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Complexity of Future Power Grids: applications of HPC for OPF operational tools

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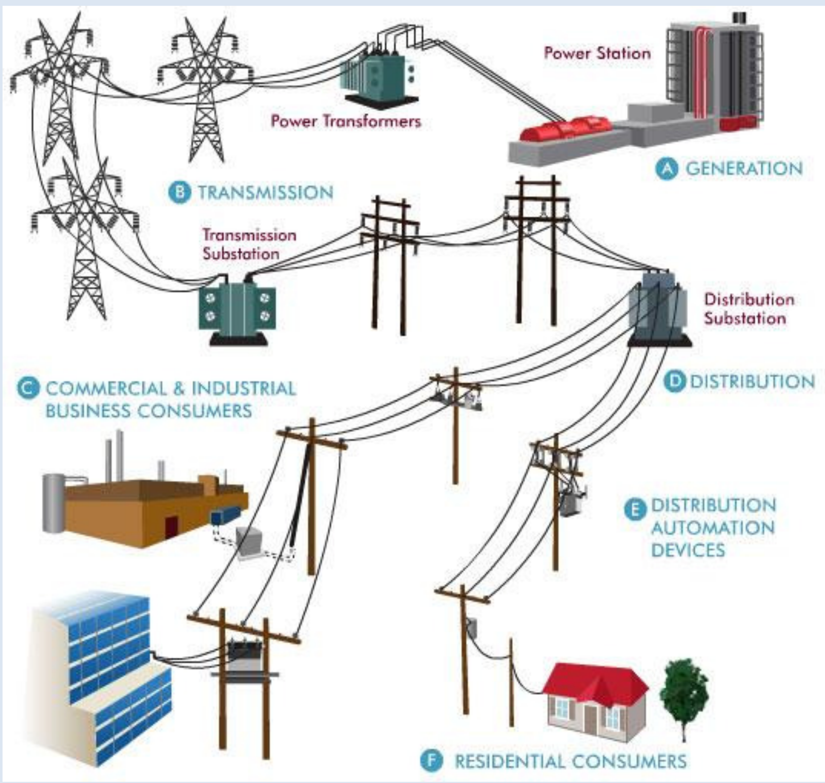
Problem description

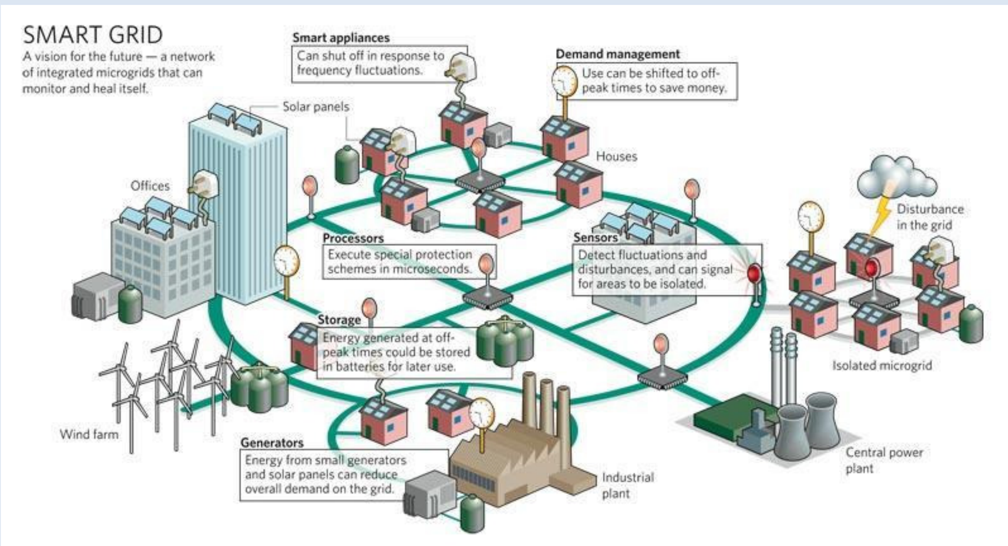
One of the major challenges in the energy sector is to ensure secure and sustainable energy supply.

