Microgrid energy management system control strategy

Conference Paper · August 2015

DOI: 10.1109/ICUE.2015.7280261

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Microgrid Energy Management System and Its Control Strategy

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Abstract—This paper presents the basis analysis of control strategies developed in microgrid control structure, when it is integrated with microsources. Due to weather conditions, the microgrid system used an unavoidable input power perturbation, produced by the renewable energy. This perturbation causes unbalance in power system between the energy produced and consumed, as well as creating output voltage and frequency to fluctuate. Therefore, different methods of energy management systems employed in microgrid, in order to stabilise the system are discussed. Among those energy managements, the control strategy of the load management have been developed and analysed through MATLAB/ SIMULINK simulation. The simulation results justified the stability of the microgrid operation under irregularities of the input voltage. The flow chart transition method based on graphical transition state is employed to maintain the output voltage of the microgrid; this was attained by switching ON and OFF certain unnecessary loads upon considering the available input power.

Keywords: Energy Management System (EMS), MATLAB/Simulink, microgrid, transition state flow, sensitive and non-sensitive loads, PI controller,

1 INTRODUCTION

Microgrid tends to solve the problems of energy crisis that faces the words [1], [2]. Those problems are the energy pressure indicated by the rapid increased number of end users, which increases the demand in electrical energy. The energy produced by a power plant is considerably reduced before reaching the customers, due to losses that take place through a long distance of the transmissions lines between the power plants and distribution points. Also, it is not simple to insert new automated systems to the ageing of infrastructures that have been installed for years [3], [4].

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Considering all the above-mentioned problems, it is clear that the conventional power plants can no longer promise safety, reliability, and sustainable energy for worldwide. The introduction of DG appears as the solution of choice for this matter; it is the key to improving electrical supply [6].

Basically a microgrid involves the integration of multiple distributed energy collection sources; the electricity from these sources is gathered, processed and distributed to meet the demand loads. While power electronics interfaces with micro energy forming a single entity, this operation requires a control system. Such a control system is needed, not only to provide flexibility, but also to preserve the specific energy output and the power quality [7], [8]. Microgrids supply electricity to small communities such as small towns, universities, and industrial areas; they can operate in two ways, either connected to a grid or in stand-alone mode. It is essential to adopt a flexible control to a microgrid in order to be seen by a primer grid as a single controllable unit [9], [10].. A connected microgrid is defined as a grid that is connected to a utility grid at a static switch called the point of common coupling (PCC), and cooperates with the utility grid by adjusting the power balance of the utility grid in terms of facilitating the import/export of power. On the other hand, a stand-alone microgrid is referred to as a utility grid which is disconnected from the utility grid at the PCC, and operates autonomously[11], [12].

Microsource is the core unit of microgrid, and DG mostly employed non-conventional energy such as renewable energy source (RES) which include wind power, solar power, biomass are used to generate small electrical power from (normally less than 50 MW). The problems of energy losses through the transmission line are considerably reduced since the power plants are usually very close to the consumer [4], [13], [14], [15]. The power generated by DG based renewable are environment friendly compared to the conventional energy. One of the most popular renewable energy sources is solar energy because it is abundant, accessible and easily converted into electricity [16].

Nevertheless, the renewable energies have a tendency to dependent highly on weather conditions, which is a disadvantage of it. Since the power from the DG generator and consumed by it load, depends on the weather conditions [17], [18]. So the non-maintenance of power produced and consumed, will lead to frequency and voltage fluctuations, and it is quite difficult to determine and monitor consumer usage at any given time [17], [20], [19]. Distributed generation can then be subjected to discrepancies in consumer usage and this can lead to severe stability problem reducing the system reliability. As a result, microgrids powered by DG, operating in a stand-alone controllable system mode, the problem of balancing a cluster of loads regarding the available power generated. Balancing a cluster of loads will ensure that that the entire system operates without overloading at all times.

