LAPORAN TAHUNAN
PENELITIAN HIBAH BERSAING

Peningkatan Stabilitas Sistem Tenaga Listrik Melalui Optimasi Pengendalian Aliran Daya

Tahun ke-2 dari rencana 3 tahun

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LAMPIRAN

RINGKASAN

Penelitian ini mempunyai tujuan jangka panjang yaitu merancang-bangun sistem pengendalian aliran daya yang optimal menggunakan unified power flow controller (UPFC) untuk peningkatan stabilitas sistem tenaga listrik dalam bentuk perangkatkeras yang bekerja berdasarkan processor yang berbasis metode neuro fuzzy adaptif. Keaslian penelitian ini adalah penggunaan metode neuro fuzzy adaptif dengan fungsi keanggotaan fuzzy yang teroptimasi sehingga penentuan nilai awalnya menjadi lebih akurat. Selain itu, metode neuro fuzzy adaptif ini sebagai basis metode untuk perancangan perangkat-keras UPFC, sepengetahuan pengusul belum dilakukan peneliti lain. Diperlukan waktu tiga tahun untuk mencapai target utama luaran ini.

Dengan bantuan Matlab, diharapkan diperoleh model UPFC yang valid. Aplikasi metode neuro fuzzy adaptif dapat membuat unjukkerja UPFC yang lebih baik dalam mengendalikan aliran daya sistem tenaga listrik pada kondisi statis dan dinamis, dibanding metode lain. Sebelumnya telah dilakukan perancangan UPFC berbasis metode konvensional, dan hasil yang diperoleh masih perlu ditingkatkan. Pada penelitian tahun pertama ini target luarannya adalah model perangkat-lunak UPFC, publikasi seminar internasional, dan publikasi jurnal internasional.

Kata-kata kunci: *Pengendalian aliran daya, stabilitas sistem tenaga listrik, UPFC, optimasi, neuro- fuzzy.*

BAB I. PENDAHULUAN

I.1 Latar Belakang dan Permasalahan yang akan Diteliti

Perkembangan sistem tenaga listrik akibat pertumbuhan beban sistem yang semakin tinggi harus dibarengi dengan peningkatan kapasitas sistem transmisi yang ada. Optimalisasi kapasitas sistem transmisi yang ada jauh lebih ekonomis dan ramah lingkungan dibandingkan dengan membangun sistem transmisi yang baru (Saadat, 1999). Guna meningkatkan kapasitas sistem transmisi yang ada, maka diperlukan sistem pengendali aliran daya yang andal, sekaligus juga berfungsi untuk mengendalikan aliran daya pada sistem transmisi daya listrik (Mithulananthan dan Cafiizares, 2004). Dalam operasionalnya, pengendali aliran daya tersebut harus mampu mengendalikan aras tegangan listrik dan aliran daya aktif dan reaktif tanpa mengurangi tingkat stabilitas dan keamanan sistem transmisi (Kannan dkk, 2004). Teknologi pengendalian seperti ini telah dikenal sejak tahun 1980an, yang disebut dengan teknologi *Flexible Alternating Current Transmission Systems* (FACTS) (Al-Awami, 2007). Piranti FACTS mampu meningkatkan stabilitas sistem tenaga listrik dengan karakteristik pengendalian yang cepat dan mampu mengkompensasi rugi-rugi saluran transmisi dengan baik. Akan tetapi hasil kendali aliran daya dan kompensasi rugi-rugi saluran transmisi yang diperoleh dengan menggunakan piranti FACTS masih belum optimal. Guna membantu mengoptimalkan kinerja FACTS, maka pada tahun 1990an ditemukan teknologi *Unified Power Flow Controller* (UPFC) (Eldamaty dkk, 2005).

UPFC merupakan generasi teknologi terbaru dari FACTS yang berfungsi mengendalikan dan mengoptimalkan aliran daya pada sistem transmisi daya listrik. Piranti UPFC pada dasarnya terdiri dari kombinasi dua piranti kompensator yaitu *Static Synchronous Compensator* (STATCOM) dan *Static Synchronous Series Compensator* (SSSC) (Sheng dkk, 2007). STATCOM dan SSSC saling terhubung dengan jaringan pengendalian DC. Seluruh parameter saluran transmisi daya listrik, yaitu impedansi, tegangan, dan sudut fase, dapat dikendalikan secara simultan oleh UPFC (Lu dkk, 2007). Keunggulan lain UPFC adalah kemampuannya dalam mengendalikan aliran daya aktif dan daya reaktif saluran transmisi serta tegangan bus sistem. Akan tetapi, metode yang digunakan dalam membangun kerja UPFC masih berbasis algoritma konvensional yang menggunakan logika tegas (Morsli dkk, 2012). Metode berbasis algoritma konvensional ini mengalami kesulitan dalam mengendalikan aliran daya untuk sistem transmisi daya listrik multimesin yang sangat dinamis, yaitu sistem yang mengalami perubahan beban listrik sangat cepat dari waktu ke waktu. Oleh karena itu, dalam penelitian ini akan dikembangkan metode berbasis neuro-fuzzy adaptif yang diterapkan pada UPFC dan *Phase Shifting Transformer* (PST) guna mengendalikan aliran daya secara adaptif pada sistem transmisi daya listrik yang sangat dinamis.

Dalam penelitian ini, permasalahan yang akan diteliti adalah:

1. Bagaimana merancang *Unified Power Fow Controller* (UPFC) berbasis metode neuro fuzzy adaptif.
2. Bagaimana menguji *Unified Power Fow Controller* (UPFC) hasil rancangan pada sistem tenaga listrik multimesin.
3. Bagaimana membandingkan kinerja UPFC hasil rancangan dengan UPFC jenis lain yaitu UPFC konvensional.
4. Bagaimana menganalisis unjukkerja UPFC dalam mengendalikan aliran daya pada sistem tenaga listrik multimesin dalam keadaan statis dan dinamis.

I.2 Tujuan Khusus

Tujuan khusus penelitian ini adalah:

1. Merancang *Unified Power Fow Controller* (UPFC) berbasis metode neuro-fuzzy adaptif.
2. Menguji *Unified Power Fow Controller* (UPFC) hasil rancangan pada sistem tenaga listrik multimesin.
3. Membandingkan kinerja PSS hasil rancangan dengan UPFC jenis lain yaitu UPFC konvensional.
4. Menganalisis unjukkerja UPFC hasil rancangan dalam mengendalikan aliran daya sistem tenaga listrik multimesin dalam keadaan statis dan dinamis.
5. Mempublikasikan hasil-hasil penelitian dalam bentuk seminar dan jurnal baik nasional maupun internasional, serta memberikan rekomendasi kepada operator sistem transmisi daya listrik tentang penggunaan UPFC.

BAB II. TINJAUAN PUSTAKA

Studi mengenai pengendalian aliran daya listrik dan piranti UPFC telah banyak dilakukan guna mendapatkan UPFC yang berunjukkerja tinggi. UPFC adalah piranti pengendali aliran daya listrik yang merupakan kombinasi dari *Static Synchronous Compensator* (STATCOM) dan *Static Synchronous Series Compensator* (SSSC) (Sheng dkk, 2007). Usaha untuk meningkatkan unjukkerja UPFC hingga saat ini terfokus kepada pengembangan algoritma yang digunakan dalam pengendali UPFC (Morsli dkk, 2012). Dalam penelusuran pustaka yang telah dilakukan, beberapa metode telah diusulkan untuk pengendali UPFC. Allaoui dkk (2007) mengusulkan pengendali kokoh (*robust*) dalam pengembangan UPFC. Pengembangan pengendali kokoh (*robust*) dalam UPFC juga dilakukan oleh Guo dkk (2009). Penggunaan metode berbasis logika fuzzy dalam pengendalian sistem tenaga listrik sudah sangat popular, di antaranya dilakukan oleh Harmas dkk (2007) dan Hameed dkk (2008). Selanjutnya penggunaan algoritma genetika guna mendapatkan pengendalian yang optimal bagi UPFC telah dilakukan oleh Mahabuba dan Khan (2008).

Mubeen dkk (2008) melakukan investigasi unjukkerja UPFC dalam mengendalikan aliran daya pada saluran transmisi daya listrik. Rancangan UPFC yang dibuat menggunakan model sumber-sumber tegangan untuk menganalisis kinerja UPFC dalam mengatur daya aktif, daya reaktif, dan profil tegangan transmisi. Model tersebut digabungkan dengan algoritma Newton-Raphson untuk studi aliran daya. Hasil simulasi dalam perangkat-lunak Matlab menunjukkan bahwa UPFC hasil rancangannya mampu mengatur tegangan pada lima bus sistem tenaga listrik, dan juga mampu mengendalikan daya aktif dan daya reaktif secara simultan.

Saribulut dkk (2008) menganalisis unjukkerja UPFC berbasis logika fuzzy murni. Dalam hal ini dilakukan analisis perbandingan beberapa pengendali yang digunakan dalam UPFC yaitu pengendali P, PI, PID, dan pengendali logika fuzzy. Pengendali logika fuzzy yang digunakan mengadopsi sistem inferensi Takagi-Sugeno. Studi kasus dilakukan untuk berbagai kondisi operasi sistem tenaga listrik. Berdasarkan hasil yang diperoleh, pengendali logika fuzzy mempunyai unjukkerja yang lebih baik dibanding pengendai P, PI, dan PID.

Sreedevi dan Jenopaul (2011) mengusulkan rancangan UPFC berbasis pengendali logika fuzzy guna mengendalikan parameter-parameter UPFC. Dalam penelitiannya dilakukan ujicoba dan analisis unjukkerja UPFC pada variasi beban yang tinggi, tetapi hanya menggunakan model sistem tenaga listrik mesin-tunggal. Model UPFC yang digunakan hanya menggunakan metode fuzzy murni dan belum diujicoba pada sistem tenaga multimesin.

Morsli dkk (2012) meneliti tentang rancangan UPFC yang bertujuan untuk meningkatkan stabilitas sistem tenaga listrik pada kondisi aliran daya listrik yang mengalami perubahan. Rancangan UPFC yang digunakan adalah berbasis pengendali fuzzy adaptif dan dibandingkan dengan pengendali proporsional-integral (PI). Hasil pengendalian menggunakan PI dan fuzzy adaptif sangat efektif dalam memperbaiki stabilitas transien sistem tenaga listrik.

Berdasarkan tinjauan pustaka di atas, maka sangat menarik untuk dilakukan penggabungan logika fuzzy dan jaringan neural artifisial dalam membangun UPFC yang bersifat adaptif, sehingga mampu mengendalikan aliran daya pada sistem tenaga listrik dengan baik, baik kondisi statis maupun dinamis.

BAB III. METODE PENELITIAN

III.1 Pengantar

Penelitian yang akan dilaksanakan adalah perancangan model UPFC berbasis neuro fuzzy adaptif dan melakukan pengujian model UPFC tersebut dalam model rangkaian sistem tenaga listrik multimesin. Alat yang digunakan dalam penelitian ini terdiri dari perangkat-keras (*hardware*) dan perangkat-lunak (*software*), diantaranya:

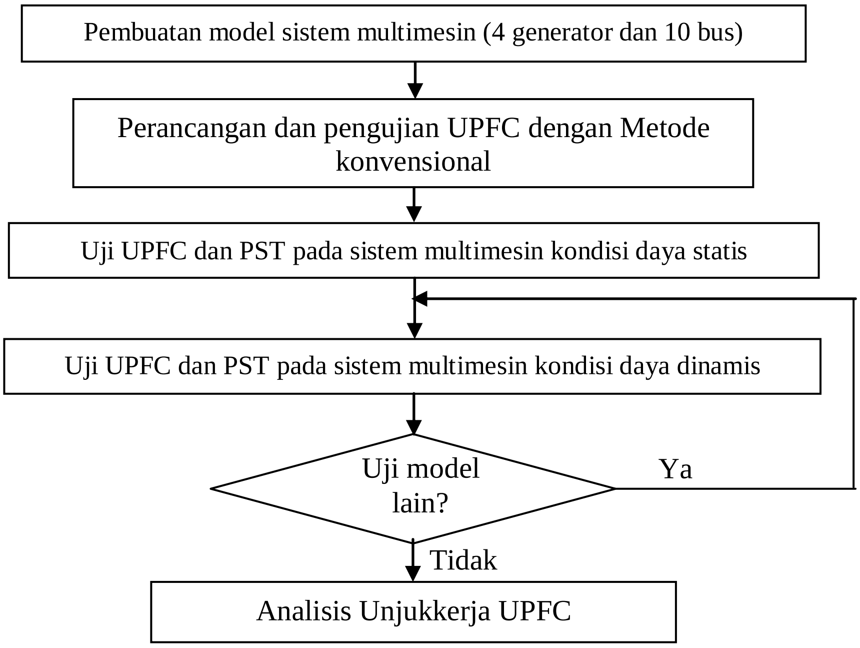
1. Perangkat-keras (*hardware*)

   Perangkat-keras yang digunakan adalah satu unit notebook merk Toshiba dengan spesifikasi memori 4 GB dan processor Intel Core 2 Duo 1.8 GHz.

