Intelligent Sense-Making for Smart Grid Stability

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Abstract-- **The power systems of the future – smart grids - will see an increase in both renewable energy sources and load demand, thus increasing the need for fast dynamic reconfiguration of system parameters to handle energy and load dispatches. Power systems will need to be monitored continuously to maintain stability under normal and abnormal operating conditions and when facing disturbances. A combination of system state prediction, dynamic power flow, system optimization, and solution stability checking will allow for a more reliable, affordable, efficient and clean power grid.**

The optimization and control systems on a smart grid will require a computational systems thinking capability to handle the uncertainties and variability that exist in a smart grid environment. The concept of sense-making based on computational intelligence methods, including neural networks, fuzzy logic and swarm intelligence, as well as online measurements from a smart grid to provide 'situational' awareness in the context of stability, is introduced in this paper.

Index Terms — **computational intelligence, intelligent agents, sense-making, situational awareness, smart grid, stability, transient stability assessment, wide area monitoring and control.**

I. INTRODUCTION

THE complexity of the electric power infrastructure continues to grow with increasing load demand and the integration of renewable sources of energy and energy storage. Traditional electric grid models will not achieve accurate system representation in time; thus, control and optimization operations of the electric power grid (or smart grid) will become a challenging task [1].

Situational awareness is critical for secure and efficient smart grid operation. A general definition of situational awareness (SA) is that it is the perception of environmental elements within a volume of time and space, the understanding of their meaning, and the prediction of their states in the near future. SA by control room operators is of great importance for secure operation of the electric power grid. Despite the importance of analytical methods, continuous data sense-making is critical for ensuring the stability of a smart grid. More information (a lot of data) does not necessarily matter in critical operations; rather, what is important is to prioritize the understanding of what matters at the respective instances. It is also critical that an understanding be gained from a shared view since the power grid is interconnected, and its dynamics are spatial and temporally connected. A paper from researchers at the Pacific Northwest National Laboratory (PNNL) introduced new ways of looking at the problem of SA to increase the situational awareness of grid operators [2]. Ongoing research at PNNL is examining the benefits of applying advanced analyses in the speed and quality of responses to violations or potential violations. These researchers project that by transcending traditional human factor/visualization studies, research on sense-making for SA in power grid operation may offer a promising direction for improving human system performance in power grid operations.

Accurate and timely communication of states of generation, transmission and distribution systems is critical for ensuring the stability of interconnected smart electric power grids. The report on the Northeast Blackout on August 14, 2003, showed the difficulty of getting reliable information from the state estimation software/simulations, contingency analysis results, and critical status of power lines relating to the status of systems outside of the individual areas [2]. A failure in SA occurred mainly due to lack of shared information across control areas, leading to a cascaded blackout.

Intelligent systems that increase the abilities to plan, to learn, to understand complexity, to share understanding across neighboring areas, and to take appropriate actions to ensure stability are desired. This panel paper introduces computational intelligence as a promising and potential approach for intelligent sense-making in the context of stability and security analysis in a smart grid environment.

II. INTELLIGENT SENSE-MAKING

Sense-making is a process by which individuals attach a meaning to an experience [3]. Sense-making is at the heart of learning cognitive skills and has to be engaged in often in highly uncertain situations. Gathering more and more information does not always reduce uncertainty. Other concerns reside with the information sensed. Is it trustworthy? Does it conflict with or is it controversial given what is known? If so, then the data to be analyzed becomes complex. In the smart grid environment, depending on the type of decisions to be made and controls to be used, the time to act upon the understanding derived may be limited. Recognizing/identifying the right dots in the data (and information) is the critical component to time-constrained

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sense-making. An important characteristic that a computational systems thinking machine should possess is an ability to communicate 'information' from data, 'knowledge' from 'information,' and 'understanding' from 'knowledge' at the respective levels in a timely manner (Fig. 1).

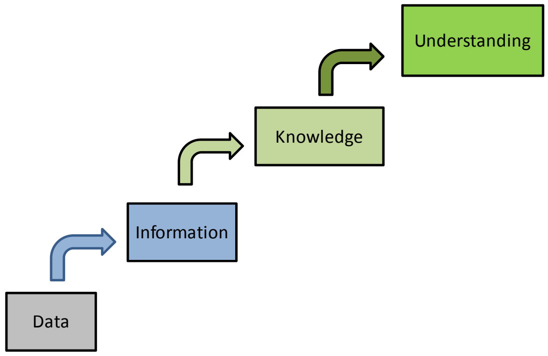

Fig. 1 Converting data into understanding.

Feedback control allows device/component/system outputs to be regulated and system operation to be maintained in stable operating regions. Feedback is essential for learning skills, procedures and routines, but not for learning facts or gaining insights. Feedback is not sufficient for learning in complex environments. Sometimes, it leads to difficulty in understanding complex situations and may cause distortion. Intelligent sense-making is essential for learning facts and insights in complex situations, especially when under time constraints. Framing relevant data is important (Fig. 2). Data can be fitted into frame and vice-versa [4]. Waiting for too much information prior to taking action may lead to degradation in system performance and stability depending on the time constant of the issue in question. Faster than real-time computations (including solution verifications) are necessary for reliable, efficient and optimal operation of a smart grid.

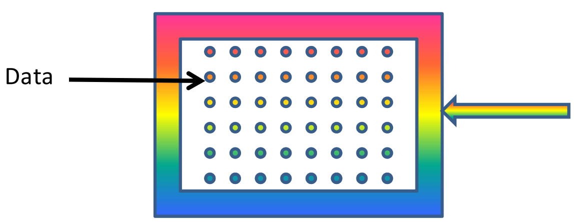

Fig. 2 Data/frame model of sense-making.

