Proceedings of the ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference
IDETC/CIE 2017
August 6-9, 2017, Cleveland, Ohio, USA

DETC2017-67485

ENERGY INFORMATICS AND FRACTIONAL CALCULUS

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ABSTRACT

Energy informatics (EI) is relatively a blossoming and dynamic research area especially in today's green manufacturing world. Using renewable energy and clean technology are the keys to a revitalization of the world manufacturing and job creation. Green manufacturing, which reduces resource use, waste and emissions and saving the energy, has become the priority for the manufacturers. Therefore, EI has come into a desirable solution. The fractional calculus (FC) is a mighty tool which can characterize the complex properties of the natural and social phenomena. In this paper, we have provided an overview on the current EI by describing current research topics and methods and then pointed out an outlook of how this new field might be evolved with FC in the coming future.

INTRODUCTION

Energy is the underlying heartbeat of the global economy—a critical factor in the production of nearly all goods and services in the modern world. Clearly, given the critical role of energy, the driving imperatives in any economy are ensuring security of supply, maintaining competitiveness and overseeing the transition to a low-carbon future. Energy informatics (EI) is the application of information technologies to this highly demanding field. EI is relatively a newborn and dynamic research area, which was first proposed around 2010 by Watson *et al.* [1]. Moreover, it is concerned with analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems [2]. Within the past decade, this topic has boosted much more significance and it would be a very promising field in the coming future [3, 4]. On April 18th, 2011, Prof. YangQuan Chen gave a seminar talk on "Gegenbauer Processes and Energy Informatics" at University of Pretoria. In this seminar, he introduced a new class of models known as k-factor Gegenbauer autoregressive moving average (GARMA) and its applications in time series modeling and prediction in EI. This is particularly attractive in modeling complicated time series signals with long memory and seasonality in EI, such as wind speed, high-frequency trading data, power consumption, energy price etc. Therefore, EI requires optimal collection and analysis of energy data-sets to support optimization of energy distribution and utilization in networks or grids.

The fractional calculus (FC) or fractional order calculus (FOC) got birth 300 years ago, and the research on FC has witnessed its boom in the past decades. It has been acknowledged that the complex characteristics of the phenomenon can be seized by the FC, while they may be somehow failed to be

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achieved by the classical integer order calculus (IOC). From this perspective, FC can be regarded as a powerful tool dealing with intricate systems, such as the sociology, hydrology, biology etc. Therefore, a more comprehensive model can be provided for the real systems and events at all levels of scale and complexity. Inherently, there are substantial advantages to entraining on the study of FC, particularly in situations where fractional operators match the dynamics of the convoluted problem.

Generally speaking, the scope of the EI research can be divided into two parts: Energy efficiency and renewable energy supply [1]. Currently, many organizations have an opportunity to tackle sustainable development while improving productivity, reducing costs, and increasing profitability. However, their indigent environmental practices may inevitably result in many forms of waste—unused resources, energy inefficiency, noise, friction, and emissions are all waste products that subtract from economic efficiency. In essence, the absence or redundancy of information may exhaust optimal possible solutions from the perspective of feedback control theory. The basic idea of EI can be expressed quite concisely [1]:

$$\text{Energy} + \text{Information} < \text{Energy}. \tag{1}$$

Fundamental requirements in this respect lie in the strategic management of supply and adapting its overall generation and distribution. Impacting on these challenging goals will be a variety of factors, including advances in renewable, e-mobility and green technologies and so forth. Managing this changing environment is not an easy task. Knowing how to create intelligent IT solutions for smart grids, smart city infrastructures & energy supply system may come to help. This not only requires well-educated engineers and experts be able to design and/or operate future smart grids, smart city infrastructures and enhanced energy supply systems, but also needs fractional calculus view of complexity. Herein we propose to adopt a fresh perspective of EI entailed by the use of FC.