2. Perangkat-lunak (*software*)
   a. Metode neuro fuzzy adaptif dalam perancangan UPFC.
   b. Matlab-Simulink untuk mengimplementasikan rancangan UPFC dan PST dalam bentuk simulasi guna menguji kinerjanya pada sistem tenaga listrik multimesin.

III.2 Jalan Penelitian

III.2.1 Penelitian yang sudah dilakukan



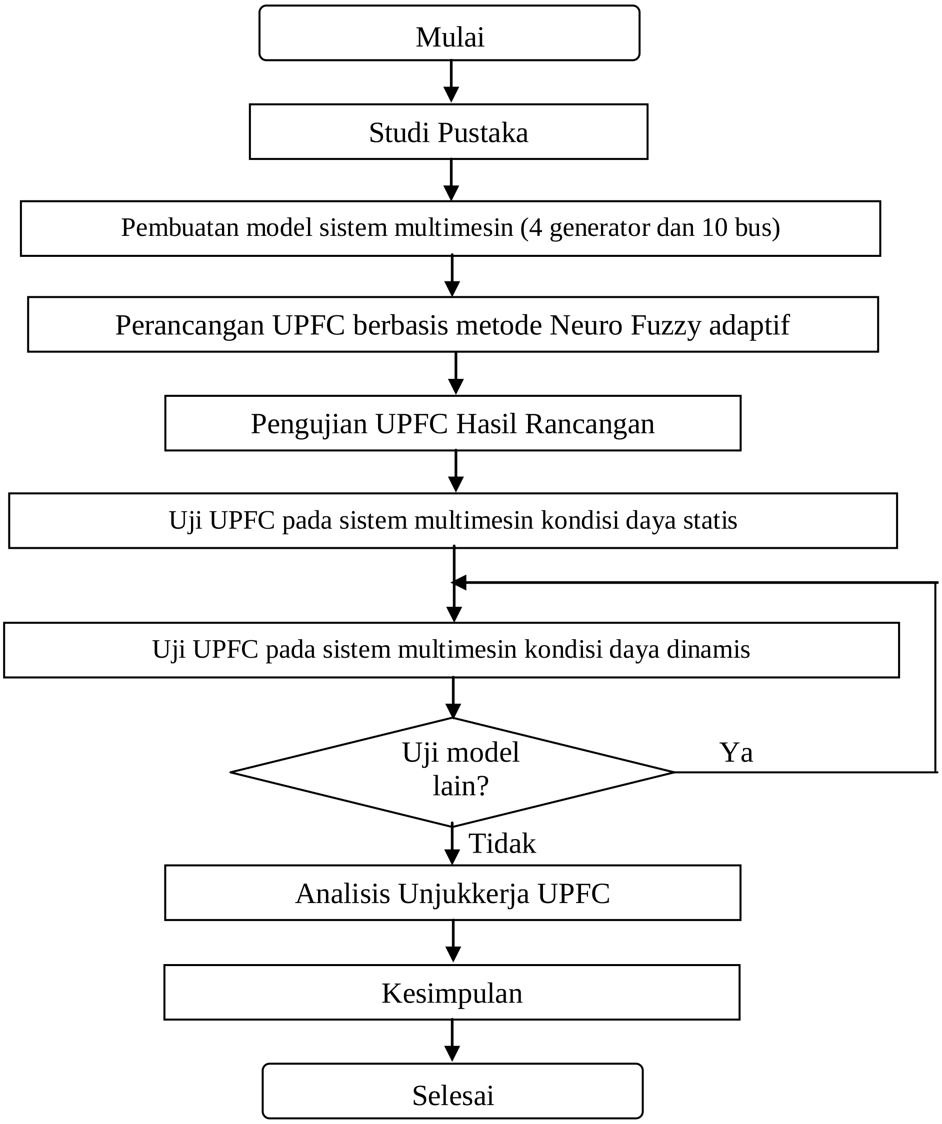
Gambar 3.1. Langkah-langkah penelitian yang sudah dilakukan

Penelitian yang sudah dilakukan adalah perancangan model UPFC dengan metode konvensional dan mengujicoba unjukkerjanya. Langkah-langkah yang sudah dilakukan seperti ditunjukkan pada Gambar 3.1.

III.2.2 Penelitian yang akan dilakukan pada tahun pertama

Pada tahun pertama, target utama luaran penelitian adalah model UPFC berbasis metode neuro fuzzy adaptif yang telah teruji secara simulatif dan siap untuk dikembangkan dalam rancangan perangkat-keras.

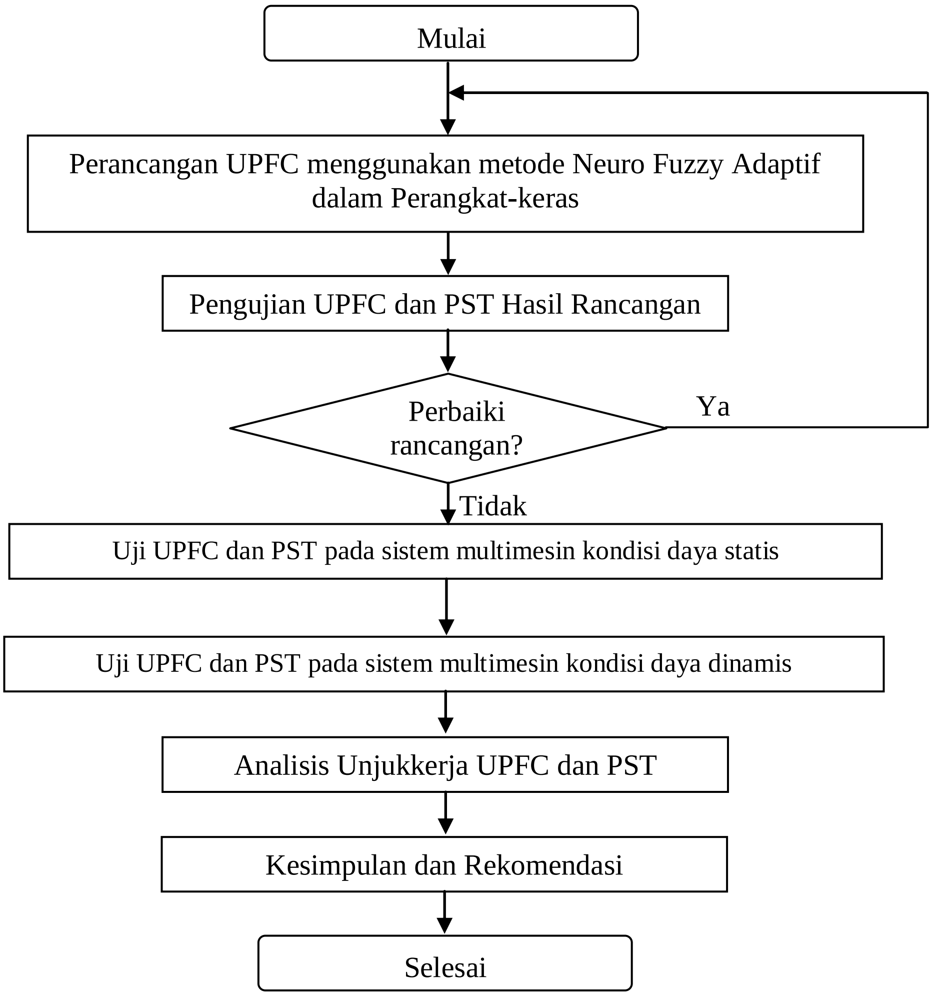
Langkah-langkah penelitian tahun kedua ini dirangkum dalam suatu diagram alir seperti terlihat pada Gambar 3.2.



Gambar 3.2. Diagram alir langkah-langkah penelitian pada tahun pertama.

III.2.3 Penelitian yang akan dilakukan pada tahun kedua

Pada tahun kedua, target utama luaran penelitian adalah model UPFC berbasis metode neuro fuzzy adaptif yang telah teruji secara simulatif diimplementasikan dalam perangkat-keras dan selanjutnya diuji kinerjanya pada sistem multimesin dalam lingkup laboratorium, menggunakan *power system simulator*. Langkah-langkah penelitian tahun kedua dirangkum dalam suatu diagram alir seperti terlihat pada Gambar 3.3.

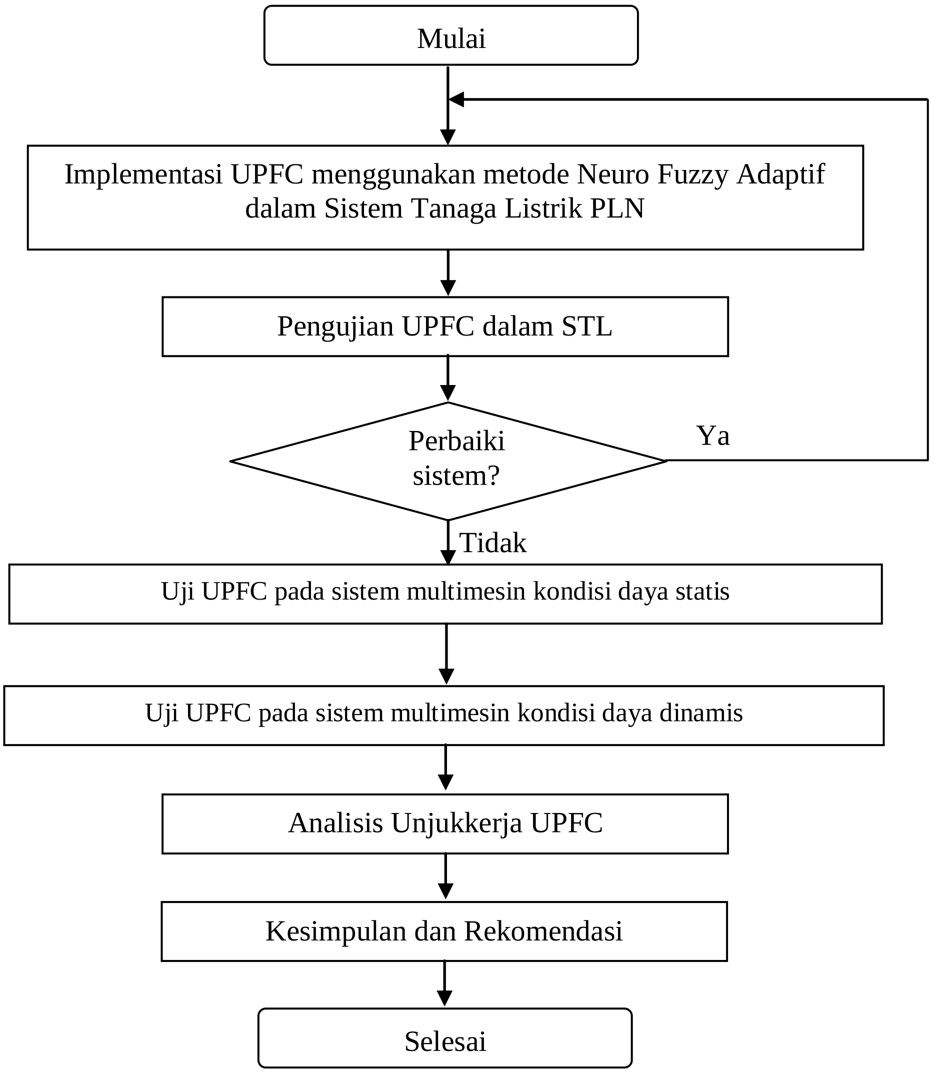


Gambar 3.3. Diagram alir langkah-langkah penelitian pada tahun kedua.

