Protection and Design of Distributed Energy Generation System (Microgrid)

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Abstract—As penetration of distributed generation (DG) increases at the distribution level, managing these systems effectively becomes increasingly challenging. One proposed way to manage these systems is through the adoption of microgrids. A microgrid is a distribution level network made of several loads and DG sources that operate as a single aggregate load or generation source. Microgrids can either operate connected to the grid, or in the case of a grid fault, in an islanded mode. In this paper, we use Matlab Simulink's SimPowerSystems to model a small portion of distribution network as if it were a microgrid. We add a mix of renewable DG sources and one dispatchable source, which at maximum output can produce more power than the average microgrid load. We then simulate the four major fault types at each bus in both grid-connect and island modes and analyze fault currents and voltage levels in order to determine how the protection scheme of the distribution network would need to be changed to facilitate microgrid functionality. We show that standard protection methods are insufficient and propose the use of digital relays connected to breakers.

Index Terms—Fault Analysis, Microgrid, Protection.

I. INTRODUCTION

Due to the increased concern over global climate change, the demand for clean sustainable energy sources has increased greatly. One of the major problems with these sources, such as wind and solar, is integrating them into the larger power grid. One proposed way is to have distributed renewable generation sources integrated into a microgrid. A microgrid is defined as a low to medium voltage network of small load clusters with Distributed Generation (DG) sources and storage [1]. It can operate connected with the larger grid or islanded in the event of a grid fault. A microgrid is controlled by a single controller and is viewed as a single load or generation source by the larger system. It can be operated in industrial, commercial, and/or residential areas. One major challenge with operating a distribution level microgrid with Renewable Energy Sources (RES) connected to the system with inverters is protection against faults. In this paper we analyze fault currents on a larger system of distribution network than that used in [1], [2]. Our system is protected with a standard distribution protection scheme. Our objective is to see how the protection will need to be changed to facilitate microgrid operation with the inclusion of DG sources and islanding capabilities. Our system was built and simulated in Matlab Simulink's Sim Power Systems..

II. SYSTEM TOPOLOGY AND DG MODELS

A. System Description

A microgrid usually consists of small segments of a distribution network connected to local DG units and loads. The system used in this study is an 18-bus network with a load capacity of 3.03 MVA connected to a 10 MVA transformer. This system is the example distribution system shown in [3] with line parameters and feeder source impedance given. The phase loads of each bus were also given and are shown in Table 1. The system is protected using fuses and reclosers on the overhead lines and breakers on the underground lines. To this system we added four solar arrays, two wind turbines, and one diesel generator. The solar arrays are each connected to three-phase inverters and provide a total of 2,256 kW. The wind generators provide an additional 500 kW to the grid. During islanded operations, additional generation and load following is provided by a 300 kW diesel generator. The one line diagram of the system is shown in Fig. 1.

TABLE I
BUS LOADS FOR THE MICROGRID IN FIG. 1, BLANK AREAS INDICATE UNCONNECTED PHASES

	Phase A		Phase B		Phase C	
BUS	P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (kW)	Q (kvar)
3	117	73	121	65	90	98
4	97	33	86	35	91	36
6	46	15	77	23	64	19
7	100	65				
8			85	32		
9					354	180
13	75	34	75	34	75	34
14	111	53				
15					176	34
16	89	63	89	63	89	63
17			314	126		
18	210	99				

B. Models of DG Sources

The inverter connected to the solar arrays is a current converter made with a three-phase IGBT/Diode Bridge controlled by a PWM generator with a voltage/current controller. The PWM has a carrier frequency of 4,320 Hz.

This is connected in series to an LC low-pass filter for improved power quality. An additional LC filter was used in the input to maintain the quality of the dc input signal. The input is any dc source rated between 50 kW and 570 kW and 5 kV. The output is a three-phase 12.47 kV system. Maximum allowable current is limited to 90 A, approximately twice the maximum power current. This is an adaptation of the inverter used in [4].

