Analisis Probabilitas Aliran Daya Optimum Menggunakan *First Order Second Moment Method* (FOSMM) pada Sistem Distribusi Listrik

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Outline

1. Pendahuluan
2. First Order Second Moment
3. Penerapan FOSMM pada POPF
4. Hasil dan Analisis
5. Penutup

Latar Belakang

Dalam STL Terinterkoneksi Pedjadwalan optimal ekonomi sangat diperlukan

Economic Dispatch

Constraints saluran

Optimal Power Flow

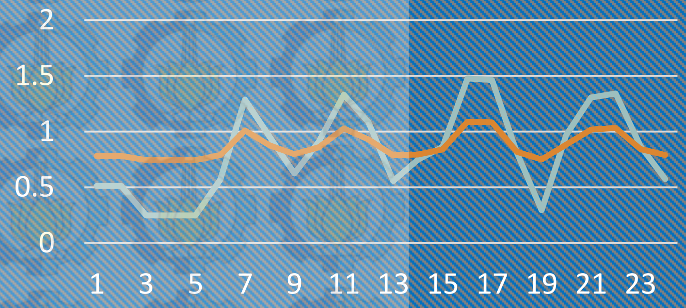
Statis

Beban Tak Tentu

Kurang Akurat
Tidak Sesuai

Probabilistic Optimal Power Flow

First Order Second Moment Method



Optimal Power Flow

AC OPF

Optimal Power Flow

Solusi optimal untuk *objective function*

Memperhatikan batasan aliran daya dan batasan operasi lainnya (generator, transmisi, tegangan, dll)

$$F(x) = min \sum_{i=1}^{n_g} a_i P_{gi}^2 + b_i P_{gi} + c_i$$

TABLE 2: MAJOR TYPES OF POWER SYSTEM PROBLEMS

General problem type	Problem name	Includes voltage angle constraints?	Includes bus voltage magnitude constraints?	Includes transmission constraints?	Includes losses?	Assumptions	Includes generator costs?	Includes contingency constraints?
OPF	ACOPF, or Full ACOPF	Yes	Yes	Yes	Yes		Yes	No
OPF	DCOPF	No	No; all voltage magnitudes fixed	Yes	Maybe	Voltage magnitudes are constant	Yes	No

Tujuan

1

- Mengembangkan perencanaan tenaga listrik dengan POPF menggunakan pendekatan ekspansi deret Taylor dalam metode *First Order Second Moment Method* (FOSMM).

2

- Membuat progam pembebanan eknomis distribusi energi listrik dengan POPF berbasis pendekatan *First Order Second Moment Method* dengan batasan kapasitas saluran dan mempertimbangkan kondisi perubahan terhadap beban selama 24 jam

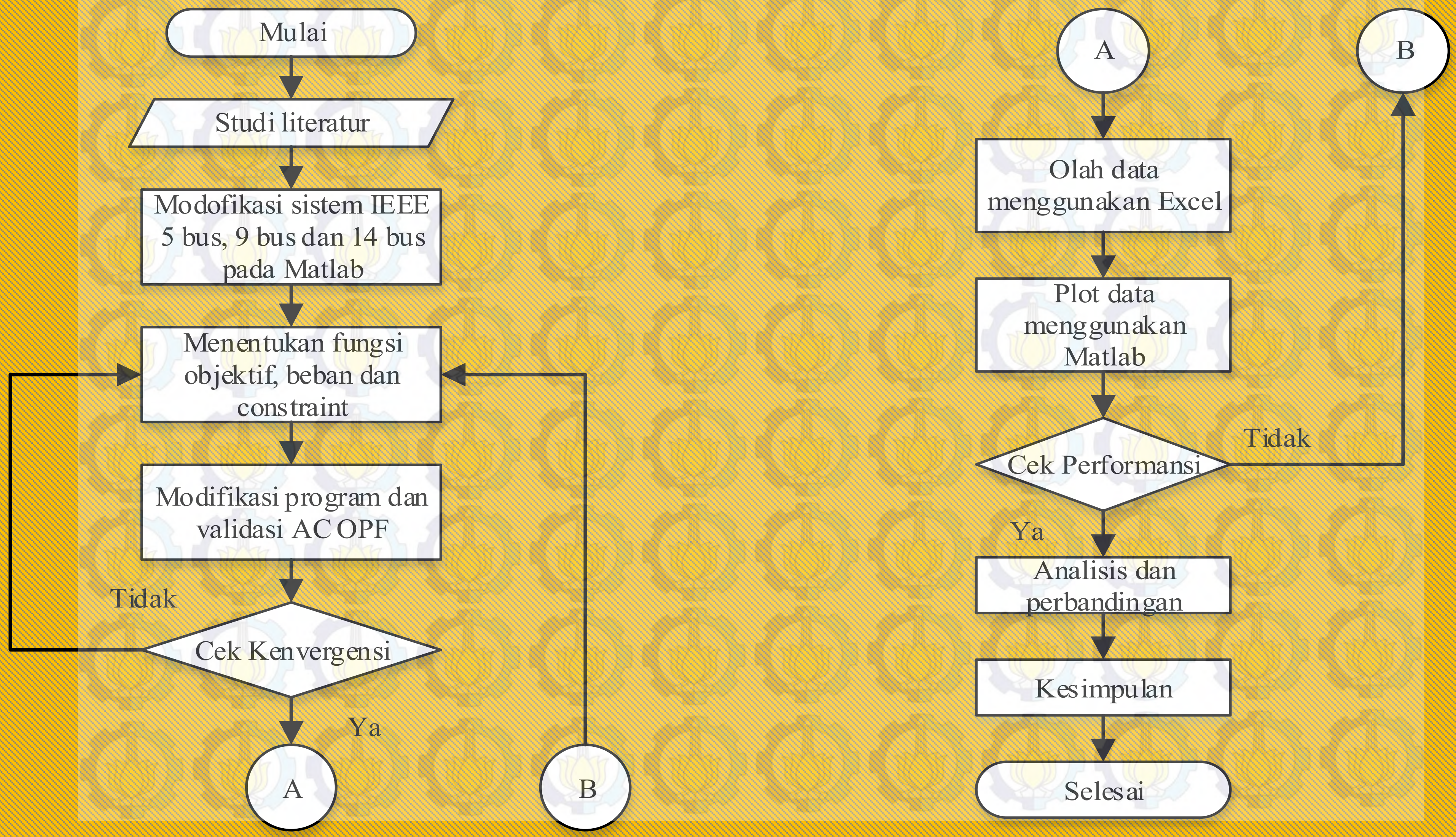
3

- Membuat perbandingan penggunaan POPF metode FOSMM dengan AC OPF.

