

Active and Reactive Power Scheduling Optimization using Firefly Algorithm to Improve Voltage Stability Under Load Demand Variation

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ABSTRACT

This paper presents active and reactive power scheduling using firefly algorithm (FA) to improve voltage stability under load demand variation. The study involves the development of firefly optimization engine for power scheduling process involving the active and reactive power for wind generator. The scheduling optimization of wind generator is tested by using IEEE 30-Bus Reliability Test System (RTS). Voltage stability of the system is assessed based in a pre-developed voltage stability indicator termed as fast voltage stability index (FVSI). This study also considers the effects on the loss and voltage profile of the system resulted from the optimization, where the FVSI value at the observed line, minimum voltage of the system and loss were monitored during the load increment. Results obtained from the study are convincing in addressing the scheduling of power in wind generator. Implementation of FA approach to solve power scheduling revealed its flexibility and feasible for solving larger system within different objective functions.

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1. INTRODUCTION

Most current power system networks have been developed to supplement the fast-growing demand for power. As a result, the design of these power system become complicated and a new approach to optimize the power system is needed to ensure the system can operate at its best.

Power scheduling comprises of two tasks which are unit commitment and power dispatch to fulfil the power demand and these tasks are to be performed effectively within the generation's constraints and limits. The power dispatch will ensure the generation cost to be at the minimum. Meanwhile, reactive power scheduling is suggested to reduce the power system loss. [1].

Load Demand varies throughout the time thus the system will need to have the ability to sustain a stable condition. As the load demand increased towards the limit which it can stand, the system is at risk of collapse [2]. The Fast Voltage Stability Index (FVSI) is a method to determine the stability of the system as the line index shows 0 to 1 where 1 showing the system is at the verge of collapse [3]–[5]. Voltage stability is the term used when a system is in equilibrium during nominal operation [6]–[7]. Besides improving the

stability of the system, this study also will be looking at the reaction of the system loss and voltage profile of the system.

FA is used to optimize the IEEE 30-bus system with varying loads. The FA is used as it has the ability to solve multi-objective and also fast convergence rate [8]–[9]. The scheduling is done to all generators and synchronous condensers. This paper presents active and reactive power scheduling optimization using firefly algorithm to improve voltage stability considering load demand. Results from this study revealed that the system stability improved based on the reduction of the value of FVSI. Besides that, the bus voltage profile and the system loss were also improved after the optimization.

2. RESEARCH METHOD

2.1. Problem Formulation

In this paper, the main objective of the optimization process is to improve the voltage stability in the system. Voltage stability is represented by using FVSI value. The objective function of the optimization and the formula of FVSI can be represented as:

$$OF = \min(FVSI_{sr}) \quad (1)$$

$$FVSI_{sr} = \frac{4Z_{sr}^2 Q_r}{V_s^2 X_{sr}} \quad (2)$$

where $FVSI_{sr}$ is the FVSI value of line connecting s^{th} bus to r^{th} bus, Q_r is the reactive power flowing into r^{th} bus, V_s is the voltage value at s^{th} bus, Z_{sr} and X_{sr} are the impedance and reactance of the line while s and r are the sending bus number and receiving bus number respectively.

During the optimization process, there are several various which needs to be satisfied. The first constraint is to ensure that the real and reactive power generated by the generation units and the wind generator should be within the range of its minimum and maximum operation limit. The constraints can be expressed as:

$$P_g^{min} \leq P_g \leq P_g^{max} \quad (3)$$

$$Q_g^{min} \leq Q_g \leq Q_g^{max} \quad (4)$$

where P_g is the active power output of the generation unit, Q_g is the reactive power output of the generation unit, P_g^{min} and P_g^{max} is the minimum power output limit and maximum power output limit of the generation unit while Q_g^{min} and Q_g^{max} are the minimum reactive power output limit and maximum reactive power output limit of the generation unit.

