Design and simulation of a software defined networking-enabled smart switch, for internet of things-based smart grid

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ABSTRACT

Using sustainable energy is the future of our planet earth, this became not only economically efficient but also a necessity for the preservation of life on earth. Because of such necessity, smart grids became a very important issue to be researched. Many literatures discussed this topic and with the development of internet of things (IoT) and smart sensors, smart grids are developed even further. On the other hand, software defined networking is a technology that separates the control plane from the data plan of the network. It centralizes the management and the orchestration of the network tasks by using a network controller. The network controller is the heart of the SDN-enabled network, and it can control other networking devices using software defined networking (SDN) protocols such as OpenFlow. A smart switching mechanism called (SDN-smgrid-sw) for the smart grid will be modeled and controlled using SDN. We modeled the environment that interact with the sensors, for the sun and the wind elements. The Algorithm is modeled and programmed for smart efficient power sharing that is managed centrally and monitored using SDN controller. Also, all if the smart grid elements (power sources) are connected to the IP network using IoT protocols.

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1. INTRODUCTION

The use of renewable energy is becoming not just a technology trend but rather a necessity for planet earth preservation. Sever climate changes and recent giant ice caps being separated from the north pole into the ocean is a sign that we need to replace the current energy sources with more earth-friendly substitutes. These substitutes are clean renewable energy sources that uses sun, wind and even ocean tides to generate electricity in a clean manner. Due to the reason that there are multiple renewable sources to generate electricity, we need to use technology to manage and operate these sources in the most efficient way possible. This management uses sensors readings and internet of things (IoT) protocols to manage, operate and transition between these sources effectivly. The usage of these sensors and protocols nowadays is the heart of most technological breakthroughs in the topics of smart homes, smart cities, and smart grids. IoT Smart grid typically consists of four types:

a) Smart home, this is for home usage. Small, scaled version that is used in the perimeter of the house only. This implementation typically uses IoT only and might be connected to other types of the smart grid.
b) Micro smart grids, institutes or factories that runs individually using renewable energy sources.
c) Smart grid, multiple micro grids connected at a city-wide scale.
d) Super grid, this interconnects multiple smart grids at a country-wide scale.

To continue our conversation about smart grids and the usage of IoT and sensors, we need to address one more important issue, which is how to connect the sensors and the smart grid to the data network. Nowadays the Internet is used as a communication channel to connect smart cities, smart homes, and smart grids. But because of the inherited communication latency of the data network and the lack of a centralized management, more work and research are needed in this area to overcome both issues. Software defined networking solves these issues as it adds a control layer on top of the current infrastructure of the data network. This will be beneficial as it will provide centralized management of the smart grid for better orchestration of the tasks. An software defined networking (SDN) controller can manage the smart grid using pre-programmed rules and it communicates with the infrastructure network using southbound and northbound application programming interfaces (APIs). Because of the limited power that the natural sources (sun, wind) can provide, we need an efficient method to switch between multiple sources. As well as connecting a traditional coal based or oil-based energy source that act as a last resort for power generation in case the renewable sources failed. This paper will discuss the design of such switching mechanism and it will address and use the key technologies mentioned above. The rest of this paper is organized as the following, the next section will position the contribution of the paper to the existing research. The third section will discuss recent research in the area of smart-connected grids. The fourth section will discuss the proposed model (SD-smgrid) with both parts (the smart grid and the SDN). The fifth section will show the simulated model and the results obtained from the simulation. And the conclusion of the work will be on the last section.

2. POSITIONING OF THE CONTRIBUTION (SD-SMGRID-SW)

An SDN-based connected smart grid switch is a new concept that is derived from the need of an SDN-ready smart grid that can be easily connected and used with an SDN-enabled data network. In contrast other implementations of SDN in smart grid discussed mostly power calculations with a very basic to nonexistent implementation details on how it will function with Real SDN controller. Due to this ambiguity in the current related literature, it becomes very difficult to implement such smart grids with real SDN-enabled networks. Our proposed model is Implementation ready, although it covers theorical and algorithmic details. We will use simulation and network emulator software to connect the proposed simulated design with a real SDN controller.

3. RELATED WORK

Efficient energy management is a very important issue that concerns most grid operators. Several literatures studied smart grid management and effective operation. Rafik *et al.* [1] proposed an approach that uses multiple criteria in the exploitation the sensor networks to harvest the energy and re-distributing it on multiple locations.

