Decentralized Real-Time Power System Analysis: A Conceptual Framework for the Future Grids

S. M. Kouhsari
Dept. of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR.
Email: smk@intelectri.com

S. M. Mazhari
Dept. of Electrical Engineering
Amirkabir University of Technology, Tehran, Iran
Email: mazhari@aut.ac.ir

ABSTRACT

This short note tries to propose a somewhat different structure of the prevalent power system analysis approaches as a research idea for the near future power grids. It proposes a change in attitude to deal with power system basic analysis such as load flow, fault analysis, transient stability, harmonic analysis, and so on; the new attitude seem more suitable than prevalent frameworks for the coming power grids in which privatization, restructuring and data security accompanied by advanced communication and measuring facilities are all came to each other. The letter emphasis on a customer-by-customer decentralized approach which leads us to have real-time analysis of a *n*-million busbar system on *n*-million computers somehow communication transactions are substantially limited, measurements are reduced, restructuring policies are met, and the entire previously research advancements such as parallel processing and optimization based features are applicable in the new platform.

1. INTRODUCTION

While hardware based technology aspect of power systems has been faced with several changes during recent years, the software based advancements are mostly confined to improvements in forecasting, energy management systems and data mining related features [1-4]. Thus, the scope of developing software tools which are dedicated to the future power systems has raised several concerns for both researchers and utilities [5-6].

As discussed in the specialized literature, the future power grids would be smart grids enhanced by several types of advanced tools which supply different type of customers [7]. Some literature describes the future systems as combination of multi-Micro Grids or even multi-Nano Grids [8].

Considering the future power grid, it would be much larger and more complex than the current networks; thus, a set of comprehensive and detailed analyses are needed to ensure an accurate design and reliable operation of such a bulk system [9]. However, computational burden as well as unavailability of detail network data of all areas would be an important issue.

In addition, the existing centralized based approach for analysis which is traditionally used to analyze power systems is faced with serious challenge as the need for faster computation and decision making increases. [10-12].

This short note addresses a decentralized real-time analysis to deal with the coming power grids. Indeed, it is a simple proposal trying to invite a portion of researchers focusing on the basic power system analysis problems to employ the best analysis framework for the future power grids, emancipating our minds/tools from centralized analysis to probability find something better.

2. WHERE WE ARE?

In this section, first briefly describe management/operation structure of power systems and then represent the prevalent analysis framework of the power grid in utilities.

1.1. Prevalent Power System Management Structure

Prior to the 20th century, most electricity customers throughout the word were served by regulated, vertically-integrated, monopoly utilities that handled electricity generation, transmission, local distribution an billing/collections [9]. However, in today’s power industry the restructuring of such utilities into separate generation, transmission and distribution companies has introduced competition at all levels and improved overall system performance. Moreover, the retailers are activated at the distribution level and nonprofit organizations

(ISOs[1], DSOs[2]) are introduced to manage market players and insuring secure operation of the whole network.

Besides the above, most utilities hire advanced measuring devices (such as PMUs[3]) and the prevalent SCADA[4] system is updated with the WAMPC[5] facility. Furthermore, extensive attempts have been taken to settle advanced control schemes and energy efficiency modules.

1.2. Prevalent Power System Analysis Structure

The current power grid has faced with some changes/improvements from the power system analysis point of view, as remarked bellow [1]:

- The new facilities made it possible to have more accurate data;
- The communication media made it possible to have values measured in long distance;
- The improved measurements made it possible to better deal with issues such as transient state estimation, transient optimal power flow, real-time security assessment, and so on;
- The huge amount of data made it possible to have improved forecasting modules;
- The parallel processing algorithm and graphical processor units made it possible to efficiently analysis large-scale power systems.

Despite the above mentioned changes, the centralized analysis of power system remained unchanged; the basic power system analysis are mostly conducted in a centralized approach by transmitting measurements and system data to the central controls (CCs). Fig. 1 shows a simple network in which communication media sends the measurement data to an ISO to analysis the whole network; the same structure happens for DSOs or even in introduced Smart Grids.

