Linked Data Based Power Grid Management

Invited Paper

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Abstract - A data model for a power delivery system is developed in this work, that combines the power grid data with the general geo-political and socio-economical data from web and data hubs. It is based on the power grid ontology, that covers the required entities and connection properties for topology and measurements annotation in a power system. In order to proof the proposed model, several data queries and reports are presented and evaluated on recently published data sets. Few end-user tools are conceptually explored in order to note the usability for power companies as well as citizens.

Keywords - power grid, ontology, query, monitoring

I. Introduction

Smart grids have already explored the benefits of information and communications technology (ICT) applied in the power systems. However, the large amount of data generated in the smart grids requires appropriate data modeling, data processing and data publishing to result in a real smart grid data understanding for the power supplying companies as well as the energy consumers. The grid of the future would tend to transform the manual operations, along with the electro-mechanical components, into a ”smart grid” and automated processes, that will require further data collection and processing, so a comprehensive data modeling will be essential [1]. The smart grid is always followed by the smart energy management, that is open for the challenges of big data-driven smart energy management in IT infrastructure, data collection and governance, data integration and sharing, processing and analysis, security and privacy, and professionals [2].

The knowledge retrieved from the collected and processed data is useful in any part of the power grid. The data-driven approach is applied to wind turbine power generation performance monitoring using supervisory control and data acquisition (SCADA) data in [3] and the results demonstrate high accuracy in detecting the abnormal power curve profiles. An optimal power flow paired with the load control is achieved using data-driven concept in [4], resulting in computational efficacy of the distributionally robust approach and trade off between cost and robustness of solutions driven by data. Power grid data modeling has been considered in [5] and a central ontology layer has been introduced. It uses a common interconnection layer for all agents and it offers unified access to the stored data, infor- mation and knowledge. An electric power knowledge theory model is proposed in [6]. It was based on ontologies and the semantic web technologies and focused on the solution of the problem of normalized modeled knowledge for the management and analysis of electric power big data.

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In the field of data science there has been produced an advanced set of standards and tools for data modeling, that could also apply in the field of power system’s data management. One such initiative is the Schema.org [7], promoted by Google and Microsoft. It unifies the different existing data schemes and becomes a standard. Schema.org is actually considered as one of the main drivers for the adoption of the semantic Web principles worldwide, by a broad number of organizations and individuals in their real businesses [8].

Schema.org is already applied in different fields. A health information representation, querying, and visualization system by using Linked Data tools has been developed in [9] and have imported more than 20,000 HIV-related data elements on mortality, prevalence, incidence, and related variables. Semantic tools have been applied in the home health care systems and a cloud-based reasoning and mapping system has been built in [10] with Ontology Web Language (OWL), Resource Description Framework (RDF), Simple Protocol and RDF Query Language (SPARQL) and SPARQL Inferencing Notation (SPIN). An approach that provides integrated and situational information on different tourism-related topics is presented in [11] and the authors introduce an adaptation concept based on semantic descriptions of user context and integrated information sources and describe a prototype implementing that concept. The ongoing effort on using Linked Data technologies to improve the online visibility of touristic service providers from Innsbruck and its surroundings is presented in [12]. A contribution in the field of transportation applied to the city of London, UK is explored in [13] and a novel framework to address accessibility information barriers by establishing a linked data repository for publishing, linking and consuming the open accessibility data.

The community has already launched data portals that offer data from different fields, such as DBPedia[1] and its SPARQL endpoints[2] and WikiData[3]. DBpedia is a crowd-sourced community initiative to extract structured information from Wikipedia and make this information available on the Web. By combining the power grid data with the general geo-political and socio-economical data from such web and data hubs, certain indicators for a city or country could be calculated, that will simplify power grid quality evaluation and possibly

[1] DBPedia, http://wiki.dbpedia.org/

[2] SPARQL endpoints, http://live.dbpedia.org/sparql and https://dbpedia.org/sparql

[3] WikiData, https://www.wikidata.org/

enable ranking of the cities and countries by that indicators [14].