2 MICROGRID CONTROL LAYER

The microgrid control system makes sure that the ensemble of control tasks is achieved. The entire control operation is located at three control layers in the microgrid as can be seen in Fig. 2.1. These control levels are the following [1]:

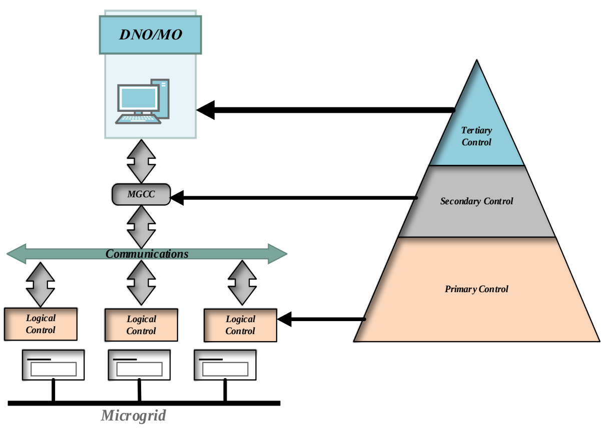


Fig. 2.1: Microgrid communication: local and centralised controller

(Vandoorn et al., 2013)

- The primary level is the lower level containing the local control which is responsible for the control of DERs, some local load, and the balance of the active and reactive power. At this level some decisions can be made locally when a microgrid is operating in decentralised control, while when operating in centralised control, it will receive set point from MGCC.
- The second level refers to the microgrid central control (MGCC); it is the area where DER clusters are integrated into the microgrid. The MGCC is in charge of stabilizing the voltage and frequency within a specific, limited range, at the PCC. Also, it is responsible for the active and reactive powers dispatched from an individual DER.
- The third level is the distribution network operator (DNO) control incorporating a market operator (MO), which is situated in the main grid. This presents the upper management area and it facilitates the buying and selling of energy between consumers.

In this paper the focus will be on the primary level

3 MICROGRID ENERGY MANAGEMENT SYSTEM AND ITS CONTROL STRATEGY

3.1 Microgrid Energy Management System Functions

A The microgrid is similar to a small power system which encompasses various components such as DG units, controllable loads, and interconnected and communicated storage devices, all operating together as a single system by using power electronic interfaces and controls for flexibilityto meet the demand loads and including energy storage and load management functions. When power electronics interfaces with micro energy forming a single entity, its operation requires a control system. Such a control system is needed, not only to provide flexibility, but also to preserve the specific energy output and the power quality.

3.1.1 Load management

To preserve the balance of microsource power generated and load power, the load management method tends to distribute microsource output accordingly to the selected load to guarantee the normal power supply to the load. Especially, when the microgrid operates in island mode, to prevent the overload operation.

3.1.2 Mode switching and ON-OFF control

The microgrid has the ability to be connected to a utility grid at a static switch called the point of common coupling (PCC), and cooperates with the utility grid by adjusting the power balance of the utility grid in terms of facilitating the import/export of power. On the other hand, the microgrid can be disconnected from the utility grid at the PCC, operates autonomously known as stand-alone microgrid. When failure happens, the switching ON-OFF controls will automatically transit from the island mode to the Grid mode. It can achieve a seamless transition between two modes of operation. This will isolate the microgrid from the rest of the network, the microgrid will the sensitive load until the main grid is ready to operate again.

3.1.3 Microsource control functions

Moreover, power electronic systems will interact with microsources and local controllers, and in the process carry out the following functions: active and reactive power control; data storage for fast load tracking; and load sharing through power-frequency control, being mainly with droop control. Multiple control strategies have been introduced to eliminate or lower the current flow among parallel distributed generation source.

3.1.4 Management of energy storage devices

Energy storage systems are used to support the distribution network at peak load time, when the use of electricity by consumers is high. This energy storage helps microgrid in balancing the power between the loads and generation units, by providing energy whenever the microsource units have insufficient energy to power the load. The management of the batteries includes power management, charging, discharging, control the output voltage, the active and reactive power and participate with the active and reactive power control.

4 MICROGRID SYSTEM DESCRIPTION

The autonomous microgrid model is made up of a battery which represents (wind or solar energy), an inverter, an LC filter and loads. The loads consist of sensitive and the non-sensitive loads power and both are available within the microgrid system. The system is designed to maintain the sensitive load power permanently connected to the microgrid, while the connectivity of the non-sensitive load depends on the magnitude of the input voltage generated by the renewable energy shown in Fig. 4.1. However, the control algorism consists of load management which makes load follows the power produced by the renewable energy in order to maintain the output voltage constant. Due to the fact, that load size and input power capacity can affect the autonomous microgrid system operation. The LCS control will monitor the system through the V_d component of dq0 transformation by determining whether or not the non-sensitive load will be connected/ disconnected though the circuit breaker to the system microgrid. This method is disposed to preserve the phase-to-ground V_{rms} at 230 V, which implies a peak output voltage waveform of 563 V. This interaction between load and power is analysed.

