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Critical Load Serving Capability by Microgrid using 100% Renewable Energy

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SUMMARY

In order to improve the resilience of power systems, there is interest in developing the capability to form microgrids when abnormal situations occur. In some cases, the microgrid is used to minimize the adverse impacts on the most critical loads, such as hospitals, government offices, and police stations. The costs associated with failure to supply critical loads are significant. Therefore, the ability to create a microgrid largely using existing generation assets with only the addition of control devices can result in improved reliability, greater level of services, and in significant savings during major events. For instance, a significant portion of the power supply to Spokane city in the northwest region of North America comes through a single 500kV line. If the line goes down, under some circumstances the city grid could go down. The main objective of this paper is to perform a study establishing the feasibility of forming a microgrid to supply high priority loads in the city, while disconnecting from the main grid, by using hydroelectric and solar generation available in the area. These transitions will occur while establishing and maintaining stability of the microgrid. Modeling and analysis of the entire microgrid network is done in Powerworld® that demonstrated the feasibility of forming the microgrid. The model development and validation are described along with the analysis and results of several studies.

KEYWORDS

Microgrid, Powerworld, SynerGEE, Hydro generation, PV System, Steady state, Transient stability, Power outages, Forecast, Smart grid

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1. INTRODUCTION

The contingencies that can arise in a power system which can cause major power outages include extreme weather and natural disasters, major generation failures, loss of transmission lines, and cyber-attacks [1]. The electricity demand-growth indicate that microgrids could play a significant role in the future evolution of energy service provision [2].

The last decade has seen blackouts around the world due to natural disasters. For instance, the destructive northwest windstorm on 17 November 2015 adversely affected the power network in and around the city of Spokane. Around 180000 customers lost power within the service area of the utility immediately after the storm and it took around ten days to restore power completely. If there had been a microgrid in place, the outage time for critical loads cold have avoided by improving the resilience of the system. The regional utility is considering establishing a microgrid with two hydro generation facilities supplying a major proportion of the critical load in case of a severe contingency. This microgrid is somewhat unique since it will be predominantly supplied by existing hydro generation. The IEEE 1547 series of standards [3], [4], and [5] are considered while planning the microgrid.

This paper is organized as follows. Section 2 discusses acquiring the model data and organizing it. Section 3 deals with modeling of microgrid in Powerworld. Section 4 describes the analysis and simulation results followed by conclusion in Section 5.

2. MICROGRID ENERGY RESOURCE MODEL DATA

Fig.1 shows the one-line diagram of the transmission network within the city and including the area covered by the microgrid. A significant amount of power comes from the 500kV line shown in the figure; it steps down to 230kV and further to 115kV at substation 10 and substation 9 respectively. The 115kV transmission network connects various substations with circuit breakers at each substation, which can be operated remotely. It is important to define the electrical boundaries of the microgrid before modeling the system, as it needs to be isolated from rest of the power grid by opening breakers at the Points of Common Coupling (PCC). So, substations 1, 2, 3, and 4 are identified as boundaries, which are supplying most of the critical loads in microgrid from external generation. Breakers B1, B7, B8, and B13 will be opened when there is a contingency to form a microgrid, which will be supplied by two hydro generators located at substation 2 and photovoltaics distributed throughout the microgrid area.

The microgrid model data was acquired from the utility serving the region. The critical loads within the scope of microgrid have meters which report hourly load and generation data to the utility. This data is very useful for understanding the behaviour of the loads and generation over the course of a year. The loads are prioritized based on the utility's requirements and relative importance of each load. The line parameters were gathered from three incumbent models in two different software tools used by the utility Powerworld and SynerGEE Electric. Distribution transformer parameters were provided by the utility. Based on the data acquired, several analyses and case studies to determine the feasibility of a microgrid and estimate the functional requirements.

