Fuzzy Logic Based Active Power Generation Dispatching Considering Intermittent Wind Power Plants Output

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***Abstract*— Nowadays, renewable energy becomes a very interesting topic to be investigated for its continuity. In this research, type of renewable energy investigated is wind energy, which is a very promising technology to reduce the thermal power plants operating costs in the generation process, whether as a stand-alone, micro-grid or in an interconnected system. Nevertheless, the fluctuated wind energy (WE) will affect both the output of wind power plants (WPP) as well as the stability of the system. This paper presents a scheme for active power flow generation dispatching as a solution of the fluctuated WPP's output in an interconnected system in line with the fluctuated wind speed condition. The proposed active power generation scheme uses fuzzy logic controller (FLC). In this FLC, wind's speed assumptions are used as the input, whereas the outputs are the active power generated by the WPP and the thermal power plants (TPP). This FLC based active power generation provides guidelines for the system's operator for their daily power dispatching hence they can supply power continuously while maintaining system's stability.**

Keywords: renewable energy, fuzzy logic controller (FLC), wind power plant (WPP), thermal power plant (TPP), wind energy (WE).

I. INTRODUCTION

Renewable energy now becomes a very interesting research idea to be investigated for its continuity. In electric power system, integration of renewable energy for electricity generations can be in form of photovoltaic (PV) [1], wind energy (WE) generation [2, 3], or the both [4, 5, 6, 7]. These papers proposed the best dispatching solutions for the electric power system utility. Many methods were developed such as simulation of software [4]. Work in [1] proposed a method based on artificial intelligent (AI) application whereas researches in [7, 8, 9] developed a simple method to a complex method. Research in [10, 11, 12, 13] observed optimal placement of renewable energy generations for both active and reactive power generation.

The WE is very promising energy to reduce operation cost in the generation process as a stand-alone system [7], micro-grid [14], or as part of an interconnected system [15]. However, the WE is fluctuated so that it will influence WPP's output and the system's stability [9]. Therefore, a power generation dispatching should be designed considering the wind's output to ensure the power supply's continuity and reliability.

The generator modelling for wind turbine generally uses doubly fed induction generator (DFIG) [16, 17, 18, 19, 20, 21, 22]. Paper [16] presents a load shedding design considering DFIG with trajectory sensitivity factor (TSF) method based on sensitivity of voltage dynamic to determine the most sensitive location. Paper [17] correlated the conversion system of WE on WPP with DFIG. This work focused on the control of active and reactive power used fully-fuzzy direct power control (FFDPC) method on the wind turbine self. Vector control method to organize the changed of active and reactive power between machine and grid was presented in [18], meanwhile [19] provided an overview of research over the last 30 years which employed DFIG. Research in [20] analyzed fault current contribution with the way to control negative sequence fault current on DFIG wind turbine during asymmetric disturbance. Paper [21] gave an extensive review of previous researches that have been published either as analysis, modelling, or restoration low voltage ride through (LVRT) on wind turbine and [22] presented the new scheme to maximize output WT with DFIG without using wind data or anemometer.

This research arises as a form of our concern for the Indonesian Government's policy in its program to reduce carbon dioxide emission in the world. One of the Indonesian Government program is bilateral cooperation between Indonesian and the United States of America (the USA) to build WPP in South Sulawesi Sidrap Regency with 70 MW capacity [23]. The local utility concerns about the reliability and the continuity of power supply once the WPP operates. Therefore this paper presents a fuzzy logic controller (FLC) based active power generation dispatching as a solution of the concern to WPP's output in the interconnected system due to the fluctuated wind speed. However, to ensure the

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interconnected system can supply continuously and stable, a deep research on wind speed forecasting should be done.

This paper is organized as follow. Section II provides an overview on power flow analysis (PFA) method, the Southern Sulawesi power systems and DFIG modelling. Section III describes FLC design algorithm, Section IV elaborates results of simulation and analysis whereas Section V concludes the main findings of the research.