BASICS OF FRACTIONAL CALCULUS

The origins of FC can be dated back to the 1690s, and its theory was developed mainly in the 19th century. Over the years, a lot of applications have been found within the range of FC viscoelasticity [5], heat transfer phenomena [6] and control engineering [7–9], bioengineering [10], traffic modeling [11, 12], game theory [13], etc.

The fractional-order integral of the integrable function $f(t)$ with $\alpha \in \mathbb{R}_+$ is defined as:

$$_aD_t^{-\alpha} f(t) = \frac{1}{\Gamma(\alpha)} \int_a^t \frac{f(\tau)}{(t-\tau)^{1-\alpha}} d\tau, \tag{2}$$

where $\Gamma(\cdot)$ is the Gamma function, $_aD_t^{-\alpha}$ is the fractional integral of order α in $[a, t]$. The αth Riemann-Liouville fractional-order derivative of function $f(t)$ is defined as:

$$^{RL}_{a}D_t^{\alpha} f(t) = \frac{1}{\Gamma(n-\alpha)} (\frac{d}{dt})^n \int_a^t \frac{f(\tau)}{(t-\tau)^{1-n+\alpha}} d\tau, \tag{3}$$

where $n = [\alpha] + 1$ and $[\alpha]$ denotes the integer part of α. The Caputo fractional-order derivative of order α of funtion $f(t)$ is defined as:

$$^{C}_{a}D_t^{\alpha} f(t) = \frac{1}{\Gamma(n-\alpha)} \int_a^t \frac{f^{(n)}(\tau)}{(t-\tau)^{1-n+\alpha}} d\tau, \tag{4}$$

where $n = [\alpha] + 1$.

From the above definitions of fractional-order differential operators, lots of complex dynamic systems with complex memory behaviors can be more properly described by FC intrinsically. In fact, most naturally occurring phenomena were found to obey the power-law relation, and many researchers found that this stunning innovation may derive from the inherent results of the linear fractional-order differential equations by the Mittag-Leffler function, which exhibits a power-law asymptotic behavior [14]. Therefore, power-law related topics, such as its origins and validation, have become an active area of research [15, 16]. Therefore, FC is being widely used to analyze the random signals with power-law size distributions or power-law decay of correlations [5, 17].

For instance, the sharp spikes or occasional bursts of outlying observations cannot be described by the conventional Gaussian models. Since non-Gaussian signals and noises tend to produce large-amplitude fluctuations from the average value more frequently than Gaussian ones do, they are most likely coming from non-Gaussian signals and noise, like colored noise rather than white noise [18]. Stable distributions provide a useful theoretical tool for this type of signals and noises [19]. A univariate distribution function $F(x)$ is stable if and only if its characteristic function has the form:

$$\phi(t) = exp\{jat - \gamma|t|^{\alpha}[1 + j\beta\,\mathrm{sign}(t)\omega(t,\alpha)]\}, \tag{5}$$

where

$$\omega(t,\alpha) = \begin{cases} \tan\frac{\alpha\pi}{2}, & \text{if } \alpha \neq 1 \\ \frac{2}{\pi}\log|t|, & \text{if } \alpha = 1 \end{cases}, \tag{6}$$

$$\mathrm{sign}(t) = \begin{cases} 1, & \text{if } t > 0 \\ 0, & \text{if } t = 0 \\ -1, & \text{if } t < 0 \end{cases}, \tag{7}$$

and

$$-\infty < a < \infty,\ \gamma > 0,\ 0 < \alpha \leqslant 2,\ -1 \leqslant \beta \leqslant 1. \tag{8}$$

An α stable characteristic function (or distribution) is determined by four parameters: α, a, β and γ. α is called the characteristic exponent. A small value of α will imply considerable probability mass in the tails of the distribution. That is, the smaller α is, the heavier are the tails. $\alpha = 2$ corresponds to the Gaussian distribution (for any β). γ is a scaling parameter called the dispersion. It is similar to the variance of the Gaussian distribution. β is a symmetry parameter. $\beta = 0$ indicates a distribution symmetric about a. In this case, it is called symmetric α stable or $S\alpha S$ distribution. a is a location parameter [19]. The characteristic exponent α for distribution can be calculated using McCulloch's method, which provides consistent estimators for all four parameters.

