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Transmission Loss Minimization Using Artificial Intelligent Algorithm for Nordic44 Network Model based on Hourly Load Variation

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Abstract: Optimal power flow is a nonlinear optimization method to enhance the performance and flexibility of a power system. This paper explores the use of particle swarm optimization (PSO) algorithm as an artificial intelligence technique to solve a single objective function of the optimal power flow problem. The objective function is the minimization of the transmission power losses by keeping the equality and inequality constraints on their secure limits. To test the effectiveness of the proposed method, different scenarios of the Nordic 44 model include maximum import to Norway and maximum export from Norway to the other Nordic networks, as well as hourly load data variations are tested with MATLAB software. The Nordic 44 model is the test system that has been used to analyze stability and control problems that are relevant to the Nordic power network. The test results show the convergence and effectiveness of the proposed method to solve OPF problem compared to Genetic Algorithm (GA) as intelligent method and OPF by MATPOWER as the other classical method to test convergence and effectiveness of the proposed method to solve OPF problem under various load cases (heavy and light loading) of Nordic 44 test system.

Keywords: Optimal Power Flow (OPF), Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Classical method, Minimization Power Losses, Nordic 44 Network Model.

1. INTRODUCTION

Optimization is a nonlinear mathematical formulation and has been used in power system planning and operation to improve flexibility, reliability and security of electrical power networks (Radziukynas.V, 2009). The goal of optimization on electrical power networks is to maximize or minimize objective functions like minimization of generation costs or transmission losses, or to maximize the voltage stability and improvement of voltage profiles (Pandya, 2015). In recent years, OPF has been in the center of attention by many researchers to solve optimization problems on the electrical power network since Carpentier introduced the idea of OPF analysis in 1962 (Deng, 2016). The aim of OPF is to optimize the selected objective functions with satisfying the equality and inequality constraints (Immanuel, 2015). OPF is the part of SCADA (supervisory, control and data acquisition) that has responsibility to remote measurement and control via RTU (remote terminal units) and EMS (energy management system) and it consists of online applications software for power system optimization and control such as LF (load flow), OPF (optimal power flow) and economic dispatch (Momoh, 1997).

Throughout the last two decades, various techniques proposed to find the optimal power flow solutions based on computer programming and mathematical formulations. These techniques introduced based on two categories that classified as conventional and intelligent algorithms. Recently the most significant conventional methodologies, which has been used in many research papers, are included linear programming, nonlinear programming, gradient method, interior point method and quadratic programming (Immanuel, 2015). Conventional methodologies suffer from several disadvantages like slow running, lack of convergence to find global optimum solution and the immense time of mathematical calculation. Therefore, intelligent algorithms developed and applied to solve optimization problems to overcome the drawbacks of classical methods, which have applied to solve OPF problems based on stochastic global search optimization techniques. In most recent research papers, The most prominent intelligent methods to solve the OPF problem are introduced as following genetic algorithm (GA), particle swarm optimization (PSO) algorithm, Imperialist competitive algorithm (ICA) and cuckoo search method (Goyal, 2015). PSO algorithm is one of the A class of metaheuristics algorithms, which introduced based on the search population technique and inspired by the social behavior of a group of animals like bird flocks or fish groups (Sunil Joseph, 2013). PSO algorithm as one of the effective optimization methods has been successfully applied to solve many complex optimization techniques based on population and social group of animals like bird flocking and fish groups, which are nonlinear and multi-model. PSO algorithm has various advantages to solve OPF problems like fast convergence; few control parameters, useful for multi-model space and very easily adaptive for both integer and discrete optimization problems (Gao, 2019).

Recently, in many research papers various methodologies proposed to solve optimal power flow problems with considering single objective function and multi-objective functions as following;