III.2.4 Penelitian yang akan dilakukan pada tahun ketiga

Pada tahun ketiga, target utama luaran penelitian adalah model UPFC berbasis metode neuro fuzzy adaptif yang telah teruji dalam skala laboratorium diimplementasikan dalam perangkat-keras dan selanjutnya diuji kinerjanya pada sistem tenaga listrik multimesin milik

PT. PLN (Persero). Langkah-langkah penelitian tahun ketiga dirangkum dalam suatu diagram alir seperti terlihat pada Gambar 3.4.



Gambar 3.4. Diagram alir langkah-langkah penelitian pada tahun ketiga.

BAB IV. HASIL YANG DICAPAI

IV.1. Metode Neuro Fuzzy Adaptif

Jika O_i^k menunjukkan keluaran simpul ke-i pada lapis ke-k, maka masing-masing lapis dapat dijelaskan sebagai berikut:

Lapis 1. Setiap simpul i dalam lapis ini merupakan simpul adaptif yang menunjukkan bahwa keluaran yang dihasilkan tergantung dari parameter yang menyusun simpul ini. Fungsi simpulnya dapat dinyatakan sebagai berikut:

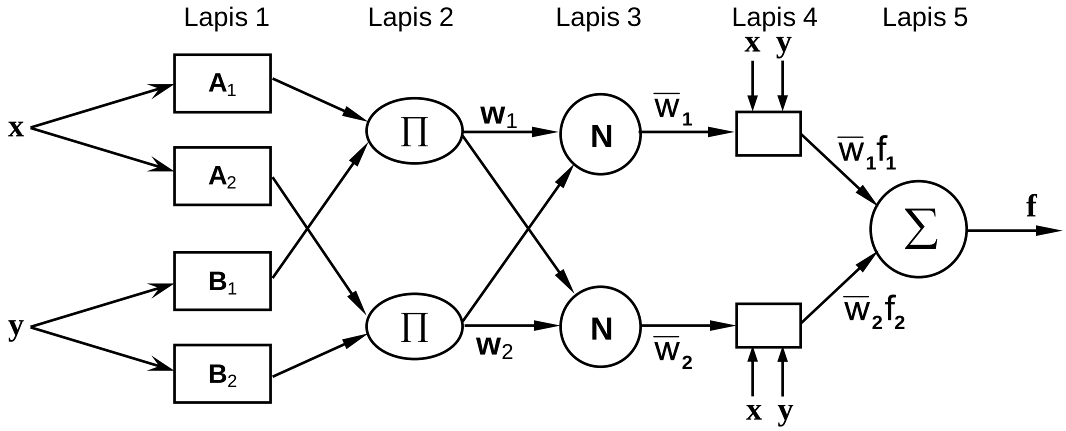
$O_i^1 = \mu_{Ai}(x)$, untuk i = 1, 2, ..……...…..(1)

atau, $O_i^1 = \mu_{Bi-2}(y)$, untuk i = 3, 4 ..…...……..(2)

dengan x dan y masing-masing merupakan masukan pada suatu simpul adaptif A_i dan B_i. Nilai O_i^1 adalah nilai keanggotaan himpunan fuzzy (A_1, A_2, B_1, B_2). Fungsi keanggotaan pada simpul-simpul adaptif masukan memiliki parameter-parameter yang sesuai dengan jenis fungsi keanggotaan yang dipakai. Biasanya digunakan fungsi bel umum:

$$\mu_A(x) = \frac{1}{1 + \left[\frac{x - c_i}{a_i}\right]^{2b_i}} \qquad ..……...…..(3)$$

Himpunan parameter yang membentuk fungsi keanggotaan ini dikenal sebagai parameter premis.



Gambar 4.1. Arsitektur ANFIS model Sugeno orde satu dengan dua masukan dan dua aturan.

Lapis 2. Pada simpul-simpul di lapis ini proses perkalian nilai keanggotaan yang masuk masing-masing simpul tanpa memiliki parameter seperti pada lapis 1. Keluaran simpul ini dinyatakan:

$O_i^2 = w_i = \mu_{Ai}(x) \text{ x } \mu_B(y)$, i = 1, 2. ……..……..(4)

Setiap simpul memiliki keluaran yang dikenal dengan kuat penyulutan.

Lapis 3. Simpul-simpul lapis ini merupakan simpul biasa yang melakukan proses normalisasi yaitu membandingkan kuat penyulutan ke-i dengan kuat penyulutan total yang masuk pada masing-masing simpul:

$O_i^3 = \overline{w} = \frac{w_i}{w_1 + w_2}$, i = 1, 2. ……….…..(5)

Lapis 4. Simpul-simpul pada lapis ini merupakan simpul adaptif yang terparameterisasi. Keluaran dari simpul-simpul tersebut adalah perkalian dari kuat penyulutan ternormalisasi dengan fungsi konsekuensi yang merupakan kombinasi linier dari variabel masukan. Parameter-parameter yang berhubungan dengan simpul-simpul pada lapis ini dikenal sebagai parameter konsekuensi. Keluaran dari simpul-simpul pada lapis ini:

$O_i^4 = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i)$ ……….…..(6)

dengan $\overline{w}_i$ adalah kuat penyulutan ternormalisasi dan (p_i, q_i, dan r_i) adalah parameter konsekuen dari simpul ke-i.

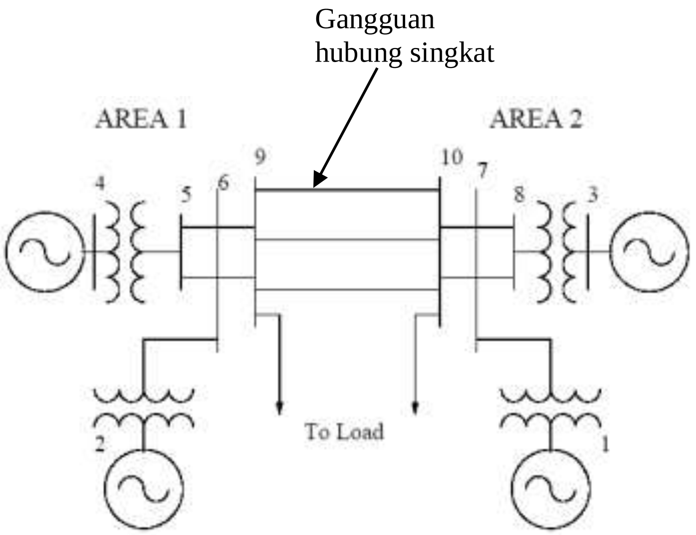
Lapis 5. Keluaran dari simpul ini merupakan jumlah dari seluruh masukan yang memasuki simpul keluaran, dengan persamaan sebagai berikut:

$O_i^5 = \sum \overline{w}_i f_i$ ……..……..(7)

4.2. Pemodelan Sistem Multimesin

Model sistem tenaga listrik multimesin yang digunakan adalah sistem tenaga listrik yang terdiri dari dua area dengan jumlah generator adalah 4 unit dan jumlah busnya adalah 10 buah, seperti terlihat pada Gambar 4.2 (Robandi dan Kharisma, 2008). Sistem multimesin terdiri dari dua area yang saling terhubung oleh saluran transmisi sepanjang 220 km. Tegangan nominal sistem yang digunakan adalah adalah 230 kV. Masing-masing area mempunyai dua buah generator sinkron dengan kapasitas yang sama yaitu 900MVA pada tegangan 20 kV.

Diagram rangkaian sistem tenaga listrik multimesin pada Gambar 4.2 diimplementasikan dalam perangkat lunak Matlab-Simulink guna dilakukan simulasi sistem tenaga listrik yang mengalami gangguan pada saluran transmisi. Komponen masing-masing area diperlihatkan pada Gambar 4.3, Gambar 4.4, dan Gambar 4.5.



Gambar 4.2. Sistem multimesin standar IEEE untuk 4 generator 10 bus yang diberi gangguan pada saluran transmisinya.

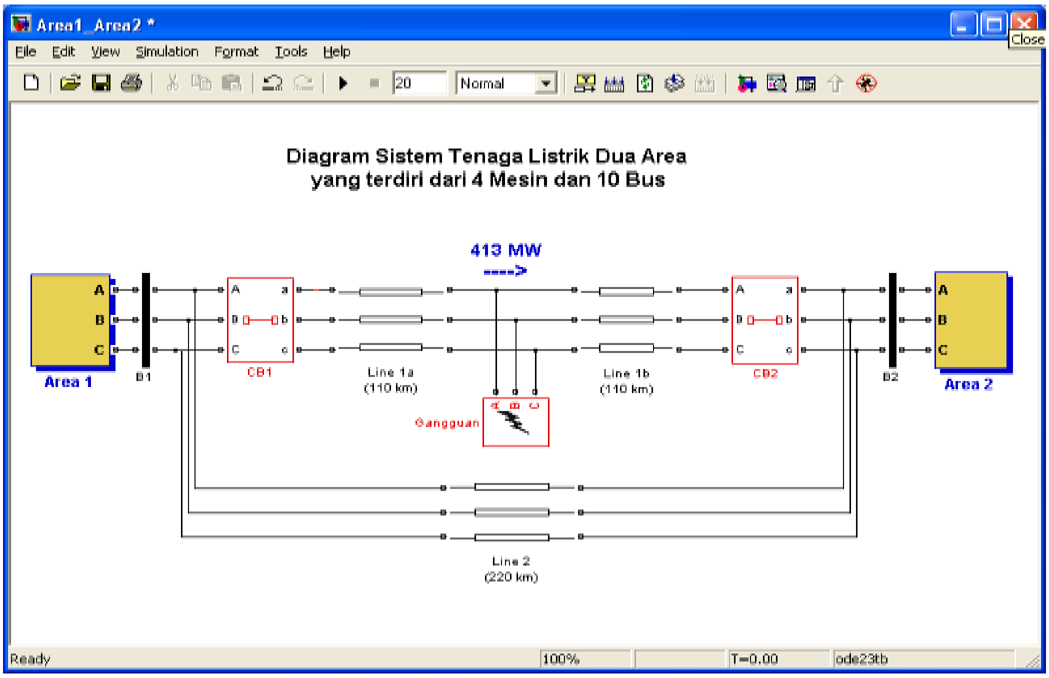
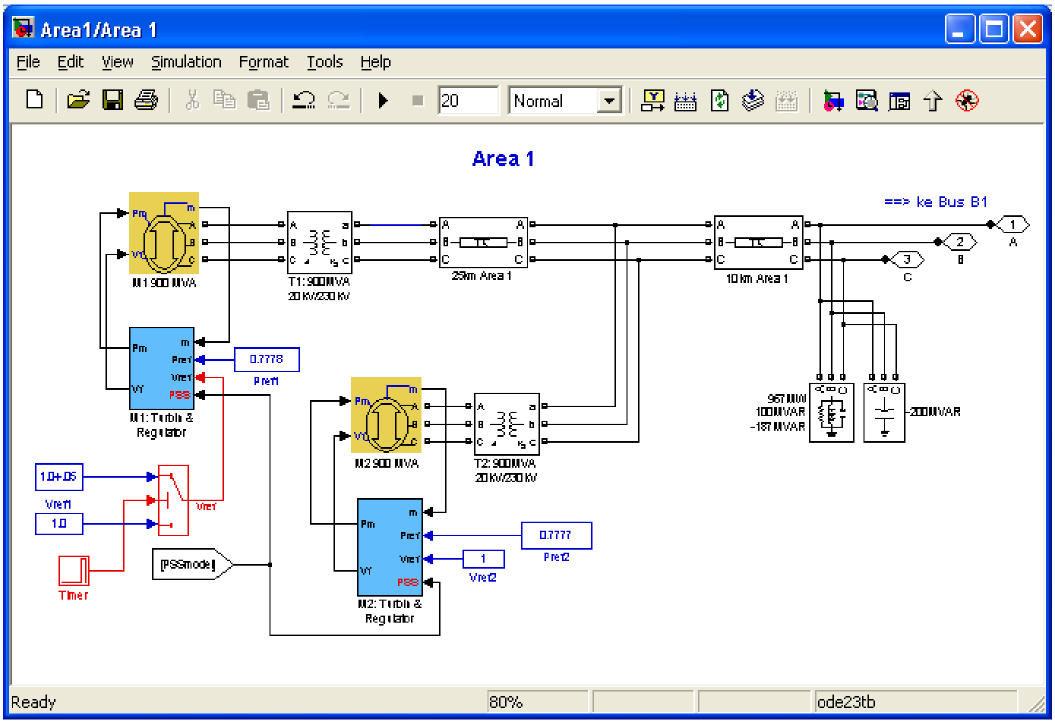
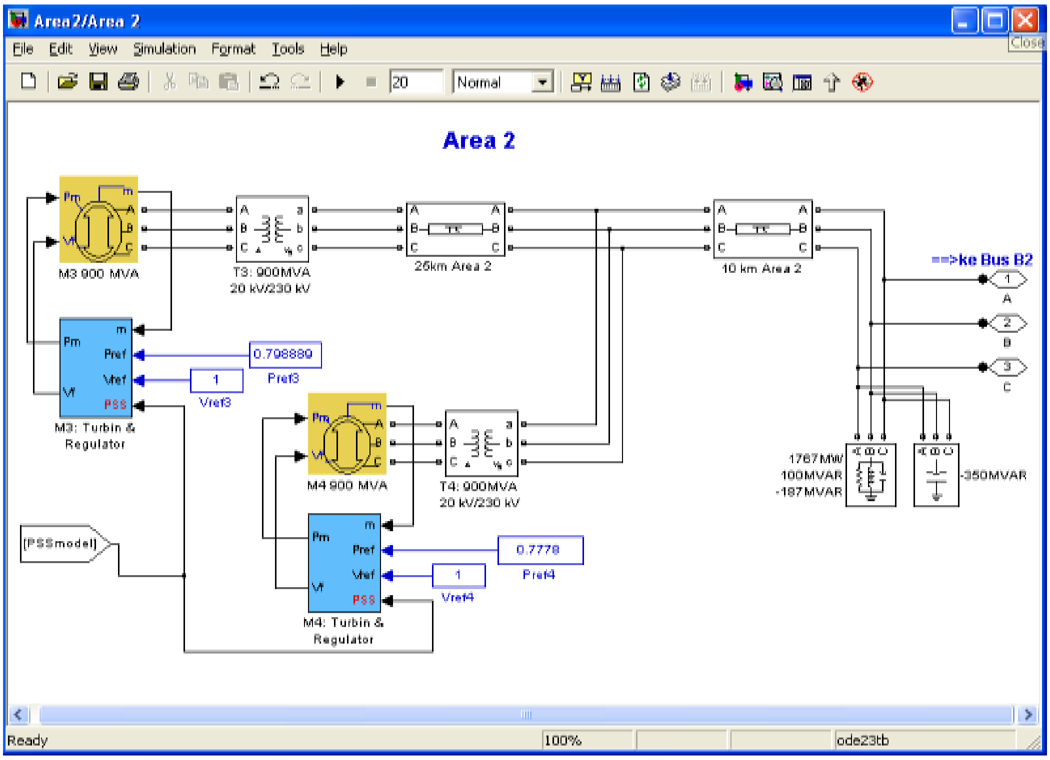