The diesel motor model used in this study is a modified version of the one used in [5] and is connected to a 300-kW/12.47-kV synchronous generator Simulink block.

The wind turbines are based on the wind turbine Simulink model demonstrated in [6]. This turbine is connected to a 100-kW and 400-kW squirrel-cage induction generators. The turbines are given constant wind input needed for maximum capacity generation.

The model for the PV modules is a simple single diode approximation with two resistors as shown in Fig. 3. This circuit is used to model a Sharp ND-Q0E2U 160-W module with I-V characteristics obtained from [7]. The resistor values are computed with the equations given in [8]. Though this model is not the most accurate, we feel it is sufficient for this study as the current limiting features of the inverter will dominate the dynamics in fault simulation. This module model is used to construct 564-kW arrays.

The DG sources are placed in desirable areas, with the diesel generator supplying a balanced three-phase load which will most likely be industrial and have a backup power supply. The solar arrays are all, with the exception of the array at bus 12, placed with loads to simulate the aggregate effect of rooftop solar panels on homes and businesses. The wind turbines are placed on buses without loads as usually large turbines are placed in wide open areas or hilltops near transmission.

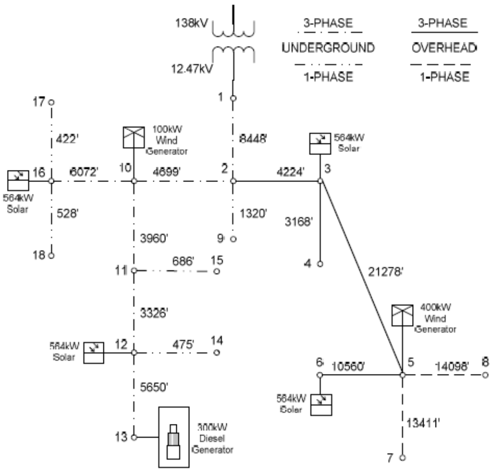

Fig 1

C. Modeling of PV Array

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 4.1 and/or by an equation as in (1).

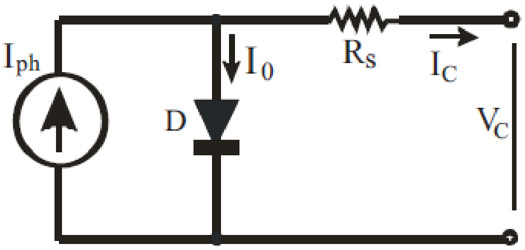

Fig. 2

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

$$Vc = \frac{AkTc}{e} \ln\left(\frac{Iph + Io - Ic}{Io}\right) - RsIc$$ Equation I

A possible model of a photovoltaic array and inverter [4] was researched. After verifying the theory its features were modeled in Simulink. This proved moretime consuming and complicated than intended. Like the theory, the modelworked both under load and no load conditions.Figure 3.4 shows the model of the PV array system. The blocks of mostinterest are shown on in the top layer as seen in the diagram

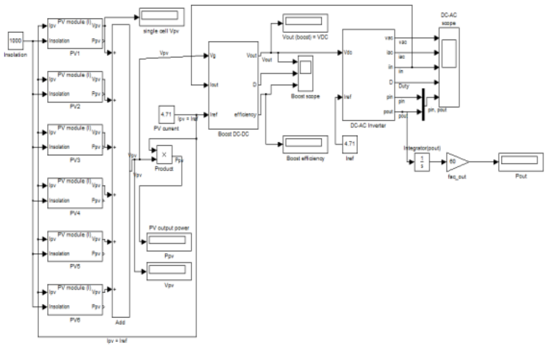

Fig. 3

D. Modeling of Wind System

A generic model of the High-Penetration, No Storage, Wind-Diesel (HPNSWD) system is as shown in fig below. This system presented in this uses a 480 V, 300 kVA synchronous machine, a wind turbine driving a 480 V, 275 kVA induction generator, a 50 kW customer load and a variable secondary load (0 to 446.25 kW).