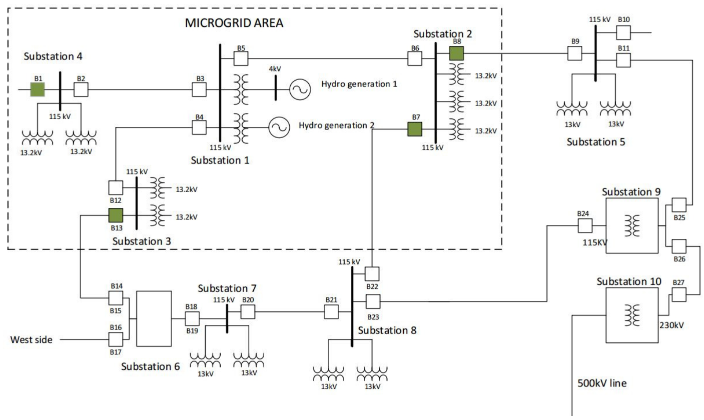

Fig.1. Transmission network around the area of microgrid (The microgrid boundary is marked)

A. Hydro Energy Potential and Limits

United States Geological Survey (USGS) [6] provides record of the water flow data of the river where the hydro generation facilities are located. Fig. 2a shows the monthly average discharge of water measured in cubic meters per second averaged over the period from 1891-2016. Analysing this data shows the flow high enough for maximum generation only during a few days in winter and spring. In summer and fall, the river has less generation capacity. The two hydro generators in this microgrid have a potential of generating 10 MW and 15 MW under maximum water flow conditions.

B. Solar energy potential

Solar energy generation has potential to supplement the microgrid in during the periods of low water flow. National Renewable Energy Laboratory (NREL) [7] has records of solar radiation at sites across the United States using three different photovoltaic systems. Fig.2b shows the solar radiation data averaged over a period of 30 years from 1961-1990 in the city. It is evident from the data that solar energy is high during summer and fall seasons. Photovoltaic generation can compensate the low water availability during these seasons, if there is sufficient installation of photovoltaic panels along with proper controls. The PVWatts Calculator [8] developed by NREL estimates the amount of solar energy that the rooftop of a given building can supply if photovoltaic cells were installed on the roof. The roof top area of buildings housing the critical loads in this study was estimated with the help of this tool to understand the potential solar energy generation. Analyzing the data shows that there is very good potential of solar energy (10.3 MW installed DC capacity) during summer and fall from these buildings.

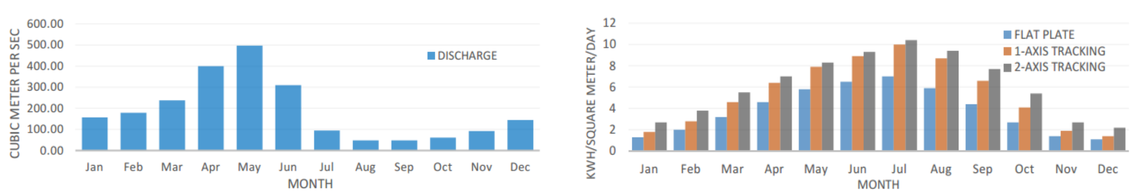

Fig.2. a) Monthly average river discharge from 1891-2016, b) Solar radiation average in the city for 30 years

C. Critical load profile analysis

The metering data acquired from the utility for the past three years was used to model each critical load. The Energy Charting and Metrics (ECAM) [9] tool is utilized to analyze the load profiles of critical loads based on data from a three-year average of hourly load profile of critical loads. ECAM generates an hourly average of four different seasons with each hour averaged over the respective season. Fig.3a shows the load profile of all the critical loads in four seasons for illustration. It can be interpreted from the data that the load varies with the time of day and the peak maximum demand is during the late afternoon hours. The demand for power is higher in the summer, followed by spring, fall and winter for the microgrid.