Gonzalez *et al.* [2] studied how an effective to build a cluster network using SDN. They also studied the performance gain using the distributed approach over the traditional static approach. Rinaldi *et al.* [3] introduced and characterized the internet protocol (IP)-based communication paradigm with SDN bridges that is operated overpower line communication in order to reach the last-mile application such as smart meters and smart inverters.

Abujubbeh *et al.* [4] presented an overview for integrating software-defined wireless sensor networks (SDWSN) concepts in smart grid to solve the challenges and to improve network performance. Rinaldi *et al.* [5] in their paper they presented an application for SDN in the management of distributed energy resources over the smart distribution grid. Priyadharshini *et al.* [6] presented a smart metering based on IoT that will help in the energy management of the technology of the smart grid.

Hosseinian *et al.* [7] in their work they presented a blockchain based deployment for IoT in smart homes and distribution networks. They discussed the massive high scaled transactions created because of the small scale microsources as they call it. Rojas [8] in their paper they discussed how to create a platform for data analysis generated from smart meters, they implemented the platform on a multicore edge-based hardware.

Salkuti [9], discussed in the literature policies and standards of the smart cities. As well as challenges in the implementation of smart cities such as cost, and privacy security. Chanda and Samanta [10] in his literature discussed the vulnerability of the grid-based system. By examining the model of the power flow. The literature also discussed efficiency analysis.

4. PROPOSED MODEL DESIGN

4.1. Smart grid switch

In this paper we propose a new model called software-defined smart grid switch, or in short (SD-smgrid-sw). In the first part of the model design, we will show the modeling of the smart grid switch. In this paper the suggested switch will choose the most efficient power source based on some preference. This smart switch is capable of selecting from multiple power sources and it will always provide the consumer with power using the most efficient power source [11], [12].

Also, the smart grid switch will be connected to multiple sensors using IoT protocols to maintain low overhead and it will be connected to an SDN controller for management and control in the control plane using northbound API (the SDN controller model will be discussed in the next section). Figure 1 show the general algorithm of the proposed SD-smgrid-switch model. The switch operates based on a decision from the centralized SDN controller. The smart switch represents the application plane of the SDN paradigm [13], [14].

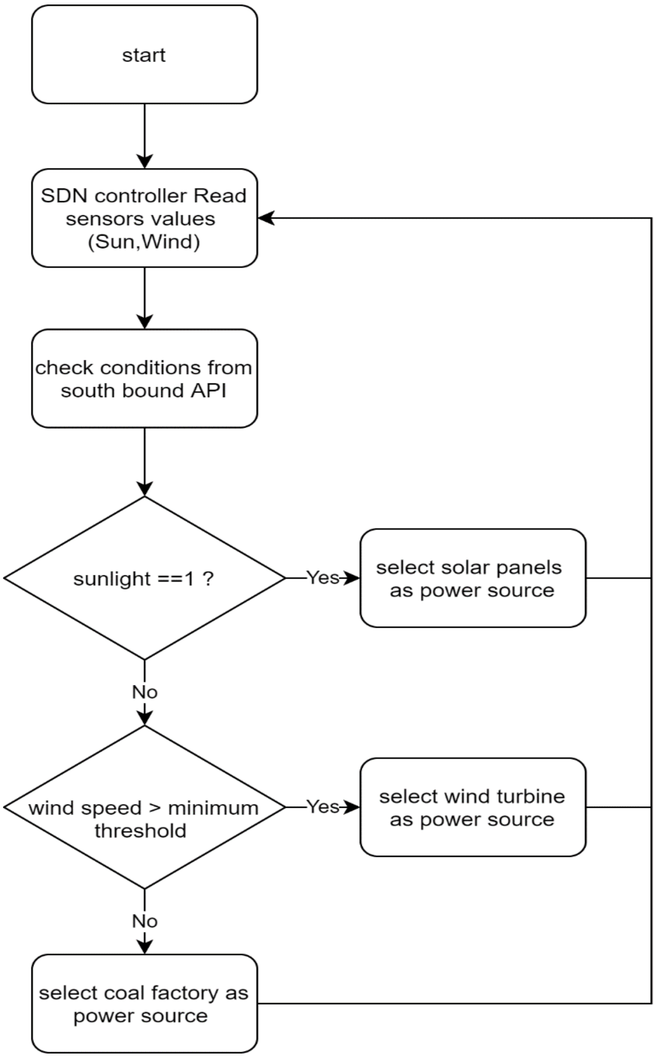

Figure 1. SD-smgrid-switch model flowchart

4.2. The environment

All the environments were built as APIs and are called form the smart switch for decision making. Table 1 show the different values of the (sun) parameters during different times in the simulated environment which simulate different hours of the day [15], [16]. Table 2 shows the (wind) environmental variable, in which we simulated the direction, variance and speed of the wind.