At low wind speeds both the induction generator and the diesel-driven synchronous generator are required to feed the load. When the wind power exceeds the load demand, it is possible to shut down the diesel generator. In this all-wind mode, the synchronous machine is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand.

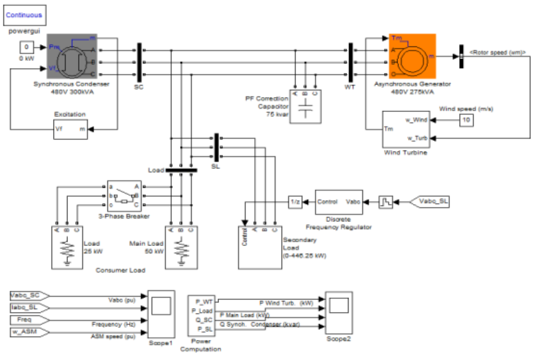

Fig 4

E. Modeling of Diesel System

A plant consisting of a resistive and motor load (ASM) is fed at 12.47KV from a distribution 32 kV network through a 6 MVA 32/12.47 kV Wye-Delta transformer and from an emergency synchronous generator/ diesel engine unit (SM). The 32 kV network is modeled by a simple R-L equivalent source (short-circuit level 1000 MVA) and a 5 MW load. The asynchronous motor is rated 2250 HP, 2.4 kV and the synchronous machine is rated 3.125 MVA, 2.4kV. The SM excitation is performed by the standard excitation block provided in the machine library. The diesel engine and governor system are modeled by a Simulink® block. Initially, the motor develops a mechanical power of 2000 HP (1.49 MW) and the diesel generator is in standby, providing no active power. The synchronous machine excitation system controls the 2400 V bus B2 voltage at 1 pu. At t = 0.1 s, a three-phase to ground fault occurs on the 32 kV system, causing opening of the 32kV circuit breaker at t = 0.2 s

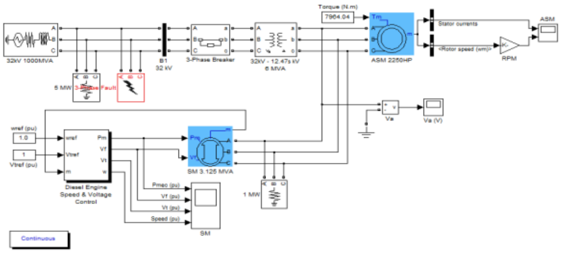

Fig 5

F. Matlab Model for Microgrid

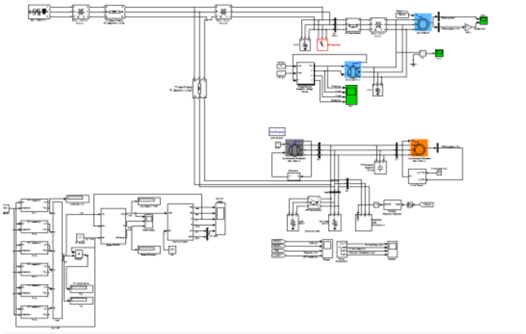

Fig. 6

In this study, we are interested in evaluating the maximum and minimum fault currents at each bus in the microgrid. The system was built in Matlab Simulink using the Sim Power System toolbox. The system is simulated using Simulink's ode3 with a fixed time step of 1 microsecond. The four major faults—single line to ground, line to line, double line to ground, and three phase faults—are initiated in the system 0.1 second after the system had reached steady state and is sustained for another 0.4 second. This allows the rms values of the symmetric fault currents to be measured. The fault impedance is chosen as 1mΩ. The system is only simulated in the islanded mode as the fault currents at each bus for the original system configuration are given in [3]. Faults with DG source contributions in grid-connect mode can therefore be easily computed using superposition. Fault currents are measured on both the high (closest to substation) and low (farthest from the substation) side of the fault as most locations had generation on both sides. Currents are also measured at the high and low buses, (where high and low mean the same as above) that would need to have backup protection if the devices at the particular bus should fail. Additionally, a three phase power flow study is conducted for three cases: (1) on the original system, (2) on the grid connected microgrid system, and (3) on the islanded system with the utility system isolated to compare the operating currents with the fault currents.