4

- Membuat perbandingan penggunaan metode FOSMM pada sistem IEEE 5 bus, 9 bus dan 14 bus.

Metodologi


Mulai
Studi literatur
Modofikasi sistem IEEE 5 bus, 9 bus dan 14 bus pada Matlab
Menentukan fungsi objektif, beban dan constraint
Modifikasi program dan validasi AC OPF
Tidak
Cek Kenvergensi
Ya
A
B
A
Olah data menggunakan Excel
Plot data menggunakan Matlab
Cek Performansi
Tidak
B
Ya
Analisis dan perbandingan
Kesimpulan
Selesai

FIRST ORDER SECOND MOMENT METHOD

Probabilistic-Optimal Power Flow

Probabilistic Optimal Power Flow

AC POPF

TABLE 2: MAJOR TYPES OF POWER SYSTEM PROBLEMS

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OPF	ACOPF, or Full ACOPF	Yes	Yes	Yes	Yes		Yes	No
OPF	DCOPF	No	No; all voltage magnitudes fixed	Yes	Maybe	Voltage magnitudes are constant	Yes	No

Probabilistic Optimal Power Flow

- Solusi optimal untuk *objective function* dengan pendekatan statistik seperti *mean,* simpangan baku dll
- Memperhatikan batasan aliran daya dan batasan operasi lainnya (generator, transmisi, tegangan, dll)

$$Pgi - Pdi - Pi(V, \theta) = 0$$

$$Qgi - Qdi - Qi(V, \theta) = 0$$

$$Pgi\ min < Pgi < Pgi\ max$$

$$Qgi\ min < Qgi(V, \theta) < Qgi\ max$$

$$Vi\ min < Vi < Vi\ max$$

First Order Second Moment Method

AC POPF

FOSMM adalah metode pendekatan linierisasi suatu fungsi yang tidak linier menggunakan ekspansi *Deret Taylor.*

$$F(x) = min \sum_{i=1}^{n_g} a_i P_{gi}^2 + b_i P_{gi} + c_i$$

$$F(x) = a_i P^2{}_{g1} + b_i P_{g1} + c_i + a_i P^2{}_{g2} + b_i P_{g2} + c_i + a_i P^2{}_{g3} + b_i P_{g3} + c_i$$

Dengan menggunakan *first order* dan mengambil nilai rata-rata dari nilai P, didapatkan pendekatan rata-rata fungsi objektif dari F(x):

$$\bar{F}(x) = F(x) + 2a_i\mu_{g1} + b_i + 2a_i\mu_{g2} + b_i + 2a_i\mu_{g3} + b_i$$

Sehingga didapatkan pendekatan linieriasai FOSMM sebagai berikut:

$$\boxed{\bar{F}_0 = F\left(x'^0\right) + \nabla F(x'^0)^T x'^0}$$

Mean Value First Order Second Moment

AC POPF

Pada metode FOSMM, data yang digunakan adalah nilai rata rata (μ) dan simpangan baku (σ). Dimana nilai ini didapatkan dengan menurunkan fungsi objektif masing masing variabel.

$$\mu = F(\bar{x}_0) + \sum_{i=1}^{n} \frac{\delta F(x)}{\delta x_i} (\bar{x}_i - x_0)$$

$$\sigma^2 = \sum_{i=1}^{n} \sum_{j=1} \frac{\delta F(x)}{\delta x_i} \frac{\delta F(x)}{\delta x_j} Cov(x_i . x_0)$$

Nilai simpangan baku diperoleh dari akar varians σ^2

Nilai rata-rata menggambarkan nilai keseluruhan di sistem, sedangkan simpangan baku adalah sebaran nilai diantara nilai rata-rata.

PROFIL SISTEM DAN BEBAN

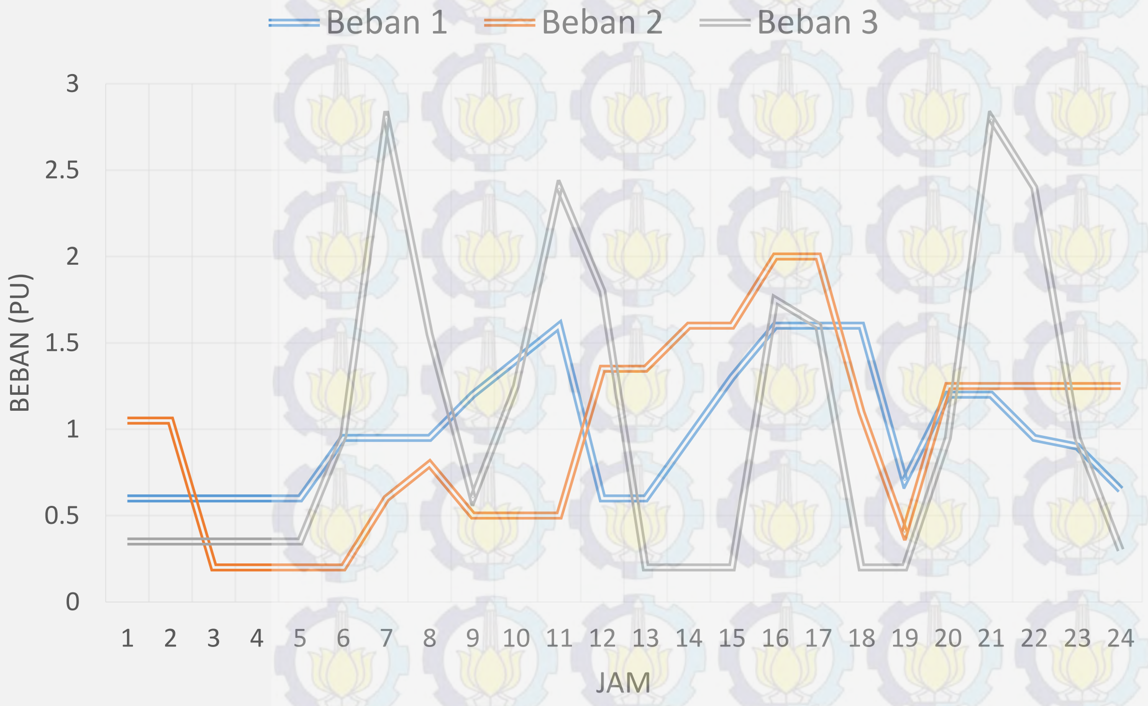
Dynamic Load, 5 Bus, 9 Bus dan 14 Bus

Beban Dynamic

24 Jam

Beban yang digunakan adalah beban variabel selama 24 jam sesuai dengan standar yang ada pada Paper (2)