The next constraint which should be considered is the power balance constraints. In this constraint, total power generated in a power system should cater the load demand as well as the losses in the system. This constraint holds true for both active and reactive power balance. In active power balance, power generated by the generation unit and power produced by the wind generator, P_{Gw} should cater the active power demand, P_{demand} and real power loss, P_{loss} . In reactive power, the power generated by the generation units as well as injected reactive power, Q_{inj} should cater the reactive power demand, Q_{demand} and the losses, Q_{loss} . These constraints can be expressed as:

$$P_{demand} + P_{loss} = \sum P_g + P_{Gw} \quad (5)$$

$$Q_{demand} + Q_{loss} = \sum Q_g + \sum Q_{inj} \quad (6)$$

Grid connected wind turbines produce real power which depends on the wind speed, V_w . The wind turbine will only start to generate at a cut in wind speed and the maximum power generated is in between 15ms^{-1} and cut-out speed [10]. The cut in wind speed is 5ms^{-1} and the cut-out speed is 25ms^{-1} . The cut-out speed is set to reduce the risk of the turbine to rotate too fast and experience mechanical failure, thus the brake is applied to the wind rotors. The power curve of the modelled wind turbine used in this study can be expressed as:

$$P_{Gw} = \begin{cases} 0 & V_w < 5ms^{-1} \\ 0.017 \times V_w^3 & 5ms^{-1} \leq V_w < 15ms^{-1} \\ 60 & 15ms^{-1} \leq V_w \leq 25ms^{-1} \\ 0 & V_w > 25ms^{-1} \end{cases} \quad (7)$$

Figure 1 shows the process of active and reactive power scheduling optimization by using FA. The process starts by determining the least loadable bus and the weakest line in the system. Load increment at the selected load bus will be done and the un-optimized FVSI of the weakest line, minimum bus voltage and transmission loss are monitored. Firefly algorithm optimization is then conducted, and the optimized values are monitored for any changes. The process is repeated until the maximum loadability of the bus is reached.

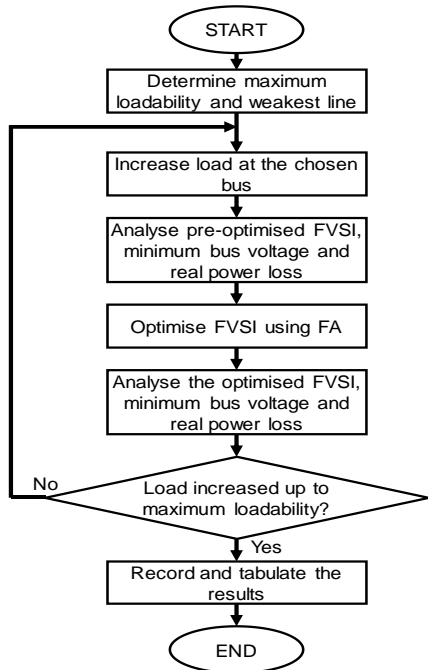


Figure 1. Active and Reactive Power Scheduling Optimization Process

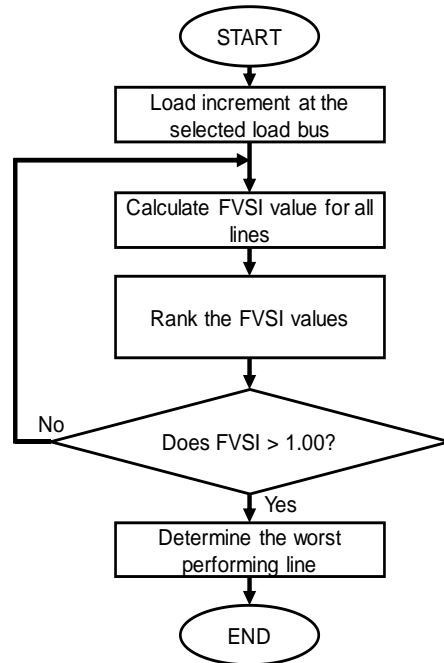


Figure 2. Flow Chart to Determine Worst Performing Line

2.2. Algorithm for weakest line identification

The weakest bus of the system needed to be identified before the weakest line of the system can be selected for observation. The weakest bus is determined by sorting the least maximum loadability of each bus. The steps to determine the weakest bus:

- Increase load at selected bus.
- Execute load flow analysis
- Increase load at selected bus until load flow diverges.
- The load at bus is recorded when the load flow diverged.
- Proceed step i until iv for the next bus.
- Sort the bus with the least maximum bus loadability when all busses are done.
- Determine weakest bus with lowest maximum loadability.

