = (y_{i0} + y_{1i} + y_{2i} + \ldots + y_{ni}) V_i - y_{1i} V_1 - y_{2i} V_2 - \ldots - y_{ni} V_n \]

For the active power and reactive power values on bus i are as follows:

\[ P_i + jQ_i = V_i I_i \]  
\[ I_i = \frac{P_i + jQ_i}{V_i} \]

2.2. Shunt Capacitor

Solution to regulating the voltage profile on the bus is to inject shunt capacitors in the transmission, distribution system, or the main substation and load. Basically the capacitor is a tool to inject reactive power (VAR). In figure 2 bus 1 is the sending bus and bus 2 is the receiving bus. The channel has Ω impedance (R+jX).

![Figure 2 Transmission Line to Load](image2)
values are obtained [22], so that phasor diagrams are obtained as shown below:

**Figure 3** Phasor diagram

\[ V_1^2 = (V_2 + \Delta V)^2 + \Delta \delta^2 \tag{7} \]

When:

\[ \Delta V = \frac{P}{V_2} + \frac{Q}{V_2} \tag{8} \]

\[ \Delta \delta = \frac{P}{V_2} + \frac{Q}{V_2} \tag{9} \]

\( \Delta \delta \) usually will be smaller than \( V_2 + \Delta V \), so we get the following equation:

\[ V_1^2 = (V_2 + \Delta V)^2 \text{ atau } V_1 = (V_2 + \Delta V) \tag{10} \]

Then, the voltage on the transmission line is:

\[ V_1 - V_2 = \Delta V = \frac{P}{V_2} + \frac{Q}{V_2} \tag{11} \]

Description:

- \( V_1 \) = send of voltage.
- \( V_2 \) = receiver of voltage.
- \( P \) = active power.
- \( Q \) = Reactive power.
- \( \Delta V \) = between \( V_1 \) and \( V_2 \)

Based on the formula above the \( Q \) value can be categorized as shunt capacitor.

### 2.3. Flowchart

Model the problem with ETAP 12.6 application to calculate newton rapson power flow on madura 150 kV electricity power system. The research phase of the capacitor placement study for voltage profile at the time of contingency at Madura 150 kV electricity power system includes the flow chart in figure 4 below.

**Figure 4** Capacitor Placement Flowchart For Voltage Profile When contingency at Madura 150 kV electricity power system.

### 2.4. Research data

This research data is electricity system 150 KV Madura includes a Single line diagram of Madura 150 kV electricity power system with region sub-system Krian 1.2 Gresik, Data transmission line parameters, Data transformer, Bus data, Peak-load data.

### 3. RESULT AND DISCUSSION

#### 3.1. Madura 150 kV electricity power system

Madura island included in region krian subsystem – 1.2 – gresik consisting of 5 substations (GI) with GI Bangkalan, GI Gilitimur, GI Sampang, GI Pamekasan, GI Sumenep to meet the load needs of Madura island which when peak load happens can reach 200 MW (PT. PLN APB REGION 4). Single line is shown in figure 5 below:
Power flow at the normal condition (before contingency) shows Madura 150 kV electricity power system in good condition, each bus connected to the system works well to deliver electrical energy according to the demand of each bus without overload or undervoltage. There show the table of results from the simulation of load flow during normal conditions (before contingency) with peak load in table 2:

### Table 2. Voltage result of Madura 150 kV electricity power system Before Contigency (Normal)

| No. | Bus ID          | Voltage (kV) |
|-----|-----------------|--------------|
| 1   | Infinity (Kenjeran) | 145.08       |
| 2   | Infinity (Ujung)   | 144.72       |
| 3   | Gilitimur         | 143.8        |
| 4   | Bangkalan         | 142          |
| 5   | Sampang           | 139.8        |
| 6   | Pamekasan         | 137.9        |
| 7   | Sumenep           | 136.8        |

Based on table 2 and there show Madura 150 kV electricity power system is in good condition because it is still within the threshold or standard regulation of the Minister of Energy and Mineral Resources CC2.0:2007 where the minimum voltage limit is -10% and the maximum voltage limit is +5%.

