Applications of High Performance Computing to Arrive to Renewable Energy Solutions

HPC and Renewable Energy

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Abstract – This paper presents past, present, and future attempts at arriving at renewable energy solutions with the use of high performance computing. It compiles several efforts and methods at the will of different organizations and computing companies. It will discuss various technologies used and figures produced as a result of computation dedicated to these fields. A highlight of renewable energy within high performance computing includes but is not limited to wind energy which most of our tangible evidence will pertain to. This paper concludes with a hypothetical approach to what the future holds for renewable energy in computing.

Additional Key Words and Phrases – renewable energy, high performance computing, wind energy, wind farm, solar energy, exascale

I. Introduction

Prevalence in the necessity of eradication of fossil fuel use as a primary energy source has increased greatly at *least* in the past decade as a result of steep increase in global carbon emissions [3]. Most recently exemplified in the 2022 increase in gas prices in the United states various demographics such as farmers have been financially devastated by their necessity to fossil fuel consumption [25]. World organizations such as the International Energy Agency have issued statements facilitating the necessity to generate more energy through renewable sources in the future [11].

A. *Politics*

Since 2016, 38 countries including the United States have declared a state of climate emergency [2]. In the realm of philosophical considerations ethical concerns with significant pertinence to the future of renewable energy have been raised. Bjorn Lomborg, previous director of the Danish Government's Environmental Assessment Institute, provided an analysis regarding widespread climate panic [13]. The Danish environmentalist assured that advances in technology with focus in renewable energy are realistic as well as momentous to deciphering the frontiers of our deteriorating climate [13].

It is important to highlight that using computing to save the environment is not a notion without controversy. High performance computers utilize clusters in order to operate. These clusters often run in parallel and are composed of compute nodes which execute tasks as needed [22]. They are what run the decision making behind high performance computing [23].

With that in consideration it can be inferred that such technology would require power to operate all said clusters at once. In fact the 2010 era NVIDIA Tesla GPU featured in the Tianhe-1A supercomputer reported 4.04 megawatts of energy consumption [17]. To put it into perspective that is about $1.27 million per month of electricity dedicated to this type of computing if it is operating for only eight hours daily. This is mostly due to how incredibly power intensive it is to cool these computers down.

Luckily solutions to these issues currently exist and are already being implemented in modern computing. One option is to simply build data centers in colder climate areas to save on the electricity it already costs to cool these computers. This has been done to data centers in Iceland, but has proven to be incredibly unethical due to land consumption and an unnecessary use of natural space [1]. Liquid cooling is a more common response to energy conservation within high performance computers which will be entailed further in discussion of some of the U.S.'s most environmentally efficient data centers.

B. *Computing*

A dynamic production of technical solutions is pertinent to resolving climate issues. A consideration to make is the sensitive nature of time in climate. Due to these grounds it is imperative to present and embrace high performance computing as a viable explication of increased efficiency in renewable energy options. Optimization of renewable energy sources will be categorized as optimization of renewable energy production as well as optimization of renewable energy options. In the case of high performance computing the dialogue will surround small scale and large scale production of solar and wind energy options along with improvement of existing energy options such as wind turbines and solar panels.

II. Past Solutions

Due to the recent nature of the declaration of climate emergency, preliminary renewable energy solutions as a result of high performance computing are scarce. Despite lack of archaic uses there is evidence of high performance computers being used for renewable energy as early as 2004. As of recently the United States Department of Energy has offered funding to resources surrounding high performance computing [19]. Prior to this though, there were a handful of significant supercomputers and projects surrounding this method of computing which have paved the way for modern high performance computing regarding renewable energy issues. They will be found below described at length chronologically to their release.

A. *Jaguar →Titan – 2004 →2012*

The Oak Ridge National Laboratory (ORNL) commissioned high performance computer Jaguar in

2004 categorized as a Cray XT supercomputer in partnership with Cray, Inc. [26]. One of its many major tasks was surrounding energy security– overall it "delivered more than 1.4 billion core hours in 2011… for computational simulations" [26]. Jaguar was a 2.3 petaflop system meaning it has the ability to calculate 2.3 quadrillion calculations per second [26]. It was said to be working on renewable energy sources such as generating nuclear power reactors through aforementioned simulations [20].

Its main focuses were examining reactor efficiency in order to optimize life span as well as run time [20]. ORNL went on to upgrade the outdated XT system to an XK7 in 2011 [26]. After this upgrade, high performance computer Titan was commissioned and performed almost ten times faster than jaguar at 20 petaflops or 20 quadrillion calculations per second [26]. This jump in speed strongly pertained to the change in node boards (from XT to XK7) in conjunction with the addition of NVIDIA Tesla processors and overall processor upgrade which we see very frequently in modern high performance computers [26]. Titan's workloads were broken down into three categories the first of which being energy security [26]. This means that one third of the purpose that Titan served was arriving at energy solutions– it is evident that high performance computers with this much dedication to energy become far more scarce as the years go on and they are assigned more diverse tasks.