Diagram Sistem Tenaga Listrik Dua Area
yang terdiri dari 4 Mesin dan 10 Bus

Gambar 4.3. Implementasi sistem multimesin standar IEEE untuk 4 generator dan 10 bus dalam Matlab-Simulink yang diberi gangguan pada saluran transmisinya.



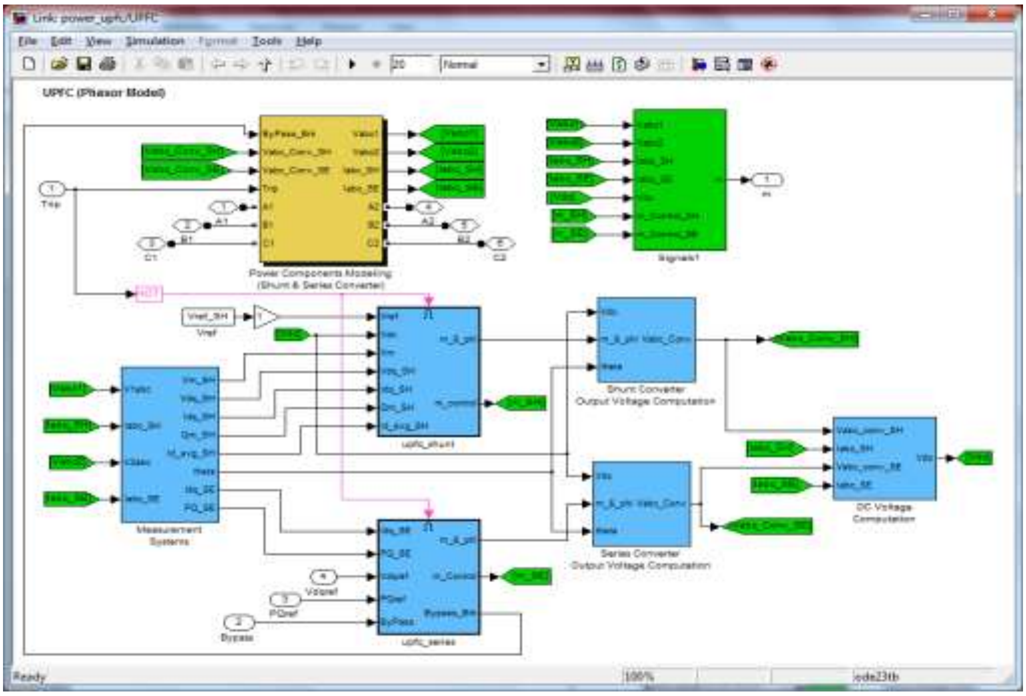
Gambar 4.4. Komponen Area 1 dari sistem multimesin yang ditunjukkan pada Gambar 4.3.



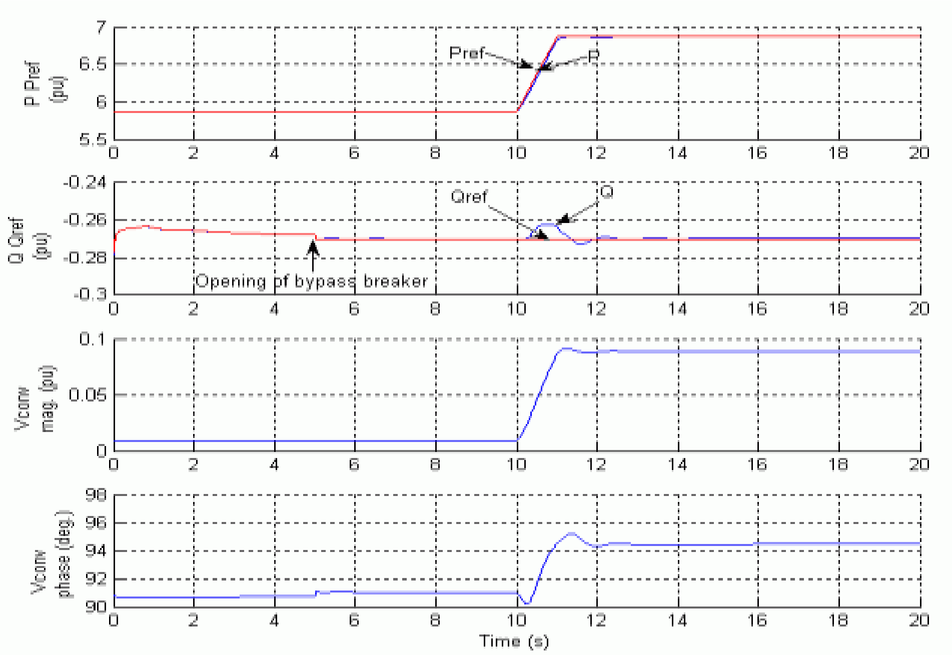
Gambar 4.5. Komponen Area 2 dari sistem multimesin yang ditunjukkan pada Gambar 4.3.

IV.3 Perancangan UPFC dengan Metode Konvensional

UPFC digunakan untuk mengendalikan aliran daya pada sistem transmisi daya listrik 500 kV /230 kV. Hasil rancangan UPFC dengan metode konvensional ditunjukkan pada Gambar 4.6.

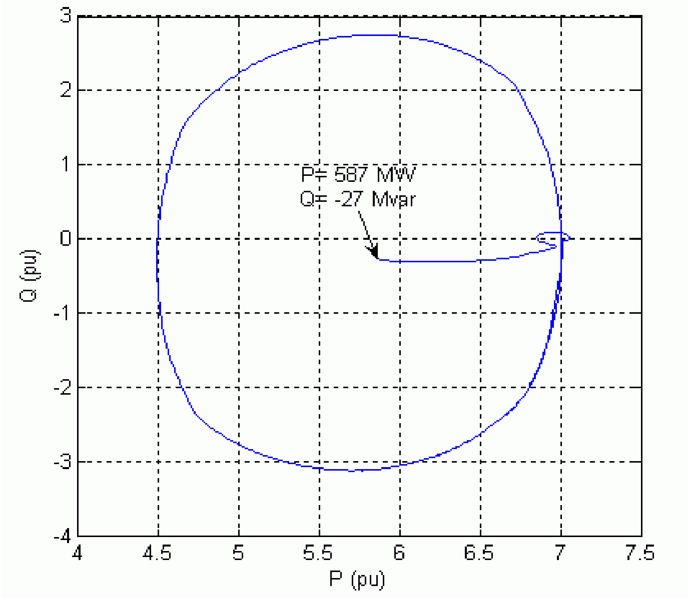


Gambar 4.6. Model UPFC konvensional di Matlab-Simulink



Gambar 4.7. Tanggapan dinamis UPFC terhadap perubahan beban sistem tenaga listrik dari 587 MW menjadi 687 MW.

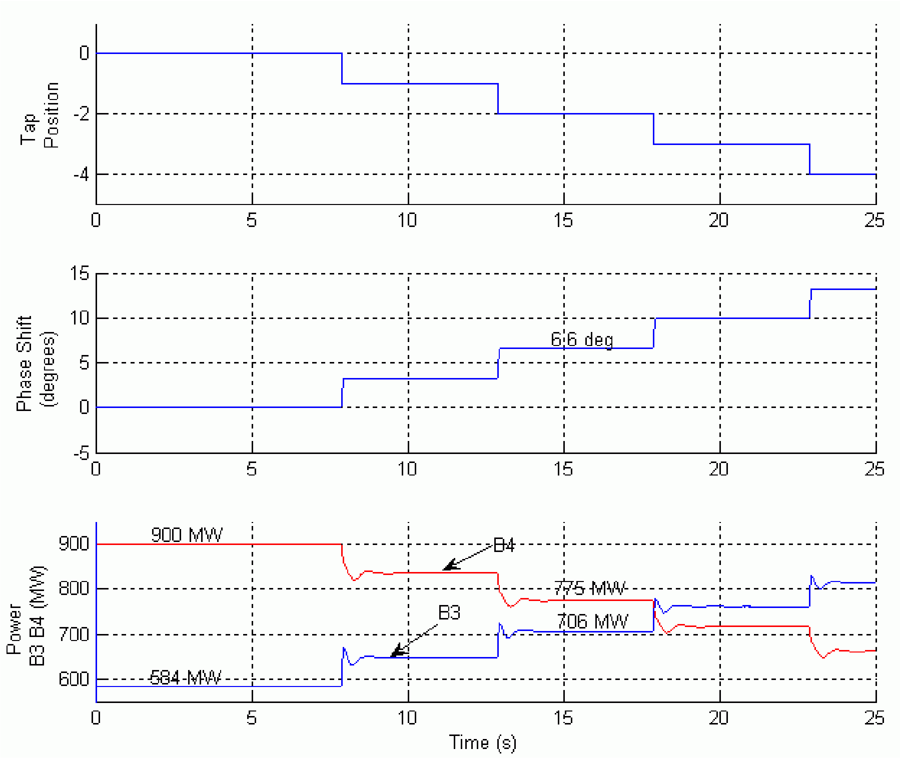
Selanjutnya pada Gambar 4.7 ditunjukkan hasil tanggapan dinamis UPFC terhadap perubahan beban sistem tenaga listrik dari 587 MW menjadi 687 MW. Gambar 4.8 memperlihatkan daerah keterkendalian UPFC.