Autoregressive fractionally integrated moving average (ARFIMA(p,d,q)) processes are widely used in the modeling of long range dependence (LRD) time series, where p is the autoregressive order, d is the level of difference, and q is the moving average order [20]. The intensity of self-similar of ARFIMA is measured by the parameter d, which is related to the Hurst exponent [21, 22]. In 1989, Gray *et al.* proposed a new class of long memory GARMA models, which generalized the ARFIMA model by using Gegenbauer polynomial expansions [23]. It is allowed for long-term dependency in stationary models associated with any frequency $f \in [0, 0.5]$. Thus, GARMA model is believed to be particularly more appropriate for data with slowly damping autocorrelations with a cyclic pattern.

ENERGY INFORMATICS

Environmentally sustainable development is one of the foremost concerns identified according to a worldwide survey of the issues dominating the future by the United Nations [24]. Consequently, EI is a promising research filed that combined with energy management with computer science (CS) and information & communication technology (ICT). Now it arouses so much attention that some academic departments even establish the center for EI, such as the University of Southern Denmark and University of Southern California (USC). The overall EI academic community cannot afford to be a bystander in tackling environmental sustainable development and resource conservation. The future applications of the EI areas may lie within the following fields:

1. Smart Cities by investigating the synergies between demand patterns and supply availability of energy flows in cities and communities to improve energy efficiency, increase integration of renewable sources, and provide solutions for extreme situations, like the accident of stampede and contagious disease.

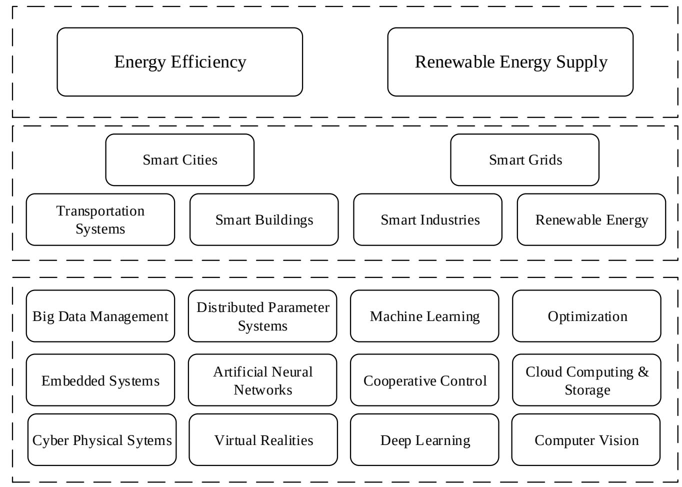

FIGURE 1. MAIN SCOPES OF EI RESEARCH [25]

2. Smart Grids by developing ICT-centred solutions for coordinating the supply and demand in environmentally sustainable energy networks.
3. Smart Buildings by developing optimal solutions for improving the energy efficiency of buildings such as heating, ventilation and air conditioning (HVAC), lighting and elevators.
4. Smart Industries including the solutions for improving the energy efficiency and predictability of energy intensive industrial processes, without compromising process and product quality.
5. Transportation Systems by integrating computing and networking technologies so as to realize the full potential of cyber physical systems (CPS)reducing our dependence on fossil fuels and our greenhouse gas emissions, such as optimizing delivery truck routes, avoiding traffic congestion.
6. Renewable Energy by transforming traditional gasoline vehicles to the electric vehicles with smart batteries and utilizing sustainable energy like wind and solar energy as power sources.

Fig. 1 highlights the main scopes of EI research. The development of EI is driven by two overall goals energy efficiency and renewable energy supply. In the context of these themes, a number of use cases have already emerged, for instance commercial buildings and residential buildings, industrial plants, public transportation. It should be also noted that this categorization introduced is based on the author's understanding, which can be of difference from diverse angles. In addition, most of the fields are overlapped and interacted with other fields, and they are not mutually exclusive. Inevitably, it is difficult to claim boundaries between them. As stated in the beginning of this article, the underlying EI problems are no longer within one stakeholder. For example, the allocation of the charging stations for the EVs can be categorized in the Smart Cities as well as Renewable Energy and Transportation Systems. Wind and solar energy are currently used to power many building ventilation devices, and this topic could also be assorted in the Smart Buildings and Renewable Energy, which could be also related to the Smart Grids.