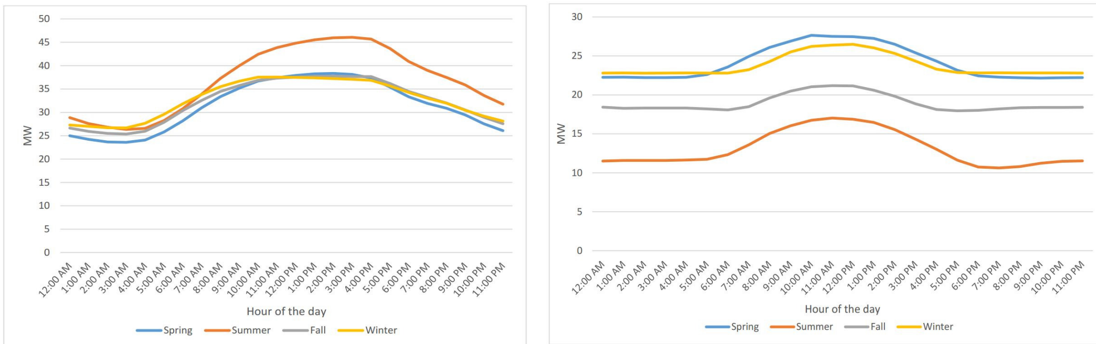

Fig.3. a) Critical load-1 profile averaged over a 24-hour period in 4 seasons b) Combined average generation output profile over 24-hour period in 4 seasons

D. Generation profile analysis

The metering data from the two generators was acquired for three years (2013-2015). It is further analyzed to produce hourly averages of the generation for the four different seasons. The same ECAM tool was utilized to analyze these generation profiles and compare them to the demand for the critical loads. Fig. 3b shows the combined real power generation profile of the averaged output of the two hydro generators over the last three years plus the solar energy potential. The maximum total generation is 27MW in spring and the maximum is 16 MW in summer.

Based on the mismatch between total load and total generation, load will need to be shed. At present the critical loads can only be picked up or dropped at a monolithic load. Only a subset of the critical loads can be supplied in summer, even with the photovoltaic generation added.

3. MODELING OF THE MICROGRID

A validated model of the microgrid needs to be developed prior to performing analysis. The generation, transmission and distribution systems in the microgrid footprint are already modeled, but in different simulation packages. The generators and transmission lines are already modeled in Powerworld [10] as part of the larger Western Electricity Coordinating Council (WECC) transmission model. Some of the critical loads within the distribution system are already modeled in a separate, disconnected Powerworld model with different base values from the transmission model. The remainder of the distribution network that supplies the other critical loads, such as hospitals, federal buildings and universities, are modeled in SynerGEE [11]. The transmission system is modeled at 115kV voltage level, and the distribution system is at 13.2 kV voltage level, which also steps down to 480 V at critical loads. Fig. 4 shows the unified microgrid modeled in Powerworld that is modeled incorporating data from the above disjoint models.

