

# Optimal power flow for power system interconnection considering wind power plants intermittency

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## Abstract

The rise of global warming issues and limitation of fossil resources encourages a large number of power plant construction generated by renewable energy. One of the promising renewable energy power generation is the wind power plant. However, the variable of wind speeds may cause problems to its management system and power dispatch of the power grid. The fluctuation of energy demand and wind speed are the main issues regarding the wind power plants (WPP) integration into interconnected power systems. Optimal power flow (OPF) method will determine the optimal operating conditions of the electric network that experiences physical and operational barriers. Factors that determine the optimal point are formulated based on the optimization algorithm method. The primary purpose of the method is to specify the settings of the OPF variable controls and systems of equations that optimize the value function of the objective. The selection of this function should be analyzed carefully based on the electrical power system's technical and economical aspects. Currently in Indonesia, 70 MW capacity of WPP have been built in the Sidrap Regency in the Southern Sulawesi power system and this WPP will be integrated with other thermal generations in the interconnected power system to supply a 1050-1100 MW maximum load. This study evaluates the WPP's output considering the WPP intermittency constraint (the various wind speed) then assesses the optimal power flow results for the Southern Sulawesi case.

*Keywords: integrated power systems; intermittency; optimal power flow; wind power plant*

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## 1. Introduction

The rise of global warming issues and limitation of fossil resources encourages a large number of power plant construction generated by renewable energy. One of the promising renewable energy power generation is the wind power plant. Wind power plants (WPPs) are environmentally friendly and has a promising low cost power generation.

At the moment, wind energy is one of the alternative energy sources that has become a new consideration for power generation resources. However, the variable of wind speeds may cause problems to its management system and power dispatch of the power grid. The fluctuation of energy demand and wind speed are the main issues regarding the WPP integration into the interconnected power system.

In the process, integrating WPPs into the system provides a new challenge in the economic dispatch due to the output that depends on natural conditions [1, 2]. Optimal Power Flow (OPF) method will determine the optimal operating conditions of the electric network that experiences physical and operational barriers [3 - 7]. Factors which are the optimal point will be formulated and solved by using optimization algorithm accordingly. The primary purpose of the method is to specify the settings of the

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OPF variable controls and systems of equations that optimize the value function of the objective. The selection of this function should be analyzed carefully based on the electrical power system's technical and economical aspects.

There has been many researches on OPF considering WPP's integration. Research in [8] explained about how Demand Dispatch (DD) could improve the system's ability to handle wind intermittency with probabilistic forecast method. Authors in [9] proposed probability density function (PDF) method to solve OPF constraints in the IEEE 30 bus and the IEEE 118 bus illustrations. Biogeography based optimization (BBO) algorithm was compared with Monte Carlo method (MCS) to find the better algorithm for multi objective OPF in [10]. The study in [11] defined about how non-dominated sorting genetic algorithm (NSGA) method numerically could solved OPF constraints more rational and effective. How group search optimization (GSO) could solve multi objective OPF (MO-OPF) better than Monte Carlo method (MCS) was explicated in [12]. The investigation in [13] mentioned about how interval optimization (PIO) method could solve wind power OPF (WP-OPF) on a numerical test in the IEEE 30 bus system.

Currently in Indonesia, 70 MW capacity of WPPs have been built in the Sidrap Regency in the Southern Sulawesi power system and this WPP will be integrated with other thermal generations in the interconnected power system to supply a 1050-1100 MW maximum load [14]. More details of the Southern Sulawesi power system can be found in [15-17]. The power utility will need to plan the dispatch for a wide range of wind speed and various loads. Therefore, the OPF study for the Southern Sulawesi power system is important to maintain the system's stability and reliability. This study evaluates the WPP's output considering the WPP intermittency constraint (the various wind speed) then assesses the optimal power flow results for the Southern Sulawesi case.