Authors in [15] address the energy performance of a household and the ontology of a household micro-system, while taking into account the possibility of it being controlled via energy management systems (EMS). A step towards using ontologies to describe the knowledge, concepts, and relationships in the domain of solar irradiance forecasting is proposed in [16] with a goal to develop a shared understanding for diverse stakeholders that interact with the domain. A preliminary ontology on solar irradiance forecasting, SF-ONT, was created and validated on three use cases. The OEMA (Ontology for Energy Management Applications) ontology network is presented in [17]. This ontology is an attempt to unify existing heterogeneous ontologies that represent energy performance and contextual data. The paper describes the OEMA ontology network development process, which has included ontology reuse, ontology engineering and ontology integration activities. Scholars in [18] focus on power grid modelling based on open and publicly available data from OpenStreetMap using open source software tools. A complex systems representation as tightly integrating components in the physical space (sensors, actuators) is proposed in [19], with advanced software algorithms in the cyber-space, that were called Cyber-Physical Systems (CPS). A Key Performance Indicator (KPI)-based, linked data methodology is proposed in [20] to systematically support the identification and analysis of stakeholders, the extraction of key performance information and master data that underpin stakeholders' goals. The research explored in [21] describes an open linked dataset containing data on energy efficiency improvements, i.e., recommendations and measures taken based on energy audits, from both Sweden and the US, i.e., from the Swedish Energy Agency and the US Department of Energys Industrial Assessment Centers (IAC), respectively. Authors in [22] provide a comprehensive overview of the state-of-the-art and related work for the theory, distribution, and use of the Smart Grid Architecture Model (SGAM), an approach that has been developed during the last couple of years, provides a very good and structured basis for the design, development, and validation of new solutions and technologies. The feasibility of a data integration approach that uses available ontologies and avoids ontology alignment is explored in [23]. The approach is based on the RDF representation of diverse datasets, the semantic description of these using available ontologies and the integration of these by matching literals between datasets, instead of establishing semantic links, is presented. A conceptual framework is developed and tested in the context of a simple but typical scenario where Building Information Modeling (BIM) has to be integrated with heterogeneous data sources in order to perform several analyses.

An implementation of the Universal Smart Energy Framework (USEF) through a multiagent system and a novel semantic web ontology is presented in [24]. It aligns and enriches relevant existing standards. A collective platform for raising awareness on climate change is developed in [25]. The platform collects data from smart plugs, and exports appliance consumption information and community generated energy tips as linked data, that enables users to view and compare the actual energy consumption of various appliances, and to share and discuss energy conservation tips in an open and social environment.

Considering the existing problems in the power grid systems and encouraged by the achievements of schema.org in other fields, in this paper we extend schema.org to cover the field of power grid systems. We develop the power grid ontology (PGO), i.e. a data scheme for data annotation, based on the schema.org vocabulary.

This is the outline of the paper. In Section II we explore the power grid ontology and explain the data entities and relations. The usage benefits, such as reports and queries, from a data repository based on the ontology are presented in Section III. Section IV concludes the paper and addresses the future work opportunities.

II. Power Grid Ontology

The power grid ontology (PGO), shown in Fig. 1, introduces a data model for power distribution system's data annotation. PGO is developed on the top of schema.org and reuses and inherits many entities and properties (marked with s: in Fig. 1). However, for the most specific domain requirements new entities and properties are introduced (marked with pgo: in Fig. 1). The core entity is *Node* that represents a node in the power network, such as *generator, substation, pillar* of a *transmission line* and a *power meter*. Generators could be *renewable* such as *windturbine, solar, biomass, geothermal* and *hydroturbine* and *nonrenewable* such as *nuclear, coal, natural gas, crudeoil* and *petroleum*.

Every node has its geographical location, represented by *GeoShape* and *GeoCoordinates*, including longitude, latitude and optionally a postal address. In every node several measurements (such as voltage, current, frequency, active and reactive power) could be conducted periodically or continuously, defined by the *dateCreated* for the measurement record. In multi-phase systems, the measurements could be taken by different phase, represented by (*Phase*) in the ontology.

Two nodes could be connected with a connection (*Link)* that is addition- ally described by *length*, *operator*, *impedance*, *frequency*, number of *cables* and number of *wires*. Every link could be a part of a *Transmission Line*, thus providing a more comprehensive big-picture of a whole geographical area or a city, towards a smart grid and a smart city.

After a sufficiently large data set is annotated with the PGO, it could be used to generate (periodically and continuously) a set of reports, such as to find the most over-loaded node or transmission line or to find the nodes with a variable frequency or the most frequent voltage drops. Few other reports/queries could be as follows:

- List the transmission lines with a voltage under certain level;

