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Steady State and Dynamic Performance Assessment of a Conceptual McMaster Campus Microgrid

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SUMMARY

Microgrids are local power distribution networks containing a combination of local loads and distributed energy resources, that can operate in either the grid-connected or off-grid mode. Microgrids provide a mechanism for optimal control local loads and distributed energy resources, thus offering improved network resilience against external disturbances and potential reduction in electricity costs. When a major disturbance occurs on the main transmission grid, a microgrid can isolate itself from the main grid and continue to supply power to all or some customers in the off-grid mode. This paper evaluates the feasibility of a conceptual McMaster University microgrid, referred to as the MacGrid, from the perspective of steady state and dynamic performance during unintentional separation from the main grid.

McMaster University has a student population of more than 33000 and its main campus is comprised of about 300 acres of property in Hamilton, Ontario. The university campus is fed from Burlington substation of the main transmission grid, via two 115-kV overhead transmission lines. In this paper, the University campus and the Medical Centre are considered one network even though they are under separate administrative authorities. The MacGrid has approximately 26 MW supplied through a 13.8 kV underground cable radial distribution system. Currently, the MacGrid contains a 5.7 MW gas-fired generator and six 1.8 MW diesel generators. McMaster is currently undertaking a planning study to identify the merits of installing a new 10 MW peaking generator on campus to reduce its Global Adjustment costs as a Class A customer.

This paper first describes the development of the load flow model for the MacGrid, based on the available single line diagrams and estimated feeder line impedances. Next it will present load flow simulation results on the voltage performance of the MacGrid under grid-connected and off-grid mode of operation. The analysis has also included the new 10-MW peaking generator under consideration.

After the steady state load flow analysis, transient stability simulation results will be presented to illustrate the frequency transients of the MacGrid post-separation from the main grid. In performing transient stability simulations, the study network was reduced to a 9-bus equivalent system with the transmission grid represented as an infinite bus and the local generators were modelled in detail with both excitation and speed governing control systems included. The contingency simulated was the sudden separation of the MacGrid from the main transmission grid without fault.

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Based on best estimate network data and typical dynamic models, preliminary results show that the MacGrid will exhibit satisfactory voltage and frequency performance after sudden disconnection from the main grid. However, this will only be the case if proper Remdial Action Systems such as generation and load rejection protection schemes are implemented. The paper provides a good experiential learning resource to undergraduate and graduate power engineering students who want to enhance their knowledge of power system analysis.

KEYWORDS

Microgrid, load flow analysis, power system dynamic simulations, frequency stability analysis
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1.0 INTRODUCTION

Microgrids are local power distribution networks containing a combination of local loads and distributed energy resources, that can operate in either the grid-connected or off-grid mode. Microgrids provide a mechanism for optimal control local loads and distributed energy resources, thus offering improved network resilience against external disturbances and potential reduction in electricity costs. When a major disturbance occurs on the main transmission grid, a microgrid can isolate itself from the main grid and continue to supply power to all or some customers in the off-grid mode. This paper evaluates the feasibility of a conceptual McMaster University microgrid, referred to as the MacGrid, from the perspective of steady state and dynamic performance during unintentional separation from the main grid.

McMaster University has a student population of more than 33000 and its main campus is comprised of about 300 acres of property in Hamilton, Ontario. The university campus is fed from Burlington substation of the main transmission grid, via two 115-kV overhead transmission lines. In this paper, the University campus and the Medical Centre are considered one network even though they are under separate administrative authorities. The MacGrid has approximately 26 MW supplied through a 13.8 kV underground cable radial distribution system. Currently, the MacGrid contains a 5.7 MW gas-fired generator and six 1.8 MW diesel generators. McMaster is currently undertaking a planning study to identify the merits of installing a new 10 MW peaking generator on campus to reduce its Global Adjustment costs as a Class A customer.

Microgrid design and operation has been a major research topic in the power industry. In [1], Ahsham et al reported on the modelling and analysis of a microgrids powered by renewable energy sources. Conte el al presented the equivalent modelling of reciprocating engine generators for microgrid frequency response analysis [2]. Katiraei [3] described the computer simulation modeling and analysis of the dynamic behaviour of reciprocating engines during islanding transition. Papaioannou el al [4] studied the influence of diesel generators on frequency stability for isolated grids with high wind power penetration. Moreover, Che el al [5] presented a primary frequency response based rescheduling for enhancing microgrid resilience.