III. SIMULATION RESULTS

A. Photovoltaic Array System Results

For each power source, the individual components were attempted separately, as seen in Figure 4.1. The starting point was modeling of the PV array. It was hard to accurately test the individual components before the system was completed. However, when all components were completed it worked as expected. There was some issues with the system which arose when a step in insolation was applied to the input of the array. Further research was carried out to try and understand why this was happening. As a result of the research, meticulous checking and testing, the errors have been amended. The result is a system which very closely resembles the desired system response [4].

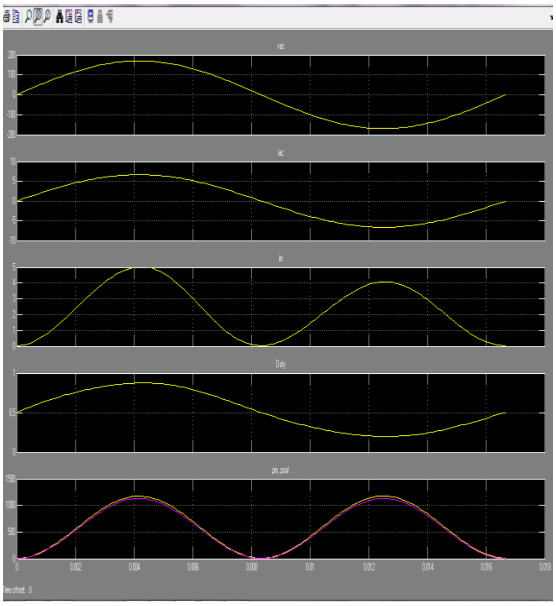

Fig 7

B. Wind System Results

The wind speed (10m/s) is such that the wind turbine produces enough power to supply the load. The diesel generator (not simulated) is stopped and the synchronous machine operates as a synchronous condenser with its mechanical power input (Pm) set at zero. The example illustrates the dynamic performance of the frequency regulation system when an additional 25 kW customer load is switched on.

When simulation is run, voltages, currents, powers, asynchronous machine speed and system frequency on the two scopes are observed. Initial conditions (x Initial vector) have been automatically loaded in workspace so that simulation starts in steady state.

As the asynchronous machine operates in generator mode, its speed is slightly above the synchronous speed (1.011 pu). According to turbine characteristics, for a 10 m/s wind speed, the turbine output power is 0.75 pu (206 kW). Because of the asynchronous machine losses, the wind turbine produces 200 kW. As the main load is 50 kW, the secondary load absorbs 150 kW to maintain a constant 60 Hz frequency. At t=0.2 s, the additional load of 25 kW is switched on. The frequency momentarily drops to 59.85 Hz and the frequency regulator reacts to reduce the power absorbed by the secondary load in order to bring the frequency back to 60 Hz. Voltage stays at 1 pu and no flicker is observed.