Figure 2 shows the steps in determining the weakest line which will be observed for this study. Load will be increased at the selected load bus gradually and FVSI of each line is determined for each increment. The increment is done until a line’s FVSI reaches above 1. This line is considered as the weakest line in the system during load increment at the selected bus. After determining the weakest line, the optimization is done and the FVSI of the line will be monitored.

2.3. Firefly Algorithm

FA has been founded by Dr. Xin-She Yang at Cambridge University in 2007 [11]. Firefly algorithm is based on fireflies living in nature which usually found in the woods of tropical area. The algorithm will be using the attractiveness of a solution, the same technique used by fireflies in the nature to attract the opposite sex for reproduction [12]. The fireflies are drawn to the more attractive or flashy lights emitted by the others regardless the sex orientation. There are several variables that need to be considered before a firefly can see the lights emitted. The emitted lights will be less attractive due to nature's constraints such as air mist and water contents in the air caused by rain as well as by an increase in distance [12].

The known advantage of FA over the existing classical optimization method is its fast convergence speed [13]. As stated in [14] and [15], it has a better performance compared to other popular optimization algorithms such as particle swarm optimization and artificial bee colony. Firefly algorithm also has other advantages when solving problems; the solution or the attractiveness of the firefly is not gender specific. Attraction level is proportional to the level of brightness while the brightness of the solution is based on the objective function [11]. The optimization process using FA is briefly discussed as in Figure 3 [16].