Whether to cede control to the human or the algorithm always poses a dilemma for developers of decision-suppoert systems. In order for the latter to be selected, computer and information technology should become intelligent. The development of a reflective, analytical decision-support system is preferred in this case [4].

A computational system's three strands of thinking that will be needed in an evolving, uncertain and variable complex environment such as a smart grid will be systems thinking for sense-making, systems thinking for decision-making and systems thinking for adaptation. In other words, there are sense-making agents, decision-making agents and adaptation agents. In the center of all these systems-thinking agents is a knowledge base that continuously evolves and refines itself. The knowledge base learns and unlearns facts and insights over time. A single computational systems-thinking machine is shown in Fig. 3. For a smart grid, several of these will co-exist (locally, regionally and globally) in harmony while coordination and communication are enabled between similar and different agents. Collaboration between co-existing agents is essential for sense-making, decision-making and adaptation.

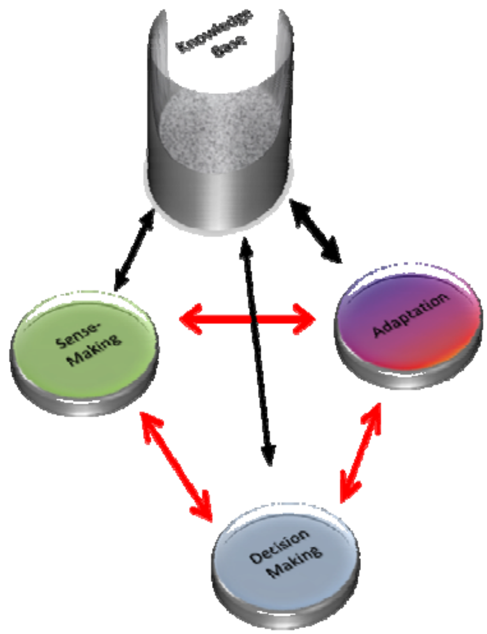

Fig. 3 Computational systems-thinking machine - the integrated cycle of sense-making, decision making and adaptation. The knowledge base is the domain expertise and experience gathered.

III. Sense-Making for Smart Grid Stability

Some key challenges associated with real-time stability assessment in power systems [5] are: the large numbers of contingencies and the sequence of events typically needed to provide accurate stability assessment; the wide range of operating conditions and topology of the power system (smart grid), which makes the operating space very complex; the speed by which the stability assessment can be assessed in real-time; the large number of measurements available in the power system; the lack of methods to enhance the correlations between measurements and the stability assessment; and the lack of an effective assessment index.

Computational intelligence methods such as neural networks, fuzzy logic, swarm intelligence and adaptive critic designs are promising potential approaches for implementing fast, intelligent sense-making [6], [7]. Also promising is a fuzzy logic-based approach for evaluating power network stability.

Echo-state network-based estimation of voltage stability load index from data streaming from phasor measurement units is an intelligent way to assess the voltage stability when plug-in electric vehicles take part in vehicle-to-grid (V2G) and grid-to-vehicle (G2V) operations [8]. Wide-area monitoring is essential for sharing information between neighboring areas to carry out optimal decisions and implement controls. As interconnections increase, and elements of power systems have the ability to plug-and-play and behave as sinks or sources, advanced monitoring systems enabled with learning capabilities will be needed, including cellular neural networks and stochastic identifiers [9], [10].

These approaches allow for controllers to respond quickly and accurately in order to ensure system stability and minimization of cost, emissions and deviations from desired reference values [10] - [12].

IV. Conclusion

The smart grid environment is an adaptive, complex environment housing lots of uncertainties and variability. In order to achieve the benefits of a smart grid, optimization and control actions must be at their best at all times, and this will require computational intelligence systems. Computational systems-thinking machines that carry out intelligent sense-making will become essential to maintain and enhance the stability, security and safety of the smart grid, given its evolving nature.

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Biography

Ganesh Kumar Venayagamoorthy (S'91, M'97, SM'02) received his PhD degree in electrical engineering from the University of Natal, South Africa. Currently, he is an Associate Professor of Electrical and Computer Engineering, and the founder and Director of the Real-Time Power and Intelligent Systems (RTPIS) Laboratory at Missouri University of Science and Technology (Missouri S&T). He was a Visiting Researcher with ABB Corporate Research, Sweden, in 2007.

His research interests are in the development and applications of advanced computational algorithms for real-world applications, including power systems stability and control, smart grid applications and sensor networks. He has published over 360 articles in refereed journals and conference proceedings. He is a lead-principal investigator on a 2008 NSF Emerging Frontiers in Research and Innovation Award.

Dr. Venayagamoorthy is a recipient of several awards, including a 2007 US Office of Naval Research Young Investigator Program Award, a 2004 NSF CAREER Award, the 2010 Innovation Award from the St. Louis Academy of Science, the 2010 IEEE Region 5 Outstanding Member Award, the 2006 IEEE Power and Energy Society Walter Fee Outstanding Young Engineer Award, a 2007 Missouri S&T Teaching Commendation Award, a 2006 Missouri S&T School of Engineering Teaching Excellence Award, a 2008, 2007 and 2005 Missouri S&T Faculty Excellence Award and a 2009 Missouri S&T Faculty Research Award.

Dr. Venayagamoorthy has been involved in the leadership and organization of many conferences and editorial boards of IEEE Transactions, including serving as the Chair of the 2011 IEEE Symposium of Computational Intelligence Applications in Smart Grid (CIASG). Dr. Venayagamoorthy is a Fellow of the Institution of Engineering and Technology (IET), UK, and the South African Institute of Electrical Engineers. He is a Senior Member of the International Neural Network Society (INNS) and a Member of the American Society for Engineering Education. He is member of the Board of Governors of INNS.