In [8] S.Pandya has tried to show the effectiveness of the PSO algorithm as an intelligent method to solve optimal reactive power dispatch by considering different objective functions including minimization the power losses, improvement the voltage profile and improvement the voltage stability. This algorithm has been tested to solve OPF problems on various IEEE test networks. The obtained simulation results compared with the other methods to prove the effectiveness of the proposed algorithm (Pandya, 2015).
In [1] Z.Deng has stated two classification of intelligent algorithms such as Genetic algorithm and particle swarm optimization (PSO) algorithm to solve multi-objective function of optimal power flow problems. The objective functions are minimizing the cost, power losses and voltage deviation while adjusting equality and non-equality constraints. The algorithms are applied on IEEE 30 bus system and the results of simulation are compared with the other optimization methods (Deng, 2016).
In 2018, Akelifi evaluated the performance of hybrid particle swarm optimization algorithm and Moth flame optimizer (PSO-MFO) algorithm to solve OPF problem with considering equality and inequality constraints. The proposed method tested on several IEEE networks including IEEE 30 and 57 Bus network. The simulation results illustrate the effectiveness of the proposed method to optimize the control variables and results compare the good convergence of hybrid PSO-MFO with the original PSO and MFO methodologies. The objective functions are minimization the fuel cost, improvement the voltage stability and minimization the transmission losses.
M.A. Abido proposed PSO algorithm to optimize OPF control variables, which tested on IEEE 30 network. Several objective functions considered to solve OPF problems including the minimization the fuel cost, Improvement the voltage stability and voltage profile. The simulation results concluded the effectiveness and robustness of proposed method to solve OPF problem.
J.Radosavljević suggested two artificial intelligent method including the new particle swarm optimization (PSO) and the gravitational search algorithm (GSA) for solving OPF problems. Several objective functions that included to solve OPF problem are; minimization the fuel cost and improvement the voltage profile. The proposed algorithm (PSOGSA) illustrates the robustness and high quality solutions for solving OPF problems.

In present paper, the OPF problem has been solved using particle swarm optimization (PSO) algorithm as one prominent artificial intelligent method and Newton Raphson as conventional method under hourly load variation during 2018 year. The effectiveness of the proposed algorithm is tested on the Nordic 44 test model, which is relevant for Nordic power grid and has been used to analyze stability and control problems. In order to comprehensive evaluation of OPF analysis in day to day planning of power systems, a number of Scenarios is extracted from Nordpool market database to be analyzed by Nordic 44 power system model. The purpose of this paper is to prove the proposed method to minimize the transmission power losses by analysis two Scenarios of Nordic power system included Maximum export from Norway (23. Jan. 2018, 00:00 – 01:00) and Maximum import to Norway (25. Des. 2018, 15:00 – 16:00) based on every hour of the 2018 year. These extracted data represent power flow for each of 8760 hours in 2018 for generation, consumption and exchange between countries in Scandinavia and from the Nordic power system to outside systems.

In addition, this paper compares proposed algorithms including Particle swarm optimization algorithm (PSO), Genetic Algorithm (GA) as artificial intelligent algorithms and interior point method (IPM) of MATPOWER as a classical technique to solve OPF problem. The solution results presented the convergence and robustness of PSO algorithm compared to the other methodologies to solve OPF problem due to easy to apply, fewer control variables and lower time of convergence to global optimal solution for two Scenarios of Nordic 44 power system model.

This paper organized as follows; Section 2 describes an overview of the optimal power flow problem and different types of objective functions and the equality and inequality system constraints and the description of penalty function. Section 3 presents the concept of the particle swarm optimization (PSO) algorithm and the application of PSO into optimal power flow problem is discussed. Section 4 presented the simulation results to analysis the performance of PSO algorithm compared to the other methodologies like Genetic algorithm and IPM method that it is tested on several scenarios of Nordic 44 model including Max import to / max export from Norway to the other European networks. Finally, the conclusion is drawn in the Section 5.

2. PROBLEM FORMULATION

Nowadays, OPF problems have the vital role to improve the grid flexibility, economic efficiency and secure operation of power network as well as has an efficient tool for planning and operation of future power systems (Immanuel, 2015). OPF is the nonlinear mathematical formulation for solving nonlinear optimization problems that consists of nonlinear objective function while satisfying security and operation of nonlinear constraints (Sunil Joseph, 2013). In mathematical concept, the goal of OPF is minimizing a specified objective function by optimizing the set of control variables, while satisfying both equality and non-equality constraints. The formulation of objective functions based on the number and nature of objectives can be devided in two main groups including single objective function and multi-objective function (Sharma, 2014). A single objective function is a problem where only one objective function can be optimized such as minimization of power losses, while multi-objective optimal power flow introduced as the group of objective functions to achieve a reasonable solution between different

objectives including power losses, voltage stability and reduction of the cost of generators. One of the noticeable differences between single and multi-objective functions is the trade-off between different the objectives since some of them are conflict together that with maximize one objective can be caused to minimize the other objective functions. The goal of multi-objective function is to find the set of optimal trade off solutions that is as close as optimal solutions. Researchers have studied about main challenges of multi-objective optimization based on different perspectives including; quality solutions, generation of Pareto optimal set solutions, find the single solution that provides the satisfaction for different objectives, selection the best solution from the Pareto set, etc (Sharma, 2014).
The mathematical formulation of single objective function can be formulated as below:

Objective function	f(x,u)	(1)
Equality constraints	g(x,u)=0	(2)
Inequality constraints	h(x,u)≤0	(3)

Where f(x,u) is the objective function that can be optimized using several methodologies, g(x,u) is equality constraints that referred to power flow equations while h(x,u) is inequality constraint of power system operation (Sharma, 2014).

In addition, U represents the vector of independent control variables including active power of generators expect slack bus, the magnitude of generators bus Voltage, tap setting of transformers and reactive power of compensations (Khunkitti, 2019). The vector of u can be expressed as follows;

$$u^T = [P_{G2}, \dots, P_{GN}, V_{G1}, \dots, V_{GN}, T_1, \dots, T_N, Q_{C1}, \dots, Q_{CN}] \quad (4)$$

Also, x is the vector of dependent variables including active power of slack bus, reactive power of the generator, voltage for load buses and line flows (Khunkitti, 2019). The vector for x can be mentioned as below;

$$x^T = [P_{G1}, V_{l1}, \dots, V_{lN}, Q_{g1}, \dots, Q_{gN}, S_{l1}, \dots, S_{lN}] \quad (5)$$

Where n represents the number of units.

The standard mathematical formulation of multi-objective functions for solving OPF problem with satisfying equality and inequality constraints can be expressed as follows (Sharma, 2014);

Min\Max	$f(x)=\{f_1(x,u), f_2(x,u), \dots, f_n(x,u)\}$	(6)
Subjected to	g(x,u)≤0	(7)
	H(x,u)=0	(8)

Where $f_1, f_2, \cdots, f_n$ are objective functions and g(x,u) and h(x,u) are identified as the equality and inequality constraints respectively.

2.1 Objective Function

In this paper, the aim of the proposed objective function is to minimize the total transmission power losses that can be formulated as the single objective function as follows (Deng, 2016);

$$f(x) = min(P_l) = \sum_{k=1}^{N} g_k\left(V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right) \quad (9)$$

Where P_l is the active power loss, g_k is referred to conductance of the line connected between bus I and j; V_i and V_j are voltage magnitude at bus I and j respectively; δ_i and δ_j are angle phases of voltages at bus I and j, respectively.

2.2 Constraints

The constraints of the OPF problem can be classified as equality and inequality constraints as follows (Deng, 2016);

a) Equality Constraints

The equality constraints of OPF problems are the set of power flow formulations that can be solved by Newton Raphson method, which is represented by the power flow equations as follows (Deng, 2016);

$$P_{G,i} - P_{D,i} - \sum_{j=1}^{N_B}|V_i||V_j||Y_{i,j}|cos(\theta_{i,j} - \delta_i + \delta_j) = 0 \quad (10)$$

$$Q_{G,i} - Q_{D,i} - \sum_{j=1}^{N_B}|V_i||V_j||Y_{i,j}|sin(\theta_{i,j} - \delta_i + \delta_j) = 0 \quad (11)$$

Where P_{Gi} and Q_{Gi} are the active and reactive power of generators respectively. P_{Di}, Q_{Di} are the active and reactive power of load buses. Vi and Vj are the voltage magnitude at the bus I and j, respectively. δi, δj are the voltage phase angle at the bus I and j, respectively.

b) Inequality Constraints

The inequality constraints relate to voltage magnitude (V) and tap setting of transformers (Tap), reactive power of shunt capacitors (Q_c) and generator active power (P_G) on their secure boundaries. In this paper, Voltage of generators and tap setting of transformers are defined as the constrains of the Nordic 44 test network that are expressed as formulations 12 and 13 respectively and all active power load, exchange and generation are fixed values due to Marketing reason and will not be altered through the analysis.