This paper presents a preliminary investigation of the steady state and dynamic performance of the MacGrid during the transition from grid-connected mode to off-grid mode due to a grid event. Section 2 describes the steady state and dynamic models of McMaster's 13.8 kV underground distribution system. Section 3 presents the voltage analysis results and Section 4 summarizes the frequency stability simulation results. All load flow and transient simulations were done using Siemens PSS/E simulation tool while some modelling parameters were obtained from the ETAP data libraries.

2.0 THE MAC GRID

This section describes the load flow and dynamic models of the MacGrid used in PSSE simulations.

2.1 Network Model

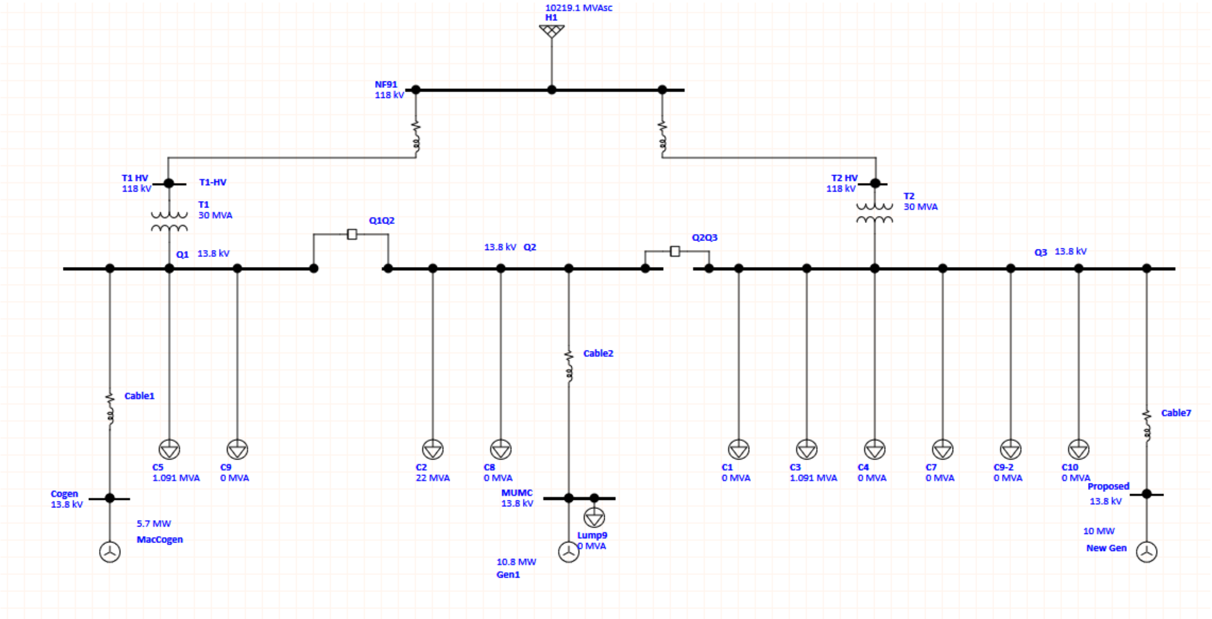
The MacGrid consists of ten 13.8 kV underground radial circuits C1 to C10, as shown in Fig. 1. Each circuit has two supply sources from the indoor 13.8 kV distribution bus located at the Central Utility Plant of the campus. The distribution bus has three sections (Q1, Q2, and Q3) connected by bus tie circuit breakers Q1Q2 and Q2Q3. Typically, each circuit is energized from one source (hence one feeder) and the second source serves as a backup. The MacGrid is connected to the main grid via two 115/13.8 kV on-load tap changing transformers T1 and T2, with each rated at 30/40/48 MVA.

Circuits C2, C3, C4 and C9 supply power to the various buildings on campus while the remaining circuits provide station service loads of the central utility plant. Currently the MacGrid has a gas-fired generator connected directly to the Q1 bus. Circuit 6 supplies power to the McMaster University

Medical Centre (MUMC) which also has six diesel generators each rated at 1.8 MW. In this paper, a proposed 10 MW gas-fired peaking generator has been included in the network model. resulting in a total campus generation capacity of approximately 26 MW. The MacGrid load flow model has been developed based on available single line diagrams and with the following assumptions applied:.