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1.  Define objective function
2.  Population of firefly initialized, n.
3.  Define light reducing factor and parameters.
4.  while iteration < max iteration
5.      for i = 1 : n
6.          for j = 1 : n
7.              Light brightness determined by objective function
8.              if ( $I_i < I_j$ )
9.                  Firefly i flies towards firefly j
10.                 Attraction changes because of change in distance
11.                 Retrieve solution
12.             else
13.                 Firefly i flies to anywhere
14.             end if
15.         end for j
16.     end for i
17.     Fireflies sorted from best to worst
18. end while

```

Figure 3. Pseudo Code of FA

The attractiveness of a firefly can be defined as in the function below:

$$\beta(j) = \beta_0 \times \exp(-\gamma r_{ij}^2) \quad (8)$$

where $\beta(j)$ is the attractiveness of j^{th} firefly while β_0 is the initial attractiveness of the firefly at distance 0, which carries the value of 1. The absorption coefficient γ with the value of 0.1 and r_{ij} is the distance between i^{th} firefly and j^{th} firefly and it can be expressed as:

$$r_{ij} = |x_i - x_j| \quad (9)$$

From (8) and (9), it shows that the attractiveness of a firefly is depending on the distance between the two fireflies, r_{ij} and the light absorption coefficient, γ . The more attractive j^{th} firefly, will attract the other fireflies or in this case i^{th} firefly to fly towards it. The flight path of the firefly can be shown in the function below:

$$x_i = x_i + \beta_0 \times \exp(-\gamma r_{ij}^2) \times (x_i - x_j) + \alpha \times (\text{rand} - 0.5) \quad (10)$$

From (10), the initial position of the firefly is moved based on the attractiveness of the other firefly and α , is the part where the firefly is moved in a random manner. The α helps the algorithm to search and explore any possible new attraction, meanwhile γ controls the speed of convergence of the algorithm. Coefficient *rand* is a random number in the range 0 up to 1.

3. RESULTS AND ANALYSIS

The results of the study are presented to address the FVSI, bus voltage and the power loss profile of the system before and after the optimization. Figure 4 illustrates the test system which is used in this study. The test system used is IEEE 30-bus system and slight modification has been done where a generator which represents a wind generator is connected at bus 7 of the system. From Table 1, bus 26, bus 30 and bus 29 have the least maximum loadability respectively which can affect the stability of the system. Therefore, this study implements load variation at bus 26. By increasing Q_d at bus 26 with 5 MVA interval; FVSI at the weakest line, bus voltage and loss are observed throughout the process.