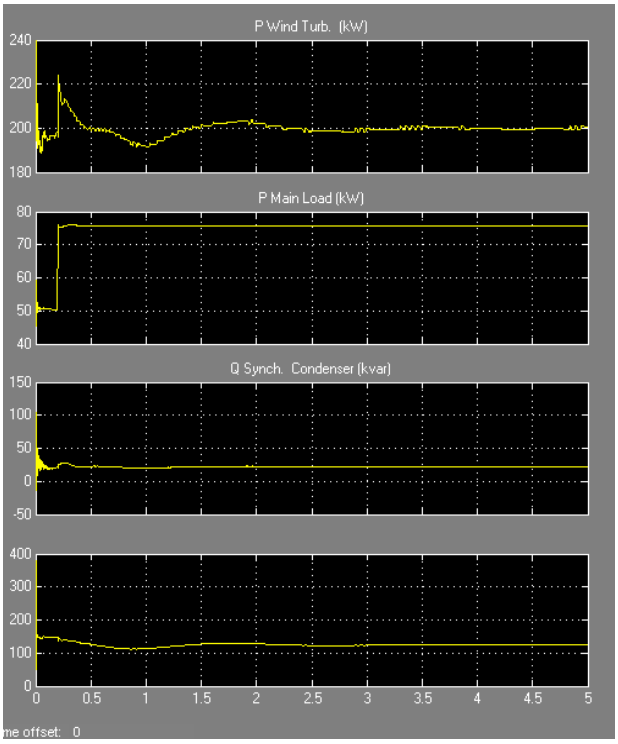

Fig 8

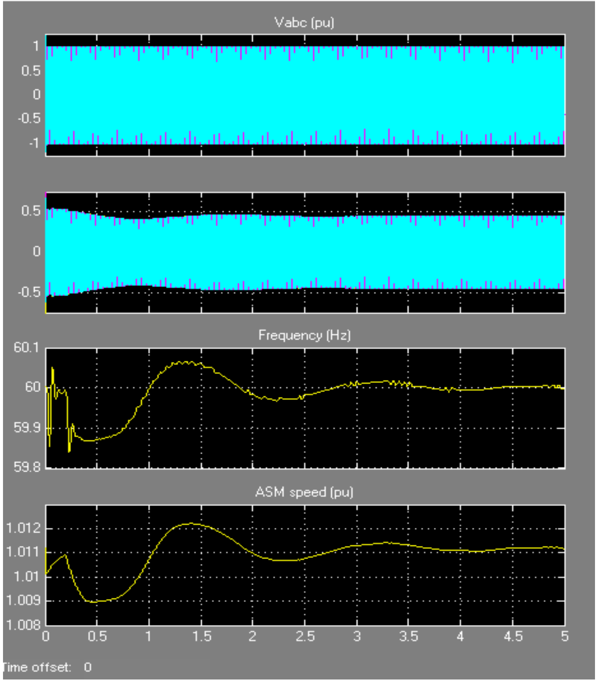

Fig 9

C.Diesel System Results

In order to start the simulation in steady-state, the synchronous machine and the asynchronous motor for the desired load flow is initialized. Specify the desired values by entering the following parameters:

Load Flow : U AB (Vrms) = 2400 , P (Watts) = 0. Specify also the ASM mechanical power by entering Pmec (Watts) = 2000*746.

Once the load flow is solved, the three line-to-line machine voltages and the three machine currents are updated. The SM reactive power, mechanical power and field voltage are displayed: Q = 856 kvar; Pmec = 844 W (power required by resistive losses in stator winding); field voltage Ef = 1.4273 pu; the active and reactive powers absorbed by the motor, slip and torque are also displayed.

The diesel engine governor and SM excitation system contain integrators and transfer functions which have also been initialized by the load flow. The initial mechanical power has been automatically set to 0.00027 pu (844 W). The initial terminal voltage Vt0 and field voltage Vf0 have been set respectively to 1.0 and 1.4273 pu. The value of the constant block connected to the torque input of the asynchronous motor has also been automatically set to 7964 N.

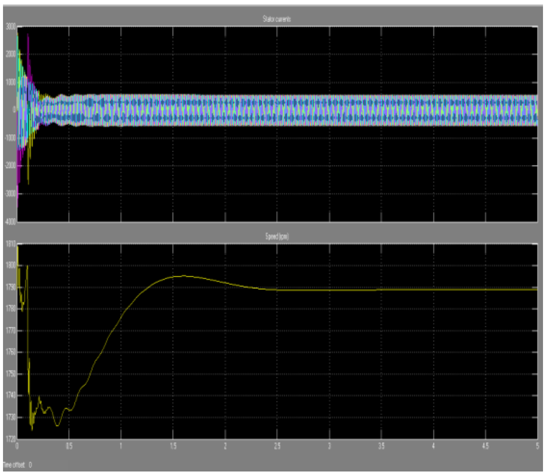

Fig 10

IV. CONCLUSIONS OF MICRO-GRID MODELLING

In this final chapter the project plan, aims and outcomes will be highlighted and summarized. The project is discussed in terms of what it aims and how it could contribute to the power industry's needs. It also explores how the project could be extended or improved and how this might be done. This includes what can be done in the future to understand micro-grid behavior, with the goal of micro-grids use and commercial development.