Table 1. Simulated (sun) environment

Night		Partial cloudy		Full sun	
Electromagnetic radiation	0.00%	Electromagnetic radiation	25.00%	Electromagnetic radiation	66.67%
Infrared	0.00%	Infrared	13.75%	Infrared	36.67%
Radiant heat	0.00%	Radiant heat	25.00%	Radiant heat	66.67%
Sunlight	0.00%	Sunlight	75.00%	Sunlight	100.00%
UV	0.00%	UV	0.75%	UV	2.00%
Visible	0.00%	Visible	10.50%	Visible	28.00%

Table 2. Simulated (wind) environment

No wind		Light breeze		windy	
Direction	19.17 degree	Direction	29.00 degree	Direction	86.8 degree
Variance(gust)	3.33%	Variance(gust)	5.75%	Variance(gust)	25.9 %
Speed	0.00 KPH	Speed	5.00 KPH	Speed	23.00 KPH

We used (1) in the simulation of this feature.

$$v = 0.836\ B3/2\ m/s \quad (1)$$

Where v is the wind speed at 10 meters over the sea level and B is the Beaufort number.

4.3. SDN implementation for the smgrid model

The smart switch is connected to an SDN controller, the controller will act as an initiator to control the switch in a centralized manner. In the same time the enviromental sensors will be connetced through an IP network to an IoT registration server using message queuing telemetry transport (MQTT) protocol [17]. The SDN implementation is modeled in Figure 2. The SDN controller controls the smart switch using PUSH configuration. The decision is based on the data collected from the data layer [18], [19].

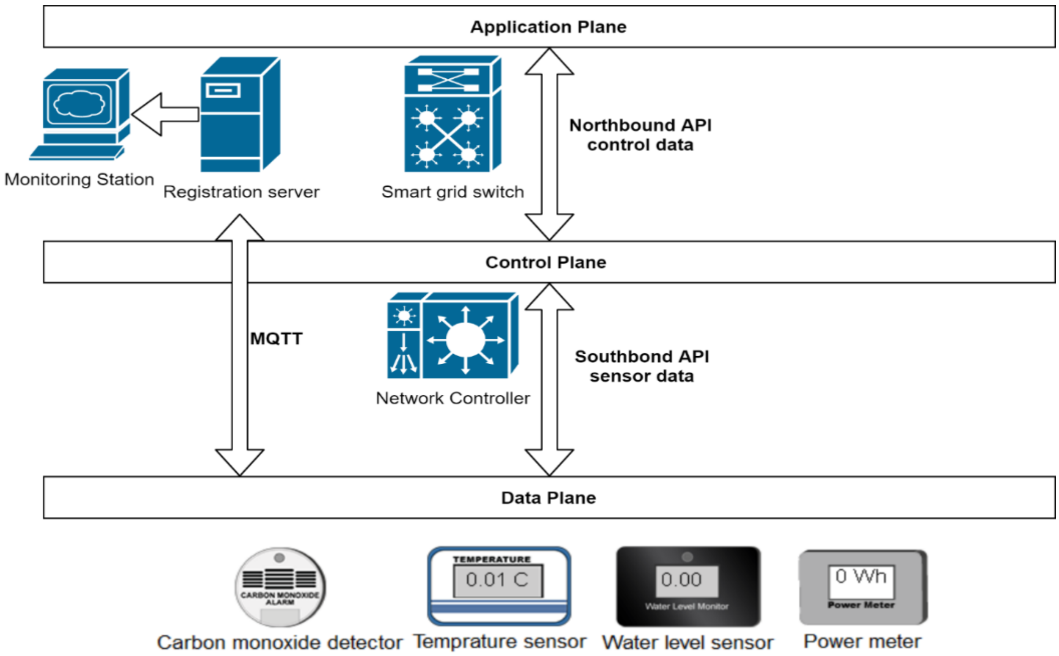

Figure 2. the SD-smgrid-sw model

5. SIMULATION AND IMPLEMENTATION OF THE SD-SMGRID MODEL

The model was simulated in PT software version 8. Smart switch was developed in JS and them imported into the simulation environment. The environment (sun and wind) was set using JS API to be accessed by the model [20]. The networking features was simulated, and a complete simulation model was built as shown in Figure 3. From the figure above we can see many parts of the system. We can notice that if the sun is up the smart switch selects the first source which is the solar panels. Based on the proposed algorithm the solar source takes precedence over other sources. In our simulation the sunrise is at 5:00 am and the sunset at 6:00 PM. Figure 4 shows the sun environmental setting [21], [22].