Base MVA = 100 MVA



Diuji dengan AC OPF

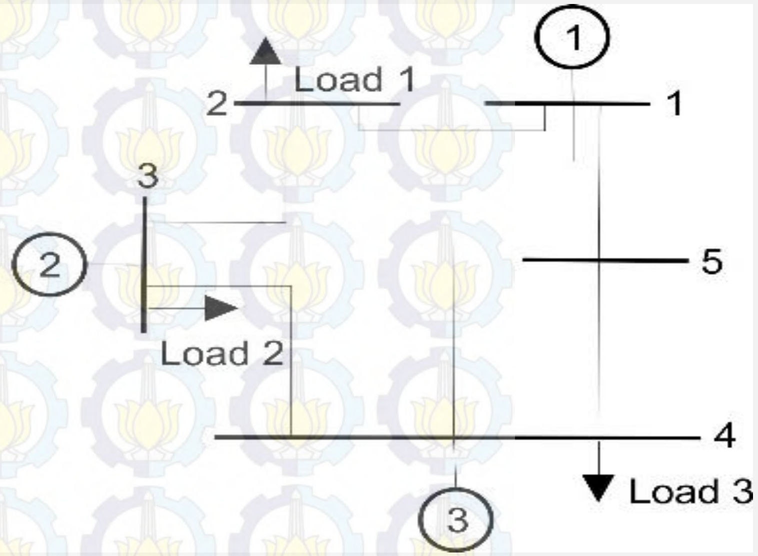
Diuji dengan POPF FOSMM

Sistem IEEE

5 Bus

Bus	Tipe	Pd (MW)	Tegangan (kV)
1	2	0	230
2	1	L1	230
3	2	L2	230
4	3	L3	230
5	1	0	230

Unit	Cost Function	P max (MW)	P min (MW)	Ramp Rate (MW/Jam)
1	$14P_1$	240	10	40
3	$40P_3$	100	10	40
4	$40P_4$	350	10	40



Memiliki 3 Generator pada Bus 1, Bus 2 dan Bus 3

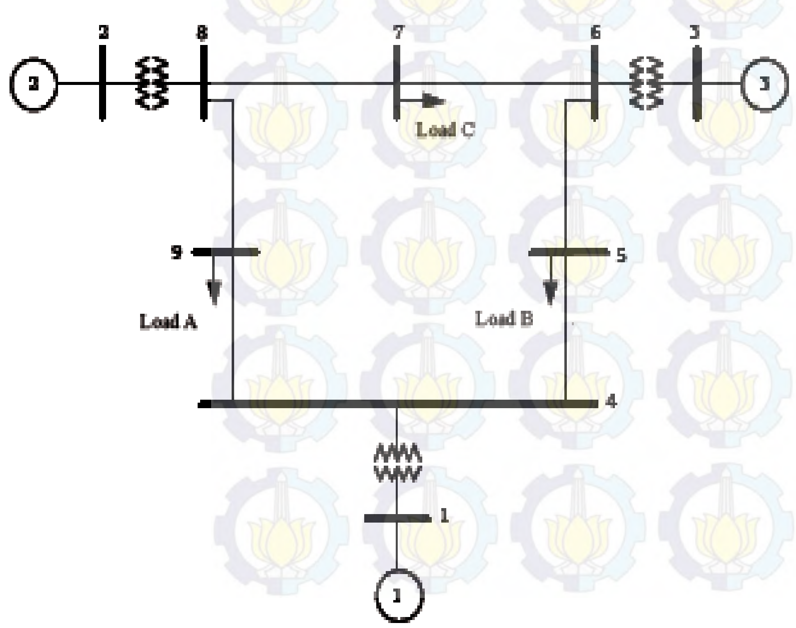
Terdapat 3 titik beban

Sistem IEEE

9 Bus

Memiliki 3 Generator pada Bus 1, Bus 2 dan Bus 3

Terdapat 3 titik beban



Bus	Tipe	Pd (MW)	Tegangan (kV)
1	3	0	345
2	2	0	345
3	2	0	345
4	1	0	345
5	1	L1	345
6	1	0	345
7	1	L2	345
8	1	0	345
9	1	L3	345

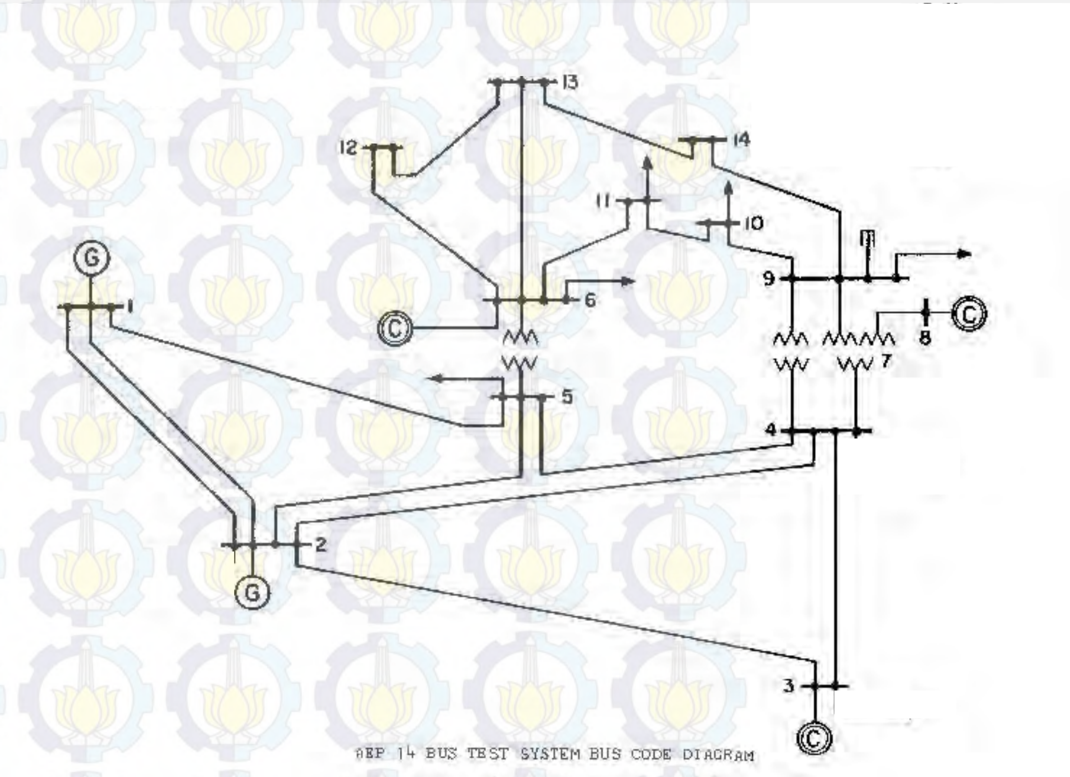
Unit	Cost Function	P max (MW)	P min (MW)	Ramp Rate (MW/Jam)
1	$0.11{P_1}^2 + 5P_1 + 150$	250	10	40
2	$0.085{P_2}^2 + 1.2P_2 + 600$	300	10	40
3	$0.1225{P_3}^2 + P_3 + 335$	270	10	40