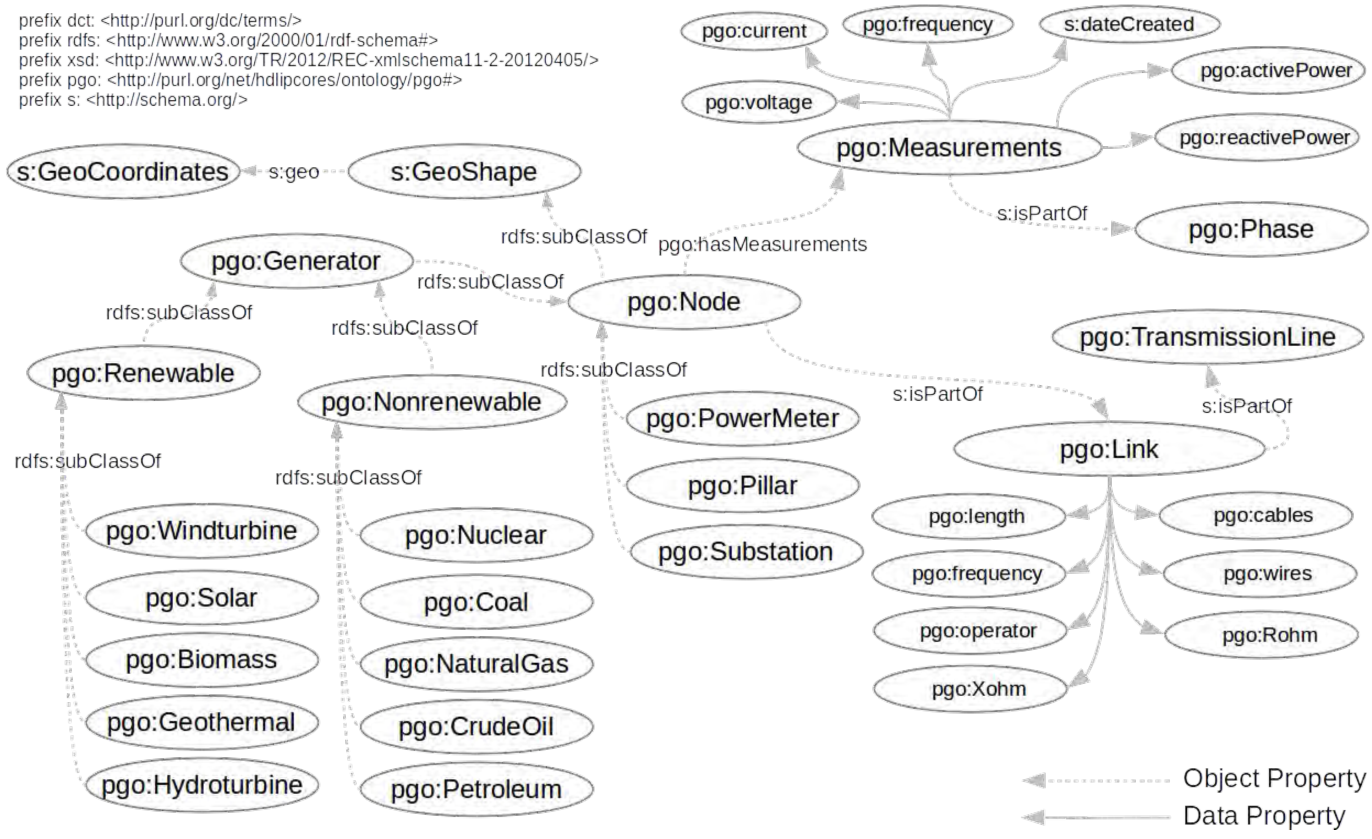

Fig. 1. Power grid ontology (PGO) provides a data model for power distribution system's data (such as network topology and continuous and periodic measurements) annotation.

- Fetch the critically overloaded transmission line;
- Fetch the critically overloaded generator;
- List nodes with the most frequent current changes;
- Fetch the average load of the nodes on a street in a city and
- List the nodes with the current under certain level.

On the other hand, advanced end-user friendly tools could be provided, such as a power distribution system city map, by analogy with the maps in [14], representing all transmission lines and nodes and possibly alarming people for any stability issues periodically or in real time. These tools would be helpful for both the power delivery companies as well as the citizens, since they will provide a high-level power network map with all required parameters for the companies. That will allow them to make in-time decisions. Whereas, there will be a real time information for a possible overload for the citizens, so they will react by switching off some of the devices, at least to protect them, and it will result in a negative feedback behavior, that will return the the power system in a stable state. Few possible types of smart-phone notifications are listed in Fig. 2.

The power grid data annotation using the PGO would be a strait forward process, since most of the node types already contain measurement units and even communication modules. For example, a small part of a street already contains tens of smart power meters, that could measure the required values and send them over network or Internet. All those nodes have their coordinates and belong to a transmission line, that is a concept and structure also provided in our ontology.

A. Annotation tool

To test the ontology, an annotation software tool[4] was developed and released as an open source code. There we provide the basic ontology entities and relations and it could be used as a Java API to build any application logic on the top of our ontology. In the API there are PGO.java and DATAREPO.java that cover entities and relations as well as the URL pattern definitions and also Anotator.java that contains the annotation methods for the data set we work with, but could be also extended for any other dataset.