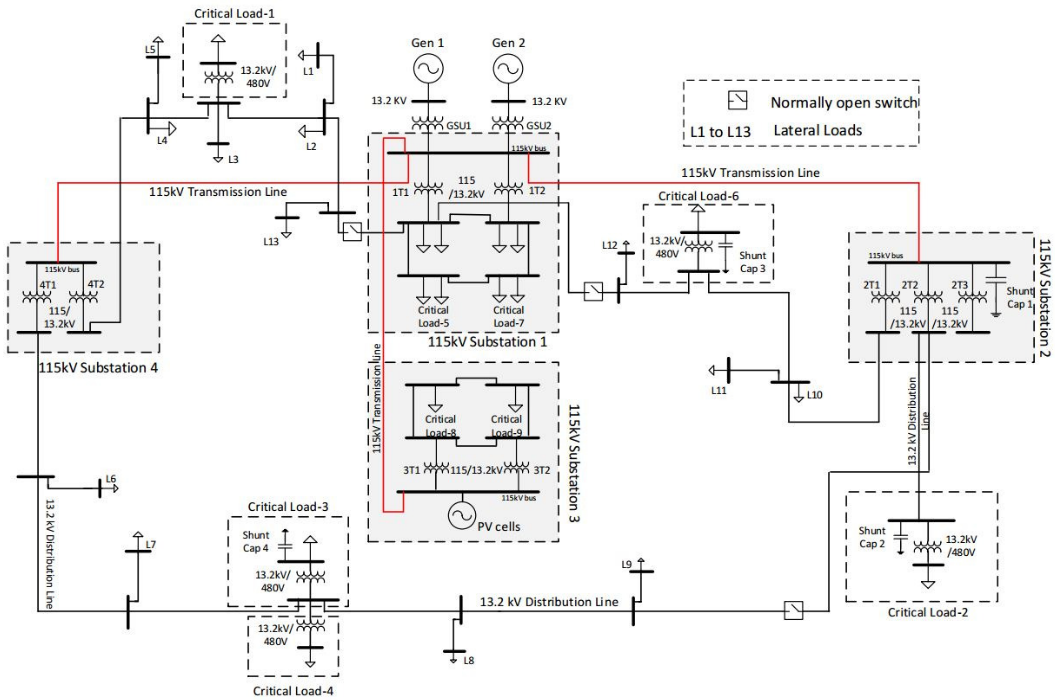

Fig.4. Final Powerworld model

Two generators, Gen 1 and Gen 2 are modeled including the stability models of machine, exciter and governor in Powerworld. They are connected to the microgrid network through two generator step up transformers GSU1 and GSU2 respectively, which steps up voltage from 13.2 kV to 115kV. There are four main substations at transmission level, each of which has step down transformers stepping down the voltage from 115kV to 13.2kV. The distribution system was modeled differently in SynerGEE.

The feeders supplying the critical loads have many lateral loads connected along the feeder. They are modeled as aggregated loads representing the Thevenin equivalent of the laterals. The non-critical lateral loads L1 to L13 are modeled with a bus, and a breaker that can isolate them. There are nine critical loads numbered 1-9 according to the priority. The critical loads 5, 7, 8 and 9 represent the equivalent of many small loads, which are supplied by four different feeders in the region. The existing system does not have capability to supply these small loads individually, so they are all modeled as an aggregate at Substation 1 and 3. Photovoltaic installations are aggregated together to be able to model as a single generator at substation-3. New shunt capacitors are placed in the model at four different locations to improve the overall microgrid voltage profile. The locations are at critical load-6, substation-2, critical load-2, and critical load-3. These locations are selected based on the initial simulation results.

4. ANALYSIS AND SIMULATION RESULTS

A. Transition to microgrid operation

The microgrid is formed if a blackout occurs. The appropriate transmission interties are identified and opened remotely to form an islanded microgrid. Then, smart switches are opened remotely using existing SCADA system and distribution fuses are opened manually where remotely operated switches are available. The hydro generators are brought back into running mode under no load condition and then connected to the microgrid transmission network. In this case, there is a chance of over voltages at different buses, so the capacitor banks need to be disconnected during this process. Finally, the critical loads are added sequentially based on the predetermined priority, with the control system ensuring voltage frequency and voltage stability. Capacitor banks are added as necessary to maintain the voltage magnitude within standard limits. The details of islanding detection and microgrid transition are not included in this paper.

B. Steady-state analysis

The power flow simulation is used as a steady-state analysis tool; it determines the quasi-steady state operating condition for a power system. The load and generation profiles are based on averaged and high and low values from 4 different seasons are considered while performing the simulations. The system is stable under the steady-state condition when the critical loads are supplied up to the hydro resource capabilities. The total generation in the model is the sum of the total critical load and system losses in the same four different seasons.

Table.1 Steady-state power-flow analysis results for four seasons

Season	Dem -and	No of loads served	Total Load (MW)	Total Gen (MW)	System losses (MW)	Voltage (p.u)				Cap1	Cap2	Cap3	Cap4
						Sub-1	Sub-2	Sub-3	Sub-4	MVAr	MVAr	MVAr	MVAr
Spring	High	6	25.37	25.9	0.53	0.9884	0.9882	0.9884	0.9884	0.6	1.5	0.6	0.9
	Low	4	5.94	6.09	0.08	1.0007	1.0007	1.0007	1.0007	0	0	0	0
Summer	High	5	22.27	22.7	0.42	0.9901	0.9899	0.9901	0.9901	0.3	1.5	0.9	1.2
	Low	4	4.06	4.09	0.03	1.0023	1.0024	1.0023	1.0024	0	0	0	0
Fall	High	6	24.31	24.8	0.48	0.9885	0.9883	0.9885	0.9885	0.3	1.5	0.3	0.3
	Low	4	3.57	3.61	0.04	1.0021	1.0021	1.0021	1.0021	0	0	0	0
Winter	High	6	23.62	24.1	0.48	0.9889	0.9887	0.9889	0.9889	0.3	0	0	0
	Low	6	11.9	11.928	0.1	0.9984	0.9984	0.9984	0.9984	0	0	0	0

The voltage is maintained within the limits as per the ANSI/NEMA C84.1-2011 standard [12]. Table 1 shows the summary of the simulation results for four different seasons each with high and low demand values. The number of critical loads supplied may vary according to the amount of generation available. Typically, the sum of the total loads and system losses will be equal to the total generation. The voltages are maintained within the limits by varying the capacitors accordingly. The capacitor banks are switched according to the season to maintain the voltages.