### 3.2. Madura 150 kV electricity power system contingency scenario

Contingencies on transmission lines in this study consist of eight outage scenarios. The outages modeled on every transmission line in Madura 150 kV electricity power system. The following contingency scenarios in the study are shown in table 3 below:

### Table 3. Scenario contingency

| Scenario | Gilitimur              |
|----------|------------------------|
| 1        | Infinity – Gilitimur A |
| 2        | Infinity – Bangkalan A |
| 3        | Gilitimur B – Bangkalan B |
| 4        | Bangkalan A – Sampang A |
| 5        | Bangkalan B – Sampang B |
| 6        | Sampang B – Sumenep    |
| 7        | Sampang A – Pamekasan  |
| 8        | Sumenep – Pamekasan    |

From the result scenario contingency, especially on the Sumenep bus is always undervoltage when a contingency scenario occurs and the Pamekasan bus is the next worst sequence with undervoltage occurring in all scenarios except scenarios 6 and 8. The Worst undervoltage occurred is scenario 7 where the Sumenep bus voltage value was 132.4 kV and the Pamekasan bus voltage value was 131.8 kV. Therefore, it is necessary to place a capacitor to improve the bus voltage and by the optimal placement of the capacitor.

3.2.1. Scenario of the centralized capacitor placement method on the worst bus sumenep

Based on equation 8 the result of shunt capacitor is 39 MVAR for bus sumenep, and the result of scenario contingency show from table 4.

### Table 4. Result Voltage On Each Bus Madura 150 kV electricity power system of the centralized capacitor placement method

| No. | Bus ID          | Before capacitor placement | After capacitor placement |
|-----|-----------------|-----------------------------|---------------------------|
|     |                 | Normal | Contingency | Normal | Contingency |
| 1   | Infinity (Kenjeran) | 145.08 | 145.08 | 145.08 | 145.08 |
| 2   | Infinity (Ujung)  | 144.72 | 144.72 | 144.72 | 144.72 |
| 3   | Gilitimur        | 143.8  | 143.6  | 144.2  | 144  |
| 4   | Bangkalan        | 142    | 141.7  | 143.1  | 142.7  |
| 5   | Sampang          | 138.9  | 138    | 142.3  | 140.9  |
| 6   | Pamekasan        | 136.8  | 131.8  | 142.7  | 141.1  |
| 7   | Sumenep          | 137.9  | 132.4  | 143.7  | 141.6  |

From table 4, that shows the undervoltage of several buses in the scenario, especially on the Sumenep bus is always undervoltage when a contingency scenario occurs and the Pamekasan bus is the next worst sequence with undervoltage occurring in all scenarios except scenarios 6 and 8. The Worst undervoltage occurred is scenario 7 where the Sumenep bus voltage value was 132.4 kV and the Pamekasan bus voltage value was 131.8 kV.

3.2.2. Scenario of the distributed capacitor placement method

Based on equation 8 the result equation 11 of shunt capacitor is 39 MVAR for sumenep, 29.78 MVAR for Sampang, 50.85 MVAR for Bangkalan, 67.41 MVAR Gilitimur and the result of scenario contingency show from table 5.
Table 5. Result Voltage On Each Bus Madura 150 kV electricity power system of the distributed capacitor placement method

| No. | Bus ID          | Before Capacitor placement | After capacitor placement | Normal  | Continency | Normal  | Continency |
|-----|----------------|-----------------------------|---------------------------|---------|------------|---------|------------|
| 1   | Infinity       | 145.08                      | 145.08                    | 145.08  | 145.08     | 145.08  | 145.08     |
| 2   | Infinity       | 144.72                      | 144.72                    | 144.72  | 144.72     | 144.72  | 144.72     |
| 3   | Gilitimur      | 143.8                       | 143.6                     | 146.8   | 146.6      | 146.8   | 146.6      |
| 4   | Bangkalan      | 142                         | 141.7                     | 146.8   | 146.3      | 146.8   | 146.3      |
| 5   | Sampang        | 138.9                       | 138                       | 148     | 146.5      | 148     | 146.5      |
| 6   | Pamekasan      | 136.8                       | 132.4                     | 148.4   | 146.6      | 148.4   | 146.6      |
| 7   | Sumenep        | 137.9                       | 131.8                     | 149.4   | 147.2      | 149.4   | 147.2      |