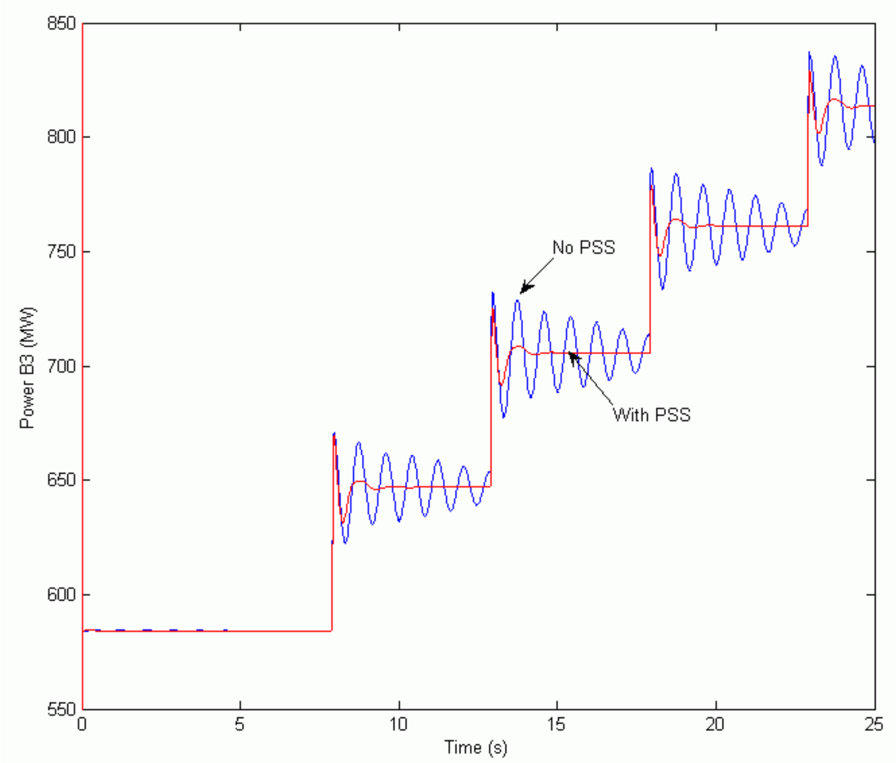
Gambar 4.8. Daerah keterkendalian UPFC.

Pada Gambar 4.9 ditunjukkan hasil pengendalian UPFC untuk daya aktif yang melalui bus B3 dan B4 dengan perubahan posisi tap PST. Berdasarkan Gambar 4.9 dapat dilihat bahwa UPFC konvensional sudah dapat memberikan respon pengendalian aliran daya listrik yang cukup baik.

Selanjutnya pada Gambar 4.10 diperlihatkan aksi PSS dalam meredam osilasi daya. Dalam rancangan ini disertakan juga peran *Power System Stabilizer* (PSS) guna mengendalikan generator pada saat terjadi perubahan beban listrik sehingga osilasi daya yang terjadi dapat berlangsung dalam waktu yang singkat. Dalam Gambar 4.10 terlihat bahwa dengan lima kali terjadi peningkatan beban listrik, generator yang dilengkapi dengan PSS dapat membuat sistem lebih stabil dalam menangani perubahan beban listrik yang dinamis.



Gambar 4.9. Hasil pengendalian UPFC untuk daya aktif yang melalui bus B3 dan B4 dengan perubahan posisi tap PST.



Gambar 4.10. Aksi PSS dalam meredam osilasi daya.

BAB V. RENCANA TAHAPAN BERIKUTNYA

Rencana penelitian selanjutnya ditunjukkan pada Tabel 5.1 sampai dengan Tabel 5.2 di bawah ini.

Tabel 5.1. Jadwal pelaksanaan penelitian tahun kedua.

No.	**Uraian Kegiatan**	**Bulan ke-**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Merancang UPFC dalam perangkat-keras										
2	Menguji UPFC rancangan dalam perangkat-keras										
3	Menguji UPFC dan PST guna mengendali-kan aliran daya sistem tenaga listrik pada power system simulator										
4	Analisis Hasil										
5	Kesimpulan dan rekomendasi								■		
6	Laporan Penelitian								■		
7	Publikasi di seminar internasional									■	
8	Publikasi di jurnal internasional										■
9	Penulisan draf Buku Ajar								■	■	■
10	Penulisan Draf Paten (HKI)										■

Tabel 5.2. Jadwal pelaksanaan penelitian tahun ketiga.

No.	**Uraian Kegiatan**	**Bulan ke-**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Implementasi UPFC dalam sistem tenaga listrik milik PLN	■	■	■							
2	Menguji UPFC rancangan dalam sistem tenaga listrik milik PLN				■						
3	Menguji UPFC guna mengendali-kan aliran daya sistem tenaga listrik pada sistem tenaga listrik milik PLN					■	■				
4	Analisis Hasil							■			
5	Kesimpulan dan rekomendasi								■		
6	Laporan Penelitian								■		
7	Publikasi di seminar internasional									■	
8	Publikasi di jurnal internasional										■
9	Penerbitan Buku Ajar									■	■
10	Pendaftaran Paten (HKI)										■

BAB VI. KESIMPULAN DAN SARAN

VI.1 Kesimpulan

Kesimpulan sementara penelitian ini adalah:

1. UPFC konvensional sudah dapat memberikan respon pengendalian aliran daya listrik yang cukup baik.
2. Generator yang dilengkapi dengan PSS dapat membuat sistem lebih stabil dalam menangani perubahan beban listrik yang dinamis.
3. Diperlukan ujicoba dengan jumlah fungsi keanggotaan fuzzy yang berbeda-beda untuk mendapatkan

VI.2 Saran

Penelitian ini dapat dilanjutkan dengan data real sistem tenaga listrik multimesin milik PLN.

DAFTAR PUSTAKA

Aghaei, J., Ara, A.L., Shabani, M., 2012, “Fuzzy Multi-Objective Optimal Power Flow Considering UPFC”, *International Journal of Innovative Computing, Information and Control*, Vol. 8, No. Feb. 2012, hal 1155-1168.

Allaoui, T., Denaı, M.A., dan Bouhamida, M., “Robust control of unified power flow controller (UPFC)”, *Journal of Electrical and Electronics Engineering (IU-JEEE)*, Vol. 7, pp. 331-343, 2007.

Al-Awami, A.T., Abdel-Magid, Y.T., dan Abido, M.A., 2007, “A particle-swarm-based approach of power system stability enhancement with unified power flow controller”, *International Journal of Electrical Power & Energy Systems*, Vol. 29, pp. 251-259, 2007.

Eldamaty, A.A., Faried, S.O., Aboreshaid, S., 2005, “Damping Power System Oscillations Using A Fuzzy Logic Based Unified Power Flow Controller”, *IEEE Conference Of CCECE/CCGEI*, May 2005.

Guo, J., Crow, M.L. dan Sarangapani, J., 2009, “An improved UPFC control for oscillation damping”, *IEEE Transactions on Power Systems*, Vol. 14, hal. 288-296.

Hameed, S., Das, B., dan Pant, V., 2008, “A self-tuning fuzzy PI controller for TCSC to improve power system stability, *Electric Power Systems Research*, Vol. 78, hal. 1726-1735.

Harmas, N.M., Abdelazis, M., dan Hamidi-Cherif, A., 2007, “Observer Based Intelligent Power System Stabilizer”, *International Journal of Electrical and Power Engineering*, Vol. 6, No. 10, hal. 1057-1063.

Kannan, S., S. Jayaram, dan Salama, M.M.A., 2004, “Real and Reactive Power Coordination for a Unified Power Flow Controller”, *IEEE Transactions on Power Systems*, Volume 19, Issue 3, 2004, hal. 1454 – 1461.

Lu, B., Hou, L., Li, B., dan Liu, Y., 2007, “A New Unified Power Flow Fuzzy Control Method”, *Innovative Computing, Information and Control, Second International Conference*, 2007, hal. 479 – 479.

Mahabuba, A., dan Khan, M.A., 2008, “Optimal Location of Power System Stabilizers in a Multimachine Power System Using Relative Gain Array (RGA) and Genetic Algorithm (GA)”, *International Journal of Electrical and Power Engineering*, 2(1), hal 19-27.

Mithulananthan, N., dan Cafiizares, C.A., 2004, “Effect of Static Load Models on Hopf Bifurcation Point and Critical Modes of Power Systems”, Thammasat International Journal of Science and Technology, Vol. 9, No. 4.

Morsli, S., Tayeb, A., Mouloud, D., Abdelkader, C., 2012, “A robust adaptive fuzzy control of a unified power flow controller”, *Turkey Journal of Elec. Eng. & Comp. Science*, Vol.20, No.1, 2012, hal. 87-98.

Mubeen, S.E., Nema, R.K., dan Agnihotri, G., 2008, “Power Flow Control with UPFC in Power Transmission System”, *World Academy of Science, Engineering and Technology*, Vol. 47, 2008, hal. 338-342.

Saadat, H., 1999, “Power System Analysis”, Int’l ed., pp. 399-441, *The McGraw-Hill Companies*, Inc., Singapore.

Saribulut, L., Tumay, M., dan Eker, D., 2008, “Performance Analysis of Fuzzy Logic Based Unified Power Flow Controller”, *World Academy of Science, Engineering and Technology*, Vol. 45, 2008, hal. 320-325.

Sheng, G.L., W.Y. Lin, dan L. Sheng, 2007, “Research on Flexible Power Supply System for Arc Furnace Based on UPFC”, *Industrial Electronics and Applications*, 2007, hal. 227-230.

Sreedevi, S. dan Jenopaul, 2011, “Fuzzy Based Controller for Damping of Inter-area Oscillations Using UPFC”, *International Journal of Electrical and Power Engineering*, Vol. 5, No. 3, hal. 125-130.

Lampiran 1

Artikel di Jurnal Internasional IJAER

(Terindeks SCOPUS)

PERFORMANCE EVALUATION OF WIND TURBINE WITH DOUBLY-FED INDUCTION GENERATOR

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ABSTRACT *: This paper presents the performance evaluation of wind turbine with doubly-fed induction generator. A stator flux oriented vector control is used for the variable speed doubly-fed induction generator operation. By controlling the generator excitation current the amplitude of the stator EMF is adjusted equal to the amplitude of the grid voltage. To set the generator frequency equal to the grid one, the turbine pitch angle controller accelerates the turbine and generator until it reaches the synchronous speed. The system is modeled and simulated in the Simulink software for modeling of all types of induction generator configurations. The model makes use of rotor reference frame using dynamic vector approach for machine model. The results of a single line to ground fault and a symmetrical three-phase ground fault is analyzed. The results show that the wind energy conversion system can normally operate in fault conditions.*

KEYWORDS - *Distributed Generation, Doubly-Fed Induction Machine, Wind Energy Conversion Systems, Performance Evaluation.*

I. INTRODUCTION

Modern electrical power systems are characterized by extensive system interconnections and increasing dependence on control for optimum utilization of existing resources. The supply of reliable and economic electric energy is a major determinant of industrial progress and consequent rise in the standard of living [1]. The growth of the power systems in the future will rely on increasing the capability of existing power transmission systems rather then building the new transmission lines and the power stations for an economical and an environmental reasons. The requirement of the new power flow controllers, which is capable of increasing the transmission reliability and controlling the power flow through the predefined corridors, will certainly increase due to the deregulation of the electricity markets. Additionally, these new controllers must be regulate the voltage levels and the flow of the real and reactive power in the transmission line to use full capability of the system in some cases with no reduction in the system stability and security margins [2]. Flexible Alternating Current Transmission Systems (FACTS) is an evolving technology based solution to help electric utilities fully utilize their transmission assets. The technology was presented in the late of 1980s [3]. FACTS devices enhance the stability of the power system with its fast control characteristics and continuous compensating capability. The two main objectives of FACTS technology are the controlling of the power flow and increasing the transmission capacity of the existing transmission lines [4].

The utilization of the existing electrical power system comes into optimal condition and the controllability of the power system is increased with these objectives. Unified Power Flow Controller (UPFC) is the member of FACTS device that has emerged for the controlling and the optimization of power flow in the electrical power transmission systems [5]. This device formed of the combination of two other FACTS devices namely as Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). These are connected to each other by a common DC link, which is a typical storage capacitor. The all parameters of the power transmission line (impedance, voltage and phase angle) can be control simultaneously by UPFC. In addition, it can perform the control function of the transmission line real/reactive power flow, UPFC bus voltage and the shunt-reactive-power flow control [6].