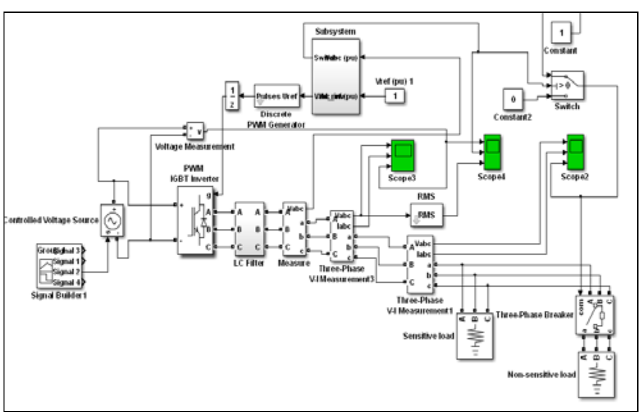


Fig. 4.1: Inverter control under load power changes

5 CONTROL ALGORITHMS OF INVERTER OUTPUT VOLTAGE

5.1 Inverter output control using the dq0 transformation + PI controller

The control method employed to regulate the inverter output voltage relies on the the combination of dq0 transformation and the PI controller. The signal voltage from the inverter terminal is transformed to dq0 frame. This dq0 frame lessens the three-phase AC quantities V_a, V_b, V_c into two DC quantities V_d, V_q and in balanced systems, the 0-component is equal to zero. It is much simpler to perform an analysis and design controllers in a three-phase system, in a dq rotating frame because all time varying state variables of the controller become DC time-invariant. The DC quantities is compared to a constant reference of value 1.The error sign from the comparator is controlled trough the PI controller block in Fig 5.1 below. The controller used, is a combination of the discrete proportional gain k_p and an integral gain $k_{I,}$ with fixed sample time. The output signal is the sum of the proportional gain, k_p and the integrator gain, k_I. The total signal and k_I and are limited by upper and lower values. Then the controlled signal is converted back to the inverse of the transformation block, dq0→abc. The virtual PLL block is connected to both transformation blocks in order to synchronize and maintain the frequency operation at 50 Hz.

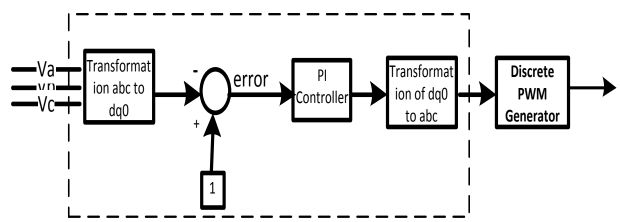
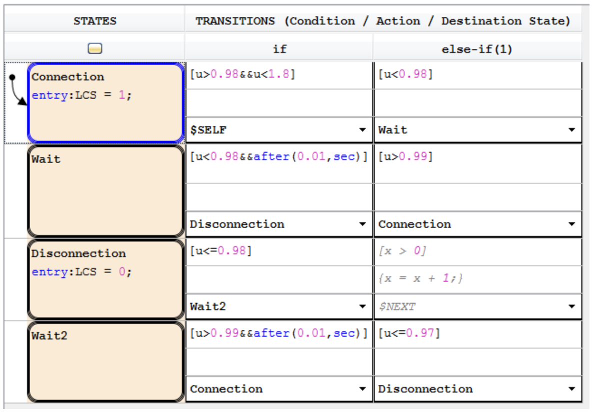


Fig 5.1: dq0 transformation + PI controller

5.2 Energy Management System Control algorithm

The energy management system (EMS) refers to the method used to monitor a specific system and to optimise its operation. In practical applications SCADA/EMS are used to monitor the system operational, also coordinates the appropriate control functions to maintain the system up running. However, the EMS is normally used for controlling energy generation and scheduling a programme for an ensemble of power network applications. EMS can also be used to control the electrical loads in a microgrid, in such a way that loads will switch on according to power produce by the renewable energy. In order to improve the efficiency of the design control, an EMS called logic control switch (LCS) is added to the system grid to further stabilize voltage control by selecting the appropriate load to match with the input power. This has been applied in EMS is implemented in MATLAB by developing an algorithm based on a flow chart as shown in Fig. 5.1 below and Fig. 5.2 below.