- All underground cables are assumed to be TECH XLPE 15 kV, 60 Hz, 3-Core and 500 MCM with impedance equal 0.1001 + 0.1105j ohms/km. Shunt capacitance is negligible.
- The maximum campus load is about 26 MW at 0.9 lagging power factor, distributed to the radial feeders according to typical load distribution factors.
- Each building load is estimated from the building annual electrical energy consumption.
- The length of each feeder line segment is estimated from the campus map.
- The impedance of all 13.8 kV-to-600 V step-down transformers is assumed to be 0.003+j0.06 pu on the transformer rated MVA base.

Figure 1 : Single Line Diagram of the MacGrid



2.2 Dynamic Models of Local Generators

Dynamic simulations were performed using Simens PSSE software. In assessing transient behaviour of the MacGrid, all loads were combined into two equivalent loads. One is placed at the Q2 bus and the other at the MUMC bus. All synchronous generators were modelled as salient pole generators. Each generator is equipped with a thyristor-controlled static exciter (EXST1) and a speed governor, either GGOV1 for gas turbine generator or DEGOV1 for diesel generator [6]. Typical modelling parameters are assumed as provided in Table 1. Modelling parameters for the governor models are based on the NEPLAN report on Turbine-Governor Models [7].

3.0 LOAD FLOW ANALYSIS RESULTS

This section presents the voltage performance of the MacGrid under grid-connected and islanded mode of operation with the campus load at peak conditions. Voltage analysis results are presented in Table 2

When the MacGrid is tied to the main grid, the two main transformers T1 and T2, which has on-load tap changing capability, are used to regulate the 13.8 kV distribution buses Q1, Q2 and Q3 to 13.8 kV, i.e.,1 pu voltage. Since all feeders are radial feeders, voltage performance of each feeder is decoupled from each other, provided the distribution bus voltage is within the regulating capability of the main transformers T1 and T2.

Table 1: Generator Dynamic Model Parameters

GENSAL		**GGOV1**		**DEGOV1**	
T'do	6.000	R	0.040	T1	1.000
T"do	0.030	TPELEC	1.000	T2	0.200
T"qo	0.060	MAXERR	0.050	T3	1.000
H	2.600	MINERR	-0.050	K	1.000
DAMP	0.000	KPGOV	27.600	T4	1.000
XD	2.000	KIGOV	7.700	T5	0.200
XQ	1.600	KDGOV	0.000	T6	1.000
X'D	0.263	TDGOV	1.000	TD	0.010
X"D	0.173	VMAX	1.000	TMAX	1.000
XL	0.180	VMIN	0.100	TMIN	0.000
S(1.0)	0.260	TACT	0.300		
S(1.2)	0.530	KTURB	1.240		
		WFNL	0.196		
EXST1		TB	0.590		
TR	0.020	TC	0.000		
VIMAX	999.000	TENG	0.000		
VIMIN	-999.000	TFLOAD	3.000		
TC	0.000	KPLOAD	2.000		
TB	0.000	KILOAD	0.670		
KA	20.000	LDREF	10.000		
TA	0.020	DM	0.000		
VRMAX	6.000	ROPEN	0.100		
VRMIN	0.000	RCLOSE	-0.100		
KC	0.000	KIMW	0.000		
KF	0.000	ASET	99.000		
TF	1.000	KA	0.000		
		TACT	0.100		
		TRATE	6.000		
		DB	0.000		
		TSA	1.000		
		TSB	1.000		
		RUP	99.000		
		RDOWN	-99.000		

Three scenarios of grid mode operation were studied, varying from no local generation dispatch (case Grid_0C_0D_0N) to maximum local generation dispatch (case_1C_6D_1N). Since the distribution bus voltage is regulated by T1 and T2, the node voltages of the campus buildings are very similar. In each case, the transmission grid was treated as the swing bus which made up any generation/load unbalance withing the MacGrid.

Under islanded mode of operation with both grid ties disconnected, each on-campus generator was used to regulate its terminal voltage to 1 pu. The 10-MW generator was used as the swing bus. Since there was enough generator active and reactive capacity to cover the maximum campus load, the node voltages in the MacGrid were similar to those when the system was under the grid mode of operation. Table 2 shows that building #33 has a low voltage of about 0.95 pu. After reviewing the load flow results, it was concluded that the low voltage was due to unusually high load distributor factor assigned to this building.