The control mechanism and the controller have an important effect on the performance of UPFC. In the literature, several control mechanisms are used in UPFC models. A fuzzy inference system described in matrix form is proposed and used to improve the dynamic control of real and reactive power [7]. Two fuzzy logic controllers based on Mamdani type fuzzy logic are used. One of the controllers is proportional fuzzy logic controller (PF-UPFC) and the other is Hybrid fuzzy logic UPFC (HF-UPFC). The selection of suitable location for UPFC is studied and composite-criteriabased fuzzy logic is used to evaluate the network contingency ranking. The power-feedback control scheme is used in the control mechanism of UPFC [8]. The power fluctuation is damped readily and the value of reactive power is minimized as possible by using several time constants. However there is no value changed in the real power. The control method of variable interval-fuzzy-mutual is used in the control mechanism of UPFC [9]. In the simulation results, there is a high overshoot values occurred both real power and bus voltage during the three phase faults applied. However, the real power value is increased but there is no value changed in the reactive power. The performance of UPFC is observed by using three different controllers [10]. In the simulation results, the variation of the real power direction can be observed easily. However, the value of reactive power is kept at zero because of there is no reactive power flow in the system.

In this paper, the capability of UPFC on controlling of the power flow and the effectiveness of controllers on performance of UPFC in the power transmission line are examined by using different control mechanisms based on PI and neuro-fuzzy controllers. In the modeling of fuzzy controller, Takagi-Sugeno Inference System is used in the decision making process and “Weighted Average” method which is the special case of “Mamdani” model is used in the defuzzification process. The Matlab-Simulink software is used to create UPFC model and to obtain the results of case studies.

II. Fundamental Theory

1. UPFC in Power Transmission Lines

A Unified Power Flow Controller (UPFC) consists of 2 forced-commutated voltage source converters (VSC) connected through a common DC link [11]. One converter is shunt-connected and the other is connected in series with the transmission line, as illustrated in Figure 1. The name “unified power flow controller” comes from the fact that it is possible for the device to control both transmitted active and reactive power as well as the AC bus voltage at the point where the shunt converter is connected (i.e., point A). The UPFC can provide different functions when the inserted series voltages v_S have different magnitudes and phase angles. It will function as a pure voltage regulator if the inserted series voltage is in phase with the AC bus voltage. It is also possible for the UPFC to function as a phase angle regulator. Each UPFC converter can independently generate or absorb reactive power. This arrangement enables the free flow of active power in either direction between the AC terminals of the 2 converters. In the case of the parallel branch of the UPFC, the active power exchanged with the system primarily depends on the phase shift of the converter output voltage with respect to the system voltage, and the reactive power is controlled by varying the amplitude of the converter output voltage. However, the series branch of the UPFC controls active and reactive power flows in the transmission line by the amplitude and phase angle of the series injected voltage. Therefore, the active power controller can significantly affect the level of reactive power flow and vice versa.

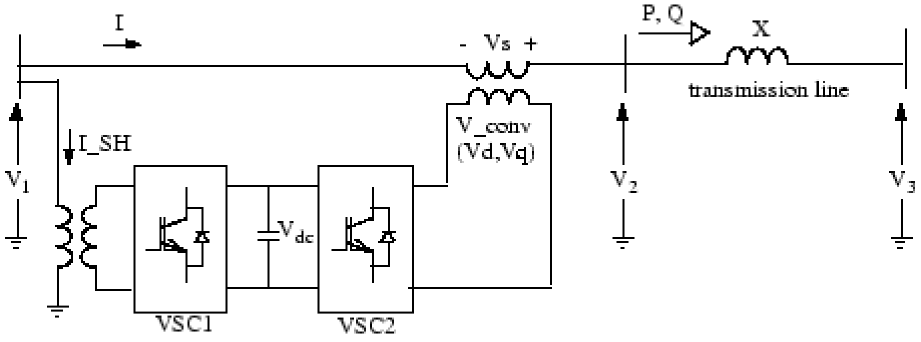


Figure 1. Circuit of a UPFC in power transmission line.

To improve the performance of the UPFC, the interaction between the active and reactive power flow control system must be reduced. In recent years, a number of investigations have been carried out to demonstrate the capabilities of UPFC as an effective power flow control [4], providing voltage control [5], transient stability enhancement [6], and oscillation damping [7-9]. It has been reported in the literature that a strong dynamic interaction exists between the active and reactive power flows through a transmission line when they are controlled by series injected voltage v_s of the UPFC. Furthermore, the UPFC is highly nonlinear because it consists of converters, power transformers, filters, and surge arrestors. Uncertainties in the power system make it difficult to model the transmission system accurately.

2. Adaptive Neuro-Fuzzy Method

During the last two decades adaptive neuro-fuzzy approach has been became a popular method in control area. In this part, a brief description of the adaptive neuro-fuzzy inference system (ANFIS) principles is given which are refered to [12-13]. The fundamental structure of the type of fuzzy inference system (FIS) could be seen as a model that maps input characteristics to input membership functions. Then it maps input membership function to rules and rules to a set of output characteristics. Finally it maps output characteristics to output membership functions, and the output membership function to a single valued output or a decision associated with the output. It has been considered only fixed membership functions that were chosen arbitrarily. Fuzzy inference system (FIS) is only applied to only modelling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model. However, in some modelling situations, it cannot be distinguish what the membership functions should look like simply from looking at data. Rather than choosing the parameters associated with a given membership function arbitrarily, these parameters could be chosen so as to tailor the membership functions to the input/output data in order to account for these types of variations in the data values. In such case the necessity of the adaptive neuro fuzzy inference system becomes obvious.

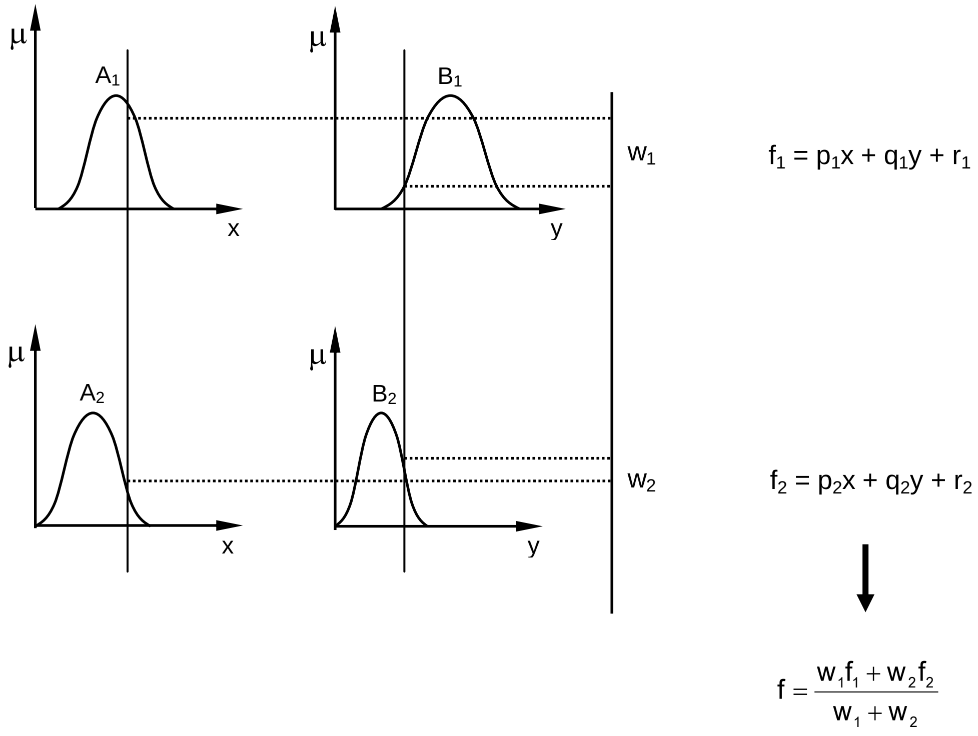


Figure 2. Sugeno's fuzzy logic model

The neuro-adaptive learning method works similarly to that of artificial neural networks. Neuro-adaptive learning techniques provide a method for the fuzzy modelling procedure to learn information about a data set. It computes the membership function parameters that best allow the associated fuzzy inference system to track the given input and output data. A network-type structure similar to that of an artificial neural network can be used to interpret the input and output map so it maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. The parameters associated with the membership functions changes through the learning process. The computation of these parameters (or their adjustment) is facilitated by a gradient vector. This gradient vector provides a measure of how well the fuzzy inference system is modelling the input/output data for a given set of parameters. When the gradient vector is obtained, any of several optimization routines can be applied in order to adjust the parameters to reduce some error measure (performance index). This error measure is usually defined by the sum of the squared difference between actual and desired outputs. ANFIS uses a combination of back propagation procedure and least squares estimation for membership function parameter estimation.

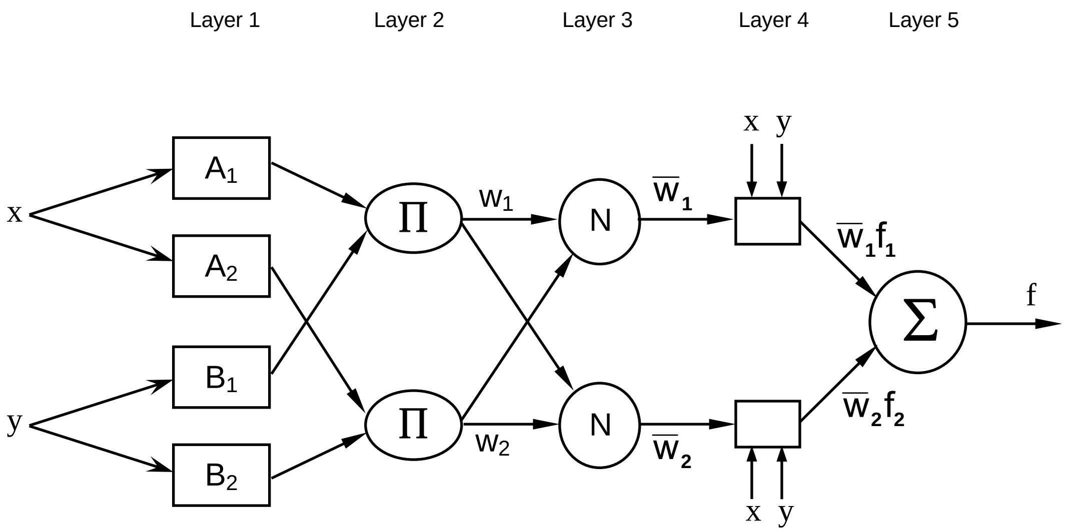


Figure 3. The architecture of the ANFIS.

The suggested ANFIS has several properties:

The output is zero-th order Sugeno-type system.

It has a single output, obtained using weighted average defuzzification. All output membership functions are constant.

It has no rule sharing. Different rules do not share the same output membership function, namely the number of output membership functions must be equal to the number of rules.

It has unity weight for each rule.

Figure 2 shows Sugeno's fuzzy logic model. Figure 3 shows the architecture of the ANFIS, comprising by input, fuzzification, inference and defuzzification layers. The network can be visualized as consisting of inputs, with N neurons in the input layer and F input membership functions for each input, with F*N neurons in the fuzzification layer. There are FN rules with FN neurons in the inference and defuzzification layers and one neuron in the output layer. For simplicity, it is assumed that the fuzzy inference system under consideration has two inputs x and y and one output z as shown in Figure 3. For a zero-order Sugeno fuzzy model, a common rule set with two fuzzy if-then rules is the following:

Rule 1: If x is A_1 and y is B_1, Then $f_1 = r_1$ (1)
Rule 2: If x is A_2 and y is B_2, Then $f_2 = r_2$ (2)

Here the output of the i-th node in layer n is denoted as On,i:

Layer 1. Every node i in this layer is a square node with a node function:

$O_i^1 = \mu Ai(x)$, for i = 1, 2, (3)

or,

$O_i^1 = \mu Bi\text{-}2(y)$, for i = 3, 4 (4)

where x is the input to node-i, and Ai is the linguistic label (small , large, etc.) associated with this node function. In other words, O_i^1 is the membership function of Ai and it specifies the degree to which the given x satisfies the quantifier Ai. Usually μAi(x) is chosen to be bell-shaped with maximum equal to 1 and minimum equal to 0, such as the generalized bell function:

$$\mu_A(x) = \frac{1}{1 + \left[\frac{x - c_i}{a_i}\right]^{2b_i}} \tag{5}$$

Parameters in this layer are referred to as premise parameters.