III. Real case scenario

Several power grid data sets have been published recently, such as SciGRID[5] and GridKit[6], that we have used in order to evaluate our concept and the ontology itself. The GridKit dataset explores the vertices and the links in Germany as

[4]Software tool, https://bitbucket.org/zdrave/pgo/overview
[5]SciGrid, http://scigrid.de/
[6]GridKit, https://github.com/bdw/GridKit

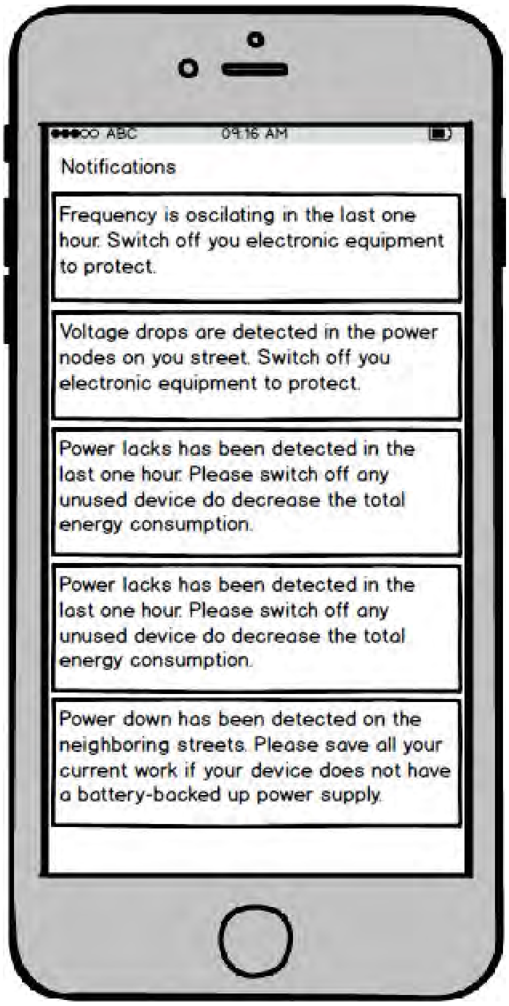

Fig. 2. Smart phone notifications.

separate files. We have annotated them and merged them in a single RDF model using the entities and the relations of our ontology. Data such as the name, geo-coordinates, voltages and links length are provided in the data set, available through our SPARQL endpoint[7].

Different types of queries could be executed against that repository. One simple illustration, would be to get a list of power plants in Germany and draw them on a map, as shown in Fig. 3. Moreover, if the power plants' data is available in real time, then appropriate status data could be also displayed, and notifications could be sent respectively. The details for the SPARQL query and results are shown in the appendix Section A in Listing 1 and Table VI.

The top ten operators in Germany, sorted by the total length of all the power distribution system links that they own is shown in Table I and the SPARQL query is presented in Listing 2.

TABLE I
TOP 10 OPERATORS BY LINKS' LENGTH.

operator	links length (m)
RWE	2.44718e+06
TenneT	2.12231e+06
TenneT TSO GmbH	1.48374e+06
50Hertz Transmission	682354.0
50Hertz	671870.0
Amprion	479220.0
50Hertz Transmission GmbH	364219.0
EnBW	318911.0
TenneT TSO GmbH;E.ON Netz GmbH	215094.0
EnBW;Amprion	202539.0

More complex queries may result in a deeper statistic as well as real time data reports. One such example is the query that returns the critical links as shown in Fig. 4. A click on the specific link would result with a pop-up window showing important data for the selected link. At the moment, there is no measurements data available, thus the data shown in Fig. 4 is only a show-case example that should illustrate the behavior. The query details are listed in Listing 3.

Furthermore, combining the power grid data with other existing data from DBPedia, could result in indicators and numbers such as power links length per square meter or number of generators and generated power per square meter or per capita. For example, the total power lines length in Germany is 10 100 km and the total population of 82 175 700 would result in a new indicator of power links length per capita with a value of $0,\ 12290738\ m$.

By combining our PGO repository (via our SPARQL end-point) and the DBPedia repository (via the DBPedia SPARQL endpoint[8], as shown in Fig. 5) and introducing a more granular indicators, we could find the cities placed in radius of 20km (or any other distance) from a power plant and calculate the total population living around the power plants, as shown in Table II. The complete SPARQL query is presented in Listing 4.

Using the data available for the substations on our SPARQL endpoint and the city population data from DBPedia's SPARQL endpoint, we can introduce a new indicator as citizens per substation. The top ten cities with population over 100 000 in Germany, ranked by population per substation are listed in Table III and the full SPARQL query is presented in Listing 5. On the other side of the ranking table, the flop (worst) ten cities ranked by this indicator are listed in Table IV.