In the current structure, the utilities may employ several approaches to analysis their own network depending on the related rules. As instance, the "utility 1" may take the following actions to have the load flow (LF) results at time *t*:

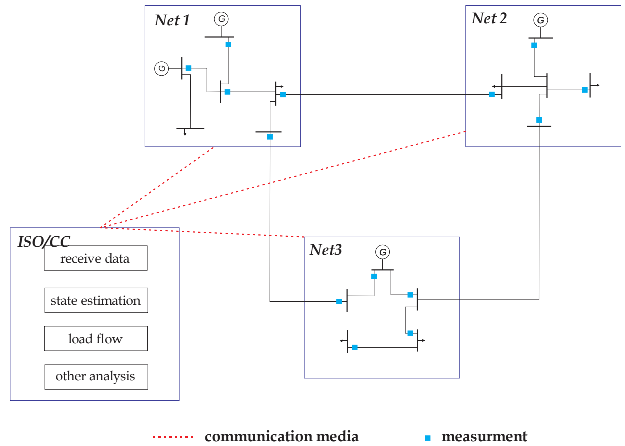

Fig. 1: A simple multi-area power system representing prevalent centralized analysis.

a) Ask ISO to run LF of the whole network at time *t* and sends back the obtained results to "utility 1";
b) Ask ISO to send the entire network data associated to time *t* to and then run LF employing computer module of "utility 1";
c) Find electrical equivalent of the external system looking from "utility 1"at time *t* and run LF employing computer module of "utility 1";

The above methods are visualized in Fig. 2.

3. WHERE WE ARE GOING?

It is expected by commentators of the energy area that renewable distributed generations much largely penetrate to the future distribution systems [3]. Moreover, expanding communication facilities along with abundant measurement devices push the current network to a smart grid in both transmission and distribution levels.

In addition, it is expected that the boom of interest in power generation at the customer sides affect the system economy and lead to completion of the power system restructuring [4].

In such situation, it is expected that power system analysis would face with some changes especially by local control schemes and advanced data mining based analysis. In addition, fast and reliable tolls would be required to gather insightful data from the information sent to the central control through distributed metering devices.

[1] Independent Service Operator (ISO)
[2] Distribution System Operator (DSO)
[3] Phasor Measurement Unit (PMU)
[4] Supervisory Control and Data Acquisition (SCADA)
[5] Wide Area Monitoring Protection and Control (WAMPC)

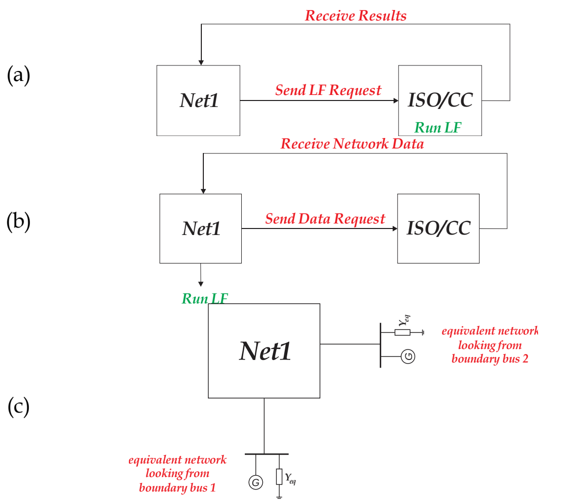

Fig. 2: Prevalent approaches to run Load flow analysis of Net1 in Fig. 1.

3. What We Need? Why We Need?

As discussed in previous sections, the centralized analysis would raise several significant issues; the most important cases can be outlined as follows:

- There is a lack of sufficient processing power as it is predicted that computational speeds a million times greater than today's high-end computers would be required for real-time analysis and control of today's interconnected networks [9]. As a matter of fact, historically, the required processing power has had an explosive rate of increase and an unpredictable nature.
- Real-time constraints due to the wide geographical areas covered by interconnected networks. For example, to limit the signal transmission delays to 2 ms round-trip, only an area with a maximum radius of approximately 150 miles can be under a central control umbrella [10].
- Lack of sufficient knowledge about some parts of the network such as some utilities and/or neighboring countries due to the presence of competitive or security considerations. Therefore, most of the centralized analysis approaches employ a reduced rather than detailed model for external networks (i.e. equivalent networks) that downgrade the integrity of the analysis results [11].