Table 1. Three Buses with the Least Maximum Bus Loadability

Bus Number	Maximum Bus Loadability (MVA)
26	33.5
30	35.1
29	38.2

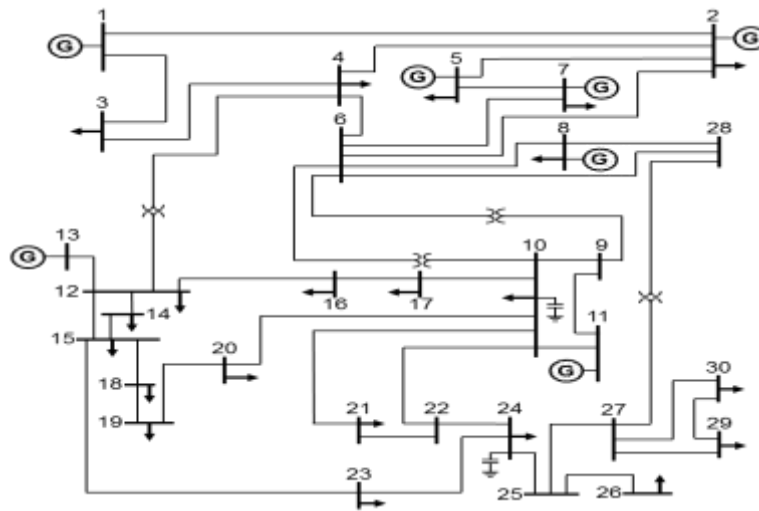


Figure 4: Modified IEEE 30-Bus System with Wind Generator Connected at Bus 7

Figure 5 shows the FVSI ranking of the lines in the power system during load increment at bus 26. The figure shows line 34 which connecting bus 25 and 26 is the weakest line which shows the FVSI of the line reached the value above 1 at 32.4 MVAR. Thus, this study will observe line 34 for the FVSI optimization.

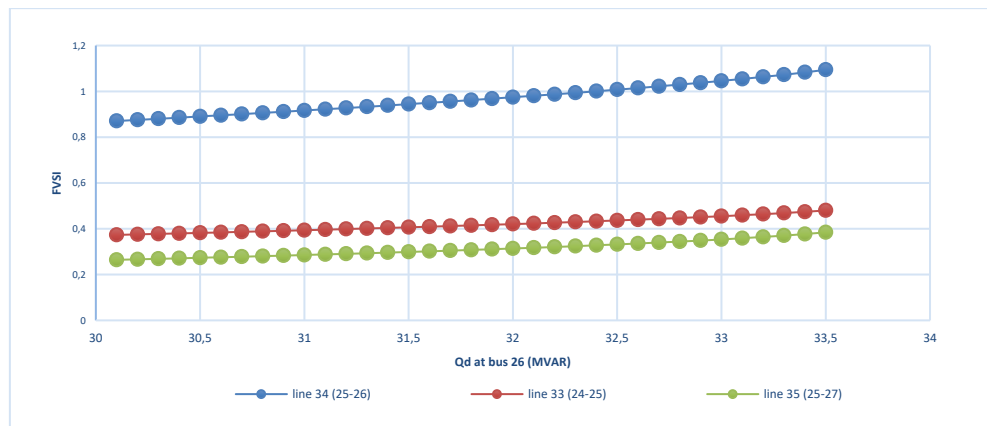


Figure 5: Stability Indices of the Weakest Bus in The System

3.1. FA for voltage stability improvement

FVSI values shows the stability of a power system. Reduced value of the index shows there is an improvement on the stability of the network. Figure 6 and table 2 show the result of FVSI before and after optimization.

From Figure 6, the index value after optimization (FVSI-FA) is reduced slightly when the load is less than 25 MVAR. The improvement of the index only becomes more apparent when the load is increased to more than 25 MVAR. Table 2 tabulates the details of the results, while Figure 6 show the FVSI profile at each variation.

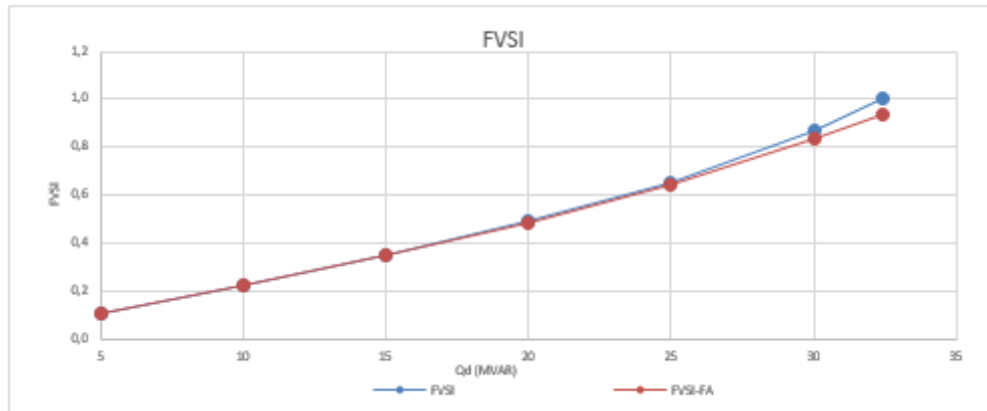


Figure 6: FVSI With and Without Optimization

Table 2. Results of Voltage Stability Improvement

Qd at Bus 26 (MVAR)	Pre-optimized FVSI (p.u)	Post-optimized FVSI (p.u)	Improvement Percentage (%)
5	0.1079	0.1078	0.1
10	0.2248	0.2235	0.6
15	0.3514	0.3492	0.6
20	0.4919	0.4884	0.7
25	0.6529	0.6477	0.8
30	0.8657	0.8433	2.6
32	1.0004	0.9667	3.4

3.2. FA for minimum bus voltage maximisation

Voltage profile of a power system can be used to indicate the health of the system. A healthy power system must maintain acceptable voltage profile to reduce the risk of overloading and system collapse due to low bus voltage. The following figure 7 and table 3 show the minimum voltage profile of the system before and after scheduling optimization.