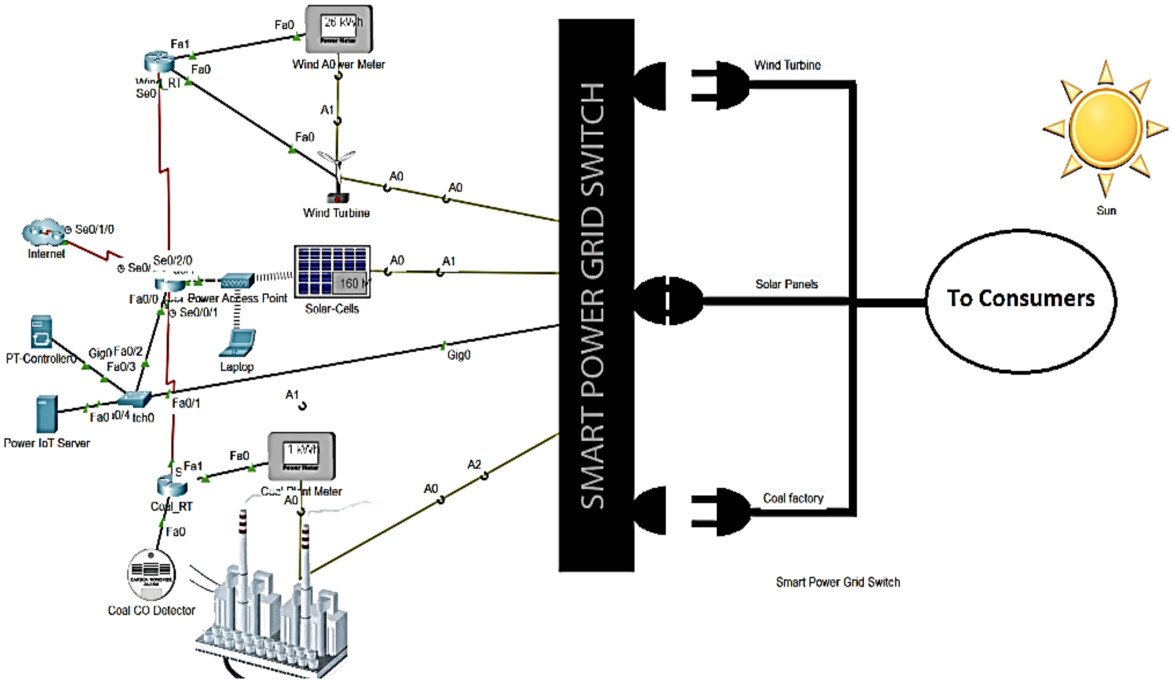

Figure 3. The simulated model

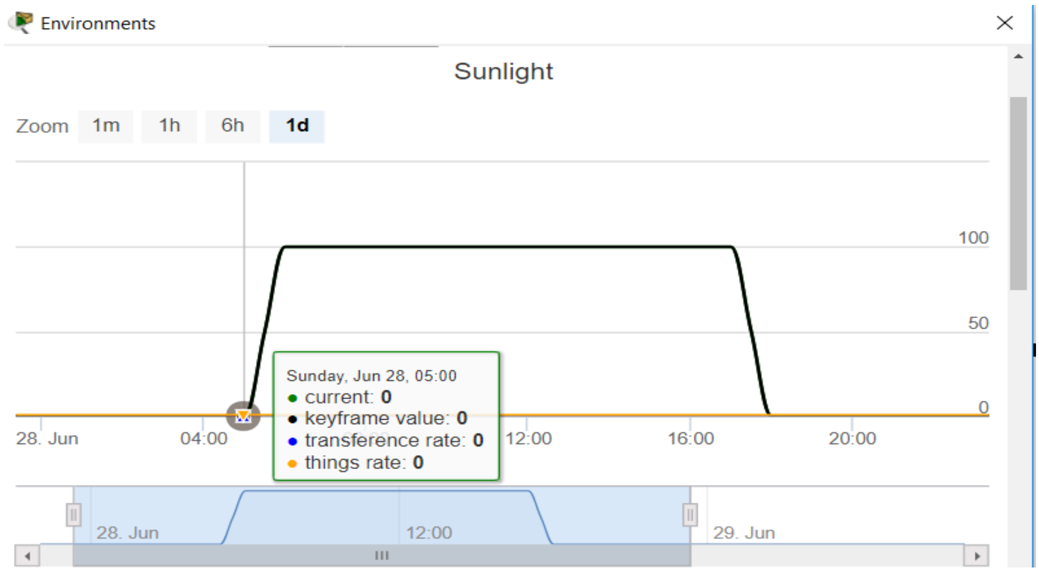

Figure 4. The (sun) environment settings

When the simulation continues, after the sunset the smart switch switches to the wind source (if the wind setting is more than 0.) also based on the proposed algorithm. wind condition in the simulation will switch between the three settings (no wind, light breeze and windy) to mimic the change that might occur in the real environment. The switch will choose wind turbine is the appropriate wind setting is chosen. Figure 5 shows the smart grid switch choses wind turbine when the sun is down (night conditions) [23].

The SDN controller is configured using cisco SDN controller, the controller is installed on a real device and connected to the simulation environment using port 58000 over http connection [24], [25]. The entire network was discovered and viewed using the cisco controller dashboard. In this case we can view the health of all the devices and sensors connected to the controller. The dashboard is shown in Figure 6. The list of the connected sensors from the simulation environment including the smart grid switch is shown in Figure 7. After successful configuration, a policy was created in the controller and the SDN controller will read data from the sensors and write the appropriate command to the smart grid switch based on the proposed algorithm [26].