$$V_{Gimin} \le V_{Gi} \le V_{Gimax} \qquad i = 1, \dots\dots, N \quad (12)$$

$$T_{imin} \le T_i \le T_{imax} \qquad i = 1, \dots\dots, N \quad (13)$$

2.3 Penalty Function

In this paper, the penalty function selected based on constraint handling mechanisms that can convert the infeasible solutions to the feasible regions in a search space, for nature-inspired algorithms like the PSO algorithm. Therefore, the penalty function can modify the objective functions based on the handling constraints method to reach feasible solutions that it adjusted the control variables in their limitations including, lower and upper bounds of voltage

magnitude, tap of transformers and reactive power of shunt capacitors (Mezura-Montes, 2011).
Therefore, the mathematical programming that used for unconstrained numerical optimization problems in their suitable limitations is called penalty function. The general formulation of penalty function can be considered as follows (Mezura-Montes, 2011):

$$\emptyset(\vec{x}) = f(\vec{x}) + p(\vec{x}) \quad (14)$$

Where;

$f(\vec{x})$ is previous objective function.
$p(\vec{x})$ is penalty function.
$\emptyset(\vec{x})$ is optimized objective function.

The equation (15) shows the penalty function can be added to the objective function (Mezura-Montes, 2011).

$$p(\vec{x}) = \sum_{i=1}^{m} r_i . max\left(0, g_i(\vec{x})\right)^2 + \sum_{j=1}^{p} c_j . \left|h_j(\vec{x})\right| \quad (15)$$

In this formulation, r_i and c_j are mentioned as penalty factors. According to the equation (14), the penalty function can be added to the objective functions, in order to reach the feasible solution and minimize the problem of constraints handling techniques (Mezura-Montes, 2011).

3. PARTICLE SWARM INTELLIGENT ALGORITHM (PSO)

Particle swarm optimization (PSO) algorithm is a population based artificial intelligent method to solve optimization problems. PSO algorithm introduced by Kennedy and Eberhart in 1995, which inspired from social behavior of bird flocking or fish grouping. PSO algorithm is based on movement of individuals in one search space to find optimal solution by updating generations in each iteration. In PSO, Each single solution is referred to particle and the collection of particles called the swarm that flown through on search space to find optimal solution. Location of each particle in search space influenced from the experience and knowledge of themselves and their neighbors (Pandya, 2015). In every iteration, each particles follow two best that all particles have memory of best experience (fitness value) that called Pbest while best value in the swarm called global best (Gbest). The advantages of PSO algorithm is fast convergence and have few control parameters to adjust and simple to implement (Pandya, 2015). The mathematical diagram of the movement of each particle in search space is illustrates as Figure1.

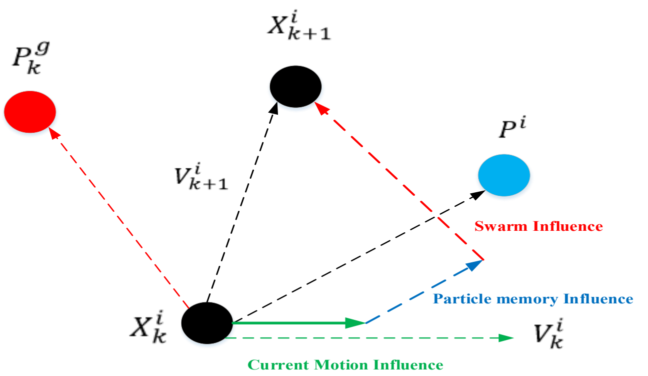

Fig. 1. The velocity and position update for each particle.

In each iteration, particles update their position based on previous location, velocity vector and best personal experience and global best experience to find new generation. Therefore, the algorithm updates the velocity and position based on formulations 16 (Pandya, 2015).

$$V_j^{k+1} = W \times V_j + C_1 \times rand_1 \times (P_{best} - X_j^k) + C_2 \times rand_2 \times (G_{best} - X_j^k) \quad (16)$$

$$X_j^{k+1} = X_j^k + V_j^{k+1}.$$

In this algorithm, the basic parameters of PSO algorithm can be described as follows (Smita, 2012):

- **Particle position, X_j^k :**

  The location of each individual (J) at each iteration of k represented the candidate solutions in search space. (Smita, 2012)

- **Particle velocity, V_j^k:**

  The velocity for moving of each particle represented by D-dimensional vector as $V_j^k = V_1^1, V_2^1, V_3^1, \dots, V_j^1$ (Smita, 2012).