Today we are living in a world that is strongly connected with each other and influenced by the flow of information—Facebook, Tweeter, Snapchat, Wechat, etc. Thus each sample and each case should not be regarded as independent when doing modeling and statistics process control (SPC). Sharing information with each other or consulting more than one experts is no longer a new thing in the Internet based society, while a better utilization of these huge data can lead to the ultimate goal—to make the entire system smarter. To build a city with smart grids and CPS, numerous factors should be taken into consideration by supervisors, politicians, scholars and engineers. Besides, all departments should stay together to fight against multiple regional crimes (e.g. drug dealers and scams criminals) and human caused catastrophes (e.g. the accident of stampede, fog & haze and nuclear explosion). Therefore, for the typical physical system which has a long-term memory can be better characterized by FC, such as in battery management, viscoelasticity modeling etc. For the large social systems, especially with human interactions making system intricate and complex, each individual should not be regarded as "smooth and uncorrelated", but rather "frictional and glued" with an exponent which measures the correlations between each other in a pow-law relation.

The real world has strong connections and coupling effects, which make it such a long memory that conventional integer order may lose something important, thus leading to the detour [26]. The bottom part of the box the Fig. 1 contains a selection of CS/IS sub-communities that related to EI. It is not hard to find these sub-communities have strong connections within the knowledge of FC. Therefore, the whole complex system should be regarded as a whole in a macro view, rather than in a simplified and isolated perspective. In the following sections, we structure research challenges in the area of EI and review some selected work focusing on high-impact EI use cases with the applications of FC.

ACHIEVEMENTS WHICH MAY BE WITHIN REACH

We next describe each of the elements in the preceding framework. After reviewing many examples of what engineers and scholars are currently doing to solve problems and how they contribute to the comprehensive understanding within the scopes of FC. It is indispensable to achieve an integrated solution that consider both the supply and demand side of energy. During the booming development of the EI, we have also carried out the literature review in several related areas and found that todays emerging CPS and big-data strategy provide an hereditary foundation

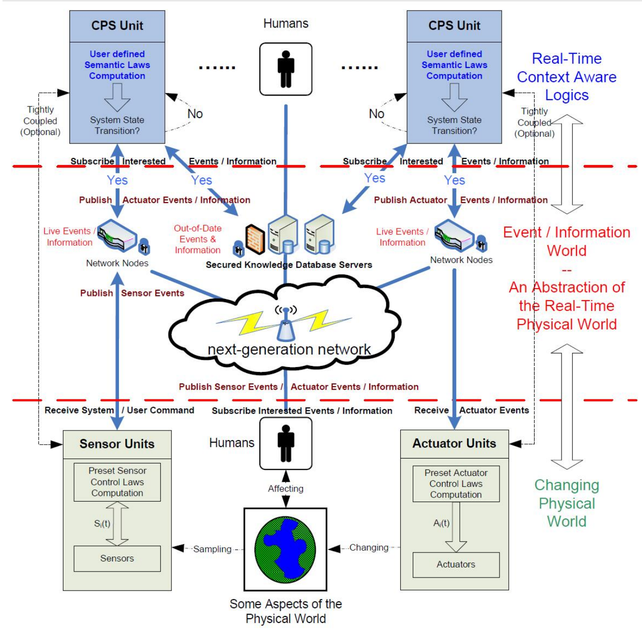

FIGURE 2. A PROTOTYPE ARCHITECTURE OF CPS [28]

for EI and FC. Therefore, it is the time to consider and reconsider this mosaic information centred world in the FC way. There are many hot keywords—Smart grids, CPS, distributed parameter systems (DPS), renewable green energy, wind energy, smart buildings, big data, machine learning, HVAC, smart city, smart elevator, electric vehicles (EVs) charging control. It is not hard to find them connected with each other and integrated with FC intrinsically.