With FA, the optimized solution managed to improve the voltage profile of the 30-bus system as depicted by Figure 7. The minimum bus voltage of the system was increased after the optimization. The numerical improvements of the minimum bus voltage were tabulated in Table 3. From the table, the minimum bus voltage drops below 0.95 p.u when the load is 10 MVAR. The optimized power scheduling technique had increased the minimum bus voltage to 0.9426 which is close to the acceptable range of bus voltage. The minimum bus voltage improvement only became apparent when the load is more than 30 MVAR.

Table 3: Results of Minimum Bus Voltage Improvement

Qd at Bus 26 (MVAR)	Pre-optimized minimum bus voltage (p.u)	Post-optimized minimum bus voltage (p.u)	Improvement Percentage (%)
5	0.9814	0.9820	0.1
10	0.9395	0.9426	0.3
15	0.8953	0.8987	0.4
20	0.8445	0.8483	0.5
25	0.7831	0.7877	0.6
30	0.6907	0.7065	2.3
32	0.6263	0.6488	3.6

3.3. FA for real power loss minimisation

Apart from the FVSI and voltage profile improvement, the optimized power scheduling technique had also improved the power loss of the transmission line. This effect can be seen from figure 8; the loss after optimization was reduced significantly on all load increment. Power loss is due to heating of the transmission line during power transmission. Reduction of the power loss will improve the efficiency of the transmission system.

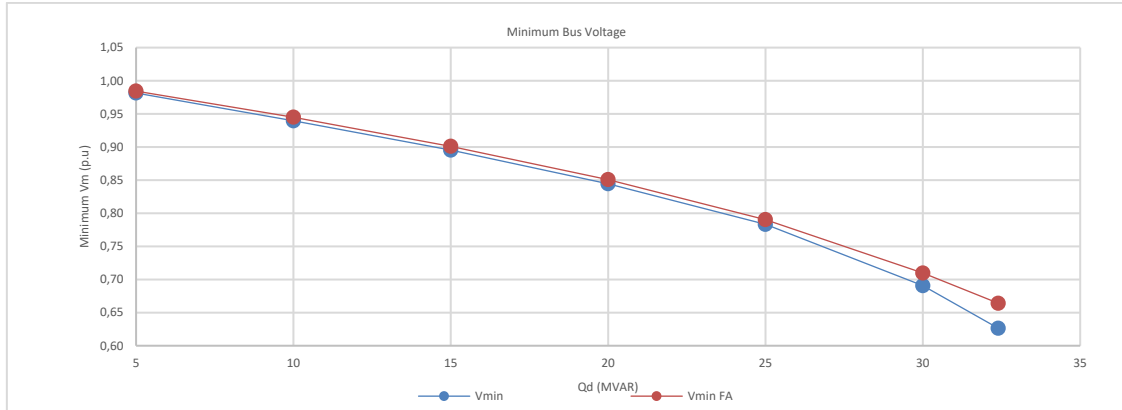


Figure 7: Minimum Bus Voltage With and Without Optimization

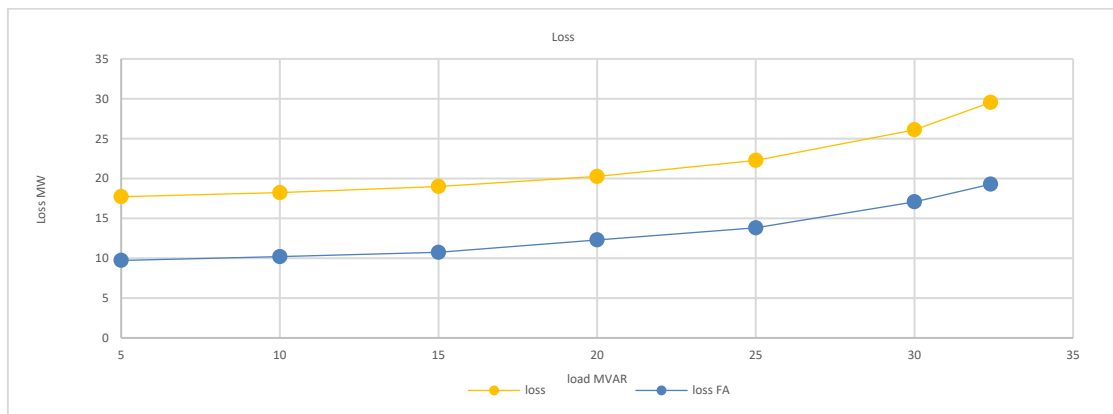


Figure 8: Real Power Loss With and Without Optimization

Table 4. Results of Real Power Loss Minimization

Qd at Bus 26 (MVAR)	Pre-optimized real power loss (MW)	Post-optimized real power loss (MW)	Improvement Percentage (%)
5	17.7175	9.9695	44
10	18.2298	10.5381	42
15	18.9997	11.1260	41
20	20.2516	12.2688	39
25	22.2671	14.1184	37
30	26.1094	17.4722	33
32	29.5444	20.3574	31

Table 4 below shows the loss improvement in percentage. In Table 4, the loss improvement is between 44% and 31%. These improvements show that active and reactive power scheduling optimization in this study gives more effect on reducing the power loss.

4. CONCLUSION

This paper has presented active and reactive power scheduling optimization using firefly algorithm to improve voltage stability considering load demand. The results show that the voltage stability of the system measured by using FVSI method improved after the scheduling technique is optimized using FA. The

optimized scheduling technique also increased the minimum bus voltage and reduced the power system loss, indicating that the performance of the network was improved.

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