Power System State Estimation using Particle Swarm Optimization

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Abstract — State estimation is the operation of assigning a value to an unspecified system state variable based on calculation from that system. In general, the process involves faulty calculation that are unnecessary. In a power system, the state variables are the voltage magnitudes and relative phase angles at the system nodes. calculation are necessary in order to evaluate the system performance in actual time for both system security control and restriction on expedite economic reform. In the past, some traditional conclusion , based on gradient approach, have been used for this persistence. This paper agitate the implementation of an artificial intelligence (AI) algorithm, the particle swarm optimization (PSO), to resolve the state estimation issue with in a power system. Two objective functions are formulated: the weighted least square (WLS) and weighted least absolute value (WLAV). The functionality of PSO over newton state estimation technique (NSE) is exposed by comparing both two solutions to the true state variable values obtain using Newton–Raphson (NR) algorithm.

Keywords — Formulation , Technique Solution , Applications of PSO in Power Systems , Hybrid Particle Swarm Optimization

- **Introduction** — Power industry is expanding rapidly in most of the countries over the world. The deregulation of power market with transmission open access has been successfully implemented in some countries. This deregulation of the electric power industry has introduced new possibilities for market participants in an efficient and secure environment. It is well understood that an electric power system can be operated in efficient, economic and secure manner, if it's states are known at present time.

It is significant for the energy management system (EMS) applications in a power system control center that the measurements permit monitoring of this power system. With the rising interest in integration of more distributed generations (DGs) to the power system, the EMS center necessities to have real-time and exact estimate values of loads, voltage magnitudes, generator and DGs power outputs, etc. requisite for a good management and planning of the network. This is only possible if all state variables (voltage magnitudes and angles at all bus) of the power system are well-known. On the other hand, only few measurements which usually contain errors are available at this center. State estimation is an significant tool for EMS, which makes it possible to estimate the state variables of the power system based on the incomplete measurements. State estimation processes fit measurements made on the system to a mathematical model in order to deliver a reliable database for other monitoring, security assessment and control functions. Abundant research has been done on state estimation techniques, and online estate estimators are being applied in many power network. In the application of state estimation, attention must be given to a number of practical problems. Telemetered values are subject to random noise and also to gross errors associated with equipment failure. To solve the power system state estimation (PSSE) problem, several authors have used outdated methods based on derivative method such as Newton, Gradient descent, linear programming methods, etc. However, it has been shown that these traditional methods have some insufficiencies. The Newton and Gradient methods both suffer from the difficulty in handling inequality constraints. On the other hand, the linear programming method suffers from oscillation and slow convergence difficulties when the iterative step is not selected correctly during the linearization of both objective and constraint functions.

Artificial intelligence (AI) algorithms are considered as a influential tool in solving nonlinear and complicated search space. The advantage of AI algorithms is due to the fact that they only need the fitness function (objective function) to guide the search, unlike the traditional algorithms which need gradient (derivative) information. One of AI algorithms is the particle swarm optimization (PSO) which has many advantages over other AI algorithms such as genetic algorithm (GA). PSO permits lower computational time and memory compared with GA, and can be effortlessly programmed with basic mathematical and logic operation. It also needs less parameter tuning. With this in mind, this paper takes over the advantages of PSO in solving PSSE problem. The corruption of telemetered raw data measurements is simulated by presenting statistically a random error in the measurements acquired after running Newton–Raphson (NR) load flow algorithm. The solutions acquired from load flow (before introducing errors) are therefore considered as true solutions and used as point of reference solutions in estimating the effectiveness of PSO solutions. Two approaches in solving state estimation problem, the weighted least square and weighted least absolute value, are used. MATLAB is used for simulation.

- **Formulation :** Objective functions are calculated by two methods: WLS and WLAV.