Cyber Physical Systems (CPS) and Distributed Parameter Systems (DPS)

CPSs are integrations of computation and physical processes. Integration of physical processes and computing is not something new. They include high confidence medical devices and systems, assisted living, traffic control and safety, advanced automotive systems, process control, energy conservation, environmental control, avionics, instrumentation, critical infrastructure control (electric power, water resources, and communications systems for example), distributed robotics (telepresence, telemedicine), defense systems, manufacturing, and smart structures [27]. At the same time, however, CPS are man-made complex systems coupled with natural processes that, as a whole, should be described by DPS in general forms. The prototype architecture for CPS is presented in Fig. 2 by [28].

Although the government and many organizations now realize that environmental sustainability is an urgent problem to address, the complex dynamics of natural and man-made systems make it futile by using integer order controls. Unfortunately, most people in the academic community are still tackling the problem in a micro view with more of the technical IOC way rather than the view of FC way. Ge *et al.* propose to characterize complex CPS in three types of fractional order models: fractional Laplacian operator, fractional power of operator and fractional derivative [29]. In the article, the authors raise three very intriguing questions—"How many actuators/sensors are sufficient and how to best configure them for a fractional DPS control process?", "Given the desirable zone shape, is it possible to control or contain the fractional diffusion process within the given zone?", if not, "how to quantify the controllability/observability of the actuators/sensors?". Ge *et al.* for the first time address the concepts of regional gradient observability for the Riemann-Liouville time fractional order diffusion system in an interested subregion of the whole domain without the knowledge of the initial vector and its gradient [30]. Moreover, they also present explicitly the closed-loop solutions to the boundary feedback stabilisation problem for the time fractional order anomalous diffusion system [31]. In addition, a general approach to the optimization of the observation horizon of moving sensor trajectories for parameter estimation of distributed systems is presented in [32]. Two important problems optimal mobile sensor trajectory planning and the accuracy effects and allocation of remote sensors are discussed in [33, 34]. An economical and robust swarm system, which associates swarm intelligence with centroidal Voronoi tessellations (CVT) is constructed to achieve static and dynamic formation control [35]. In recent years, networked control systems compose a new class of control systems including definitive problems such as delays, loss of information and data process [36]. Therefore, the fractional gain scheduled controller with delay-adaptive gains for a smart wheel is proposed as to the current networked CPS systems in [37]. What's more, load modeling is undeniable an essential pivot in the future smart grids at the limit of infinitely many loads. Thus, L.Shalalfeh and E.Jonckheere have proposed a novel way to solve the load aggregation effect in power grid using Berg load modeling and fractional dynamics [38]. Li *et al.* exhibit that power laws may yet serve as a universality of data in Cyber-physical networking systems (CPNSs), which are useful for data modeling and analysis [39].

Big Data Management

If CPS is about the integrated computation, communication and control using information from overall system, the big data strategy make CPS and DPS easy and applicable in the advent of wearable devices and cloud storage. Thanks to a decade of progress in digitizing information records, the stored data are now usable, searchable and actionable. The amount of data being digitally collected and stored is vast and expanding rapidly. As a result, the science of data management and analysis is also advancing to enable organizations to convert this vast resource into information and knowledge that helps them achieve their objectives [40]. This information is a form of "big data" not only for its sheer volume but for its complexity, diversity and timeliness [41]. However, a lot of literatures are more concerning implementing techniques e.g. Apache Hadoop to manage data rather than explore the aggregated data in depth. Why not us equipped big data with FC?