Traditional power systems were organized around centralized power generation with the unique direction of electricity flow.



Traditional power system

However, the scale and complexity of power systems have been increased significantly in the last few decades, especially on the distribution side with the growing utilization of distributed energy resources that includes renewable generation as well as technology that allows active demand participation.



Smart Grid

Operation and control of future power grids therefore require a significant change in capabilities of operational tools. There is a need for very fast computations in order to calculate frequent prices and other decision variables for systems with a large number of nodes. As the optimal power flow (OPF) presents one of the main tools used in power system operation and control, and the Interior Point Method (IPM) is becoming one of the most frequently used OPF solution algorithm, this poster describes potentials in which High Performance Computing (HPC) can be used to improve the performances of the IPM application to the OPF.

Optimal Power Flow

The optimal power flow is a a non-convex, large scale, nonlinear optimization problem which minimizes the costs of meeting the load demand for a power system while maintaining the security of the system.

Objective function - minimize the total generation cost, power losses

$$\min f\left(P_{g_i}, Q_{g_i}, V, \delta\right)$$

Equality constraints - power flow equations

$$P_k = V_k \sum_{i=1}^{N_{bus}} V_i (G_{ki}\cos\theta_{ki} + B_{ki}\sin\theta_{ki})$$

$$Q_k = V_k \sum_{i=1}^{N_{bus}} V_i (G_{ki}\sin\theta_{ki} - B_{ki}\cos\theta_{ki})$$

$$k = 1, \dots, N_{bus}$$

$$Y_{bus} = G + jB$$

$$\theta_{ki} = \theta_k - \theta_i$$

Inequality constraints - physical limits of control variables, network operating limits

$$P_{g_i}{}^{min} \le P_{g_i} \le P_{g_i}{}^{max}$$

$$Q_{g_i}{}^{min} \le Q_{g_i} \le Q_{g_i}{}^{max}$$

$$V_i{}^{min} \le V_i \le V_i{}^{max}$$

Interior Point Method

Optimization problem

Add slack variables

Make all inequality constraints into non-negativities

Replace non-negativity constraints with logarithmic barriers in the objective function

Form the Lagrange function associated with this problem

Set the first-order optimality conditions

Apply Newton's method to the set of equations coming from the first-order optimality conditions

The major computational effort is solving the large, sparse linear equation system to compute Newton direction.

OPF parallelization

The OPF parallelization is very difficult task due to its nonlinearity and a large number of different types of constraints.

In recent years, IPM has been recognized as the most efficient way to improve the performance of the OPF. Although, many different approaches have been proposed to improve efficiency and accuracy of the OPF problem based on IPM, only two of them investigated how HPC can be used to improve its performance.

(Moreira et al. 2011) used OpenMP for the parallelization of the OPF based on IPM and it is shown that the execution times decrease significantly as the number of cores used to solve the OPF increases, especially for large scale systems.

(Castronuovo et al. 2001) proposed the use of vector processing to the OPF solution through the IPM. The algorithms were implemented in Fortran 77 and it was shown that the their speed can be improved while maintaining the number of iterations to convergence.

Conclusions

The current process of optimal decision making in power systems is still challenging, especially in real time.

Typical values of number of buses in transmission network are around 1500 nodes and if we want to consider distribution network, the size of a problem becomes much bigger and we have to deal with up to hundreds of thousands of variables and constraints.

The parallel efficiency of IPM depends on the efficient parallel implementation of several key sparse linear algebra kernels.

Matrix-matrix multiplication

Linear solver

Matrix-vector multiplication

Although this is relatively new area of research, it is shown that HPC can contribute to faster solving of the OPF problem and there is a great potential for further improvement.

References

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