Sistem IEEE

14 Bus Modifikasi

Bus	Tipe	Pd (MW)	Tegangan (kV)
1	3	0	300
2	2	0	300
3	2	0	300
4	1	0	300
5	1	0	300
6	2	0	300
7	1	0	300
8	2	0	300
9	1	L1	300
10	1	L2	300
11	1	L3	300
12	1	0	300
13	1	0	300
14	1	0	300

Unit	Cost Function	P max (MW)	P min (MW)
1	$0.043{P_1}^2 + 20P_1$	332	0
2	$0.025{P_2}^2 + 20P_2$	140	0
3	$0.01{P_3}^2 + 40P_3$	100	0
6	$0.01{P_4}^2 + 40P_4$	100	0
8	$0.01{P_5}^2 + 40P_5$	100	0



Memiliki 5 Generator pada Bus 1, 2, 3, 6 dan Bus 8

Terdapat 3 titik beban

SIMULASI FOSMM PADA AC POPF

Probabilistic-Optimal Power Flow

Penerapan FOSMM di POPF

Penentuan Profil Beban → **Running OPF Statis** → **Output berupa Jacobian Matriks**

$$G(x) = \begin{bmatrix} \frac{dVai}{dPgi} & \frac{dVai}{dQgi} \\ \frac{dVmi}{dPgi} & \frac{dVmi}{dQgi} \\ \frac{dPgi}{dPgi} & 0 \\ 0 & \frac{dQgi}{dQgi} \end{bmatrix}$$

Penerapan FOSMM

di POPF

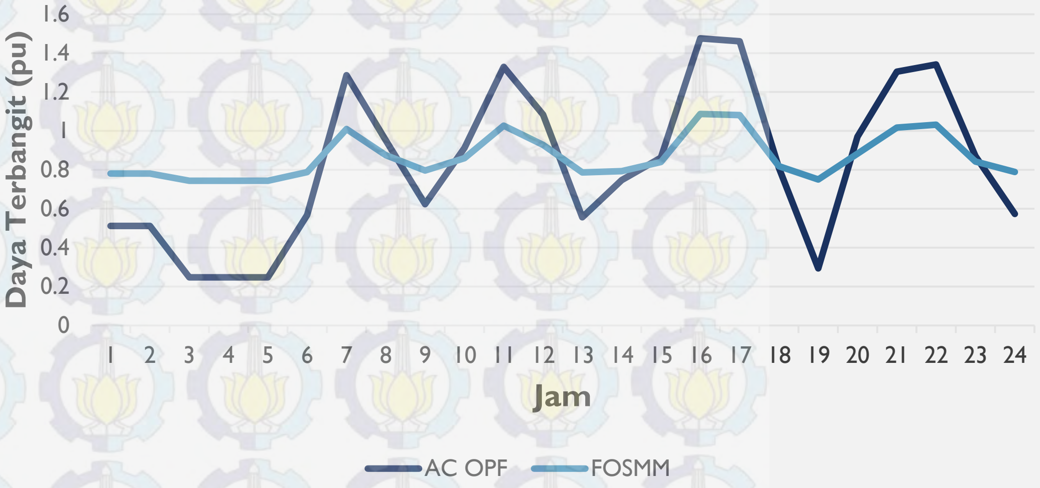
Penentuan Profil Beban → Running OPF Statis → Output berupa Jacobian Matriks

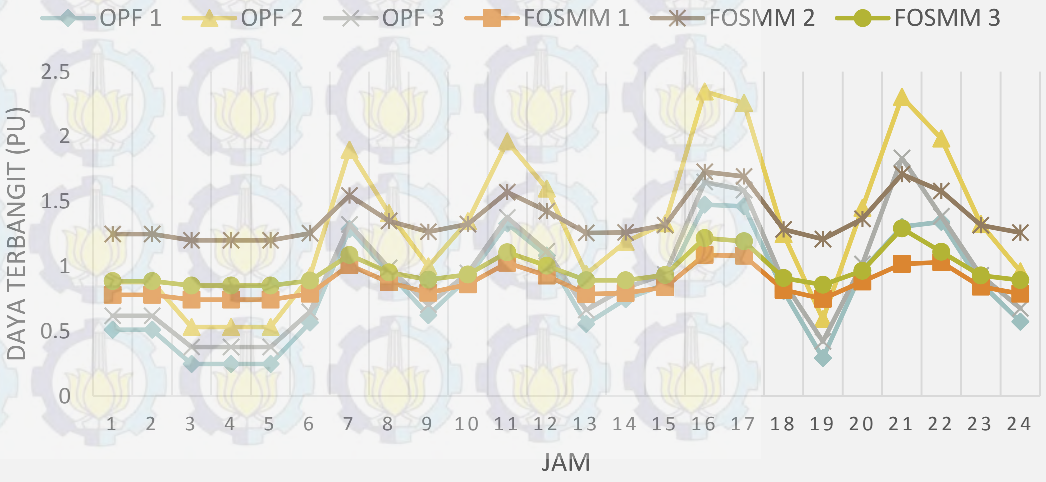
→ Validasi Jacobian Matriks → Penggunaan FOSMM → Variabel Statistik