Another indicator could be the number of power operators per city. In this case, the PGO data for the power nodes' operators has been used and combined with the geographical data (city position, population and area) from DBPedia. To improve the precision (compared to the queries in previous examples/indicators) in this indicator we did an approximation of the city with a circle, deriving the radius from the city area. The results are shown in Table V and the whole SPARQL query is presented in Listing 6.

[7]PGO SPARQL endpoint, http://hdlipcores.finki.ukim.mk/sparql

[8]DBPedia SPARQL endpoint, http://live.dbpedia.org/sparql

Fig. 3. Power Plants in Germany.

Fig. 4. Critical links in Germany.

IV. Conclusions and Future Work

A data model for a power delivery system was presented with the power grid ontology (PGO), that covered the required entities and connection properties for topology and measurements annotation in a power system. In order to proof the proposed model, several data queries and reports were presented, and few end-user tools were conceptually explored in order to emphasize the usability for power companies as well as citizens. Such a formal data model could simplify many previous power grid solutions related to the data and could significantly improve our previous work in the field of dynamic intelligent load balancing in power distribution networks [26] and reactive power compensation switch embedded in power meters [27] by semantic data annotation, that would allow semantic tools usage.

TABLE II
CITIES AND POPULATION IN RADIUS OF 20 KM FROM A POWER PLANTS.

Power Plant	Distance (m)	City	Population
Gemeinschaftskraftwerk Kiel	3021.53	Kiel	240832
Koepchenwerk	5607.79	Hagen	191241
Koepchenwerk	11579.8	Dortmund	575944
Koepchenwerk	18027.1	Bochum	361876
Kraftwerk Scholven	10144.6	Bottrop	117450
Kraftwerk Scholven	11287.4	Gelsenkirchen	260900
Kraftwerk Scholven	15564.4	Herne, North Rhine-Westphalia	166187
Kraftwerk Scholven	15747.0	Oberhausen	214990
Kraftwerk Scholven	16571.7	Essen	589075
Kraftwerk Scholven	19545.8	Bochum	361876
Statkraft Kraftwerk Knapsack II	11083.7	Cologne	1057327
TOTAL			4137698

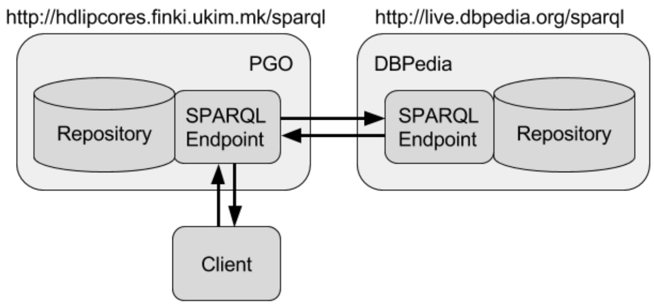

Fig. 5. Remote SPARQL endpoints. One part of the SPARQL query is executed on PGO repository and another part is forwarded to DBPedia. Afterwards, the data received from DBPedia is merged to the PGO data and additionally filtered before to be sent to the client.

TABLE III
TOP TEN CITIES (WITH OVER 100 000 POPULATION) ORDERED BY POPULATION PER SUBSTATION.

City	Population	Substations	Citizens/Substation
Hamburg	1774242	3	591414
Munich	1517868	7	216838
Nuremberg	498876	3	166292
Potsdam	161468	1	161468
Oldenburg	160907	1	160907
Mnster	300000	2	150000
Chemnitz	243521	2	121760
Jena	105192	1	105192
Hanover	518386	5	103677
Kassel	195530	2	97765

TABLE IV
FLOP TEN CITIES (WITH OVER 100 000 POPULATION) ORDERED BY POPULATION PER SUBSTATION.

City	Population	Substations	Citizens/Substation
Bottrop	117450	28	4194
Herne, North Rhine-Westphalia	166187	31	5360
Mlheim	168956	29	5826
Oberhausen	214990	30	7166
Gelsenkirchen	260900	30	8696
Braunschweig	250556	22	11388
Leverkusen	161279	14	11519
Solingen	161366	13	12412
Bochum	365406	28	13050
Krefeld	235860	15	15724

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TABLE V

CITIES (WITH OVER 100 000 POPULATION) ORDERED BY THE NUMBER OF POWER OPERATORS.