Layer 2. Every node in this layer is a circle node labeled Π which multiplies the incoming signals and sends the product out. For instance,

$$O_i^2 = wi = \mu Ai(x) \text{ x } \mu B(y), \quad i = 1, 2. \tag{6}$$

Each node output represents the firing strength of a rule. (In fact, other T-norm operators that performs generalized AND can be used as the node function in this layer.)

Layer 3. Every node in this layer is a circle node labeled N. The i-th node calculates the ratio of the i-th rule's firing strength to the sum of all rules firing strengths:

$$O_i^3 = \overline{w} = \frac{w_i}{w_1 + w_2}, \quad i = 1, 2. \tag{7}$$

For convenience, outputs of this layer will be called normalized firing strengths.

Layer 4. Every node i in this layer is a square node with a node function:

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \tag{8}$$

where $\overline{w_i}$ is the output of layer 3, and {pi, qi, ri} is the parameter set. Parameters in this layer will be referred to as consequent parameters.

Layer 5. The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals, i.e.,

$$O_i^5 = \sum \overline{w}_i f_i \tag{9}$$

III. Methodology

The procedure of this research is shown in Fig. 4. The simulation environment based on Matlab software package is selected. It is used as the main engineering tool for performing modeling and simulation of multi-machine power systems, as well as for interfacing the user and appropriate simulation programs. Matlab has been chosen due to availability of the powerful set of programming tools, signal processing, numerical functions, and convenient user-friendly interface. In this specially developed simulation environment, the evaluation procedures can be easily performed. We have used Fuzzy logic Toolbox of Matlab to develop the ANFIS model with 4 inputs and single output as given in Fig. 5.

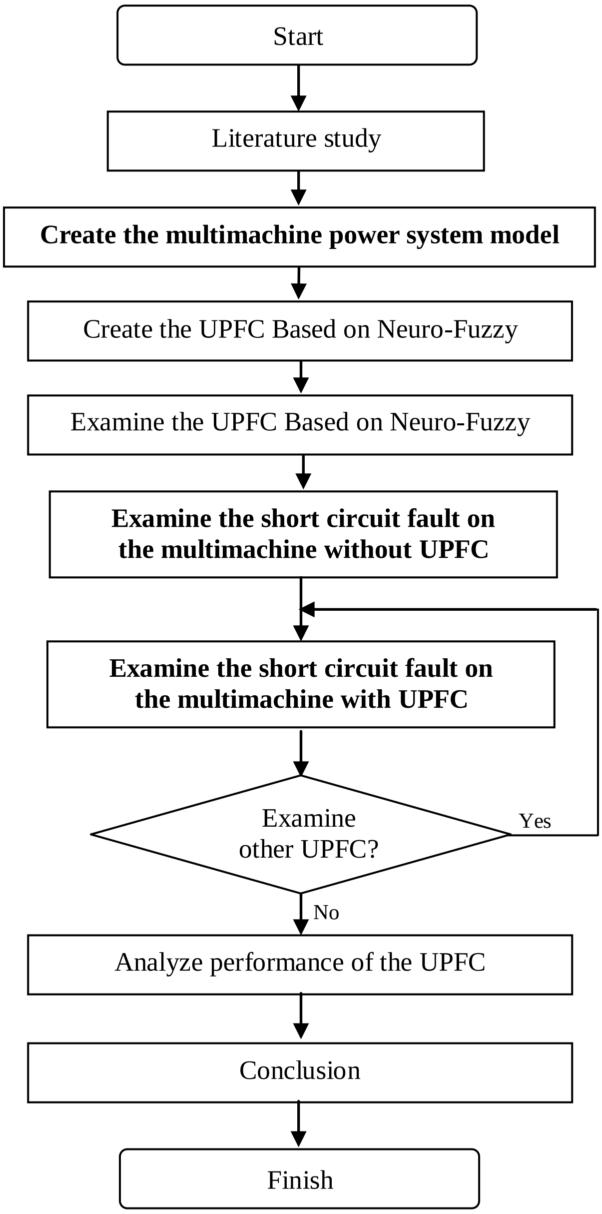


Figure 4. Procedure of the research.

IV. Result of Simulation

1. Adaptive Neuro-Fuzzy for UPFC

The design process of the Adaptive Neuro-Fuzzy (ANFIS) for power flow control using UPFC go through the following three steps:

a. Generation a suitable training data.
   In order to use the ANFIS technique for power flow control using UPFC, the input parameters limit should be determined precisely. The input parameters are obtained from recording devices sparsely located at sending end in a power system network. Due to limited available amount of practical fault data of transmission lines, it is necessary to generate training/testing data using simulation. To generate data for the typical transmission system, a computer program have been designed to generate training data for different faults.
b. Selection of a suitable ANFIS structure for a given application.

Various ANFIS are designed for UPFC to extend stability limits by modulating generator excitation to provide damping to the oscillation of synchronous machine rotors relative to one another. Membership function of inputs variable for PSS is shown in Figure 4, while the structure of Sugeno type ANFIS for UPFC is shown in Figure 5.

c. Training the ANFIS.
Various network configurations were trained in order to establish an appropriate network with satisfactory performances.

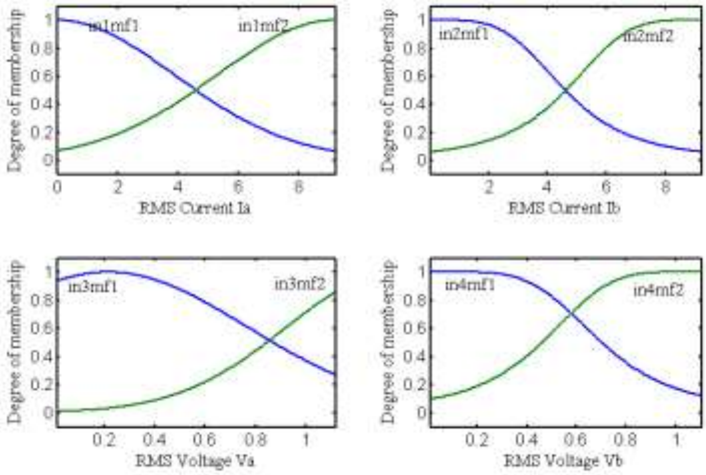


Figure 4. Membership function of Inputs Variable for UPFC

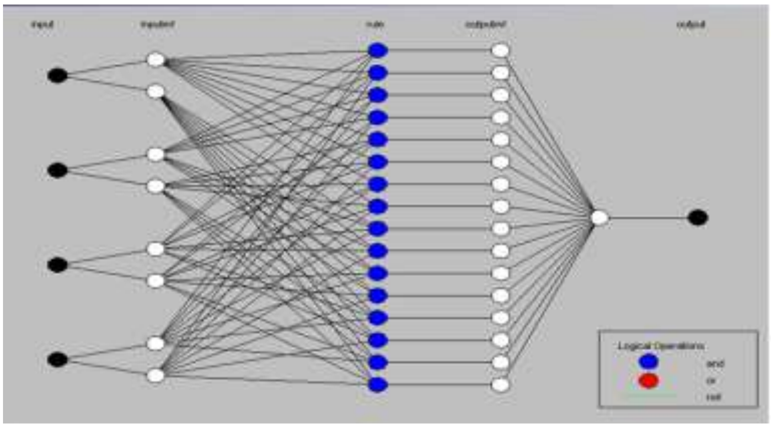
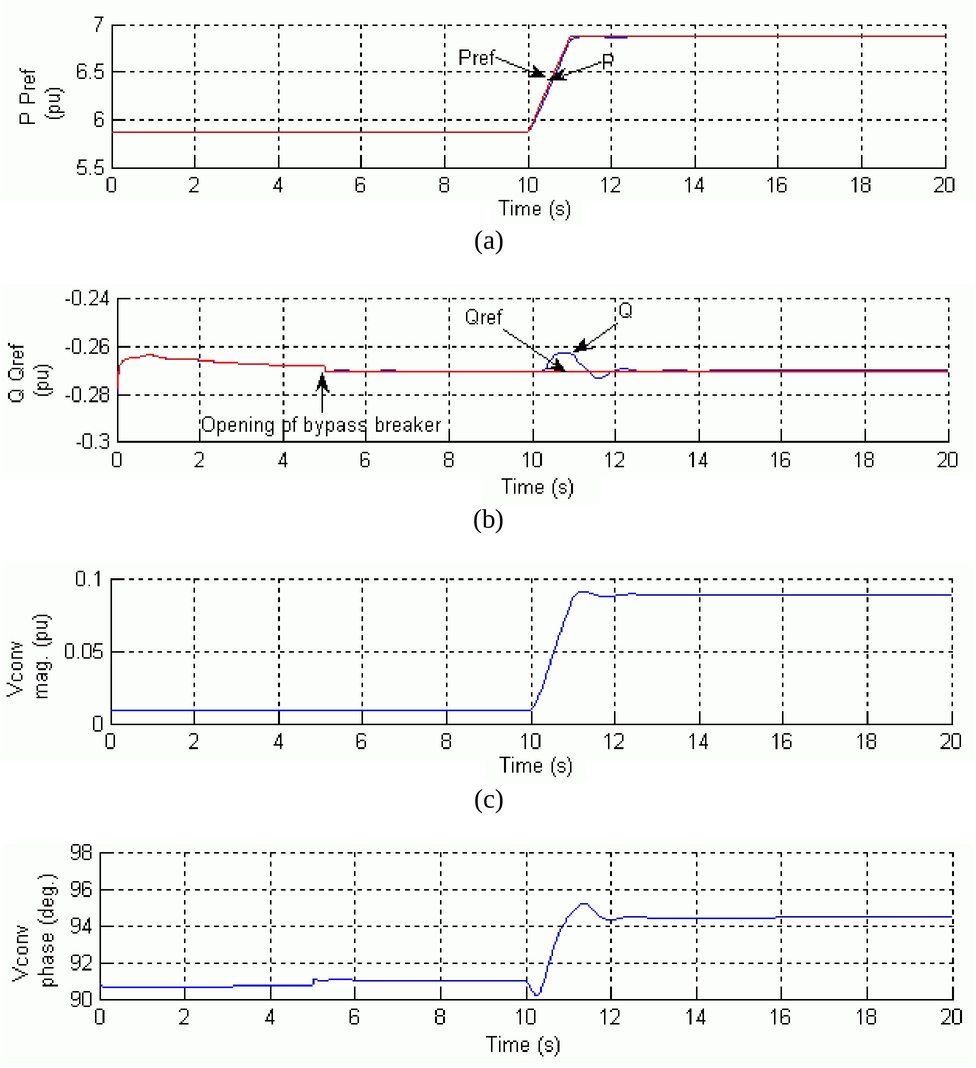


Figure 5. Structure of Sugeno type ANFIS for UPFC.

2. UPFC Model

In this study, we have made a model of a multi-machine power system in Matlab-Simulink software. A UPFC is used to control the power flow in a 500 kV /230 kV transmission system, as shown in Figure 6. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through three power transmission lines (L1, L2, L3) and two 500 kV/230 kV power transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV transmission line, 15000 MVA equivalent and to a 200 MW load connected at bus B3. Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant #2 is exported to 500 kV transmission system equivalent through two 400 MVA power transformers connected between buses B4 and B5. For this demo we are considering a contingency case where only two power transformers out of three are available (Tr2= 2*400 MVA = 800 MVA). The load flow shows that most of the power generated by plant #2 is transmitted through the 800 MVA transformer bank (899 MW out of 1000 MW) and that 96 MW is circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. The example illustrates how a UPFC can relieve this power congestion. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected through a DC bus). The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2.

Three phase fault is applied to the multimachine system. The series converter is rated 100 MVA with a maximum voltage injection of 0.1 pu. The shunt converter is also rated 100 MVA. Also, the shunt converter is in Voltage regulation mode and that the series converter is in Power flow control mode. Dynamic responses of the UPFC has shown in Figure 5. The UPFC reference active and reactive powers are set in the magenta blocks labeled Pref(pu) and Qref(pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587 MW and -27 Mvar. The Pref block is programmed with an initial active power of 5.87 pu corresponding to the natural power flow. Then, at t=10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 pu.



(a)

(b)

(c)

(d)

Figure 7. UPFC dynamic responses to changes in load of power system from 587 MW to 687 MW.