Table 2: Mac Microgrid Voltage Analysis Results

		Bus Voltage (pu)			
Bus #	**Building#**	**Grid_0C_0D_0N**	**Grid_1C_3D_0N**	**Grid_1C_6D_1N**	**Islanded**
909	9	1.0019	1.0037	0.9986	0.9939
910	10	1.0072	1.009	1.004	0.9993
911	11	0.9889	0.9907	0.9855	0.9808
916	16	0.9933	0.9951	0.99	0.9852
920	20	1.0073	1.0091	1.0041	0.9994
923	23	0.9943	0.9961	0.991	0.9863
924	24	0.9956	0.9974	0.9923	0.9876
925	25	0.9961	0.998	0.9929	0.9881
926	26	1.0007	1.0026	0.9975	0.9928
928	28	0.9878	0.9897	0.9845	0.9797
931	31	1.0031	1.0049	0.9998	0.9951
932	32	0.9964	0.9982	0.9931	0.9884
933	33	0.9522	0.9542	0.9488	0.9438
934	34	0.9885	0.9904	0.9852	0.9805
939	39	0.9867	0.9885	0.9834	0.9786
940	40	1.0016	1.0034	0.9983	0.9936
945	45	0.995	0.9969	0.9917	0.987
946	46	0.9949	0.9968	0.9917	0.9869
948	48	1.001	1.0028	0.9977	0.993
949	49	0.9983	1.0001	0.995	0.9903
950	50	0.9992	1.001	0.9959	0.9912
951	51	0.9899	0.9917	0.9866	0.9818
956	56	0.9969	0.9988	0.9937	0.9889
974	74	1.0023	1.0041	0.9991	0.9944

4.0 FREQUENCY STABILITY ANALYSIS RESULTS

The second part of the study was to examine the frequency response of the MacGrid when undergoing an unintentional separation from the main transmission grid. Both import and export scenarios were studied, with the campus diesel and gas generators on speed-droop governor control. To simplify all dynamic simulations, the network representation of the MacGrid was reduced to a 9-bus system, with one equivalent load applied at the Central Utility Plant 13.8 kV bus and another equivalent load at the McMaster University Medical Centre 13.8 kV bus.

The first analysis scenario was an import scenario in which Mac was importing 9.5 MW from the main grid to supply a peak campus load of 26 MW, with one gas generator and six diesel generators in service. After an unintentional separation from the main grid, the MacGrid was deficient of generation by about 37% and suffered a frequency collapse as shown in Fig. 2. The contingency was the tripping of the grid ties. The frequency collapse could be prevented by arming an underfrequency load rejection scheme. For the same contingency and if 9.5 MW of load was dumped after system separation, the MacGrid frequency remained steady at around 60 Hz, as shown in Fig. 1. The underfrequency load rejection scheme could be implemented via frequency relays or a central microgrid controller.