A. Project Conclusions

It is hoped that, by making use of the small and varied sources which comprise it, micro-grids may be able to make a significant contribution to the power generation and distribution market For instance, if the sun is out the PV array may provide power, if it's windy the wind turbine, if it is neither or if more power is needed, mains supply can be used. The inclusion of batteries in a micro-grid system would also allow excess power produced to be stored, or alternatively the excess power could be put into the main grid.

In this way it is expected that micro-grids could reduce pollution and deliver reliable energy in a variety of situations as discussed. Micro-grid behavior is on the whole not well understood. For this reason this project aimed to develop models suitable for analysis and investigation. The project aim was to model behavior of micro-grid's individual power sources, and time allowing a micro-grid system.

A final aim was to lay groundwork which would allow analysis for the further development of a more sophisticated model. More specifically, it involved modeling a photovoltaic cell, a wind turbine. To this end the project has been successful. All models developed will allow for investigation that will provide an understanding of micro-grids to facilitate the evolution of a more sophisticated model.

This project was carried out by way of extensive research, model design, modelling, testing and development. Each power source model was completed independently starting with the PV array.

The PV array works as expected fora changing input. This is a good result that reflects real situations well. The wind is not yet fully completed. The results thus far are very good, and it is expected they will improve prior to open day through further testing and development. These sources will be connected together to form a micro-grid. It is anticipated at least two of the three power sources will be connected together to power a single load.

B. Micro-grid Modelling and the Future

As previously discussed, the goals of this project were prescribed in terms of how the model developed will be used. The next step should be to further develop the micro-grid as a whole. It is important to learn more about how the sources interact with each other that is do they enhance or interfere with each other. More specifically their relationship to each other needs to be defined. I fall goes as anticipated and the micro-grid system as a whole is developed, the control of the system will likely be imbedded within the electronics. It could be possible to use a specialized controller to get a more stable response and to use each power source more efficiently. This should certainly be researched and considered once the power sources interaction and relationship to each other and the mains has been defined.

Another aspect that could be developed further are the individual sources within the micro-grid. This could happen on two levels. The first is the consideration of other variables for each source. For example, wind speed is not considered for the PV array and in some conditions it would prove quite significant .Also, working in pu is more desirable than actual values the full conversion of the wind system to pu would be useful. The other way is to keep the model up to date with the technology. This means as science and engineering develop more efficient technology the system should be updated also.

In the area of PV arrays technology is constantly changing and improving. As there are other power sources being considered for use in micro-grids there search and modelling of them will at some point be necessary. The sources being considered include fuel cells and batteries which provide electrical storage. They would need to go through the same process used to develop the other models, and then be connected into the micro-grid system.

The final important aspect is to obtain some actual micro-grid data (rather than data from individual power sources).Due to micro-grids being a very recent idea and therefore no data being available. As research groups race to develop accurate models and implement them this will change.

C. Final Remarks

On the whole, this project The Modelling a Micro-grid System has been successful. Models which allow for investigation of the individual power sources behavior have been developed and it is expected that a micro-grid unit will be modelled prior to open day. The project was carried out by doing extensive research and by using a design process to implement each system individually. Testing and development through understanding was also a significant part of this project. The goals of this project have been met and it is anticipated further research and development will be carried out on the system, with the goal that micro-grids will be able to make a valid, greener, contribution to the world’s growing energy needs.

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