II. POWER FLOW ANALYSIS AND THE SYSTEM'S MODELLING

A. Power Flow Analysis (PFA)

For an interconnected system, the active and reactive power flow analysis use Newton Raphson method. Newton Raphson is one of the most common techniques That used for the iterative solution of nonlinear algebraic equations. The equations can be shown in Eq. (1), (2).

$$P_k(x) = V_k \sum_{n=1}^{N} Y_{kn} V_n (i) \, Cos \, [\delta_k(i) - \delta_n(i) - \theta_{kn}] \tag{1}$$

$$Q_k(x) = V_k \sum_{n=1}^{N} Y_{kn} V_n (i) \, sin \, [\delta_k(i) - \delta_n(i) - \theta_{kn}] \tag{2}$$

Optimal power flow (OPF) method as a power flow analysis solution gives optimal settings from variable control for load control which is given to minimize an object function that has been established such as active power generation cost or transmission losses [24]. Furthermore, OPF method is also employed to manage system's congestion and network losses [25, 26, 27, 28] . OPF has been used for conventional grid operations planning without renewable energy power plan [24, 29, 30] as well as considering renewable energy as presented in [2, 3, 31, 32] . Research in [32], presents OPF that integrated with WE and solar cell.

The simple equation to calculate OPF or optimal dispatch (OD) is defined in Eq. (3). The *Kron's loss* equation is contained in Eq. (4) and operational equation cost for thermal generator (for more than one generator) including losses is defined in Eq. (5). The total generation results must be equal to demand and losses are defined in Eq. (6) whereas inequality constraints in Eq. (7) [33], as follow,

$$P_L = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j \tag{3}$$

$$P_L = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00} \tag{4}$$

$$C_i = \sum_{i=1}^{n_g} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \tag{5}$$

$$\sum_{i=1}^{n_g} P_i = P_D + P_L \tag{6}$$

$$P_{i(\min)} \leq P_i \leq P_{i(\max)} \quad i = 1, \dots, n_g \tag{7}$$

Through various derivations, it will result in the final equation as Eq. (8),

$$\sum_{i=1}^{n_g} \left(\frac{\partial P_i}{\partial \lambda}\right)^k = \sum_{i=1}^{n_g} \frac{\gamma_i + B_{ii}\beta_i}{2(\gamma_i + \lambda^k B_{ii})^2} \tag{8}$$

B. The Southern Sulawesi Interconnected Power System

Fig. 1 shows the Southern Sulawesi interconnected power system which consists of 2 substations of 275 kV, 35 substations of 150 kV, 16 substations of 70 kV and 2 Furthermore, PFA is also employed to manage system's congestion and network losses substations of 30 kV [34, 35, 36]. Meanwhile modelling of WPP that will be connected to the 150 kV Sidrap Substation can be found in [23]. Table I gives information on the active power generation data of interconnected the Southern Sulawesi power system.

Fig. 2 shows the potential locations for wind power plants in Southern Sulawesi, which one of the best location is in Sidrap Regency. The potential active power generation in Sidrap Regency is 100 MW with average wind speed level of 7,04 m/s at 50 meter of heights [37]. According to [23], if the generation data follows the IEEE standard of 2,5 MW capacity of each wind turbine, then the Sidrap WPP of 70 MW must be built with 28 wind generators. Afterwards, the power flow simulation of the Southern Sulawesi power system included the Sidrap WPP shows that the system is still stable with the voltage levels are still between the stability limit.

TABLE I. THE ACTIVE POWER GENERATION DATA OF THE SOUTHERN SULAWESI INTERCONNECTED POWER SYSTEM [38]

No.	**Active power data**		
	Type/name generator		**MW**
1.	Hydro	Bakaru	63
2.		Bili-bili	5.3
3.		Sawitto	0.75
4.		Poso 1	65.1
5.		Poso 2	64.5
6.		Poso 3	65.5
1.	Thermal	PLTU Barru 1	37.66
2.		PLTU Barru 2	28.73
3.		PLTU Jeneponto 1	114.49
4.		PLTU Jeneponto 2	107.3
5.		PLTD SWD	8
6.		PLTD Suppa	31.1
7.		PLTD Tallasa 1	15
8.		PLTD Tallasa 2	16
9.		PLTD Tallasa 3	30
10.		PLTD Tallasa 4	20
11.		PLTD Masamba	4
12.		PLTG GE	13
13.		PLTGU Sengkang GT#11	52.6
14.		PLTGU Sengkang GT#12	52.5
15.		PLTGU Sengkang GT#18	52.7
16.		PLTGU Sengkang GT#21	52.9
17.		PLTGU Sengkang GT#22	52.9
18.		PLTGU Sengkang ST#28	52.7

C. The Modelling of DFIG

Equations in steady-state voltage, current and power parameters of DFIG can be written in Eq. (9), (10), (11), (12) [16].