An outcome of this computing allocation was the development of organic photovoltaic simulations [20]. Out of necessity for accurate and efficient configurations of solar cell models, Titan was able to produce these simulations in order to expedite production of solar energy [20]. Titan assisted in arriving at the conclusion that organic solar cells were simplest for reproduction and most cost effective to transfer onto polymer film, thus providing ORNL ample collections of three dimensional models to utilize for commercial use [20]. With the evolution from Jaguar to Titan, the Oak Ridge National Laboratory proved to use high performance computing assiduously to arrive at renewable energy solutions.

B. *OMSoP – 2013*

In February of 2013 a research project titled OMSoP was initiated by the European Union with a limited time requirement to achieve a system which combines solar power energy with micro-gas turbines in order to create a new renewable energy source [5]. The project resulted in an EU-China collaboration which led to the release of OMSoP at the EU-China summit in 2015 with the intention to produce an energy system capable of 3-10 kW of electricity for small-scale use [5]. Some of these uses include powering houses and electric cars [5]. This project used high performance computing clusters in order to run complex design simulations as well as for system integration and demonstration [5]. The use of clusters in conjunction with parallelization allowed this project to be conducted within the desired small time frame which they were given [5].

C. *Peregrine – 2014*

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) began construction of their 2014 era high performance computer Peregrine in 2011 and was made available for production use in January of 2014 [27]. It was considered the world's fastest high performance computer dedicated solely to renewable energy and energy efficiency running at 1.2 petaflops or 1.2 quadrillion calculations per second [27].

Concerning hardware, the Peregrine computer features IvyBridge processors as well as SandyBridge processor based compute nodes [27]. It uses a network attached storage solution as well as a parallel file system in order to maintain speeds [27].

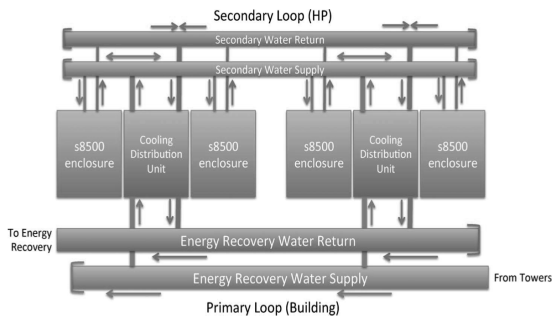

Fig. 1. Peregrine Hydronics Diagram

In conjunction with their computing dedication to renewable energy, NREL utilized hydronics to provide warm-water cooling to their reuse enclosures as pictured in Fig. 1 [27]. The National Renewable Energy Laboratory itself utilizes waste heat reuse (also shown in Fig. 1 in order to maintain a power usage effectiveness (PUE) of 1.06 which at the time became one of the most sustainable high performance computing facilities [27].

NREL assigned Peregrine's node hours to several bin areas of studies [27]. The most pertinent to this discussion are solar energy, bioenergy, and wind and water power with emphasized focus on adapting material physics in order to commercialize complex problems surrounding structure creation [27]. A strong area of focus for NREL was using "planetary boundary scales of turbine wakes" essentially to optimize wind turbine function alone and through wind farm simulations [27].

Peregrine produced something called the VASP simulation program which showed analytical capabilities to solve material problems including but not limited to transition-state energies and surface reaction [27]. It also employed weather research and forecasting modeling in order to produce visual evidence of solar and wind patterns to escalate energy sources' consumption [27]. It was eventually put into retirement in 2019 followed by its successor's release [15].

III. Present Solutions

Since the previous early two thousands to mid two thousand ten era high performance computers mentioned previously, computing power has increased tremendously. Modern high performance computers which are currently still in commission are calculating and modeling faster than ever before. The Oak Ridge National Laboratory along with the National Renewable

Energy Laboratory have each released an additional high performance computer more than doubling their initial stage super computers' processing power [21][16].

A. *Summit–2018*

The Oak Ridge National Laboratory decommissioned their prior high performance computer Titan in lieu of its successor Summit's release. At its release, Summit was declared ORNL's fastest high performance computer running at 200 petaflops or 200 quadrillion calculations per second which is approximately ten times faster than predecessor Titan [19].

Seeing as it is operational at the Oak Ridge National Laboratory a good portion of what Summit is tasked with pertains to renewable energy solutions. Their intention is for it to perform calculations on coastal jet levels in order to optimize our use and understanding of wind energy [9]. In conjunction with NREL Summit will be expanding ExaWind which is an open-source library for code pertaining to the physics of wind turbines and wind farms [4]. Testing turbine and wind farm efficiency prior to supercomputing was not something that was really achievable, so with the ability to have so many calculations run to produce simulations it is expected that wind farms will potentially be optimized by this research [4].

The ExaWind features codes including Nalu-Wind which is described as "a generalized, unstructured, massively parallel, incompressible flow solver for wind turbine and wind farm simulations", AMR-Wind described as "a massively parallel, block-structured adaptive-mesh, incompressible flow solver for wind turbine and wind farm simulations", and OpenFAST which is a wind turbine simulator [8][7][4].