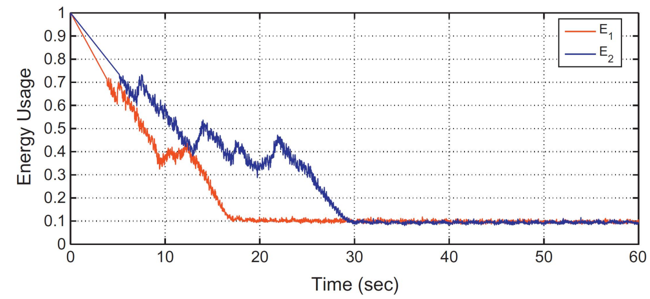

FIGURE 3. ENERGY USAGE E_1 (RED) UNDER THE FRACTIONAL ORDER CONTROLLER VS ENERGY USAGE E_2 (BULE) UNDER THE INTEGER ORDER CONTROLLER [47]

Now a lot of publications within the range of FC which could be integrated with the big data management inherently are as follows: managing cardiac disease and abnormal heart rate variability (HRV) remain challenging problems with an enormous economic and psychological impact worldwide. The HRV or the state of heart observation (SOHO) can be used to monitor the cardiac disease, abnormal psychological disorders and so on [42–44]. The heart rate dynamics can be more accurately modeled via fractional differential equations and fractal state equations [45]. Some applications of mathematical tool of the FC to biomedical signal processing to remove noise, enhance useful information, and generate fractal signals can be found in [46]. Electric lighting is one of the most primary energy consumption since the demand of immense illumination. If the usage of lighting energy is collected and stored in the cloud, these information can be used for the cognitive optimal control of the energy consumption. Yin *et al.* propose a hardware-in-the-loop prototype of an adaptive minimum energy cognitive lighting control to achieve comfortable illumination while minimizing the energy consumption in hybrid lighting. Besides, the performance of the designed controller is compared with both fractional order and integer order controllers in [47]. It can be foreseen that more EVs are available on the road in the near future, which accelerates the speed of exchanging new and charged batteries. Finally, it again goes back to the optimal solution of distribution problem via the big data strategy. With more incoming data, it would be much easier and imperative to implement FC with the big data solutions.

Cooperative Control

Transition from chaos to turbulence where the range of interaction and strength of interaction play an important role in study of system of large numbers is connected with fractional dynamics. As the long range interactions are so common in crowd of pedestrians, it is reasonable to describe the dynamics of crowd of pedestrians using FC. Possibilities of applying FC in the modeling of crowd of pedestrians have been shortly reviewed and discussed from different aspects such as descriptions of motion, interactions of long range and effects of memory in [48–50]. Besides, modeling methodologies can be divided into three parts—micro-scale, macro-scale and mesco-scale, respectively. Most of these modeling methods are based on inspirations that the crowd of pedestrians can be treated as moving particles, smoothing fluids, or granular flows in different scales. However, the modeling and control of crowd of pedestrians can be extremely difficult as existence of the long range dependence and interactions have been included [51]. Due to the features mentioned above, applying FC in the modeling of crowd of pedestrians while some phenomena observed from realities are impossible or not easy to be considered just in the framework of IOC. It has been shown that the fractional model with distributed order can be effectively used to describe the accelerating and decelerating of sub-diffusion and super-diffusion [52]. The problem of remote stabilization for fractional-order systems with input time-varying delays of $0 < \alpha < 2$ via communication network is investigated in [53]. Some simulations showing the effectiveness of the proposed controller to stabilize a FO system are also presented in the paper. The optimal maintenance planning (OMP) for sustainable energy efficiency lighting is proposed by Ye *et al.* [54–57]. In addition, this optimal control model is ultimately solved by a model predictive control (MPC) approach under the control system framework. [58] proposes an online analysis method based on a sliding Hurst window that can be applied to estimate the heart status. Using this method, the hardware requirement is notably low, and the execution time is short. Thus, it can be embedded in platforms for human robot cooperation and further used for the pattern recognition and deep learning.