- **Personal best experience, P_best:**

  The fitness value of each particle at current position compared with previous fitness values. The best one selected as the personal best value (Pbest) for each iteration (Smita, 2012).

- **Global best experience; Q_best:**

  The best position achieved up to now among all Pbest is called global bet experience (G_best) (Smita, 2012).

- **Velocity updated:**

  In each iteration, the velocity can be updated based on the personal best experience and global best experience that is expressed in the equation 16. (Smita, 2012).

- **Position updated:**

  According to the updated velocity, the position for each particle can be changed to find the new generation of PSO algorithm based on equation 16 (Smita, 2012).

- **Inertia Weight Creteria:**

  Inertia weight is calculated as stopping condition to reach the better exploration of search space such as follows:

$$W = W_{max} - \frac{(W_{max} - W_{min})}{iter_{max}} * iter \quad (17)$$

Where; W_{max} is the maximum value of weighting factor and W_{min} is the minimum value of weighting factor and Iter max is the maximum number of iteration and Iter is called as current number of iteration.

The proposed algorithm provides convergence and robustness of optimal solutions for solving the given OPF problems. The steps of implementation PSO algorithm for OPF can be expressed as following:

Step 1) Initialize the input variables between Lower bound and Upper bound.
Step 2) Generate a random population of particles.
Step 3) Employ Newton Raphson for each particle to calculate state variables and power losses.
Step 4) Calculate Fitness function based on penalty function.
Step 5) Compare the fitness function for each particle in each iteration and identified Pbest and Gbest that in the first step are equal together.
Step 6) Iteration is updated (t=t+1).
Step 7) Update the velocity and position vector to generate next iteration based on formulation 16.
Step 8) Stop criteria (such as max iteration). If satisfied go to the next step otherwise go to step 6.
Step 9) The lowest fitness function among all iterations identified as the Global best experience (Gbest) as the optimal solution.

4. SIMULATION RESULTS

In order to verify the effectiveness of the proposed method compared to the other artificial intelligent algorithm and classical method, two scenarios of Nordic 44 model are tested with MATLAB simulation environment to optimize the objective function. The Nordic 44 power system is a test system that relevant for the Nordic power network, which has been used to analyze stability and control problems. This network is a comprehensive simplification of the real power network. In Nordic power system, inside generations higher or lower than total loads due to DC connections to the other synchronism systems.

In order to comprehensive evaluation of OPF analysis in day to day planning of power systems, a number of Scenarios is extracted from Nordpool market database to be analyzed by Nordic 44 power system model. The purpose of this paper is to analysis two Scenarios of Nordic power system included Maximum export from Norway (23. Jan. 2018, 00:00 – 01:00) and Maximum import to Norway (25. Des. 2018, 15:00 – 16:00) based on every hour in 2018 year. The pre-processed data was monitored from Statnett in the period of year from 01.01.2018 to 31.12.2018 that represented the power flow for each of 8760 hours in 2018 for generation, consumption and exchange between countries in Scandinavia and from the Nordic power system to outside systems, which is represented in Figure 2. These two Scenarios of 8760 hours for 2018 are sorted out by criteria total export (negative power flow) / import (positive power flow) from / to Norway; sum for Russia (AC), Finland (AC), Sweden (AC), Denmark West (DC) and the Netherlands (DC).