City	Population	Area	Approx. Radius	Operators	Citizens/Operator	Area/Operator
Hamburg	1774242	755.0	15502.4	6	295707	125.833
Cologne	1057327	405.15	11356.2	5	211465	81.03
Dortmund	575944	280.4	9447.44	4	143986	70.1
Duisburg	488005	232.82	8608.66	4	122001	58.205
Bielefeld	327199	257.8	9058.72	4	81799	64.45
Leverkusen	161279	78.85	5009.87	3	53759	26.2833
Bochum	365406	145.4	6803.11	3	121802	48.4667
Salzgitter	106077	223.96	8443.27	3	35359	74.6533
Dresden	536107	328.8	10230.4	3	178702	109.6
Hamm	182022	226.26	8486.51	3	60674	75.42

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APPENDIX A
SPARQL QUERIES AND REPORTS

The following SPARQL queries could be directly executed at our PGO SPARQL endpoint[9] and some of them, in the background, will also use data from DP Pedia[10].

```
PREFIX rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo:
<http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s:
<http://schema.org/>

SELECT ?name ?lat ?lng
WHERE {
        ?generator rdf:type pgo:Generator .
        ?generator s:name ?name  .
        ?generator s:geo ?geoCoordinates .
        ?geoCoordinates s:latitude ?lat .
        ?geoCoordinates s:longitude ?lng
}
```

Listing 1. SPARQL to list all power plants.

TABLE VI
RESULTS: LIST OF ALL POWER PLANTS.

name	lat/lng
Gemeinschaftskraftwerk Kiel	10.1789348237874 54.3388198256183
Kernkraftwerk Grohnde	9.40954428358131 52.0343295468096
Koepchenwerk	7.45130176031297 51.4130023629132
Kavernenkraftwerk Sckingen	7.95921958358891 47.5783600004331
Solarpark	10.6123957294136 48.0313556441031
Kavernenkraftwerk Wehr	7.94281008665733 47.6530214005328
Kraftwerk Scholven	7.00616826157462 51.5997745902162
Gode Wind I	6.98646123119149 54.0178365789963
Grubengas-Heizkraftwerk	7.23233534324937 49.3579040643531
Pumpspeicherkraftwerk Hohenwarte II	11.4747302318416 50.6039905453239
Statkraft Kraftwerk Knapsack II	6.84810730266128 50.8617173194521

[9]PGO SPARQL endpoint, http://hdlipcores.finki.ukim.mk/sparql
[10]DB Pedia SPARQL endpoint, http://live.dbpedia.org/sparql

```
PREFIX rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo:
<http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s:
<http://schema.org/>

SELECT
?operator
SUM(xsd:float(?length)) AS ?total_links_length
WHERE {
        ?link rdf:type pgo:Link .
        ?link s:name ?name  .
        ?link pgo:length ?length .
        ?link pgo:operator ?operator
}
GROUP BY ?operator
ORDER BY DESC(?total_links_length)
LIMIT 10
```

Listing 2. SPARQL to show the top 10 operators by links' length.

```
PREFIX rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo:
<http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s:
<http://schema.org/>

SELECT DISTINCT
(?link) ?link_name ?node1_lat ?node1_lng
?node2_lat ?node2_lng ?length
WHERE {
?link rdf:type pgo:Link .
?link s:name ?link_name  .
?link pgo:length ?length .
?link pgo:voltage '380000' .
?link pgo:operator 'RWE' .
?link s:hasPart ?node1 .
?link s:hasPart ?node2 .
?node1 s:geo ?gc1 .
?gc1 s:latitude ?node1_lat .
?gc1 s:longitude ?node1_lng .
?node2 s:geo ?gc2 .
?gc2 s:latitude ?node2_lat .
?gc2 s:longitude ?node2_lng .
?node1 pgo:hasMeasurements ?n1Measurements .
?n1Measurements pgo:reactivePower ?reactivePower .
FILTER
(
(
xsd:float(?activePower)
/
math:sqrt(
xsd:float(?activePower)*xsd:float(?activePower) +
xsd:float(?reactivePower)*xsd:float(?reactivePower)
)
) < 0.9
)
}
```