Summit is currently still operational and one of the leading supercomputers in the United States for renewable energy research. It is in partnership with the Department of Energy. On top of the wind energy research, Summit has also been working on projects surrounding solar energy. Its "the cell's molecular machine" project focuses on adenosine triphosphate synthase simulations to optimize solar energy devices [12]. Similarly Summit's flexible, lightweight solar cells project featuring organic photovoltaic simulations is intended to broaden understanding of solar cell model configurations to potentially compete with existing solar cell models [12]. They will also be looking into modeling fusion reactors to attempt an approach to meet "growing global energy demands" [12].

B. *Eagle–2018*

The National Renewable Energy Laboratory came out with their current model high performance computer Eagle in 2018 [16]. It is considered NREL's fastest high performance computer yet running at 8 petaflops or 8 quadrillion calculations per second which is almost four times the performance of its predecessor Peregrine [16]. This also implies that it is able to perform just as many more calculations per watt of energy it consumes making it more efficient as well [16]. It also features the same efficient warm water cooling method as Peregrine.

As mentioned prior, NREL has been working on ExaWind alongside ORNL. They have been using atmospheric boundary layer simulations to further understanding pertaining to complex wind flow [14].

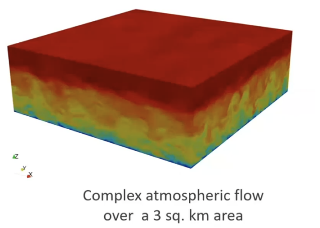

Fig. 2. Atmospheric Flow Model

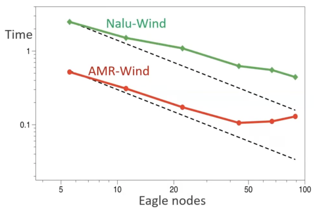

Fig. 3. Strong Scaling Performance

A representation of high and low wind speeds is represented in red and blue respectively in Fig. 2 in order to demonstrate a scale of how wind turbines experience wind [14]. NREL used both their AMR-Wind and Nalu-Wind codebases in order to test atmospheric flow's strong scaling performance [14]. Fig. 3 features visual representation of AWR and Nalu's performances. As pictured Nalu performs slower than AWR performance wise due to their varying structures. NREL is currently applying these models to design of wind turbine power generators and rotor thrusts [14].

NREL is also using similar models on ocean behavior in order to launch a potential endeavor into offshore wind power plants [4]. Their goal is to be able to simulate ocean movement in order to potentially prepare for wind farms in the ocean in order to lessen land consumption [4]. The Nalu-Wind solver has already produced simulations of how wind flows over ocean waves [4]. The Department of Energy states that they are "captur[ing] fundamental interactions" through their modeling in order to better understand "offshore atmospheric dynamics" [4].

Over the past few years NREL has been championing renewable energy research with explicit goals and objectives of accomplishment through high performance computing. A very significant portion of the laboratory's computing power has gone towards renewable energy solutions or subjects similarly related.

IV. Future Solutions

Although a lot of progress has been made through supercomputing and renewable energy already it is expected that the results are supposed to again multiply tenfold. High performance computing is undergoing a shift from petascale to exascale and is expected to transform computing efficiency greatly.

Exascale computers will be able to do quintillions of calculations as opposed to the current ability to do quadrillions of calculations [6]. It is the next generation of high performance computers which are expected to handle large volumes of data and provide even greater insight to world issues we are currently facing [6].

A. *Frontier – 2022*

The Oak Ridge National Laboratory is set out to come out with their own exascale computer titled Frontier to be the successor of Summit. Frontier will be operating at 1.5 exaflops which is said to be about 50 times faster than fastest high performance computers today [18]. Given the work that ORNL has already done with their high performance computers and with their partnership with the Department of Energy they are suspected to continue exploration into energy.

In fact ORNL has set out to make one of Frontier's main tasks being in material science and energy production [18]. Presumably Frontier will continue to contribute to the ExaWind project and be able to produce more data and simulations similarly to how Summit has. It was set out to come out in early 2022, but are still awaiting its operational release.

B. *Kestrel – TBD*

The National Renewable Energy Laboratory has announced their successor to Eagle which will be titled Kestrel. This will be another exascale computer featuring a similar liquid cooling method to previous models while still trying to maintain their PUE score of 1.036 [10].

NREL will maintain its goals surrounding wind energy while possibly expanding for research to "harness… from geothermal, water, …solar, as well as fuels" [10]. Similarly to Summit they will be focused on material sciences and future energy systems, and overall will just continue to make modeling and simulation progress in order for efficient renewable energy sources to be produced [10]. The exascale era for renewable energy will continue to follow the strong path which it is on, but with way higher computing and processing power. There is not yet a release date set for Kestrel, but construction should have begun in 2022 [10].

V. Conclusion

Initial attempts at applying renewable energy to real world computing solutions were applied at a smaller scale and due to lack of the advanced computational power did not produce groundbreaking results. With advancements in computing power and more funding behind national research it was made possible to view large strides in progress regarding data processing and simulation productions. With the advancement of simulations, efficiency of renewable energy is expected to increase as well, especially with exascale computing solutions to come. Energy in the United States is expected to transform greatly as results from high performance computing solutions continue to come out.

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