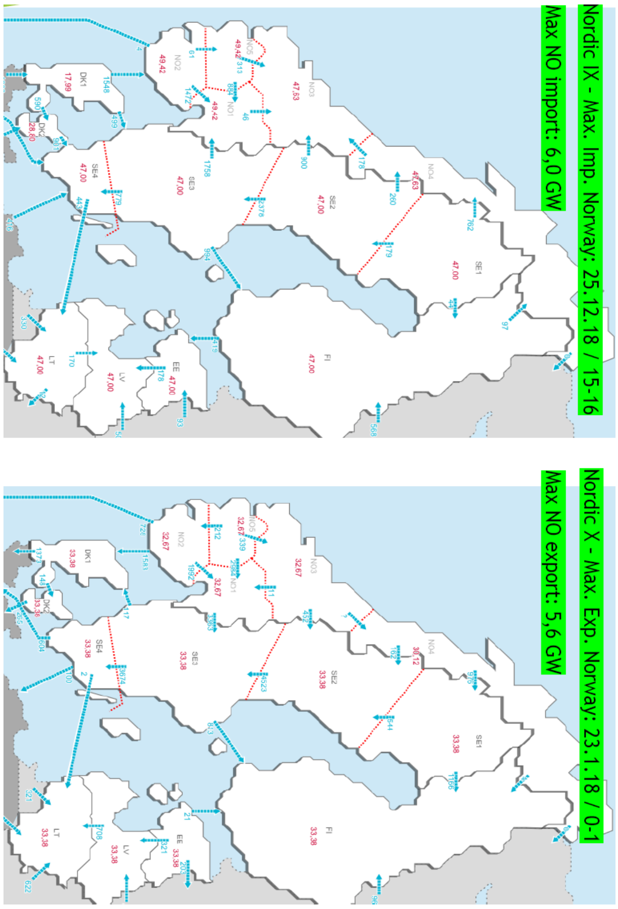

Fig. 2. Max Import to / export from Norway to the other Power network (ref. www.statnett.no).

4.1 Case 1- Max import to Norway

In this case, OPF problem is solved using PSO algorithm as intelligent method under hourly load variation based on max import of generations and loads to Norway. In this paper, the minimization of power losses as single objective function of OPF problem can be solved using Newton Raphson as conventional method and PSO algorithm as artificial method with adjusting set of equality and inequality constraints. The parameters setting of PSO algorithm are expressed in Table1.

Table 1. PSO parameters

Algorithm	nPop	W1-w2	C1-c2	Max Iter
PSO	100	0.999	2-2	200

Nordic 44 test network consists of 18 generators, 44 buses and 79 branches that extended throughout Norway, Finland, Sweden and Denmark that this system contains 30 control variables included 18 voltage buses and 12 tap of transformers. Table 2 compares the different values of control variables before and after optimization using PSO algorithm

Table 2. Values of control variables before and after optimization for case 1.

Variables	Bus Number	Before PSO	With PSO
V_1	1	1.038	1.0592
V_4	4	1.051	1.0715
V_7	7	1.059	1.0816
V_8	8	1.051	1.0549
V_9	9	1.039	1.0526
V_{10}	10	1.041	1.0497
V_{13}	13	1.030	1.0320
V_{17}	17	1.055	1.0729
V_{21}	21	1.057	1.0792
V_{24}	24	0.994	1.0176
V_{26}	26	1.054	1.0706
V_{32}	32	1.053	1.0737
V_{34}	34	1.065	1.0788
V_{35}	35	0.990	1.0176
V_{36}	36	1.062	1.0585
V_{38}	38	1.053	1.0744
V_{41}	41	1.046	1.0589
V_{42}	42	1.026	1.0383
T_1	6~7	1	0.9750
T_2	10~11	1	0.9795
T_3	12~8	1	1.0043
T_4	14~13	1	1.0482
T_5	17~18	1	1.0163
T_6	21~22	1	0.9700
T_7	21~23	1	0.9831
T_8	24~25	1	0.9456
T_9	27~33	1	0.9894
T_{10}	29~28	1	0.9707
T_{11}	32~33	1	0.9821
T_{12}	36~37	1	0.9758
Ploss (MW)		221.51	210.82

Figure 3 shows the simulation result of MATLAB software for reduction the power losses with PSO algorithm for Max import to Norway based on hourly load variation for year 2018. According to the simulation results, the total power losses for Max import to Norway reduced to 210.82 MW.

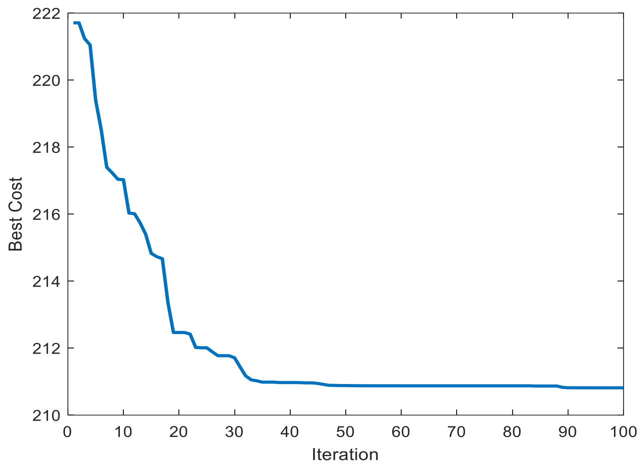

Fig. 3. Minimization of real power losses for max import to Norway network.