Weighted least square (WLS)

The objective function j(x) to be reduce to find the state variable vector x.

$$j(x) = \sum_{i=0}^{Nm}[Z - f_i(x)^2] \Big/ \sigma_i^2 \qquad \text{...... Eq (1)}$$

Where,

σ_i = variance of ith measurement;

I = 1,2,3,…., N_m;

N_m = number of measurements;

Z_i = ith measurement;

$f_i(x)$ = nonlinear function relating state variables with measurements

- **weighted least absolute value (WLAV)**

$$J(x) = \sum_{i=1}^{Nm} w_i \, |z_i - f_i(x)| \qquad \text{. . . Eq (2)}$$

Where,

W_i = weight of the measurement I ;

Nonlinear functions $f_i(x)$ are the active and reactive power injections at all buses, active and reactive power flows at all buses, and voltage magnitudes at some buses. The active and reactive power injections are given below:

$$P_i = v_i \sum_{j=1}^{Nb} v_j \, |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \qquad \text{. . . Eq (3)}$$

$$Q_i = v_i \sum_{j=1}^{Nb} v_j \, |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \qquad \text{. . . Eq (4)}$$

Where,

P_i is the active power injection at bus i ;

Q_i is the reactive power injection at bus i ;

V_i and V_j are voltage magnitude at bus i and j;

δ_i and δ_j are voltage angles at bus i and j ;

$|Y_{ij}|$ is the magnitude of bus-admittance element I , j and θ_{ij} its angle;

NB is the number of buses.

Constraints

These are the limits on the state variables (voltage magnitudes and voltage angles) at each bus:

$$V_i^{min} \leq V_i \leq V_i^{max} \qquad \text{... Eq (5)}$$

$$\delta_i^{min} \leq \delta_i \leq \delta_i^{max} \qquad \text{... Eq (6)}$$

TECHNIQUE SOLUTION

For operating restriction , exterior sanction function method is used to convert constrained minimization problem in to unconstrained minimization problem.

$$F(x) = J(x) + p(x) \quad \text{... Eq (7)}$$

Where,

F(x) is the particle fitness function;

J(x) is the objective function;

P(x) is the sanction term constraining all the state variables within their respective limits.

Particle Swarm Optimization (PSO):

Different form of the PSO algorithm were suggested but the most worth one is introduced by Shi and Eberhart . Key enchanting feature of PSO is its simpleness as it involves only two model equations. In PSO, the coordinates of each particle appear for a possible solution associated with two vectors, the position (x_i) and velocity (v_i) vectors. The size of vectors x_i and v_i is equal to the problem space dimension. A swarm contain number of particles "or possible solutions" that get going through the feasible solution space to explore optimal solutions. Each particle modernize its position based on its own best research, best swarm overall experience, and its previous velocity vector according to the following model

$$V_i^{k+1} = wv_i^k + c_1r_1(pbest_i - x_i^k) + c_2r_2(gbest_i - x_i^k) \text{ .....1}$$

$X_i^{k+1} = x_i^k + V_i^{k+1}$ 2

where

c1 and c2 are two positive constants;

r1 and r2 are two randomly generated numbers with a range of [0,1];

w is the inertia weight;

$pbest_i$ is the best position particle i achieved based on its own research; and

$gbest_i$ is the best particle position based on overall swarm research.

❖ PSO is a population-based evolutionary technique that has many key advantages over other optimization techniques like:

• It is a derivative-free algorithm different from many other conventional techniques.

• It has the flexibility to be integrated with other optimization techniques to form a hybrid tool.

• It is less sensitive to the nature of the objective function, i.e., convexity or continuity.

• It has less parameters to adjust unlike many other competing evolutionary techniques.

• It has the ability to escape local minima.

• It is easy to implement and program with basic mathematical and logic operations.

• It can handle objective functions with stochastic nature.

• It does not require a good initial solution to start its iteration process.

❖ The PSO algorithm can be best described in general as follows:

1) Each and every particle of the position and velocity vectors will be randomly initialized with the same size as the problem dimension.