$$v_{ds} = -rsi_{ds} + \left[(x_s + x_m)i_{qs} + x_m i_{qr}\right] \tag{9}$$

$$v_{qs} = -r_s i_{qs} + [(x_s + x_m)i_{ds} + x_m i_{dr}] \tag{10}$$

$$v_{dr} = -r_R i_{dr} + (1 - \omega_m)\left[(x_R + x_m)i_{qr} + x_m i_{qs}\right] \tag{11}$$

$$v_{qr} = -r_R i_{dr} + (1 - \omega_m)\left[(x_R + x_m)i_{qr} + x_m i_{qs}\right] \tag{12}$$

So the active and reactive power flow equations to grid are defined in Eq. (13) and (14), respectively,

$$P = v_{ds} i_{ds} + v_{qs} i_{qs} + v_{dc} i_{dc} + v_{qc} i_{qc} \tag{13}$$

$$Q = v_{qs} i_{qs} - v_{ds} i_{ds} + v_{qc} i_{qc} - v_{dc} i_{dc} \tag{14}$$

III. THE PROPOSED FUZZY LOGIC CONTROLLER ACTIVE POWER DISPATCHING

A. FLC Design Algorithm

This FLC based active power dispatching design has 1 input and 2 outputs. The input is the wind speed assumption, whereas the outputs are the WPP output and the TPP output.

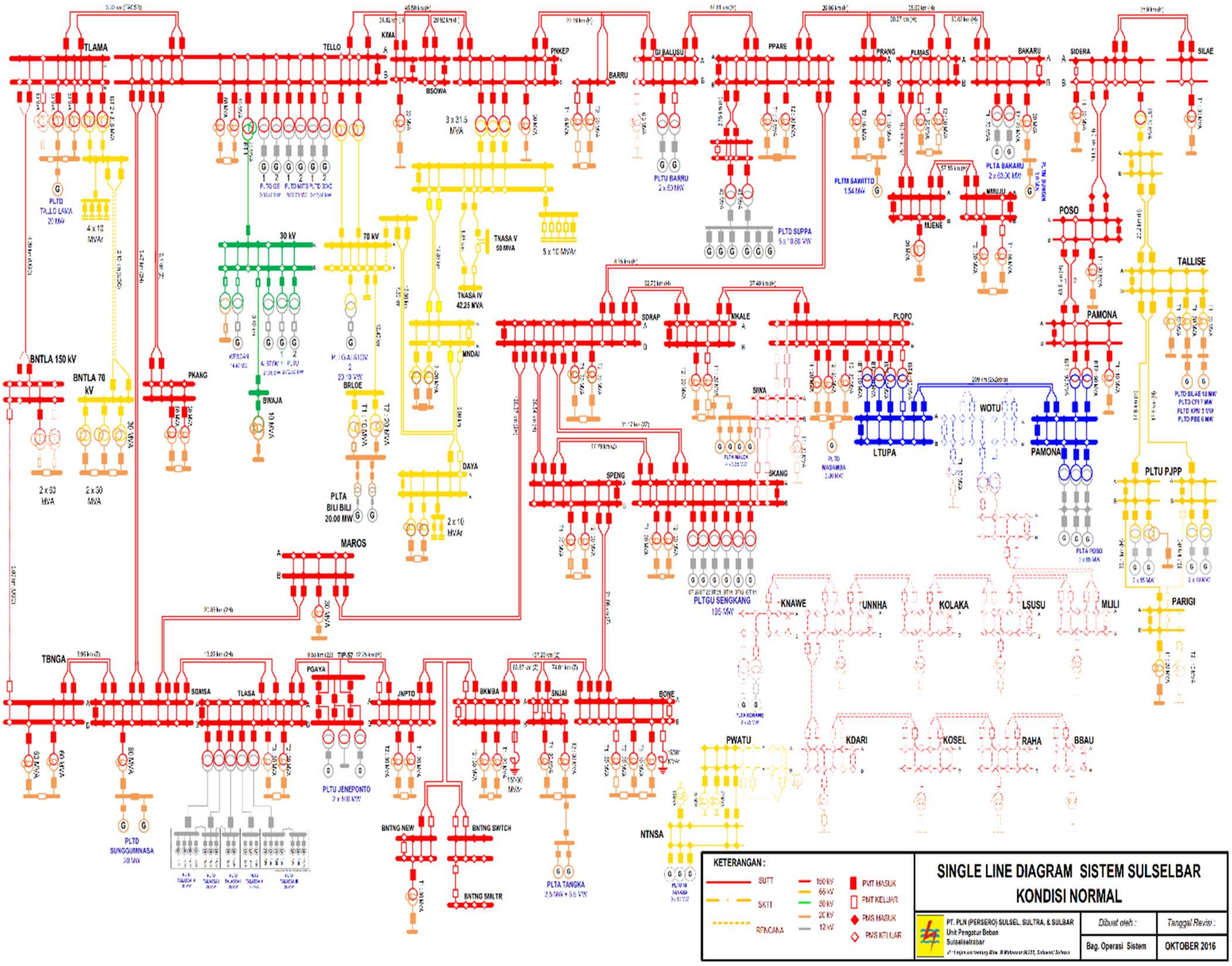

Fig. 1. Single line diagram of the Southern Sulawesi power system [34]