Battery Management System (BMS)

The electrochemical reactions inside lithium-ion battery are complicated in the running EVs, which is a highly nonlinear dynamic system. Thus, FC is widely used in the management of battery modeling, state-of-charge (SOC) estimation and its further applications on EVs. [59] uses FC model obtained by system identification to estimate crankability of battery, [60] proposes lead acid battery state of charge estimation with FC, and [61] deals with a fractional order state space model for the lithium-ion battery and its time domain system identification method. [62] proposes estimating the SOC for lithium-ion batteries, that utilizes a FO sliding-mode observer (SMO). The fractional Kalman

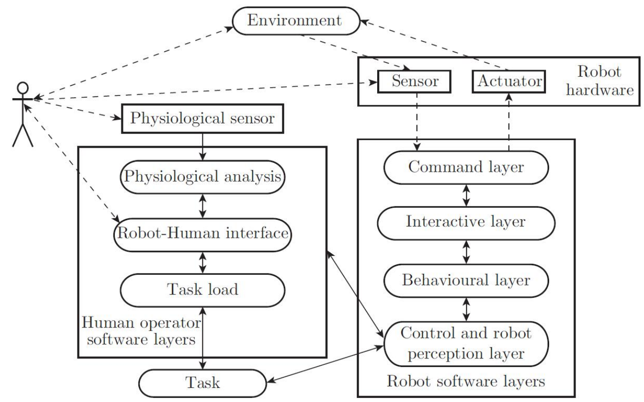

FIGURE 4. HUMAN-ROBOT COOPERATION PLATFORM IN [58]

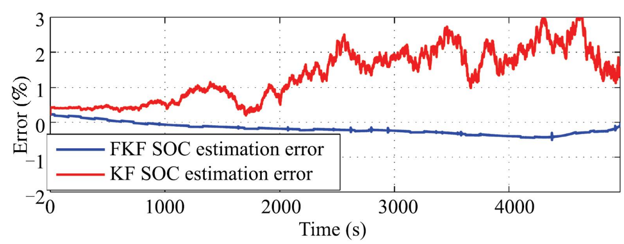

FIGURE 5. SOC ESTIMATION ERROR [63]

filter (FEF) is utilized to estimate the SOC of the lithium-ion battery based on the fractional-order model [63].

Renewable energy

Wind, solar and hydroelectricity are three emerging renewable sources of energy.

Wind Energy Wind being a weather driven renewable resource with strong dependencies on the climate system, its variability occurs in time scales ranging from minutes through hours, days and several years [64]. With the integration of wind energy into electricity grids, it is becoming increasingly important to obtain accurate wind speed/power forecasts. Kavasseri *et al.* examine the use of fractional-ARIMA (ARFIMA or FARIMA) models to model, and forecast wind speeds on the day-ahead (24 h) and two-day-ahead (48 h) horizons to parsimoniously capture time series measurements in the presence of correlations, both short term and long term. The models are applied to wind speed records obtained from four potential wind generation sites in North Dakota. The results suggest that the proposed method is able to improve the accuracy of forecasting by an average of

42% compared to the persistence method [65].

Solar Energy The indirect prediction approach on solar radiation is complicated due to the requirement of solar radiation, cloud movements and temperature information. The contribution of power production from photovoltaics (PV) systems to the electricity supply is constantly increasing. However, the PV panels provide electrical power only during the day with a peak power around the midday and power production variations may also occur due to the fluctuation of the solar irradiance. Therefore, an efficient use of the fluctuating solar power production is proposed by using forecasted information on the expected PV power production [66]. The ARFIMA model is built to characterize the long memory property in order to achieve better predictions of the PV power [67, 68]. A fractional order PI controller has been tuned for current control loop of the three phase grid-connected PV system and the system responses are compared with the responses of the closed loop system with integer order controller. Simulation results show the improvement in the performance of grid-connected PV system by using the fractional order controller [69, 70]. When small-size photovoltaic modules are adopted, optimizing the efficiency of the harvesting process and tracking the maximum power point (MPP) becomes very difficult, and the development of a photovoltaic harvester has to be preceded by extensive simulations [71]. [72] proposes a new maximum power point tracker (MPPT) called fractional order extremum seeking control for grid-connected PV systems tasks to better accommodate rapid varying solar irradiance for PV arrays. It shows that the proposed MPPT based on FC has faster convergence speed in comparison to integer order.