With such assumptions, consider the network shown in Fig. 3; this is an interconnected network

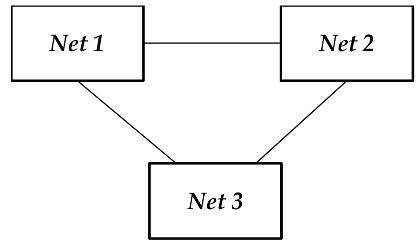

Fig. 3: An illustrative three-area interconnected power system.

with three areas (subnetworks) so that the subnetworks are connected to each other through some transmission/distribution lines. Each area is owned and operated by an independent (private) entity. There are several examples for such network such as:

- Power grid of a country which is operated by several privatized regional electric company. As an example, the Iranian power gird is operated by 16 regional electric companies; although optimal power flow and security assessment is conducted by a governmental company (Iranian Grid Management Company (IGMC), the Iranian ISO), but prevalent planning and operation are conducted by each independent utility.
- Some countries which have power transport among each other and their networks are connected to each other by some boundary buses. As an example the Iranian power grid is connected to Afghanistan and Pakistan in the east and to Turkey and Iraq in the west. Or as another example the Mexican power grid is connected to U.S. via Texas.
- A regional electric company which supplies some distribution utilities; distribution utilities are all private in Iran as several other countries.
- A distribution utility which supplies some medium/large customers such as factories, etc. by a 63 kV feeder. The customers are majority private and the utility has no information about their networks.
- Some customers/smart homes within a Microgird, or some Microgrid which are connected together (Multi-Microgrid). As an instance, two customers connected to a Micogrid can be an example of Fig. 1.

Thus, we can see that there are several situations in which there is a multi-area interconnected power network so that all/some of the subnetworks are private. In other words, we face with a structure in which a subnetwork may not have information about its neighboring areas such as network structure (transmission lines), generation/demand, harmonic sources, etc.

In this condition a power system problem can be defined so that "How a subnetwork can solve load flow (LF)/transient stability (TS)/harmonic analysis (HA) in a multi-area interconnected power system within restructured environment?" which would be the near future power grid.

The prevalent solutions are as follows:

- **Method 1:** Each subnetwork sends its network information to a Central Control (CC); the CC runs LF/TS/HA calculation and sends back the results to the subnetworks. This is something which expected to be done in Microgrids; in restructured electricity markets, the ISOs do the same job for optimal power flow and security assessment. This method is called as centralized analysis and lead to exact solutions.
- **Method 2**: Each subnetwork may use frequency-dependent equivalent for the external system. It should be noted that this method is mostly used to model the external network while a researcher would like to focus on his/her subnetwork, or concentrate on a special zone, and thus would like to reduce the computational burden by almost preserving accuracy of the solutions. These methods use two different schemes: a) some of them need detail information of the external network (such as Ybus data, P,Q of busbars); b) some others need several measurements to calculate (V/I) in the bus of interest [13].

  Since, in a privatized network the subnetworks have no access to their neighboring areas, they may not have network data (R, L, C, X, or, Ybus,...) or they may not be allowed to change/informed of the injected current (I) associated to the measured voltage (V) and thus they may not be able to find Z=V/I within privatized networks.

  Besides these, there are several changes happen in network configuration under real-life operation such as load values, as well as the harmonic sources; hence, it may not be possible to repeat this method for any changes.
- **Method 3:** Another method is to use field data as reported in [14] but it needs several calculations/measurements which may not be so useful for operation analysis considering changes in the neighboring networks. Moreover, same as the previous approach, these methods are mostly used for filter design; as they have no information about variation of the sources in the external systems they are rarely employed for LF/TS/HA calculation.

Summarizing the above approaches, centralized analysis seems the only existing method which can find exact LF/TS/HA of a multi-area interconnected power system. However, this method may face with some major deficiencies:

1) *Computational burden*: as this method solves the problem of the whole interconnected network in CC, it may not be computationally efficient especially while Time-Domain (TD) based methods are conducted.

To overcome this drawback, several distributed/parallel computing methods are introduced in literature. Hence, this deficiency has been properly overcome with the existing methods [9].