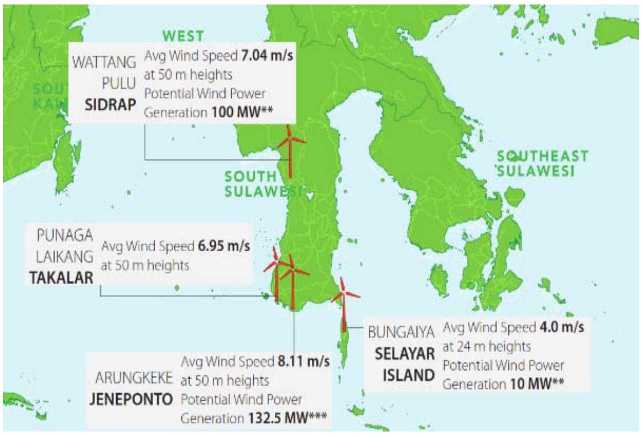

Fig. 2. Map of potential locations for wind power plants in South Sulawesi [37].

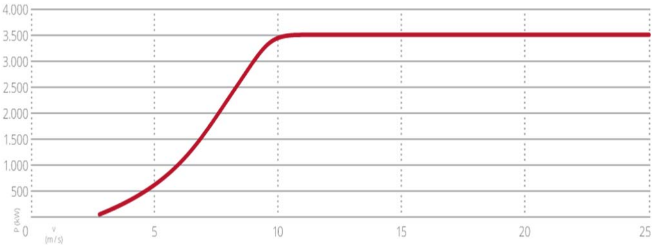

Fig. 3. The performance curve between wind turbine output and wind speed [39]

Aligned with the average wind speed data [37] and the performance curve between wind turbine output and wind speed [39] in Fig. 2 and Fig.3, then the membership functions for wind speed levels and the WPP outputs are defined in Table II and Table III, respectively. Table IV shows the membership functions for thermal power plant, which in this work, the PLTGU Sengkang is chosen. Table V displays the fuzzy rule base. Fig. 4 shows the FLC design for our active power generation dispatching.

The FLC is designed for the base load 785.23 MW [38]. The design algorithm procedure can be explained as follow:

1. Determine membership functions for the input,
2. Determine membership functions of the WPP output using the relationship between wind speed and wind turbine output based on Fig. 3 that shows the performance curve between wind turbine output and wind speed [39],
3. Determine the TPP output using PFA. The TPP here is chosen PLTG Sengkang which has 6 plants,
4. Determine fuzzy rule base.

TABLE II. MEMBERSHIP FUNCTIONS FOR INPUT

No.	**Wind Speed**			
	Levels	***m/s***		
1	Very low	0	0.83	1.66
2	Low	0.83	1.66	3.32
3	Middle	1.66	3.32	4.98
4	High	3.32	4.98	6.64
5	Very high	4.98	6.64	8.3

TABLE III. MEMBERSHIP FUNCTIONS FOR WPP OUTPUT

No.	**WPP output**			
	Levels	***kW***		
1	Very low	0	0	0
2	Low	0	0	150
3	Middle	0	150	500
4	High	150	500	1,300
5	Very high	500	1,300	2,500

TABLE IV. MEMBERSHIP FUNCTIONS FOR TPP OUTPUT

No.	**TPP output**			
	Levels	***kW***		
1	Very low	0	0	3,920
2	Low	0	3,920	7,840
3	Middle	3,920	7,840	11,760
4	High	7,840	11,760	15,680
5	Very high	11,760	15,680	19,600

TABLE V. FUZZY RULE BASE

If input	**Then**	
	WPP Output	**TPP Output**
Very low	Very low	Very high
Low	Low	High
Middle	Middle	Middle
High	High	Low
Very high	Very high	Very low

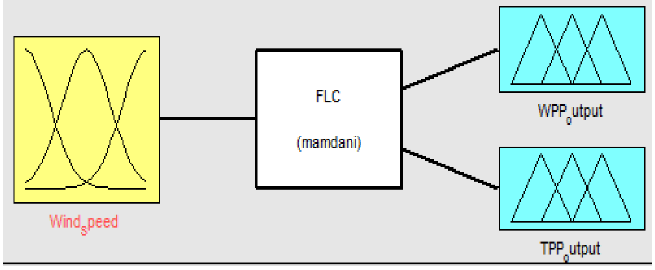

Fig. 4. Fuzzy logic design for active power generation dispatching.