This flow chart is developed to maintain further stability by automatically connecting and disconnecting non-sensitive loads. The flow chart transits from state-to-state according to the available input power in order to connect and disconnect the loads as seen in Fig. 5.3.



STATES	TRANSITIONS (Condition / Action / Destination State) if	else-if(1)
Connection entry:LCS = 1;	[u>0.98&&u<1.8] $SELF	[u<0.98] Wait
Wait	[u<0.98&&after(0.01,sec)] Disconnection	[u>0.99] Connection
Disconnection entry:LCS = 0;	[u<=0.98] Wait2	[x > 0] {x = x + 1;} $NEXT
Wait2	[u>0.99&&after(0.01,sec)] Connection	[u<=0.97] Disconnection

Fig. 5.2: EMS transition state

The EMS controls a breaker switch by connecting and disconnecting non-sensitive heavy load power according to the availability of the input battery voltage.

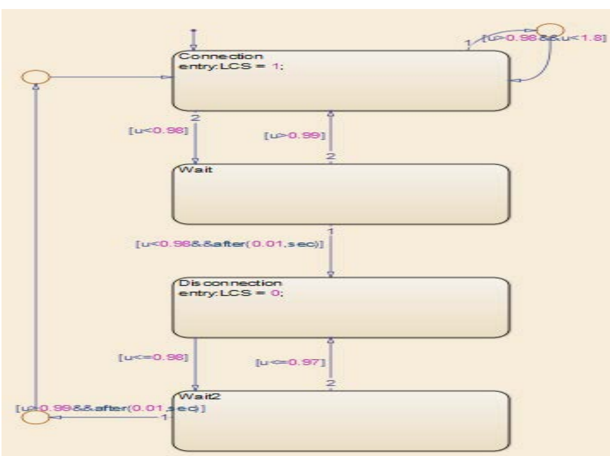


Fig. 5.3: EMS flow chart

The LCS monitors the system through the V_d component of the dq0 transformation to maintain a constant value by determining whether or not the non-sensitive load will be connected to the system. When the V_d component from the abc to dq0 transformation and the logic control switch is at normal operation, the phase-to-ground V_{rms} is 230 V and V_d = 1.

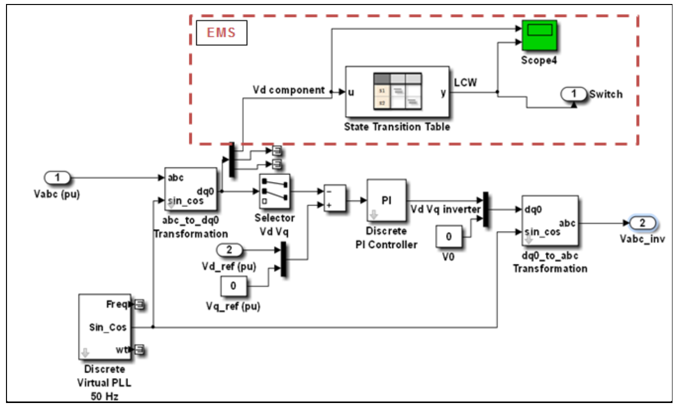


Fig. 5.4: EMS integrated with a dq0 transformation + PI controller

The logic control of the switch is based on the value obtained from V_d component. When V_d is greater or equal to 1.01 the switch is ON and when V_d is less than 0.98 the switch is OFF. Which respectively add the non-sensitive load to the system by the logic control switch, when the input voltage available can handle more loads and remove the non-sensitive load when the input voltage cannot handle an additional load.

6 SIMULATION RESULTS

Load management is used microgrid system to maintain the stability by avoiding the overloaded operation mode. Here, the simulation of input voltage magnitude the variation feed in microgrid system is operating with full loads, with essential load only and finally with the non-essential load is being switched ON and OFF regarding the input magnitude are analysed.

6.1 Inverter control operating with load (sensitive and non-sensitive) powers without activating EMS

Distinct sensitive and non-sensitive load powers are both permanently connected to the system, and operate together without LCS to stabilize the system. Fig. 6.1 above presents the input voltage, Logic control switch and phase to ground Vrms waveforms. The phase to ground Vrms is 230 V during the time intervals 340 to 430 ms and 680 to 900 ms while the input voltage magnitudes are 750 and 1000 to 798 V correspondingly.