2) *Amount of transmitting data to control center (CC)*: since the subnetworks should send their network data to CC, the amount of communicated data are high. In case of TD methods, the subnetworks should send R, L, C of lines, exact P, Q at all buses along with appropriate model of harmonic sources. While a Frequency-Domain technique is employed in CC, the subnetworks may minimize the data to admittance matrix (Ybus) and the currents injected by the sources. This amount of data needs a proper communication facility which seems as a constraint to run this method.

Moreover, as the network faces with several changes in real-life operation, the Ybus elements/sources change continuously; thus, the subnetworks should send the entire requested data for each independent run which aggravate the communication traffic.

3) *Modeling of harmonic sources*: transmitting data to a center and conducting HA in CC probably confine detail harmonic modeling. Although each nonlinear element may have a unique harmonic model, it may not be possible to send the exact model of each nonlinear device to the

CC as the subnetworks should follow a predefined pattern (protocol) to send/receive data and also the calculation process. This may also restrict emerging new harmonic sources while a TD method is used in CC.

4) *Data Security*: network structure (Ybus) as well as other technical data (P,Q, …) are valuable data which might be stolen/hacked by the beneficiaries. Several attempts should be taken to keep the centralized solution method free of such problems [15].

4. THE PROPOSED CONCEPTUAL FRAMEWORK

The idea behind this note is to have much more focused on the decentralization approaches to reach a customer-by-customer based method suited for smart grids. Each customer will have a decentralized power analyzer (DPA) which reinforced by a power system analysis software.

Thus, by having the DPA, each customer will model his own network into his DPA; a smart home with the entire electrical devices or a steel mill plant may represent two simple examples. The DPAs will be connected to the CC, but it does not send the entire data. Employing enhanced sensitivity analysis such as large-change sensitivity theory, each DPA sends the voltage of its boundary buses. As an example, a steel mill plant which has n buses sends m values to the CC if it is connected to the remaining system through m boundary buses [9-12]. Hence, the utility, or DSO/ISO does not need to model each customer and just receives the values associated to the boundary buses. Moreover, the DPAs can simply receive an exchanged current vector to reform their previous solutions.

Thus, we'll need to emancipate our minds/tools from centralized analysis to probability find something better. The decentralization might be a good choice to this aim. However, to get more familiar with the application issues of such framework, the following comments may merit consideration.

Let assume to have a huge real power system including all its generation stations, all transmission systems, all the factory plants, all the distribution systems and subsystems; we also have a simulated version of such a large network distributed in all over the world connecting globally through internet. Such a global software must have the following capabilities:

1. We must trust on the input data and parameters of such a software;
2. We must be sure that the simulated behavior follows the exact behavior of the real system;
3. We need to observe the action of the software;
4. Software needs to control all aspects of our operations. Indeed it must be capable of rescuing the followings:
   A) It must self-tune itself regarding the correction of its own data and parameters.
   B) It must predict the faults in the system. It must be capable of opening the correct circuit breakers as soon as possible, and so omitting the need for the relay actions.
   C) It must be capable to tune our governor and AVR and all the controllers e.g. transformer tap settings in order to optimize the running cost of our power system.
   D) It must check the security and the reliability of the system and in each instant of time changes the controllers in such a way to bring the system to the most secure position.

However, on the other hand software development is a hard job and requires time for its development. This shows itself more if you need a simulation software. In near future, the hardware technology will receive to a point that you can get rid of the hardware barriers. It is also possible to receive to a point that the business and political matters are not as important as it is today. It is just then that you will find yourself in a situation that you need to have appropriate software, and you have not thought about its development. We will need such a software for future power grids which would be an open source package such as Android.

To reach the optimal decentralization framework, several mathematical techniques should be come out to have multi-layer central controls. In addition, optimization algorithms should be changed somehow they can efficiently solve global problems using the limited data received from subareas. Furthermore, new investigations should be conducted to find the minimal measurement type/locations through the proposed structure. Some of these have been addressed in [9-12].

With the use of a real-time simulator, we would probably be capable of finding the fault (at least three phase fault) in any point of the network without using actual relay devices and just by measuring some limited variables of the system (contaminated with noise) in a distributed manner and order to the appropriate circuit breakers to open the fault and after opening the fault and therefore missing some loads, bringing the network to the nearly optimal operation. The readers themselves can imagine what would be the application of providing such DPA in many areas of power system including distributed generation and smart grids [16].