2) Calculate the fitness of each particle (pbest) and reserve the particle with the best fitness (gbest) value.

3) Modernize velocity and position vectors according to equation (1) and (2) for each and every particle.

4) Repeat steps 1–3 until a conclusion point of reference is satisfied.

Applications of PSO in Power Systems

Research in power system has its share in applying PSO to various optimization problems. It clearly indicates its applicability and the fast growing interest in PSO utilization in the research area.

❖ The major areas in which PSO was applied:

➢ Economic Dispatch

The objective function was formulated as a combination of piecewise quadratic cost functions instead of having a single convex function for each generating unit. This difference in the problem formulation is due to the incorporation of practical operating conditions like valve-point effects and fuel types. The system constraints included in were system demand balance with network losses incorporated and the generating capacity limits.

They utilized PSO in solving a multi objective optimization problem that includes both cost and emission functions. They combined the two objective functions by assigning a single price penalty factor to the emission function to form a single objective function.

- **Reactive Power Control and Power Losses Reduction**

In this area, PSO was used to optimize the reactive power flow in the power system network to minimize real power system losses. The control variables are automatic voltage regulator operating values, transformer tap positions, and a number of reactive power compensation equipment subject to equality and inequality constraints. They also introduced generator real power outputs as additional control variables. The difference in their problem formulation was mainly due to the inclusion of wind farms as modern integral parts of the power system networks.

- **Optimal Power Flow (OPF)**

Abido is credited with introducing PSO to solve the OPF problem . In OPF, the goal is to find the optimal settings of the control variables such that the sum of all generator's cost functions is minimized. PSO was effective in dealing with this complex optimization problem that has various equality and inequality constraints and both continuous and discrete variables. This hybrid technique improved the convergence characteristics over the traditional PSO in solving the same OPF problem.

- **Power System Controller Design**

PSO was employed in finding the optimal settings of power system stabilizer parameters. The problem was formulated as one of min-max optimization of two eigenvalue-based objective functions. In this work, the authors' goal was to find the global optimal solution of a multimodal optimization problem. PSO was also used in optimizing feedback controller gains.

- **Neural Network Training**

Neural networks emerged as a valuable artificial intelligence tool in many areas in electric power systems. The objective was to develop a model that would be able to intelligently distinguish between magnetizing inrush current and internal fault current in power transformers. PSO was employed to improve the accuracy and the execution time of the identification process.

- **Other Power System Areas**

The performance of PSO was explored in the area of power quality by improving the process of feeder reconfiguration. PSO was employed to minimize the investment and operation cost of the generation expansion planning problem. Also in this area, PSO was utilized in solving the expansion panning problem of a transmission line network. In power reliability, PSO was applied to feeder-switch relocation problem in a radial distribution system . PSO was successively applied to solve short term hydroelectric system scheduling problem

Hybrid Particle Swarm Optimization

HPSO implement the process of PSO and the logical choice process which is usually implemented by EC such as genetic algorithms (GAs). Since search process by PSO extremely turn on pbest and gbest, the searching area is bounded by pbest and gbest. On the opposite , by initiating the natural selection process ,the effect of pbest and gbest is slowly disappear by the selection and larger scope search can be realized. Agent positions with low growth values are replaced by those with high evaluation values using the selection. On the opposite, pbest information of each agent is nourish. Therefore, the depth search in a current productive area and dependence on the past high assessment position are grasp.

Conclusion

The weighted least square (WLS) and the weighted least absolute value (WLAV) both of them give the adequate results in approximate the calculation. The outcome acquire with PSO-WLS methodology give a superior approximation, using lower mathematical time in evaluating the state variables of both test case systems. The application of swarm artificial intelligence approach in the selection of optimal location of the meters has been presented. Two algorithms have been excuted. The algorithms put to use PSO and ABC approach for obtaining the optimal arrangement.
It focus on many applications in which PSO was profitably relevant still it disclose some further unresearched areas where it could be further employed like protection, restoration, etc.

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