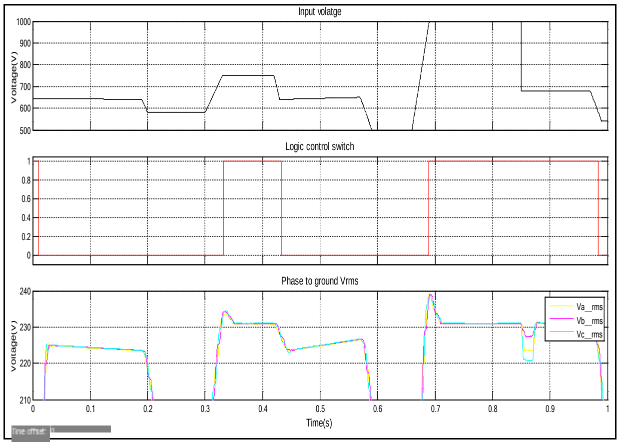


Fig. 6.1: input voltage, logic control switch and phase to ground Vrms of the loads without active EMS

The phase to ground Vrms dropped from 225 to 210 V for the remaining of simulation time. This variation and instability is due to the low input power capacity to drive the load power, which in-turn caused instability in the d component.

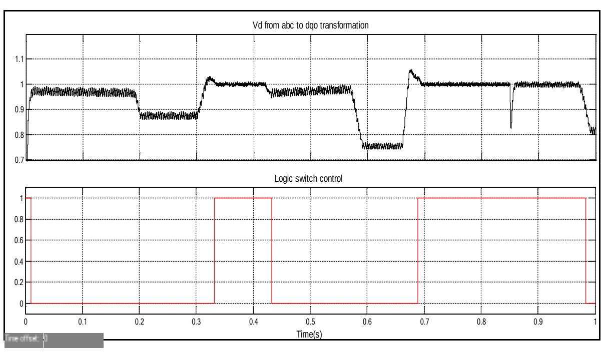


Fig. 6.2: The d component of the dq0 transformation in the loads without activating of the EMS to the system over the minimum input voltage

Fig. 6.2 below looking at the d component of the dq0 transformation varies depending on the input voltage. During the time interval from 340 to 430 ms and 680 to 900 ms, the value of the d component is ranging between 0.99 and 1.01.

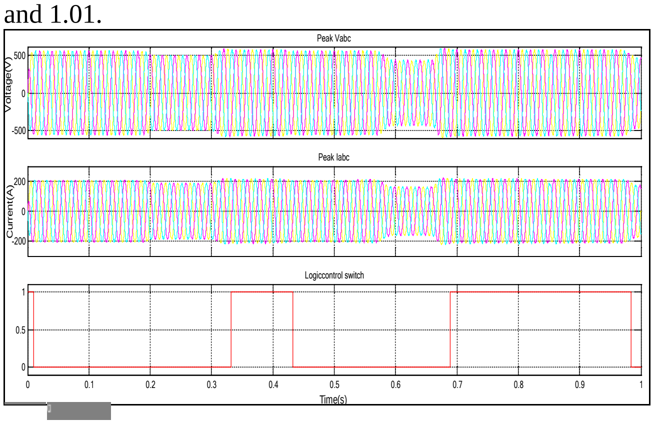


Fig. 6.3: peak output volatge an`d current in the total load without activating of the EMS to the system

Through the rest of the time, the d component value ranges between 0.96 and 0.98 compared to fig. 6.5 above where the Vd component is fluctuated between 0.98 and 1.01 through the time interval from 0 to 200 ms, 340 to 570 ms and 680 to 900 ms. This is due to the low input power capacity that drives the load power and caused instability in the d component. Fig. 6.3 shows output peak voltage waveform, when the load power is greater the input voltage, it causes slight voltage sag at the output voltage.

6.2 Inverter control operating with sensitive load power only without activating EMS

The system is analysed under input voltage variation from 500 to 1000 V, while simply the sensitive load power is connected to it. LCS is incorporated to the system microgrid to determine whether or not the non-sensitive load power can be connected to the system through a circuit breaker. However, LCS is not connected to any circuit breaker due to the absence of the non-sensitive power load in the system. So the action of the LCS does not have any effect on the system, even though, it is active in the system.