IV. SIMULATIONS AND DISCUSSIONS

Fig. 5 shows the performance curve between the input and the WPP output. The curve shows that wind speed is linear with the WPP output. Wind speed starting from 0 to 8.3 m/s and the WPP output follows the change wind speed according to the performance in ENO curve [39], from 0 to 2,500 kW.

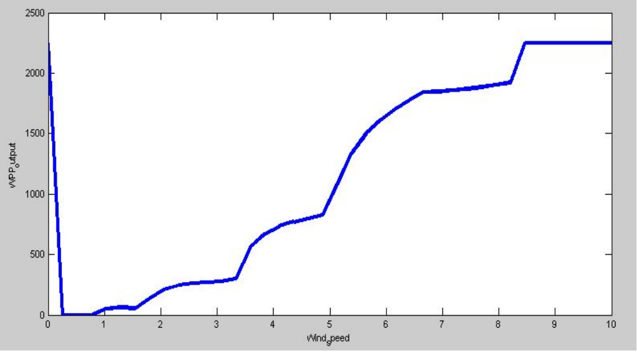

Fig. 5. Curve performance between input and WPP output

Fig. 6 informs the performance curve of FLC by comparing between the wind speed and the TPP output. The curve shows the wind speed has an inverse correlation with the TPP output. The results give how FLC can control the TPP output aligned with the fluctuated wind speed. Fig. 7 demonstrates an example of active power dispatching results. The result is described in a triangle pattern form. It is assumed that if the wind speed is high at 5 m/s, then the WPP output is high at 1110 kW and the TPP output occupies low at 5880 kW.

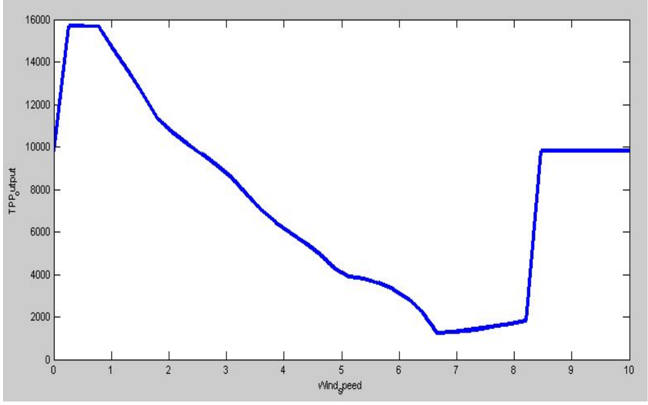

Fig. 6. Curve performance between input and TPP output

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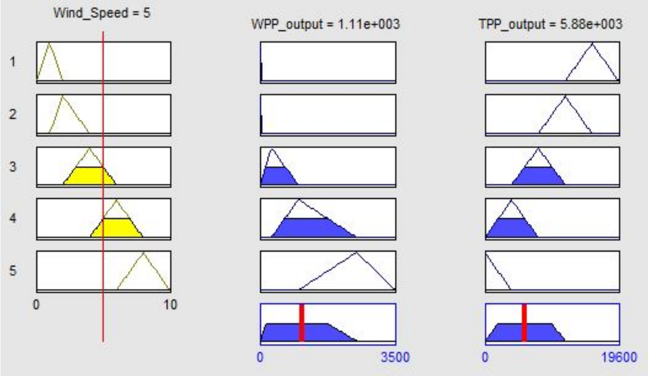

Fig. 7. The computation example of dispatching if wind speed is 5 m/s

V. CONCLUSIONS

This research is conducted regarding to problem of the system's operator about the integration of WPP to the Southern Sulawesi interconnected power system with fluctuated wind speed and WPP output. It is expected that this work can offer solution to the problem. In this study, a fuzzy logic controller (FLC) is selected to provide active power generation dispatching between WPP at Sidrap and TPP PLTGU Sengkang. The FLC is designed based on the performance curve between wind speed and WPP output, and by using PFA to determine the TPP output for each wind speed assumption.

The FLC for active power dispatching modelling has 1 input and 2 outputs. There are five level of membership functions in the wind speed input as well as both outputs. The input controls two outputs. If there is a change in the input then the outputs will adjust accordingly based on the fuzzy rules.

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