C. Transient stability analysis

Transient stability analysis was performed on the microgrid model using Powerworld. The dynamics that are considered in this paper are in the order of a few milliseconds to seconds. The dynamic machine (GENTPJ), exciter (EXST4B), and governor (HYGOV) models are included in the system model to perform the transient stability study. The generator-2 machine parameters are available from the tests conducted by utility in the machine, whereas generator-1 data is not available and approximations are made while loading the generator-1 parameters. The goal of this study is to verify how the generators behave during the startup of the microgrid, switching of loads, and fault conditions when the microgrid isolated from the main power grid.

Results obtained from one of the scenario are presented; this transient condition is when the critical load-2 (8.3MW in high summer) is added to microgrid after 2 cycles. Fig. 5a shows the frequency response, the frequency dropped to 59.54 Hz at the instant the breaker closed and it lated attained a steady-state condition after 25 cycles at 59.94 Hz. In the transient stability study, simulations normally do not bring the frequency to nominal (60Hz). Instead, the AGC control in the generators will bring the system frequency to 60Hz, which is normally in the order of minutes. Fig. 5b shows the generators response for the same transient condition. Generator-1 and generator-2 responded to the change in the load and increased output to new operating points of 10.2 MW and 10.8 MW respectively. A similar response can be observed in terms of reactive power outputs of the generators. The voltages at all the buses dropped a little and attained a steady state condition with new values within 6 cycles. The photovoltaic cells are modeled as supplying constant real power in this case. Transient models for photovoltaic cells are not included in this study.

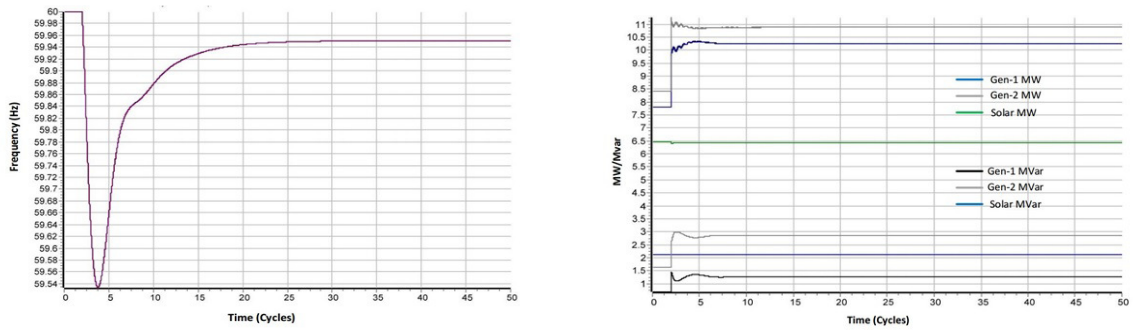

Fig.5. a) Frequency response to transient load pickup condition, b) Generators power output response for transient condition

5. CONCLUSION

This paper modeled a potential microgrid in an existing utility system as part of scoping study. The study identified the available generation resources, the critical loads based on their priority, and the microgrid system topology. Potential for solar energy generation within the area encompassed by the microgrid is estimated. The PCC breakers that need to be opened to form a microgrid were identified and electrical boundaries for the microgrid were defined. The transmission and distribution line parameters were acquired from different simulation packages and a unified model representing the microgrid was implemented in Powerworld. The measured load profiles and estimated generation resource profiles for the past three years were used to analyze the daily and seasonal behavior of different loads.

The power flow simulation was performed to identify the steady-state behavior of the system. The steady-state voltages were within limits in four seasons when the capacitor banks were switched appropriately. Transient stability cases were simulated by including the dynamic models of machines and for the set of case studies, the system attained stability after an acceptable period of time following pick up of the largest critical loads. The proposed microgrid has a very good potential to improve the resilience of the system as it is dominantly supplied by hydro generation that is very close to the critical loads.

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