In order to test the convergence of this methodology to reach the global optimum with proposed method, different initial values of control variables including voltages and transformers tap setting compared with feasible solution of OPF in PSO algorithm that illustrates in Table 3.

Table 3. PSO results for different initial values of Max import to Norway

Vg		Tap setting		Ploss (MW)
Min	Max	Min	Max	
OPF (IPM) with PSO		1	1	208.33
0.6	1	1	1	209.68
1	1	1	1	207.51
0.5	1.1	1	1	208.61
0.9	1.1	0.9	1.1	206.74
0.8	1.0	0.9	1.1	208.47

To show effectiveness of the proposed method to solve single objective function of OPF problem, PSO algorithm is compared with Genetic algorithm as intelligent method and with the MATPOWER Interior point method (IPM) as classical method. Table 4 presents the comparison of minimization the power losses with proposed methods and time of convergence to obtain global optimal solution. In addition, Table 5 shows the effectiveness of changing PSO parameters to solve OPF problem (Min the power losses). The results show that PSO algorithm gives much better results than the other intelligent and classical method.

Table 4. Comparison of results from PSO and the other methods for case 1.

Proposed methods	Ploss	Time (Second)
PSO algorithm	210.82	43.75
GA algorithm	211.49	84.76
IPM algorithm	220.82	248.47

Table 5. Effective of changing parameters of PSO algorithm for optimal solution of case 1.

MaxIter	nPop	Ploss (MW)
200	100	207.01
200	200	208.70
100	100	209.33
50	50	214.86
100	50	213.53
50	100	209.66

With comparison the effectiveness of changing parameters in PSO algorithm, it can be resulted that the power losses can be reduced more with increasing the number of population and iteration.

4.2 Case 2- Max export from Norway

In this case, the usefulness of PSO algorithm for minimizing the transmission power losses is tested for max export from Norway to the other synchronism networks. Table 6 illustrates the differential of control variables before and after implementation of the PSO algorithm and Figure 4 shows the reduction of power losses using PSO method. The simulation results illustrate the minimization of the power losses after using PSO algorithm for case 2 (Max export from Norway) of Nordic 44 model that decreased to 480.38 MW.

Table 6. Values of control variables before and after optimization for case 2.

Variables	Bus Number	Before PSO	With PSO
V_1	1	1.027	1.0547
V_4	4	1.038	1.0492
V_7	7	1.056	1.0776
V_8	8	1.028	1.0459
V_9	9	1.042	1.0633
V_{10}	10	1.033	1.0704
V_{13}	13	0.967	0.9953
V_{17}	17	1.059	1.1000
V_{21}	21	1.030	1.0688
V_{24}	24	0.942	1.0041
V_{26}	26	1.051	1.1000
V_{32}	32	1.055	1.0998
V_{34}	34	1.057	1.1000
V_{35}	35	1.043	1.0547
V_{36}	36	1.062	1.1000
V_{38}	38	1.034	1.0403
V_{41}	41	1.022	1.0359
V_{42}	42	1.020	1.0195
T_1	6~7	1	1.0068
T_2	10~11	1	1.0068
T_3	12~8	1	1.0610
T_4	14~13	1	1.0970
T_5	17~18	1	1.0020
T_6	21~22	1	0.9506
T_7	21~23	1	0.9898
T_8	24~25	1	0.9459
T_9	27~33	1	0.9748
T_{10}	29~28	1	1.0587
T_{11}	32~33	1	0.9898
T_{12}	36~37	1	1.0510
Ploss (MW)		535.59	479.53

