The large-scale integration of renewable generation in the electric grid has created a new decision-making paradigm in power system operations. New algorithms must be developed to harness the full potential of these uncertain power sources. My research goal is to develop new efficient, adaptive algorithms enabling optimal use of renewables. To do so, I aim to utilize novel online optimization models, a framework that has proven performance guarantees. Online convex optimization is particularly adapted to this problem because its training and decision-making processes run concurrently. Decisions can therefore be made faster and more dynamically than with an offline approach. I aim to expand the operating conditions under which performance guarantees can be established. Specifically, I want to prove sub-linear regret bound for an online interior-point method when applied to stochastic problems. This model would allow solving the optimal power flow in an online fashion for renewable electric systems by enabling the inclusion of time-varying constraints.

**Outline of Proposed Research**

Jean-Luc Lupien

**Title:** Online convex optimization for real-time control of renewable electric grids

**Problem statement:** The large-scale integration of renewable power sources into the modern electric power grid has created many new challenges to be addressed [1,2]. Renewable power sources are intrinsically intermittent in their power generation which creates uncertainty in power generation. High performance, adaptive and reliable operative models are crucial, in such uncertain conditions, to maximize the potential of renewable-powered grids. Additionally, renewable energy sources have much lower ramp-up times which justifies solving the optimal power flow (OPF) problem every few seconds instead of every few minutes [3]. The challenge is, therefore, to design reliable, computationally efficient algorithms capable of real-time decision-making.

I propose using an online convex optimization (OCO) approach to tackle this problem [4]. OCO is a branch of machine learning in which training and decision-making are performed concurrently. This enables fast reaction-time and adaptability while guaranteeing performance. Previous research has shown the efficacy of a second-order Newton step method in solving dynamic optimization problems [3]. However, the performance of OCO methods is limited for time-varying constraints [5]. I aim, therefore, to expand the application of the Newton step-based method to problems with time-varying constraints. This would enable better performance of online control algorithms which translates to more efficient and reliable operation of renewable grids.

**Objectives:** My objectives are to develop an online interior-point method for dynamic convex problems involving time-varying stochastic constraints and to formulate an online optimal power flow model. To do so, I must (1) adapt the Newton step algorithm to convex problems with time-invariant constraints. Once regret bounds are found for static constraints [3], I will (2) extend the method to time-variant equality constraints based on the primal-dual Newton update [6] which can more accurately model real-world settings.

Then, I will use the new method to solve the optimal power flow in real-time. First, (3) I aim to create a realistic dynamic model for the online OPF of renewables grids. Finally, (4) I will numerically test the developed approach on real grids to support my claims.

**Impact of Research:** In response to the changing power landscape, novel control algorithms need to be developed if we are to harness the full potential of renewable energy and guarantee the robustness of the grid. OCO-based algorithms can often be the methods of choice for such dynamic, uncertain challenges [7,8]. Interior-point methods, when used in offline settings, have proven to be extremely powerful and efficient [3]. To extend such frameworks to the online setting would, therefore, produce a highly competitive option in the online decision-making space. Such an option will be crucial to large-scale integration of renewable energy sources into our modern grid as it will enable grid operators to solve the optimal power-flow in real-time.

**References**

[1] J. A. Taylor, S. V. Dhople, and D. S. Callaway, “Power systems without fuel,” *Renewable and Sustainable Energy Reviews*, vol. 57, pp. 1322–1336, 2016.

[2] F.R. Badal, P. Das, S. K. Sarker, and S. K. Das. “A survey on control issues in renewable energy integration and microgrid.” *Protection and Control of Modern Power Systems*, 4(1) :1–27, 2019.

[3] A. Lesage-Landry, J. A. Taylor, and I. Shames, “Second-order online nonconvex optimization,” *IEEE Transactions on Automatic Control*, 2020.

[4] M. Zinkevich, 2003. “Online convex programming and generalized infinitesimal gradient ascent.” *Proceedings of the 20th international conference on machine learning* (icml-03), (pp. 928-936).

[5] T. Chen, Q Ling and G.B. Giannakis, 2017. “An online convex optimization approach to proactive network resource allocation.” *IEEE Transactions on Signal Processing,* 65(24), pp.6350-6364.

[6] D. P. Bertsekas, *Nonlinear programming*. Athena scientific Belmont, 1999.

[7] A. Lesage-Landry and J. A. Taylor, “Setpoint Tracking with Partially Observed Loads”, *IEEE Transactions on Power Systems,* 33(5), pp.5615-5627,2018

[8] A. Bernstein and E. Dall’Anese, 2019. “Real-time feedback-based optimization of distribution grids: A unified approach.” *IEEE Transactions on Control of Network Systems*, 6(3), pp.1197-1209.

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