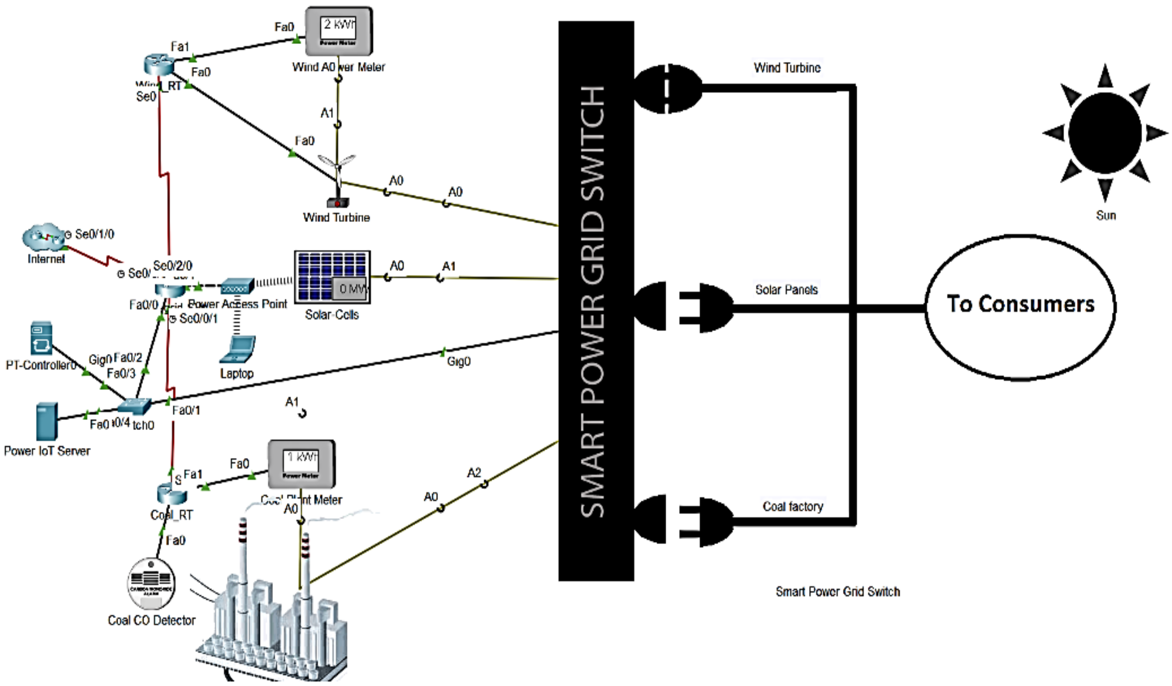

Figure 5. The smartgrid-sw switching to wind turbine source

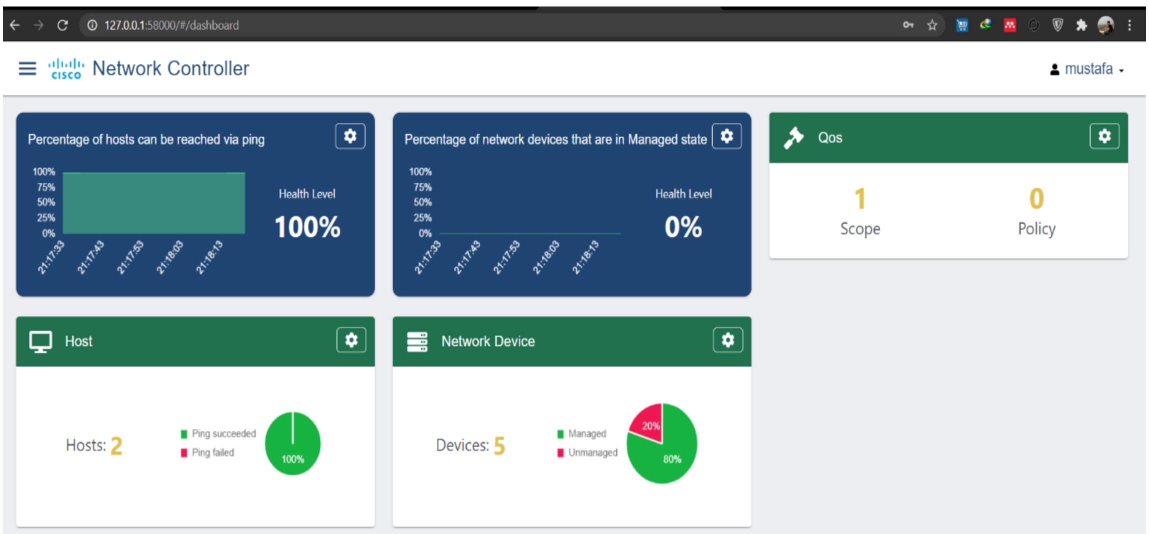

Figure 6. SDN controller dashboard

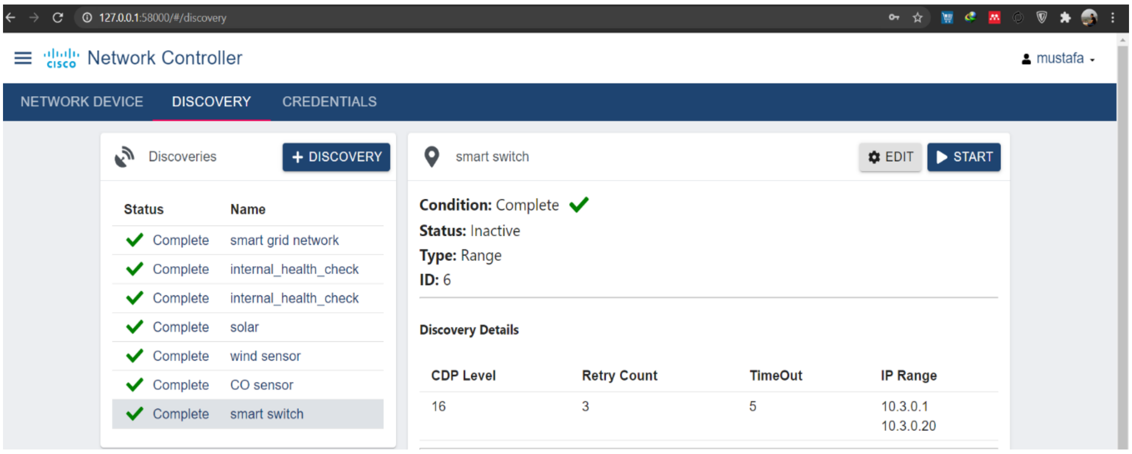

Figure 7. List of the sensors and the smart grid switch discovered in SDN controller

6. CONCLUSION

Using SDN separates the control plane from the data plane which gives more control over the network orchestration and management. Using SDN in smart grids was discussed in many of the literature, but none discussed an implementation-ready approach. In this paper a software-defined smart grid switch (SD-smgrid-sw) is developed. In this model an environment is simulated, and a network switch is being programmed using a centralized SDN controller. The implementation showed a very promising opportunity for the adaptation of SDN in smart grid applications. For future enhancements we can consider more rigorous power delivery calculations. As both the simulator and the SDN controller support programming and interaction using APIs. So, we can derive accurate prediction for the system power delivery wattage in terms of KW/H.

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