## 2. The Proposed Methodology

OPF aims to minimize fuel costs by not breaking the generator constraints. It can be formulated as follows:

$$\text{Minimize } F = \sum_{i=1}^{NG} F_i(P_{gi}) \quad (1)$$

Where,  $F$  is the total fuel costs and the  $F_i$  is the fuel cost of the  $i^{\text{th}}$  power station. Limitation of the power balance equations described equality as,

$$P_{gi} - P_{di} = \sum_{j=1}^N |V_i||V_j||y_{ij}|(\theta_{ij} - \delta_i + \delta_j) \quad i = 1, \dots, N \quad (2)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^N |V_i||V_j||y_{ij}|(\theta_{ij} - \delta_i + \delta_j) \quad i = 1, \dots, N \quad (3)$$

Where,  $P_{gi}$  is the total of active power generation of the  $i^{\text{th}}$  bus,  $P_{di}$  is the total active power load of the  $i^{\text{th}}$  bus,  $Q_{gi}$  is the total of reactive power generation of the  $i^{\text{th}}$  bus,  $Q_{di}$  is the total of reactive power load of the  $i^{\text{th}}$  bus,  $|V_i|$  is the voltage magnitude of the  $i^{\text{th}}$  bus,  $|V_j|$  is the voltage magnitude of the  $j^{\text{th}}$  bus,  $\theta_{ij}$  is the admittance angle between  $i^{\text{th}}$  and  $j^{\text{th}}$  buses,  $\delta_i$  is the voltage angle of the  $i^{\text{th}}$  bus,  $\delta_j$  is voltage angle of the  $j^{\text{th}}$  bus.

### 2.1. Inequality constraints on the systems

#### 2.1.1. Generation constraints

The real power output generation, voltage and reactive power output are limited by their minimum and

maximum limits as follow,

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad i = 1, \dots, NG \quad (4)$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max} \quad i = 1, \dots, NG \quad (5)$$

$$|V|_{gi}^{min} \leq |V|_{gi} \leq |V|_{gi}^{max} \quad i = 1, \dots, NG \quad (6)$$

Where,  $P_{gi}^{min}$  and  $P_{gi}^{max}$  are the minimum and maximum real power generation of the  $i^{th}$  generator bus, respectively,  $Q_{gi}^{min}$  and  $Q_{gi}^{max}$  are the minimum and maximum reactive power generation of the  $i^{th}$  generator bus, respectively,  $|V|_{gi}^{min}$  and  $|V|_{gi}^{max}$  are the minimum and maximum voltage magnitude of the  $i^{th}$  generator bus, respectively.

### 2.1.2. Security limits that covered voltage magnitude of the load bus

The voltage magnitude constraints of the load buses are as follow,

$$|V|_{Li}^{min} \leq |V|_{Li} \leq |V|_{Li}^{max} \quad i = 1, \dots, NL \quad (7)$$

Where  $|V|_{Li}^{min}$  and  $|V|_{Li}^{max}$  are the minimum and maximum magnitude voltage of the  $i^{th}$  load bus.

## 3. Result and Analysis

In this study, wind speed at the Sidrap Regency was downloaded from NASA [18]. Fig 1 describes wind speed fluctuations from January 2017 until December 2017 which determined that the maximum wind speed is 5.8 m/s, the average is around 3.5 m/s and the minimum is 2.5 m/s with the related WPPs output power. The highest WPP output power is 5.82 MW when the wind speed position is 5.8 m/s and its lowest output is 0.56 MW when the wind speed is less than 2.5 m/s.