Simulasi Progam

5 Bus

Jam	Pg Terbangkit (pu)			Tegangan Bus (pu)				
	1	3	4	1	2	3	4	5
1	0.7807	1.2486	0.8858	1.099	1.089	1.096	1.098	1.099
2	0.7807	1.2486	0.8858	1.099	1.089	1.096	1.098	1.099
3	0.7437	1.2002	0.8521	1.098	1.089	1.095	1.097	1.098
4	0.7437	1.200	0.8521	1.098	1.089	1.095	1.097	1.098
5	0.7437	1.200	0.8521	1.098	1.089	1.095	1.097	1.098
6	0.7885	1.2549	0.8901	1.099	1.089	1.096	1.097	1.098
7	1.0098	1.5449	1.086	1.099	1.089	1.096	1.097	1.099
8	0.8759	1.3491	0.952	1.099	1.089	1.096	1.097	1.099
9	0.7964	1.2656	0.8978	1.099	1.089	1.096	1.097	1.099
10	0.8599	1.3246	0.9368	1.099	1.089	1.096	1.098	1.099
11	1.0273	1.5713	1.108	1.099	1.089	1.096	1.098	1.099
12	0.9286	1.4255	1.004	1.099	1.089	1.096	1.097	1.099
13	0.7868	1.2575	0.8920	1.099	1.089	1.096	1.098	1.099
14	0.7936	1.2603	0.8921	1.099	1.089	1.096	1.098	1.099
15	0.8399	1.3178	0.9328	1.099	1.089	1.096	1.098	1.099
16	1.0870	1.7273	1.2172	1.099	1.089	1.096	1.098	1.099
17	1.0813	1.6919	1.1926	1.099	1.089	1.096	1.098	1.099
18	0.8189	1.2844	0.9102	1.099	1.089	1.096	1.098	1.099
19	0.7501	1.2086	0.8581	1.099	1.089	1.096	1.098	1.099
20	0.8832	1.3653	0.9649	1.099	1.089	1.096	1.098	1.099
21	1.0175	1.7090	1.2911	1.099	1.089	1.096	1.098	1.099
22	1.0322	1.5804	1.1114	1.099	1.089	1.096	1.098	1.099
23	0.8429	1.3159	0.9299	1.099	1.089	1.096	1.097	1.099
24	0.7893	1.2602	0.8939	1.099	1.089	1.096	1.098	1.099

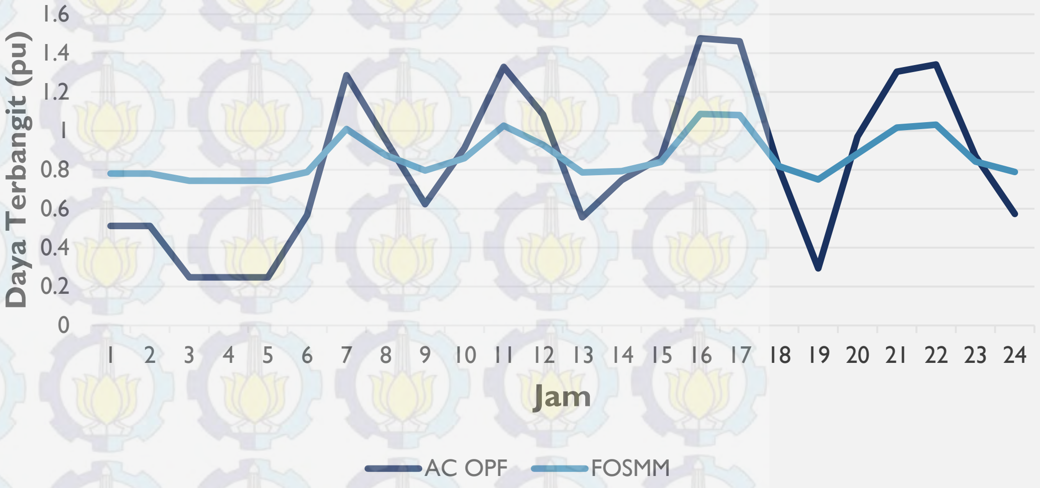


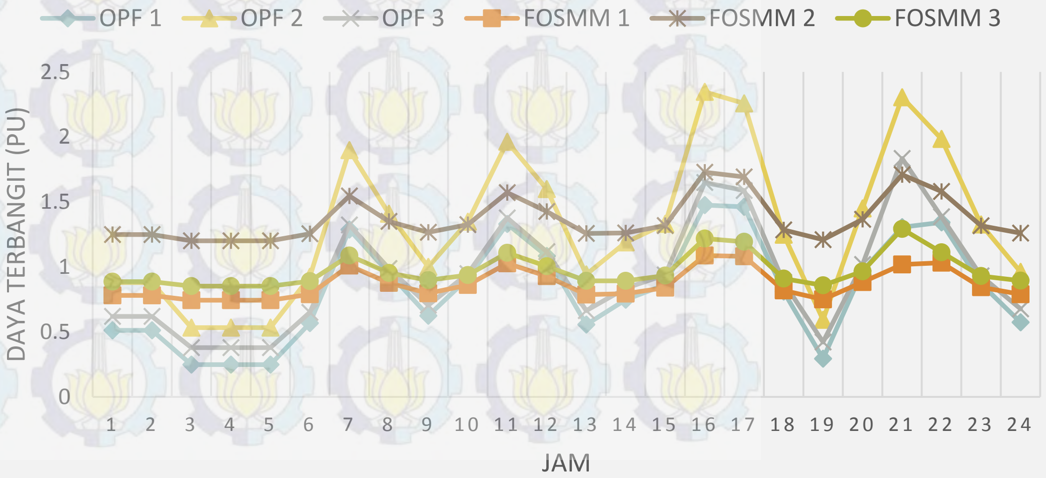


Simulasi Progam

5 Bus

i	μV_i	σV_i	$\mu\ \theta_i$	$\sigma\ \theta_i$
1	1.099122	0.037898	0.7081	0.003724
2	1.089286	0.077642	-0.9055	0.006599
3	1.096123	0.078214	-1.0615	0.006690
4	1.097950	0.093165	0.0000	0.000000
5	1.099039	0.048399	0.5828	0.004404
i	$\mu\ Pg_i$	$\sigma\ Pg_i$	$\mu\ Qg_i$	$\sigma\ Qg_i$
1	0.866778	0.404277	0.253483	0.043102
2	0.000000	0.000000	0.000000	0.000000
3	1.367219	0.404392	1.727408	0.000000
4	0.970481	0.403236	1.318733	0.000204
5	0.000000	0.000000	0.000000	0.000000