Hydroelectricity With the rapidly development of hydropower plants, hydropower plays an important role in maintaining the stability of electrical systems all over the world. However, because of lacking a comprehensive set of service and management system, how to maintain the stability of a large hydroelectric station is a challenging problem. Moreover, the long range dependence (LRD) and heavy tailedness of the cannot be described by the traditional integer mathematical models. Therefore, modeling hydrological variables using a stochastic process is not always an easy task. In the [73], the author highlights the necessity of long-memory models characterized also by a strong flexibility in modeling the low-lags autocorrelations by introducing ARFIMA models which represented a potentially powerful tool for modeling stationary hydrological records. Sun *et al.* applied the ARFIMA model to analyze the data and predict the future levels of the elevation of Great Salt Lake (GSL) [74]. The results showed that the prediction results have a better performance compared to the conventional ARMA models. Li *et al.* examined 4 models for the GSL water level forecasting: ARMA, ARFIMA, GARCH and FIGARCH [75]. They found that FIGARCH offers

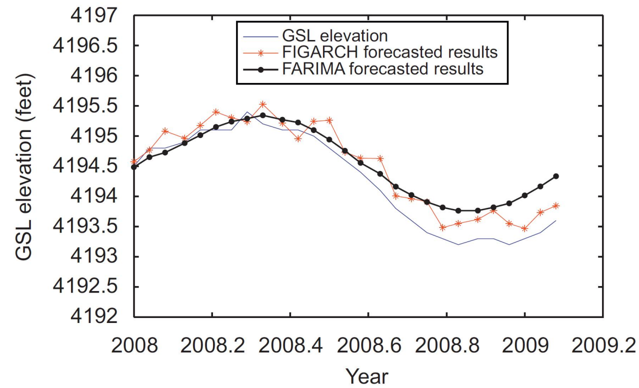

FIGURE 6. GSL ELEVATION FORECAST USING ARFIMA AND FIGARCH MODELS [22, 76]

best performance indicating that conditional heteroscedasticity should be included in time series with high volatility. Sheng and Chen proposed a new ARFIMA model with stable innovations to analyze the GSL data, and predicted the future levels. They also compared accuracy with preceding results [22, 76].

CONCLUSIONS

Due to the increasing importance of producing and consuming energy more sustainably, EI has evolved into a thriving research area that attracts much scholarly attention recently. In most cases, engineers use standard differential equations to develop the dynamic tools that they use to model, and ultimately to control the designed systems. For many applications, these tools are sufficient and effective, but in the emerging areas of EI, these conventional integer order approaches have limitations. One of the well-known limitations is that the conventional signal processing techniques simplify the analysis process, which assumed to be independent and identically distributed (i.i.d.) with weak coupling between values at different times, and at least stationary. However, in the presence of many signals non-Gaussian signals, such as financial data, communications networks data and many types of man-made noises with LRD, the conventional solutions may have many dilemmas. The spiky signals make it more outliers counted, and variables have infinite variance or variables have non-identical distribution. In fact, these non-Gaussian distributed processes can be included in the fractional processes or fractional systems, which can be best modeled by using fractional order signal processing (FOSP) technique and fractional order system identification.

From what we have discussed above, it can be clearly seen that lots of treasures that in the EI scopes can be only dug with the powerful tool of FC. It is time that we direct the relevant issues and opinions in the context of FC so as to enhance the sensitivity of scholars to the urgency of the environmental sustainability challenges for the EI community. At the same time, to our best knowledge, many problems are still open calling for research cooperation of multi-disciplines such as mathematical modelling, engineering applications, and information sciences.

ACKNOWLEDGEMENT

We would like to thank Dr. Yunning Zhang from China Three Gorges University for her constructive comments. Kai Liu is supported by a scholarship from the China Scholarship Council (CSC). YangQuan Chen acknowledges Hubei Provincial Department of Education for financial assistance through the "Chutian Scholar" program. We would like to thank anonymous reviewers for their insightful comments on the paper.

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