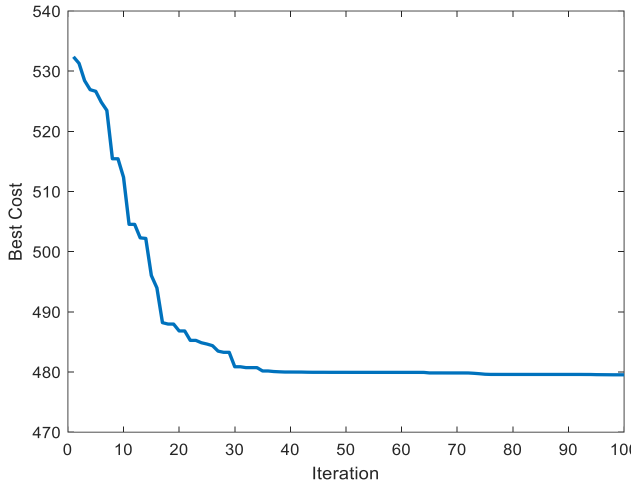

Fig. 4. Minimization of real power losses for Max export from Norway.

To test the convergence and robustness of PSO algorithm to reach the optimal solution, different initial values of control variables and OPF of MATPOWER box are presented in Table 7. According to the results, IPM from MATPOWER has the better results for feasible solution compared to the other states.

Table 7. PSO results for different initial values of Max export from Norway

Voltages		Tap setting		Ploss (MW)
Min	Max	Min	Max	
IPM with PSO		1	1	475.57
0.6	1	1	1	479.22
	1	1	1	474.65
0.5	1.1	1	1	475.35
0.9	1.1	0.9	1.1	482.32
0.8	1.0	0.9	1.1	478.60

The effectiveness of changing parameters of PSO algorithm is shown in Table 8. According to the results, by increasing the number of iterations and population in PSO algorithm the more reduction of power losses can be concluded. Table 9 shows the comparison of proposed method with the other methodologies include genetic algorithm (GA) as intelligent method and IPM of MATHPOWER for OPF analysis as classical technique.

Table 8. Effective of changing parameters of PSO algorithm for optimal solution of case 2.

Maxiter	nPop	Ploss (MW)
100	200	484.80
100	100	490.06
100	50	503.65
50	100	510.79
50	50	509.16

Table 9. Comparison of results from PSO and the other methods for case 2.

Proposed methods	Ploss	Time (Seconds)
PSO algorithm	479.53	57.75
GA algorithm	483.47	76.654
IPM algorithm	546.38	148.51

It can be concluded that PSO algorithm has the significant advantages compared the other classical and intelligent methodologies to provide optimal solution with high computational accuracy and lesser time of calculation.

For this optimization of transmission losses, the reduction of necessary generation will by this approach reduce slack bus generation, which is located at one of the big nuclear plants in southern Sweden for Nordic 44 model. Aaccording to the Nord pool database, the number of Slack bus for Nordic 44 test network is as Bus.no 3359 that Slack bus introduced a bus with a large real and reactive power output.

5. CONCLUSION

In this paper, particle swarm optimization (PSO) algorithm as the intelligent method has been tested to solve the OPF problem with optimizing the objective function on the Nordic 44 test system based on hourly load variation of total generation and consumption. The objective function is minimization of power losses and control variables are voltage magnitudes and tap setting of transformers between lower and upper bound of their restrictions and Penalty function is added to the objective function for checking the control variables on their secure limitations.

In this paper, the usefulness and effectiveness of the proposed method are analysed two Scenarios of Nordic power system included Maximum export from Norway (23. Jan. 2018, 00:00 – 01:00) and Maximum import to Norway (25. Des. 2018, 15:00 – 16:00) based on every hour of 8760 hours extracted from Nordpool market database in 2018 year for generation, consumption and exchange between countries in Scandinavia and from the Nordic power system to outside systems.

The results presented PSO algorithm is superior in finding an optimal solutions compared to other methodologies like genetic algorithm as an intelligent method and IPM of MATPOWER as a classical method. However, there are many similarities between PSO algorithm and Genetic algorithm to solve optimization problems in the sense that population search space, the performance of two algorithms are differed based on the information-sharing mechanism. GA shares information with each other and then population as one group moves toward to find the optimal solution, while PSO algorithm has not any crossover and mutation and only Gbest shares information to others. The results show the significant advantages of PSO algorithm over the other methodologies by giving the high accuracy, lesser time of convergence to optimal solution, simplicity of implementation and fewer control variables to adjust. In addition, obtained results presented the usefulness and effectiveness of the proposed method to solve OPF problem for large-scale networks like Nordic 44 model under different load variations compared to the other methods.

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