Listing 3. SPARQL to show the critical links with high reactive power.

```
PREFIX rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo:
<http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s:
<http://schema.org/>

#remote prefixes
PREFIX  dbo:
<http://dbpedia.org/ontology/>
PREFIX dbr:
<http://dbpedia.org/resource/>
PREFIX dbp:
<http://dbpedia.org/property/>
PREFIX geo:
<http://www.w3.org/2003/01/geo/wgs84_pos#>
PREFIX xsd:
<http://www.w3.org/2001/XMLSchema#>
PREFIX afn:
<http://jena.apache.org/ARQ/function#>

SELECT
?genName
MAX (
bif:acos(bif:sin(xsd:float(?lat) * 3.14159 / 180) *
bif:sin(xsd:float(?genLat) * 3.14159 / 180)+
bif:cos(xsd:float(?lat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLong) * 3.14159 / 180 -
xsd:float(?long) * 3.14159 / 180))*6371000
) as ?distance
xsd:string(?cityName) as ?city
MAX(?pop) as ?population

WHERE {

  SERVICE <http://live.dbpedia.org/sparql> {
    # The remote part of the query
       ?city rdf:type dbo:City;
             rdfs:label ?cityName;
             dbo:country ?country;
             dbo:country dbr:Germany;
             geo:lat ?lat;
             geo:long ?long;
             dbo:populationTotal ?pop .
             FILTER (lang(?cityName) = 'en')
    # End of The remote part of the query
  }#End of Service

  SERVICE <http://localhost:8890/sparql> {
    # The remote part of the query
    ?generator rdf:type pgo:Generator .
    ?generator s:name ?genName  .
    ?generator s:geo ?geoCoordinates .
    ?geoCoordinates s:latitude ?genLat .
    ?geoCoordinates s:longitude ?genLong .
    # End of The remote part of the query
  }#End of Service


FILTER(
(
bif:acos(bif:sin(xsd:float(?lat) * 3.14159 / 180)*
bif:sin(xsd:float(?genLat) * 3.14159 / 180)+
bif:cos(xsd:float(?lat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLong) * 3.14159 / 180 -
xsd:float(?long) * 3.14159 / 180))*6371000
) < 20000.0
) .

}
group by ?genName ?cityName
order by ?genName ?distance
```

Listing 4. SPARQL to show the cities and population in radius of 20 km from a power plant.

```
PREFIX rdf:
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo:
<http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s:
<http://schema.org/>

#remote prefixes
PREFIX  dbo:
<http://dbpedia.org/ontology/>
PREFIX dbr:
<http://dbpedia.org/resource/>
PREFIX dbp:
<http://dbpedia.org/property/>
PREFIX geo:
<http://www.w3.org/2003/01/geo/wgs84_pos#>
PREFIX xsd:
<http://www.w3.org/2001/XMLSchema#>
PREFIX afn:
<http://jena.apache.org/ARQ/function#>

SELECT
xsd:string(?cityName) as ?city
MAX(?pop) as ?population
COUNT(?node) as ?sustations
(MAX(?pop)/COUNT(?node)) as ?citizensPerSubstation

WHERE {

  SERVICE <http://dbpedia.org/sparql> {
    # The remote part of the query
       ?city rdf:type dbo:City;
             rdfs:label ?cityName;
             dbo:country ?country;
             dbo:country dbr:Germany;
             geo:lat ?lat;
             geo:long ?long;
             dbo:populationTotal ?pop .
             FILTER (lang(?cityName) = 'en')
             FILTER (?pop > 100000)
    # End of The remote part of the query
  }#End of Service

  SERVICE <http://localhost:8890/sparql> {
    # The remote part of the query
    ?node rdf:type pgo:Substation .
    #?node s:name ?nodeName  .
    ?node s:geo ?geoCoordinates .
    ?geoCoordinates s:latitude ?genLat .
    ?geoCoordinates s:longitude ?genLong .
    # End of The remote part of the query
  }#End of Service


FILTER(
(
bif:acos(bif:sin(xsd:float(?lat) * 3.14159 / 180)*
bif:sin(xsd:float(?genLat) * 3.14159 / 180)+
bif:cos(xsd:float(?lat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLong) * 3.14159 / 180 -
xsd:float(?long) * 3.14159 / 180))*6371000
) < 20000.0
) .

}
group by ?cityName
order by DESC(MAX(?pop)/COUNT(?node))
LIMIT 10
```

Listing 5. SPARQL to show the top ten cities (with over 100 000 population) ordered by population per substation.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX pgo: <http://purl.org/net/hdlipcores/ontology/pgo#>
PREFIX s: <http://schema.org/>

#remote prefixes
PREFIX dbo: <http://dbpedia.org/ontology/>
PREFIX dbr: <http://dbpedia.org/resource/>
PREFIX dbp: <http://dbpedia.org/property/>
PREFIX geo: <http://www.w3.org/2003/01/geo/wgs84_pos#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX afn: <http://jena.apache.org/ARQ/function#>

SELECT
xsd:string(?cityName) as ?city
MAX(?pop) as ?population
(MAX(?areaTotal) / 1000000) as ?area
MAX(bif:sqrt(?areaTotal / 3.14159 )) as ?radius
COUNT(distinct ?operator) as ?operators
(MAX(?pop)/COUNT(distinct ?operator)) as ?citizensPerOperator
((MAX(?areaTotal) / 1000000)/COUNT(distinct ?operator)) as ?areaPerOperator