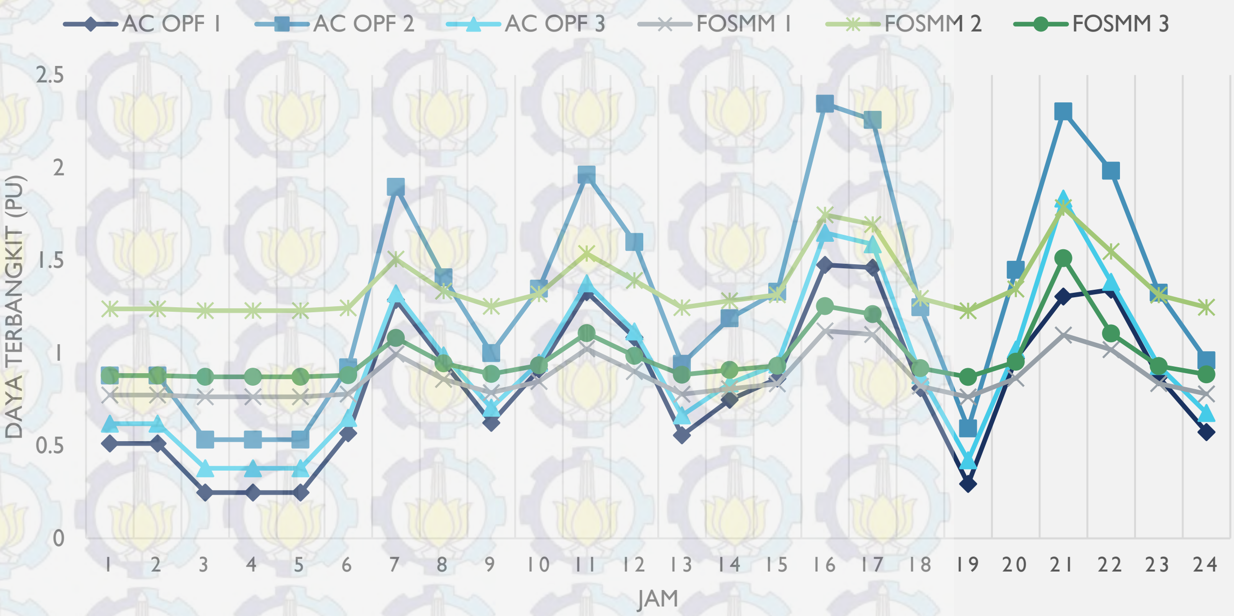


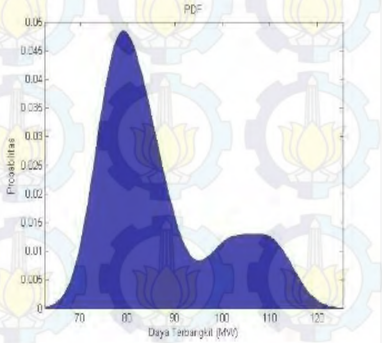
Simulasi Progam

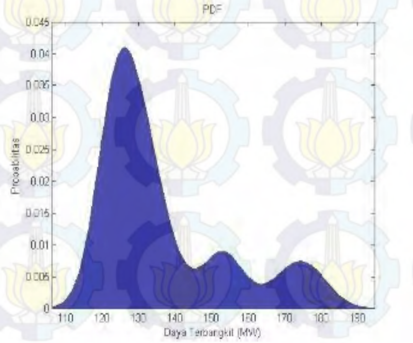
9 Bus

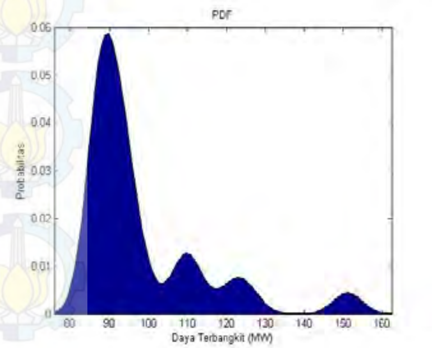
Jam	Pg Terbangkit (pu)		
	1	3	4
1	0.512	0.8787	0.6194
2	0.512	0.8787	0.6194
3	0.2478	0.5326	0.3786
4	0.2478	0.5326	0.3786
5	0.2478	0.5326	0.3786
6	0.5677	0.9228	0.6503
7	1.2867	1.8972	1.3223
8	0.9525	1.4088	0.9874
9	0.6239	0.9996	0.7054
10	0.9125	1.3476	0.948
11	1.3294	1.9622	1.3771
12	1.0839	1.5989	1.1167
13	0.5562	0.9421	0.6637
14	0.7474	1.1876	0.8363
15	0.8626	1.3307	0.9382
16	1.4756	2.3458	1.6491
17	1.4613	2.258	1.5876
18	0.8104	1.2476	0.8815
19	0.294	0.5935	0.4214
20	0.9704	1.4489	1.0183
21	1.3048	2.3038	1.8339
22	1.3418	1.9844	1.3847
23	0.8703	1.326	0.9309
24	0.5739	0.9612	0.677

Jam	Pg Terbangkit (pu)		
	1	3	4
1	0.773295	1.23908	0.878785
2	0.773295	1.23908	0.878785
3	0.763989	1.229407	0.871791
4	0.763989	1.229407	0.871791
5	0.763989	1.229407	0.871791
6	0.779244	1.243801	0.880251
7	0.994127	1.507328	1.081374
8	0.85848	1.334476	0.944774
9	0.786352	1.252562	0.887299
10	0.84733	1.318552	0.934104
11	1.022878	1.536983	1.107863
12	0.900894	1.392429	0.985469
13	0.777816	1.245245	0.883432
14	0.807749	1.282817	0.909316
15	0.834079	1.314442	0.931483
16	1.119907	1.746122	1.252993
17	1.10032	1.694155	1.210627
18	0.821312	1.295253	0.918402
19	0.763209	1.228066	0.871164
20	0.864155	1.345781	0.953149
21	1.097304	1.784732	1.511735
22	1.018501	1.54821	1.10573
23	0.835909	1.313271	0.929729
24	0.779914	1.247485	0.884719