5. CONCLUSION

Based on existent research, one can note that although computational burden and accuracy issues have been greatly resolved by developing parallel computing-based methods, the lack of observability and load identification of nearby networks, especially in the restructured environment, still remain. Additionally, information sharing is limited within the competitive structure as it may affect independency of the utilities. As a consequence, commonly used external system modelling approaches may not be effective as injected currents/network topology vary with respect to time. Hence, it is desirable to conduct an exact analysis of real-life networks in a secure and decentralized structure which can be established based on local computational resources. A decentralized customer-by-customer based approach might be a clue to this end.

6. REFERENCES

[1] G.A. Taylor, M.R. Irving, P.R. Hobson, C. Huang, "Distributed monitoring and control of future power systems via grid computing," *IEEE Power Engineering Society General Meeting*, vol. 1, no. 1, pp. 1-6, 2006.

[2] E. Ortjohann,P. Wirasanti, A. Schmelter, H. Saffour, "Cluster fractal model — A flexible network model for future power systems," *International Conference on Clean Electrical Power (ICCEP)*, vol. 1, no. 1, pp. 293-297, 2013.

[3] A.M. Farid, "Multi-agent system design principles for resilient operation of future power systems," *IEEE International Workshop on Intelligent Energy Systems (IWIES)*, vol. 1, no. 1, pp. 18-25, 2014.

[4] A. Shahsavari, S.M. Mazhari, A. Fereidunian, H. Lesani, "Fault indicator deployment in distribution systems considering available control and protection devices: a multi-objective formulation approach," *IEEE Transactions on Power Systems*, vol. 29, no. 5, pp. 2359-2369, 2014.

[5] K. Z. Ibrahim, "Bridging the gap between complex software paradigms and power-efficient parallel architectures," *International Green Computing Conference*, vol. 1, no. 1, pp. 417-424, 2010.

[6] M. Polycarpou, "Intelligent monitoring and fault tolerance in large-scale distributed systems," *Conference on Control and Fault-Tolerant Systems (SysTol)*, vol. 1, no. 1, pp. 480-486, 2010.

[7] S.M. Mazhari, H. Monsef, H. Lesani, A. Fereidunian "A multi-objective PMU placement method considering measurement redundancy and observability value under contingencies," *IEEE Transactions on Power Systems*, vol. 28, no. 3, pp. 2136-2146, 2013.

[8] L.BTong, L. Yongli, M. Tao, "Research on earthing schemes in LV microgrids," *International Conference on Advanced Power System Automation and Protection (APAP)*, vol. 2, no. 1, pp. 1003-1007, 2011.

[9] A. Kalantari, S.M. Kouhsari, "A distributed computing approach for power system analysis," *Proc. Iran. J. Sci. Technol.*, vol. 29, no. 4, pp. 399-413, 2005.

[10] A. Kalantari, S.M. Kouhsari, "An exact piecewise method for fault studies in interconnected networks," *Electrical Power and Energy Systems*, vol. 30, no. 1, pp. 26-225, 2008.

[11] S. Esmaeili, S.M. Kouhsari, "A distributed simulation based approach for detailed and decentralized power system transient stability analysis," *Electric Power Sys. Res.*, vol. 77, no. 1, pp. 673-840, 2007.

[12] V.G. Sadr, S.M. Kouhsari, "An adaptive distance relaying strategy based on global network simulation," *Euro. Trans. Electr. Power*, vol. 20, no. 1, pp. 845–861, 2010.

[13] A. Larsson, A. Germond, B. Zhang, "Application of Neural Networks to the Identification of Steady State Equivalents of External Power Systems," *International Conference on Power System Technology*, vol. 1, no. 1, pp. 1-6, 2006.

[14] K. Temma, F. Ishiguro, N. Toki, I. Iyoda, J.J. Paserba, "Clarification and measurements of high frequency harmonic resonance by a voltage sourced converter," *IEEE Trans. Power Del.*, vol. 20, no. 1, pp. 450–457, Jan. 2005

[15] M. Tajdinian, M.Z. Jahromi, K. Mohseni, S.M. Kouhsari, "An analytical approach for removal of decaying DC component considering frequency deviation," *Electric Power Systems Research*, Jan. 2016.