WHERE {

  SERVICE <http://dbpedia.org/sparql> {
    # The remote part of the query
       ?city rdf:type dbo:City;
             rdfs:label ?cityName;
             dbo:areaTotal ?areaTotal;
             dbo:country dbr:Germany;
             geo:lat ?lat;
             geo:long ?long;
             dbo:populationTotal ?pop .
             FILTER (lang(?cityName) = 'en')
             FILTER (?pop > 100000)
    # End of The remote part of the query
  }#End of Service

  SERVICE <http://localhost:8890/sparql> {
    # The remote part of the query
{    ?node rdf:type pgo:Pillar .
    ?node pgo:operator ?operator .
    ?node s:geo ?geoCoordinates .
    ?geoCoordinates s:latitude ?genLat .
    ?geoCoordinates s:longitude ?genLong .
}
     UNION {
?node rdf:type pgo:Substation .
    ?node pgo:operator ?operator .
    ?node s:geo ?geoCoordinates .
    ?geoCoordinates s:latitude ?genLat .
    ?geoCoordinates s:longitude ?genLong .
    }

    # End of The remote part of the query
  }#End of Service



FILTER(
(
bif:acos(bif:sin(xsd:float(?lat) * 3.14159 / 180)*
bif:sin(xsd:float(?genLat) * 3.14159 / 180)+
bif:cos(xsd:float(?lat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLat) * 3.14159 / 180)*
bif:cos(xsd:float(?genLong) * 3.14159 / 180 -
xsd:float(?long) * 3.14159 / 180))*6371000
) < bif:sqrt(?areaTotal / 3.14159) #10000.0 #bif:sqrt(?area / 3.14 ) * 1000 #
) .

}
group by ?cityName
order by DESC(COUNT(distinct ?operator))
LIMIT 10
```

Listing 6. SPARQL to show the Cities (with over 100 000 population) ordered by the number of power operators.

```
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:pgo="http://purl.org/net/hdlipcores/ontology/pgo#"
    xmlns:s="http://schema.org/"
    xmlns:datarepo="http://purl.org/net/hdlipcores/ontology/pgo/data#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
  <pgo:Link rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#link-175370">
    <pgo:length>458.244020145921</pgo:length>
    <pgo:operator>RWE</pgo:operator>
    <s:name>
    380 kV Hessen Ost; Trebur Nord+ S d ;380kV Trebur S d; 380 kV Trebur Nord;380 kV Hessen Ost
    </s:name>
    <pgo:voltage>380000;380000;380000;380000</pgo:voltage>
    <s:hasPart>
      <pgo:Pillar rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-48536">
        <s:geo>
          <s:GeoCoordinates rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-48536-gs-gc">
            <s:latitude>8.47704075248088</s:latitude>
            <s:longitude>50.0935645616639</s:longitude>
          </s:GeoCoordinates>
        </s:geo>
        <s:name>380 kV Hessen Ost; Trebur Nord| S d; 110 kV Kriftel Nord;380 kV Hessen Ost;
        Trebur Nord+ S d ;110 kV Kriftel Nord+ S d
        </s:name>
        <pgo:operator>RWE</pgo:operator>
        <pgo:hasMeasurements>
          <pgo:Measurements
          rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-48536-measurements">
            <pgo:voltage>380000;110000;380000;110000</pgo:voltage>
            <pgo:frequency>50;50;50</pgo:frequency>
          </pgo:Measurements>
        </pgo:hasMeasurements>
      </pgo:Pillar>
    </s:hasPart>
    <s:hasPart>
      <pgo:Substation rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-18221">
        <s:geo>
          <s:GeoCoordinates
          rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-18221-gs-gc">
            <s:latitude>8.47130677635285</s:latitude>
            <s:longitude>50.0972089406338</s:longitude>
          </s:GeoCoordinates>
        </s:geo>
        <s:name>Umspannwerk Kriftel</s:name>
        <pgo:operator>Amprion</pgo:operator>
        <pgo:hasMeasurements>
          <pgo:Measurements
          rdf:about="http://purl.org/net/hdlipcores/ontology/pgo/data#node-18221-measurements">
            <pgo:voltage>380000;110000</pgo:voltage>
            <pgo:frequency>50</pgo:frequency>
          </pgo:Measurements>
        </pgo:hasMeasurements>
      </pgo:Substation>
    </s:hasPart>
  </pgo:Link>
  </rdf:RDF>
```

Listing 7. System generated RDF description. Using the ontology, we generate appropriate RDF code to describe the power system components.