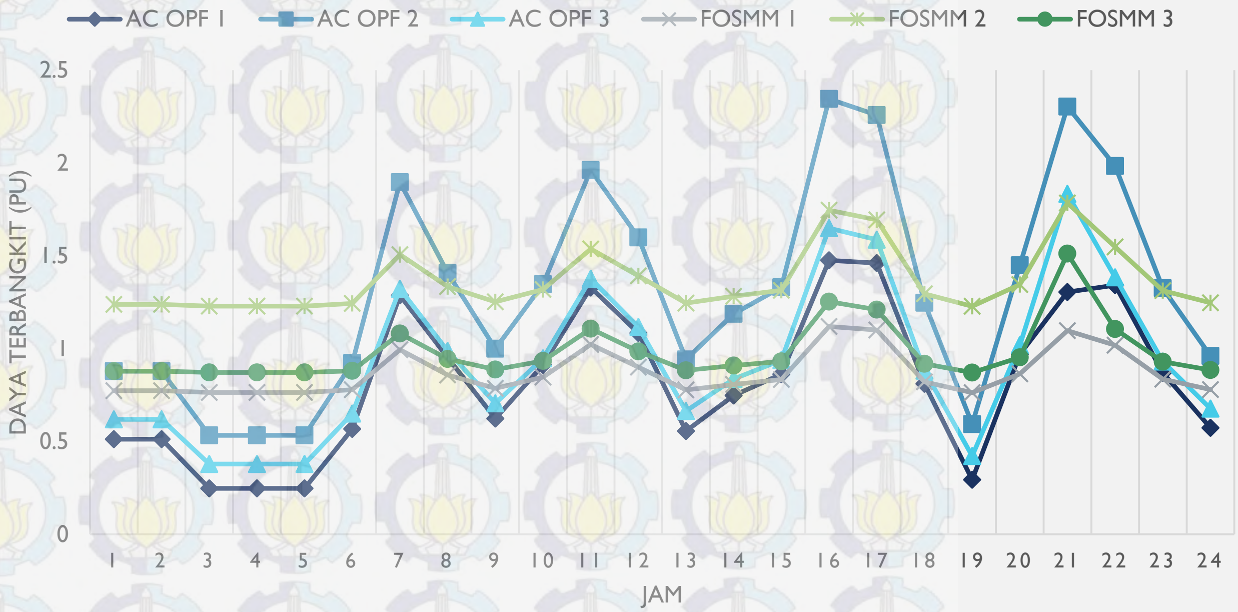


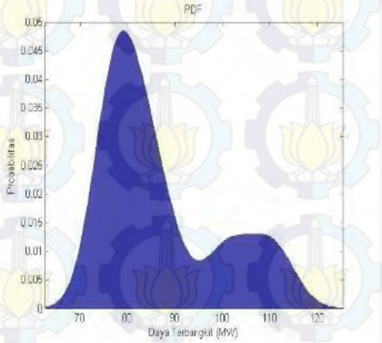


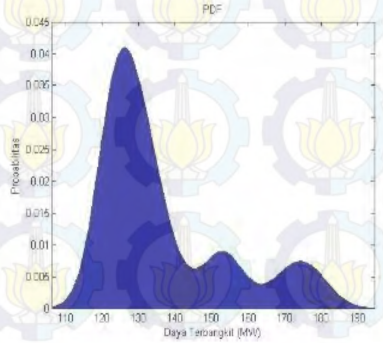
Simulasi Progam

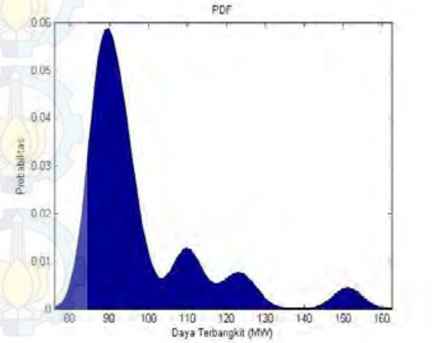
9 Bus

i	μV_i	σV_i	$\mu \theta_i$	$\sigma \theta_i$
1	1.099847	0.008288	0.0000	0.000000
2	1.099127	0.012953	-23.4580	0.133064
3	1.095492	0.009253	-25.8591	0.049061
4	1.057404	0.033954	-31.4860	0.039472
5	1.068738	0.024471	-34.1328	0.056877
6	1.094036	0.026654	-29.0148	0.026476
7	1.085191	0.021451	-31.0676	0.036359
8	1.089947	0.030553	-28.2341	0.023812
9	1.098980	0.019620	-33.6964	0.053544
i	μPg_i	σPg_i	μQg_i	σQg_i
1	0.868668	0.525532	1.073455	0.442663
2	1.366587	0.500565	0.478701	0.361568
3	0.981523	0.440442	0.958784	0.419904
4	0.000000	0.000000	0.000000	0.000000
5	0.000000	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000	0.000000
7	0.000000	0.000000	0.000000	0.000000
8	0.000000	0.000000	0.000000	0.000000
9	0.000000	0.000000	0.000000	0.000000









Simulasi Progam

14 Bus

Jam	Pg Terbangkit (pu)				
	1	2	3	6	8
1	1.841378	0.407242	0.240027	0.225013	0.219247
2	1.841378	0.407242	0.240027	0.225013	0.219247
3	1.609915	0.375927	0.278827	0.258344	0.209527
4	1.609915	0.375927	0.278827	0.258344	0.209527
5	1.609915	0.375927	0.278827	0.258344	0.209527
6	1.695409	0.38806	0.263559	0.243153	0.197224
7	1.915666	0.578258	0.5709	0.509343	0.347217
8	1.881377	0.443963	0.44994	0.417234	0.343951
9	1.865979	0.455353	0.4269	0.392801	0.325096
10	1.905476	0.472605	0.5096	0.485078	0.348411
11	1.901498	0.635781	0.54986	0.541331	0.347187
12	1.897664	0.452059	0.55386	0.517333	0.367225
13	1.846149	0.406676	0.239373	0.222565	0.287246
14	1.862231	0.484983	0.44994	0.417312	0.363342
15	1.885976	0.448498	0.5096	0.485343	0.359019
16	2.156666	0.594088	0.5709	0.51012	0.379757
17	2.136308	0.554478	0.5709	0.51012	0.371568
18	1.861838	0.444015	0.32994	0.296697	0.363708
19	1.642953	0.379815	0.273762	0.251432	0.203208
20	1.885854	0.47259	0.55034	0.489528	0.367899
21	2.195852	0.533327	0.55878	0.470384	0.356041
22	1.910311	0.532714	0.55394	0.5098	0.400598
23	1.898261	0.465511	0.53002	0.489029	0.408339
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Simulasi Progam