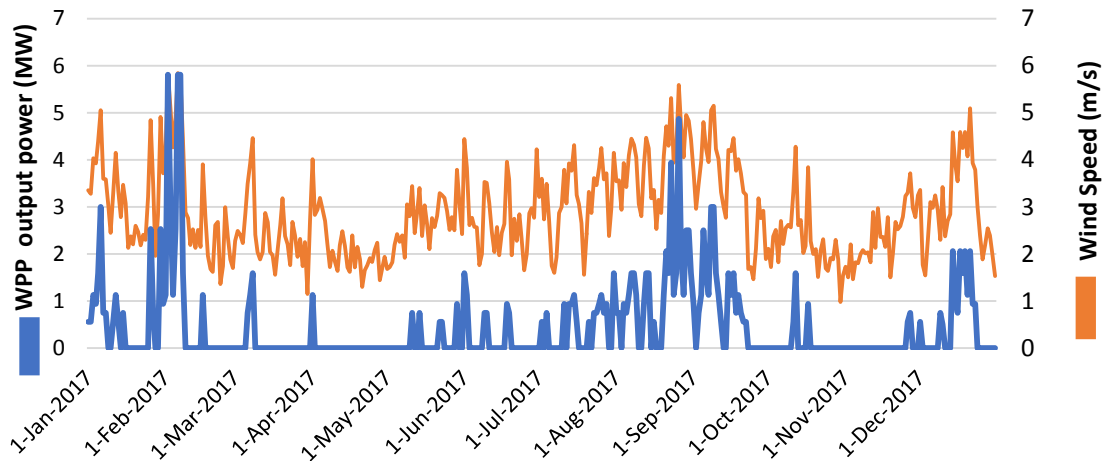


Fig. 1. Wind speed and related WPP's output for Sidrap WPP

Fig. 2 shows the total power generated and power losses of the Southern Sulawesi power systems before and after the integration of the Sidrap WPP if the wind speed is assumed to be at the maximum. Fig. 2 compares the power flow analysis results by conventional power flow (CPF) and OPF analysis which both analysis informs that the integration of the Sidrap WPP can reduce power losses and the total

power generated. This is because the Sidrap WPP's locations is quite close to the load centre, which is Makassar City. However, the OPF analysis resulted in higher power generated and higher network losses than the CPF analysis results, as this indicates that there might be some main lines that have over capacity condition if it is analysed by using OPF algorithm, hence the OPF program did some redispatching. Therefore, to minimize total power generated and losses, the Southern Sulawesi power systems needs development of new infrastructure that could connect the Sidrap WPP to the load centre, so it can minimize total power generated and power losses and to avoid the system to work in over load conditions.

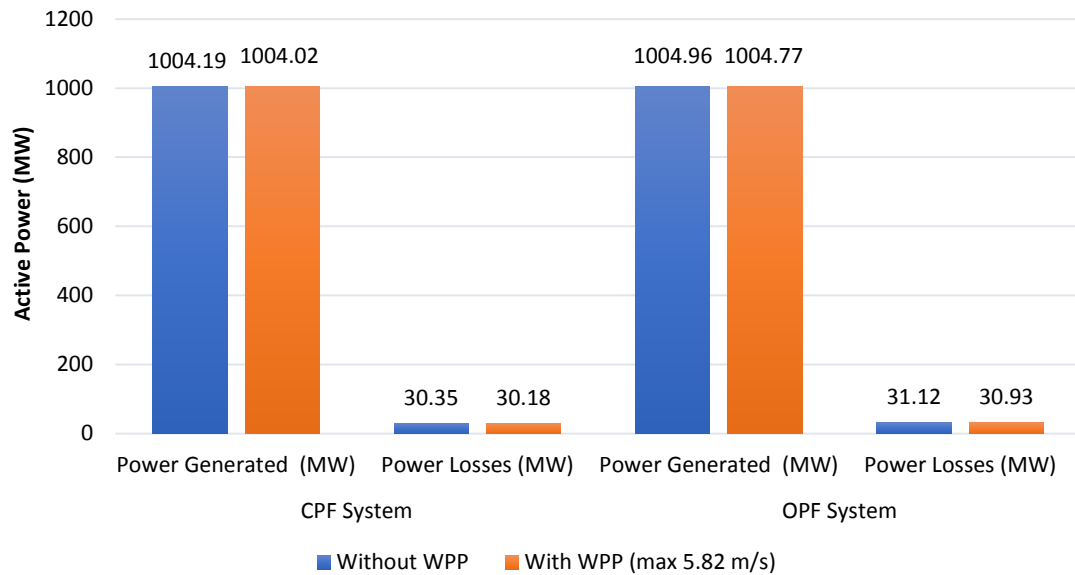


Fig. 2. Power generated and power losses condition with and without WPP

Since WPPs are absorbing reactive power [19], therefore further research in the area of reactive power compensator [20, 21] needs to be done to maintain the system's stability.

#### 4. Conclusions

Integrating WPP to interconnected power systems is quite challenging because of the wind intermittency that affects the WPP output power. The fluctuation of output power itself can be dangerous for power system's stability.

This paper compares the CPF and OPF algorithm with and without WPP integration in the Southern Sulawesi power system in Indonesia. The integration of the Sidrap WPP can decrease total power generation and power losses in the Southern Sulawesi power system if the wind speed is considered to be at the maximum. However, since OPF determined the operating conditions economically and the line capacity, the results indicated the possibility of some transmission lines or substations to have over capacity condition. Furthermore, the planning of new infrastructure should give attention to line capacity and the distance between power plants and load centers.

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