Fig.2: Import Scenario - Frequency Deviation from Nominal in PU

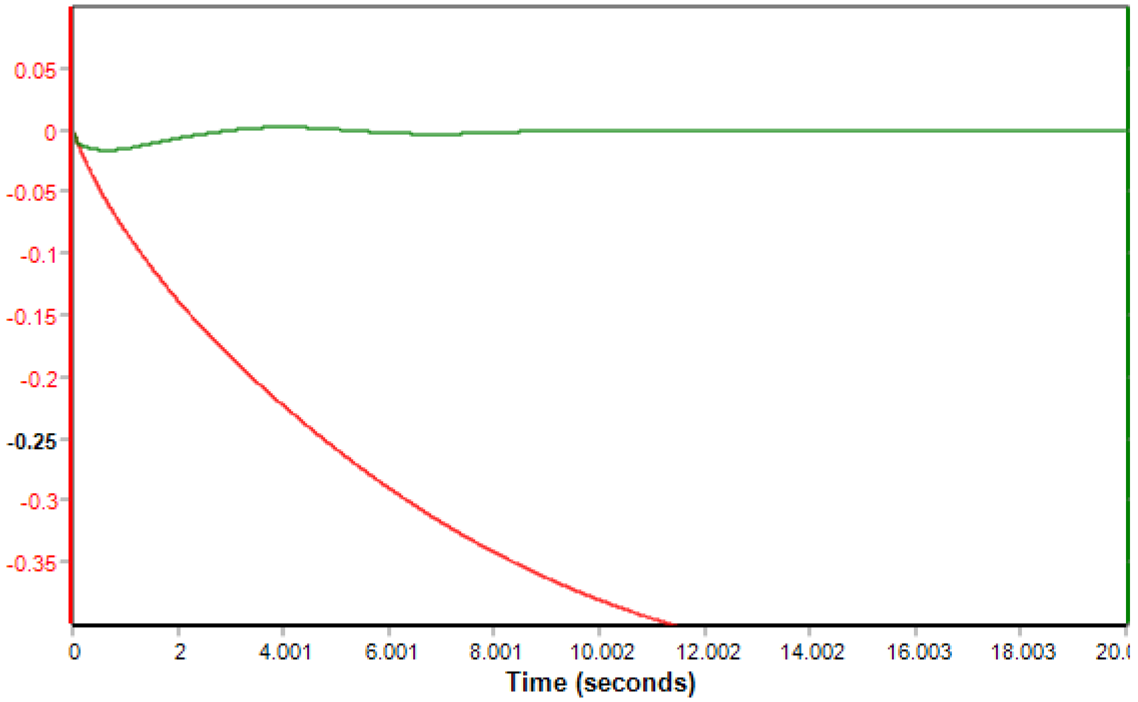
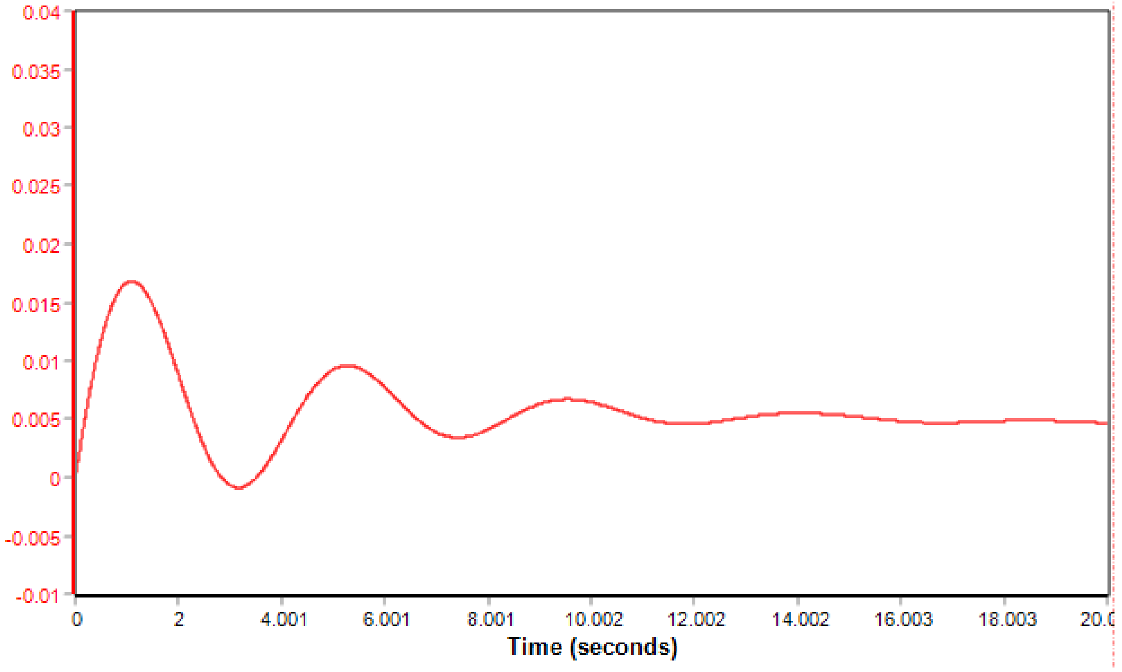


Fig.3: Export Scenario - Frequency Deviation from Nominal in PU



The second scenario was an export scenario in which the MacGrid was exporting approximately 3 MW to the main grid in addition to supplying its own campus load. In this scenario, the MacGrid had surplus generation post separation from the grid. After the loss of the grid ties, the MacGrid frequency went up initially but was regulated by the speed governor control to near the nominal value of 60 Hz, as shown in Figure 3.

5.0 CONCLUSION

A preliminary voltage and frequency stability analysis of the MacGrid has been performed to investigate the performance of the MacGrid during transition from the grid-connected mode to the off-grid mode of operation due to an unintentional islanding event. The analysis provides valuable information for the design of a microgrid controller for the MacGrid in future research work. Based on the best estimate network data and typical dynamic generator models, preliminary results show that the MacGrid will exhibit satisfactory voltage and frequency behaviour post separation from the main grid, provided proper Remedial Action Systems such as generation and load rejection schemes are implemented.

6.0 ACKNOWLEDGEMENT

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