Determining Clusters with Similar Electrical Influences in a Power Network: A Deterministic Annealing based Approach

Mayank Baranwal[a] and Srinivasa M. Salapaka[a]

I. INTRODUCTION

This extended abstract provides a tool for clustering an electrical power network with many buses into pre-specified number of groups such that buses within each group have a *similar influence* over the remainder of the network. The proposed approach is general in the sense that different notions that quantify *similarity* and that quantify *influence* can be used. For ease of exposition the approach is presented for a particular practical notion of influence; more precisely the influence of one bus on another is characterized in terms sensitivity of voltage fluctuations at one bus due to reactive power perturbations at the other bus. This notion of influence is particularly useful since it encompasses electrical connectivity rather than only the network topology; for instance, two buses that are strongly electrically coupled through the network even though not directly physically connected to each other will be considered *similar* in this notion, since voltage variation at one bus brings about similar variation at the other bus. Furthermore, the grouping of buses achieved after clustering using this notion of influence is such that the voltage fluctuations at a bus due to perturbations at buses within the same group are typically more than voltage fluctuations due to perturbations at buses from other groups.

In this abstract, the buses in a power network are represented as points in an Euclidean space, where the coordinate corresponding to each bus represents the vector of pairwise electrical couplings (or influence) between the bus and other buses in the network. The problem of clustering buses into groups is cast as a combinatorial optimization problem, which is reinterpreted as a combinatorial resource allocation problem. These problems are non convex and computationally complex. In this work, the approach for clustering buses is based on the deterministic annealing (DA) algorithm. This algorithm offers two important features: (1) ability to avoid many poor local optima and (2) has a relatively faster convergence rate when compared to approaches as simulated annealing or Lloyd's/k-means algorithms. It formulates an effective energy function parameterized by an *annealing* parameter and this function is deterministically optimized at successively increased values of the parameter. The approach is tested on the IEEE-14 bus data; the tests demonstrate the efficacy of the proposed approach. Simulation results show that perturbation at a particular bus has higher influence on the buses of its resident group and has much lesser effect on buses from other groups.

[a]Department of Mechanical Engineering, University of Illinois, Urbana-Champaign, IL 61801, USA baranwa2@illinois.edu; salapaka@illinois.edu

TABLE I
CLUSTERING RESULTS FOR IEEE-14 BUS DATA

Bus #	Bus Type	Volt mag. Operating pt	Volt mag. ($2\times V_2$)	Volt mag. ($1.5\times V_6$)	Volt mag. ($2\times V_3$)
1	Slack (B)	1.0600	1.0600	1.0600	1.0600
2	PV (Y)	1.0450	2.0900	1.0450	1.0600
3	PV (Y)	1.0100	1.0100	1.0100	2.0200
4	PQ (Y)	1.0142	1.4043	1.1021	1.2372
5	PQ (Y)	1.0172	1.4082	1.1269	1.1495
6	PV (G)	1.0700	1.0700	1.6050	1.0700
7	PQ (B)	1.0503	1.2254	1.1747	1.1496
8	PV (B)	1.0900	1.0900	1.0900	1.0900
9	PQ (G)	1.0337	1.2003	1.2530	1.1270
10	PQ (G)	1.0326	1.1705	1.3088	1.1096
11	PQ (G)	1.0475	1.1179	1.4510	1.0866
12	PQ (G)	1.0535	1.0661	1.5695	1.0607
13	PQ (G)	1.0471	1.0715	1.5421	1.0606
14	PQ (G)	1.0213	1.1276	1.3650	1.0807

II. RESULTS AND DISCUSSIONS

Table I shows the clustering results for the IEEE 14 bus data [1]. The DA algorithm is employed to obtain three natural partitions (marked by different colors in the 'Bus Type' column and also indicated by the corresponding initials). Column 3 indicates the solution of the power-flow problem in p.u. (per unit), while columns 4 and 5 indicate the effect of perturbations in generator voltage magnitudes at buses 2 and 6, respectively. As is seen in columns 4 and 5 of Table I, the *influence* of these perturbations is larger at the buses belonging to the same group (cluster) where the perturbations originate. For instance, doubling the generator voltage at bus 2 results in change in voltage magnitudes at buses 4 and 5 by about 0.4 p.u. The effect of this perturbation is less severe at other buses, which do not belong to the group formed by the buses $2, 3, 4$ and 5.

As stated earlier, two buses are deemed *close* when they have close similarity in terms of the *influences* over the entire network. Columns 4 and 6 in Table I demonstrate the effect of doubling generator voltages at buses 2 and 3, respectively. Note that these buses lie in the same group. It is easily seen that the *influences* of these perturbations over the entire network are *similar*. For instance, bus 12 is not *largely influenced* by these perturbations. The perturbations result in the changes in voltage magnitudes at bus 12 by 0.0126 p.u. and 0.0072 p.u., respectively. However, the effect is *large* on buses such as bus 7, where the changes in voltage magnitudes are 0.1751 p.u. and 0.0993 p.u., respectively.

[1]Christie, Rich. "Power systems test case archive." Electrical Engineering dept., University of Washington (2000).