14 Bus

i	μV_i	σV_i	$\mu\,\theta_i$	$\sigma\,\theta_i$
1	1.013703	0.049749	0.0000	0.129719
2	1.000392	0.063355	-2.8484	0.196366
3	0.996324	0.020093	-5.5709	0.062725
4	0.969837	0.065849	-7.6476	0.235357
5	0.973437	0.060154	-6.8689	0.218017
6	1.039712	0.044165	-15.2314	0.120283
7	1.000900	0.000000	-15.0929	0.126507
8	1.033006	0.001031	-14.0660	0.038195
9	0.988802	0.029394	-19.7029	0.038195
10	0.966709	0.031967	-22.1014	0.153235
11	0.981101	0.022071	-20.4688	0.089501
12	1.036707	0.026871	-15.5614	0.052936
13	1.031279	0.048079	-15.8272	0.073331
14	1.006544	0.027390	-17.9604	0.034968

i	$\mu\,Pg_i$	$\sigma\,Pg_i$	$\mu\,Qg_i$	$\sigma\,Qg_i$
1	1.862895	0.384025	0.000154	0.007678
2	0.462206	0.390874	0.034560	0.008334
3	0.417336	0.386249	0.084242	0.006685
5	0.000000	0.000000	0.000000	0.000000
6	0.383586	0.387356	0.129017	0.007730
7	0.000000	0.000000	0.000000	0.000000
8	0.312729	0.385115	0.239946	0.006900
9	0.000000	0.000000	0.000000	0.000000
10	0.000000	0.000000	0.000000	0.000000
11	0.000000	0.000000	0.000000	0.000000
12	0.000000	0.000000	0.000000	0.000000
13	0.000000	0.000000	0.000000	0.000000
14	0.000000	0.000000	0.000000	0.000000

KESIMPULAN dan SARAN

Probabilistic-Optimal Power Flow FOSMM

Kesimpulan

Tugas Akhir

- *First Order Second Moment Method* (FOSMM) dapat digunakan sebagai pembagian pembebanan pembangkit pada model *Probabilistic Optimal Power Flow* (POPF).
- Output dari POPF adalah nilai rata-rata dan simpangan baku masing-masing variabel, dimana rata-rata merupakan nilai rata-rata keseluruhan sistem dan simpangan baku merupakan besarnya sebaran data.
- Hasil perhitungan FOSMM memiliki persebaran data yang kecil namun memiliki rata-rata yang serupa dengan model AC OPF
- Pada sistem 9 dan 14 bus, hasil FOSMM memiliki tingkat akurasi yang lebih tinggi daripada sistem 5 bus. Hal ini disebabkan karena perbedaan matriks Jacobian di sistem 5 bus sangat besar setiap jamnya.

- Membandingkan dengan metode POPF yang sudah ada seperti MCS atau metode estimasi titik.
- Mempertimbangkan *ramp rate* generator.
- Mengembangkan POPF menjadi *unit commitment* sehingga semakin mendekati keadaan *real* sistem.

Daftar Pustaka

Tugas Akhir

[1] A. G, Muljo Adji, “Gambaran Umum Pengelolaan Sistem Jawa Bali”, Ekspose Sekuriti Sistem Jawa Bali, Jakarta, 2005.

[2] Li, Xue, Yuzeng Li, dan Shaohua Zhang. 2008. “Analysis of Probabilistic Optimal Power Flow Taking Account of the Variation of Load Power”. IEEE Trans. Power Syst., Vol 21, No. 3 992-999.

[3] Zou, Bin and Qing Xiao. 2013. “Solving Probabilistic Optimal Power Flow Problem Using Quasi Monte Carlo Method and Ninth-Order Polynomial Normal Transformation”. IEEE Trans. Power Syst.

[4] M. E. El-Hawary dan G. A. N. Mbamalu. 1991. “A Comparison of Probabilistic Perturbation and Deterministic Based Optimal Power Flow Solutions”. IEEE Trans. Power Syst., vol. 6, no. 3, pp. 1099–1105,

[5] M. Madrigal, K. Ponnambalam, dan V. H. Quintana. 1998. “Probabilistic Optimal Power Flow”. Proc. IEEE Can. Conf. Electrical and Computer Engineering, Waterloo, ON, Canada, pp. 385–388.

[6] A. Schellenberg, W. Rosehart, dan J. Aguado. 2004. “Cumulant Based Probabilistic Optimal Power Flow (P-OPF)”. Proc. Int. Conf. Probabilistic Methods Applied Power Systems, pp. 506–511.

[7] A. Schellenberg, W. Rosehart, dan J. Aguado. 2005. “Cumulant-Based Probabilistic Optimal Power Flow (P-OPF) With Gaussian And Gamma Distributions”. IEEE Trans. Power Syst., vol. 20, no. 2, pp. 773–781, May 2005.

[8] Saadat, Hadi, “Power System Analysis”, McGraw-Hill, 1999

[9] Ameli, Mohammad Taghi, Moslehpour, Saeid, Golnazsadat, Mahdavikhah, “Determining the Spinning Reserve In Power Systems By Corrected Recursove PJM Method”, Proc. of the 2008 IAJC-IJME International Conference, 2008.

[10] Billinton, R., Allan, R.N, “Reliability Evaluation of Power Systems”, Pitman Publisher, Boston, 1984.

[11] Gooi, B., Mendes, D.P, Bell, K.R.W, dkk, “Optimal Scheduling of Spinning Reserve”, IEEE Trans. Power Systems, vol.14 no.4, November 1999.

[12] Su, Ching-Tzong, Lin, Chi-Min, Wang, Yung-Fu, “Economic Dispatch and Spinning Reserve Scheduling for Generation Transmission Sistems”, IEEE MELECON 2004, Dubrovnik, Kroasia, Mei 2004. [13] Chapman, Stephen J., “Electric Machinery Fundamentals”, McGraw-Hill, 2005.

[15] Marsudi, Djiteng, “Operasi Sistem Tenaga Listrik”, Graha Ilmu, Yogyakarta, 2006.

[16] Marsudi, Djiteng, “Pembangkitan Energi Listrik”, Erlangga, Jakarta, 2006.

[17] Xiao, Qing. 2015. “Comparing Three Methods for Solving Probabilistic Optimal Power Flow”. Electric Power System Research 124 (2015) 92-99.

TERIMA KASIH

Analisis POPF menggunakan FOSMM