Based on table 4 and table 5, that shows the best capacitor placement is the capacitor placement distribution method with the value of each bus of the Madura electricity power system being more optimal than the centralized capacitor placement method. From the result this paper uses the distribution capacitor placement method, the value of distribution capacitor placement method is sumenep 24.93 MVAR, sampang of 29.78 MVAR, Bangkalan of 50.85 MVAR, Gilitimur of 67.41 MVAR with the voltage on each bus that was still by the threshold or standard Regulation of the Minister of Energy and Mineral Resources CC2.0: 2007 with a minimum voltage limit of -10%.

4. CONCLUSION

Based on the results of the contingency scenario carried out on the Madura 150 kV Electricity power System, the voltage and active power flow on each bus have changed. The results showed that the worst undervoltage impact occurred in scenario 7 where the value of the Sumenep bus voltage decreased to 132.4 kV and the value of the bus voltage of Pamekasan was 131.8 kV. The centralized capacitor placement method is carried out on the Sumenep bus with an injection of a negative power of 24.93 MVAR. The centralized capacitor placement method can increase the bus voltage profile above the standard minimum value used. The distributed capacitor placement method is carried out by measuring the reactive power on each bus Sumenep 39 MVAR, Sampang 29.78 MVAR, Bangkalan 50.85 MVAR, Gilitimur 67.41 MVAR. The results of the voltage profile show that the voltages of all load buses are above the standard. The voltage standard used is the Regulation of the Minister of Energy and Mineral Resources CC2.0: 2007 with a minimum voltage limit of -10%.

REFERENCES

[1] Y. Mohamad, “Perbaikan Tegangan Bus Akibat Gangguan Kontingensi dengan Menggunakan Injeksi Sumber Daya Reaktif,” ARTIKEL, vol. 1, no. 93, Mar. 2013, Accessed: Aug. 30, 2020. [Online]. Available: https://repository.ung.ac.id/karyaimiah/show/93/perbaikan-tegangan-bus-akibat-gangguan-kontingensi-dengan-menggunakan-injeksi-sumber-daya-reaktif.html.

[2] R. A. Zakaria, “Analisa Undervoltage Load Shedding Pada Sistem Jawa-Bali 500 Kv Untuk Mencegah Voltage Collapse,” Undergraduate, Institut Teknologi Sepuluh Nopember, 2017.

[3] A. M. N. Putra and A. Y. Dewi, “STUDI ANALISA KESTABILAN TEGANGAN SISTEM 150 kV BERDASARKAN PERUBAHAN TEGANGAN (APLIKASI PT. PLN BATAM),” J. Tek. Elektro, vol. 2, no. 1, Art. no. 1, Jun. 2013, Accessed: Aug. 30, 2020. [Online]. Available: https://ejournal.itp.ac.id/index.php/telektro/article/view/10.

[4] J. E. Ruiz-Castro, “Preventive Maintenance of a Multi-State Device Subject to Internal Failure and Damage Due to External Shocks,” IEEE Trans. Reliab., vol. 63, no. 2, pp. 646–660, Jun. 2014, doi: 10.1109/TR.2014.2315922.

[5] W. D. Oliveira, J. P. A. Vieira, U. H. Bezerra, D. A. Martins, and B. das G. Rodrigues, “Power system security assessment for multiple contingencies using multway decision tree,” Electr. Power Syst. Res., vol. 148, pp. 264–272, Jul. 2017, doi: 10.1016/j.epsr.2017.03.029.

[6] M. Aien, A. Hajebramhi, and M. Fotuhi-Firuzabad, “A comprehensive review on uncertainty modeling techniques in power system studies,” Renew. Sustain. Energy Rev., vol. 57, pp. 1077–1089, May 2016, doi: 10.1016/j.rser.2015.12.070.

[7] J. V. Canto dos Santos, I. F. Costa, and T. Nogueira, “New genetic algorithms for contingencies selection in the static security analysis of electric power systems,” Expert Syst. Appl., vol. 42, no. 6, pp. 2849–2856, Apr. 2015, doi: 10.1016/j.eswa.2014.11.041.