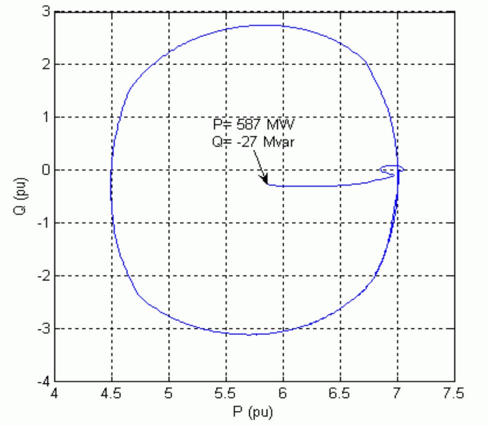


Figure 8. Controllability region of UPFC.

Further results are shown in Figure 7. The figure shows the UPFC dynamic response to changes in load of power system from 587 MW to 687 MW. Figure 8 shows the controllability region of UPFC. In Figure 8 are shown the results of UPFC control for active power through bus B3 and B4 with tap position changes of PST. Based on Figure 8, it can be seen that the neuro-fuzzy UPFC is able to provide a response that controls the flow of electrical power is good.

In Figure 9 is shown the action of PSS in damping power oscillations. In this design also included the role of Power System Stabilizer (PSS) in order to control the generator in the event of changes in the electrical load so that power oscillations that occur can take place in a short time.

V. Conclusion

In this study, neuro-fuzzy based method is applied to the UPFC for adaptively controlling the power flow in electric power transmission systems multimachine very dynamic. Three phase fault is applied to the multimachine system. The results are taken to be consideration of neuro-fuzzy controller. The neuro-fuzzy controller show a low overshoot occurred during the fault in results. According to results that UPFC improves the system performance under the transient and the normal conditions. However, it can control the power flow in the transmission line, effectively.

VI. Acknowledgements

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References

[1] K.R. Padyar, “Power System Dynamics, Stability and Control”, *John Wiley and Sons,* 1996.

[2] L. Saribulut, M. Tumay, and I. Eker, “Performance Analysis of Fuzzy Logic Based Unified Power Flow Controller”, *World Academy of Science, Engineering and Technology,* 45, 2008, 320-325.

[3] Y. H. Song, A. T. Jons, “Flexible AC Transmission Systems (FACTS)”, *IEE Power and Energy Series,* 30, 1999.

[4] B. Lu, L. Hou, B. Li, Y. Liu, “A New Unified Power Flow Fuzzy Control Method”, *Innovative Computing, Information and Control, Second International Conference,* 2007, 479 – 479.

[5] A.T. Al-Awami, Abdel-Magid, Y.T., dan Abido, M.A., “A particle-swarm-based approach of power system stability enhancement with unified power flow controller”, *International Journal of Electrical Power & Energy Systems*, 29, 2007, pp. 251-259, 2007.

[6] S. Kannan, S. Jayaram, M. M. A. Salama, “Real and Reactive Power Coordination for a Unified Power Flow Controller”, *IEEE Transactions on Power Systems*, 19(3), 2004, 1454 – 1461.

[7] A.A. Eldamaty, Faried, S.O., Aboreshaid, S., “Damping Power System Oscillations Using A Fuzzy Logic Based Unified Power Flow Controller”, *IEEE Conference Of CCECE/CCGEI*, May 2005.

[8] T. Allaoui, Denaı, M.A., dan Bouhamida, M., “Robust control of unified power flow controller (UPFC)”, *Journal of Electrical and Electronics Engineering (IU-JEEE)*, 7, 2007, 331-343.

[9] J. Guo, Crow, M.L. dan Sarangapani, J., “An improved UPFC control for oscillation damping”, *IEEE Transactions on Power Systems*, 14, 2009, 288-296.

[10] S. Hameed, Das, B., dan Pant, V., “A self-tuning fuzzy PI controller for TCSC to improve power system stability”, *Electric Power Systems Research*, 78, 2008, 1726-1735.

[11] S. Morsli, Tayeb, A., Mouloud, D., Abdelkader, C., “A robust adaptive fuzzy control of a unified power flow controller”, *Turkey Journal of Elec. Eng. & Comp. Science*, 20(1), 2012, 87-98.

[12] T. Takagi, M. Sugeno, “Fuzzy Identification of Systems and Its Applications to Modeling and Control”. *IEEE Transaction on Systems, Man and Sybern*, 1985, 1: 116-132.

[13] Jang, J.S.R., "ANFIS: Adaptive-Network-based Fuzzy Inference System", IEEE Trans. Syst., Man, Cybern., 23, 1993. 665-685.

[14] Syahputra, R., Robandi, I., Ashari, M. (2015). Reconfiguration of Distribution Network with DER Integration Using PSO Algorithm. TELKOMNIKA, 13(3). pp. 759-766.

[15] Syahputra, R., Soesanti, I., Ashari, M. (2016). Performance Enhancement of Distribution Network with DG Integration Using Modified PSO Algorithm. Journal of Electrical Systems (JES), 12(1), pp. 1-19.

[16] Syahputra, R., (2012), “Distributed Generation: State of the Arts dalam Penyediaan Energi Listrik”, LP3M UMY, Yogyakarta, 2012.

[17] Syahputra, R., Soesanti, I. (2016). Design of Automatic Electric Batik Stove for Batik Industry. Journal of Theoretical and Applied Information Technology (JATIT), 87(1), pp. 167-175.

[18] Soesanti, I., Syahputra, R. (2016). Batik Production Process Optimization Using Particle Swarm Optimization Method. Journal of Theoretical and Applied Information Technology, 86(2), pp. 272-278.

[19] Syahputra, R., Robandi, I., Ashari, M. (2015). PSO Based Multi-objective Optimization for Reconfiguration of Radial Distribution Network. International Journal of Applied Engineering Research (IJAER), 10(6), pp. 14573-14586.

[20] Syahputra, R. (2010). Fault Distance Estimation of Two-Terminal Transmission Lines. Proceedings of International Seminar on Applied Technology, Science, and Arts (2nd APTECS), Surabaya, 21-22 Dec. 2010, pp. 419-423.

[21] Syahputra, R., Robandi, I., Ashari, M., (2014), “Distribution Network Efficiency Improvement Based on Fuzzy Multi-objective Method”. IPTEK Journal of Proceedings Series. 2014; 1(1): pp. 224-229.

[22] Syahputra, R., (2013), “A Neuro-Fuzzy Approach For the Fault Location Estimation of Unsynchronized Two-Terminal Transmission Lines”, IJCSIT, Vol. 5, No. 1, pp. 23-37.

[23] Jamal, A., Suripto, S., Syahputra, R. (2017). Power Flow Optimization Using UPFC Based on Neuro-Fuzzy Method for Multi-machine Power System Stability. International Journal of Applied Engineering Research (IJAER), 12(6), pp. 898-907.

[24] Jamal, A., Suripto, S., Syahputra, R. (2016). Performance Evaluation of Wind Turbine with Doubly-Fed Induction Generator. International Journal of Applied Engineering Research (IJAER), 11(7), pp. 4999-5004.

[25] Syahputra, R., Robandi, I., Ashari, M. (2015). Performance Improvement of Radial Distribution Network with Distributed Generation Integration Using Extended Particle Swarm Optimization Algorithm. International Review of Electrical Engineering (IREE), 10(2). pp. 293-304.

[26] Syahputra, R., Robandi, I., Ashari, M. (2014). Optimization of Distribution Network Configuration with Integration of Distributed Energy Resources Using Extended Fuzzy Multi-objective Method. International Review of Electrical Engineering (IREE), 9(3), pp. 629-639.

[27] Syahputra, R., Robandi, I., Ashari, M., (2013), “Distribution Network Efficiency Improvement Based on Fuzzy Multi-objective Method”. International Seminar on Applied Technology, Science and Arts (APTECS). 2013; pp. 224-229.

[28] Jamal, A., Syahputra, R. (2013). UPFC Based on Adaptive Neuro-Fuzzy for Power Flow Control of Multimachine Power Systems. International Journal of Engineering Science Invention (IJESI), 2(10), pp. 05-14.

[29] Syahputra, R., (2012), “Fuzzy Multi-Objective Approach for the Improvement of Distribution Network Efficiency by Considering DG”, IJCSIT, Vol. 4, No. 2, pp. 57-68.

[30] Syahputra, R., Robandi, I., Ashari, M. (2014). “Optimal Distribution Network Reconfiguration with Penetration of Distributed Energy Resources”, Proceeding of 2014 1st International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE) 2014, UNDIP Semarang, pp. 388 - 393.

[31] Jamal, A., Syahputra, R. (2014). Power Flow Control of Power Systems Using UPFC Based on Adaptive Neuro Fuzzy. IPTEK Journal of Proceedings Series. 2014; 1(1): pp. 218-223.

[32] Soedibyo, Ashari, M., Syahputra, R. (2014). “Power loss reduction strategy of distribution network with distributed generator integration”, Proceeding of 2014 1st International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE) 2014, UNDIP Semarang, pp. 404 - 408.

[33] Syahputra, R., Robandi, I., Ashari, M. (2014). Performance Analysis of Wind Turbine as a Distributed Generation Unit in Distribution System. IJCSIT), Vol. 6, No. 3, pp. 39-56.

[34] Syahputra, R., Soesanti, I. (2016). DFIG Control Scheme of Wind Power Using ANFIS Method in Electrical Power Grid System. International Journal of Applied Engineering Research (IJAER), 11(7), pp. 5256-5262.

[35] Syahputra, R., Robandi, I., Ashari, M., (2012), “Reconfiguration of Distribution Network with DG Using Fuzzy Multi-objective Method”, International Conference on Innovation, Management and Technology Research (ICIMTR), May 21-22, 2012, Melacca, Malaysia.

[36] Syahputra, R., Soesanti, I. (2015). Power System Stabilizer model based on Fuzzy-PSO for improving power system stability. 2015 International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), Surabaya, 15-17 Oct. 2015 pp. 121 - 126.

[37] Syahputra, R. (2016). Application of Neuro-Fuzzy Method for Prediction of Vehicle Fuel Consumption. Journal of Theoretical and Applied Information Technology (JATIT), 86(1), pp. 138-149.

[38] Jamal, A., Suripto, S., Syahputra, R. (2015). Multi-Band Power System Stabilizer Model for Power Flow Optimization in Order to Improve Power System Stability. Journal of Theoretical and Applied Information Technology (JATIT), 80(1), pp. 116-123.

[39] Syahputra, R., Wiyagi, R.O., Sudarisman. (2017). Performance Analysis of a Wind Turbine with Permanent Magnet Synchronous Generator. Journal of Theoretical and Applied Information Technology (JATIT), 95(9), pp. 1950-1957.

[40] Syahputra, R. (2017). Distribution Network Optimization Based on Genetic Algorithm. Jurnal Teknologi, Journal of Electrical Technology UMY (JET-UMY), 1(1), pp. 1-9.

[41] Syahputra, R., Soesanti, I. (2015). “Control of Synchronous Generator in Wind Power Systems Using Neuro-Fuzzy Approach”, Proceeding of International Conference on Vocational Education and Electrical Engineering (ICVEE) 2015, UNESA Surabaya, pp. 187-193.

[42] Syahputra, R., Robandi, I., Ashari, M., (2011), “Control of Doubly-Fed Induction Generator in Distributed Generation Units Using Adaptive Neuro-Fuzzy Approach”. International Seminar on Applied Technology, Science and Arts (APTECS). 2011; pp. 493-501.

[43] Jamal, A., Syahputra, R. (2016). Heat Exchanger Control Based on Artificial Intelligence Approach. International Journal of Applied Engineering Research (IJAER), 11(16), pp. 9063-9069.

[44] Syahputra, R., Soesanti, I. (2016). An Optimal Tuning of PSS Using AIS Algorithm for Damping Oscillation of Multi-machine Power System. Journal of Theoretical and Applied Information Technology (JATIT), 94(2), pp. 312-326.

[45] Syahputra, R., Soesanti, I. (2016). Power System Stabilizer Model Using Artificial Immune System for Power System Controlling. International Journal of Applied Engineering Research (IJAER), 11(18), pp. 9269-9278.

[46] Syahputra, R., Soesanti, I. (2016). Application of Green Energy for Batik Production Process. Journal of Theoretical and Applied Information Technology (JATIT), 91(2), pp. 249-256.

[47] Syahputra, R., Suripto, S., Soedibyo, Soesanti, I. (2017). Application of Clonal Selection Immune System Method for Optimization of Distribution Network. Journal of Theoretical and Applied Information Technology (JATIT), 95(15), pp. 3604-3612.