[8] A. A. Abdelsalam, A. A. Eldesouky, and A. A. Sallam, “Classification of power system disturbances using linear Kalman filter and fuzzy-expert system,” Int. J. Electr. Power Energy Syst.,
[9] P. Pruski and S. Paszek, “Calculations of power system electromechanical eigenvalues based on analysis of instantaneous power waveforms at different disturbances,” Appl. Math. Comput., vol. 319, pp. 104–114, Feb. 2018, doi:10.1016/j.amc.2017.01.057.

[10] F. Fatehi, M. Rashidinejad, and A. A. Gharaveisi, “Contingency Ranking Based on a Voltage Stability Criteria Index,” in 2007 Large Engineering Systems Conference on Power Engineering, Oct. 2007, pp. 142–147, doi:10.1109/LESCPE.2007.4437368.

[11] J. Zhao and H. Chiang, “A Enhanced Contingency Selection Method with respect to Multiple Contingencies for On-line Voltage Stability Assessment,” in 2006 International Conference on Power System Technology, Oct. 2006, pp. 1–6, doi:10.1109/ICPST.2006.321779.

[12] J. J. Grainger, Power System Analysis. McGraw-Hill, 2003.

[13] C. Mozina, “Undervoltage Load Shedding,” 2007 60th Annu. Conf. Prot. Relay Eng., 2007, doi:10.1109/CPRE.2007.359889.

[14] M. Klaric, I. Kuzle, and T. Tomisa, “Simulation of undervoltage load shedding to prevent voltage collapse,” in 2005 IEEE Russia Power Tech, Jun. 2005, pp. 1–6, doi:10.1109/PTC.2005.4524395.

[15] S. S. Ladhani and W. Rosehart, “Under voltage load shedding for voltage stability overview of concepts and principles,” in IEEE Power Engineering Society General Meeting, 2004., Jun. 2004, pp. 1597-1602 Vol.2, doi:10.1109/PES.2004.1373142.

[16] N. Shekhawat, A. K. Gupta, and A. Kumar Sharma, “Voltage Stability Assessment Using Line Stability Indices,” in 2018 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering (ICRAIE), Nov. 2018, pp. 1–4, doi:10.1109/ICRAIE.2018.8710435.

[17] R. A. Zahidi, I. Z. Abidin, H. Hashim, Y. R. Omar, N. Ahmad, and A. M. Ali, “Study of static voltage stability index as an indicator for Under Voltage Load Shedding schemes,” in 2009 3rd International Conference on Energy and Environment (ICEE), Dec. 2009, pp. 256–261, doi:10.1109/ICEENVIRON.2009.5398637.

[18] G. Radman, A. Pama, J. Powell, and D. Gao, “Dynamic Voltage Stability Improvement using coordinated control of dynamic VAR-sources,” in 2007 iREP Symposium - Bulk Power System Dynamics and Control - VII. Revitalizing Operational Reliability, Aug. 2007, pp. 1–6, doi:10.1109/IREP.2007.4410541.

[19] P. Fransco, “STUDI KESTABILAN BERDASARKAN PREDIKSI VOLTAGE COLLAPSE PADA SISTEM STANDAR IEEE 14 BUS MENGGUNAKAN MODAL ANALYSIS,” Undergrad. Thesis Electr. Eng. RSE 62131 Fra 2011, Feb. 2011, Accessed: Aug. 30, 2020. [Online]. Available: http://digilib.its.ac.id/ITS-Undergraduate-3100011043048/15455.

[20] S. Punitha and K. Sundararaju, “Voltage stability improvement in power system using optimal power flow with constraints,” in 2017 IEEE International Conference on Electrical, Instrumentation and Communication Engineering (ICEICE), Apr. 2017, pp. 1–6, doi:10.1109/ICEICE.2017.8191914.

[21] N. Ibrahimii, A. Gebremedhin, T. A. Folkestad, and I. Norheim, “Impact of distributed capacitors on voltage profile and power losses in real low voltage distribution networks,” in 2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018), Apr. 2018, pp. 1–8, doi:10.1109/CPE.2018.8372527.

[22] B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayake, and G. Strbac, Electric Power Systems. John Wiley & Sons, 2012.