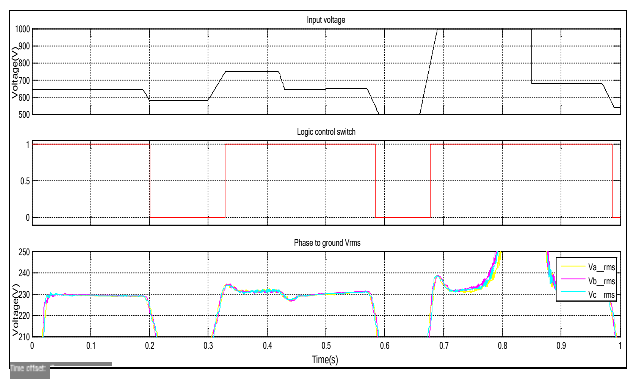


Fig. 6.4: input voltage, logic control switch and phase to ground Vrms without activating EMS to the system over the minimum input voltage

Fig. 6.4 below shows the input voltage, Logic control switch and phase to ground Vrms. The LCS is ON during the time intervals 0 to 200 ms, 340 to 570 ms and 680 to 900 ms whilst the corresponding input voltages are 645 V, 750 to 645 V and 1000 to 798 V respectively. Also, the nominal phase to ground Vrms is 230 during the same period as LCS is ON and for the rest of the simulation time the phase to ground Vrms is less than 210 V when the input voltages are 590 V and 500 V respectively.

Fig. 6.5 above illustrations that the d component of the dq0 transformation varies depending on the input voltage during the time intervals 0 to 200 ms, 340 to 570 ms and 680 to

900 ms for the magnitude voltage of 645 V, 750 to 645 V and 1000 to 798 V respectively. At same time, d component value ranges between 0.99 and 1.01. Throughout the remains time intervals, the d component ranges between 0.96 and 0.98. Comparing to Fig. 6.2 above where the phase to ground is 210 V during the time interval from 0 to 200 ms, 340 to 570 ms and 680 to 900 ms. This is due to the low input power capacity to drive the load power and caused instability in the phase to phase Vrms.

Fig. 6.6 below shows output peak voltage waveforms when the load power is greater than the input voltage, it causes a slight voltage sag. This is observed in the output voltage at the time intervals 200 to 340 ms and 570 to 680 ms.

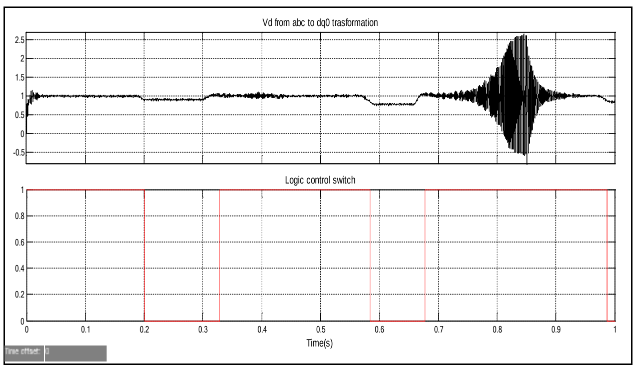


Fig. 6.5: The d component in the sensitive load without activating EMS

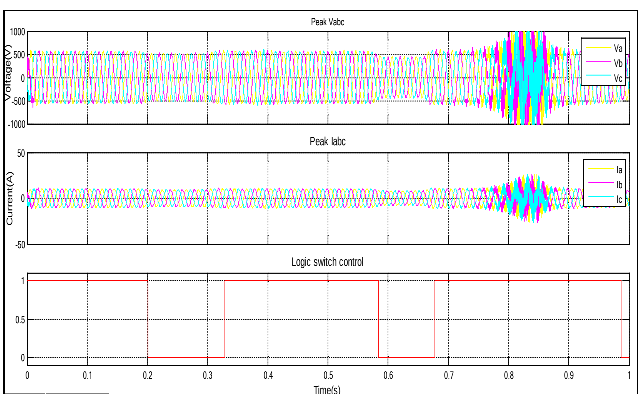


Fig. 6.6: Peak output voltage and current waveforms without activating EMS

6.3 Inverter control operating with Sensitive and non-sensitive loads with EMS over the minimum input voltage

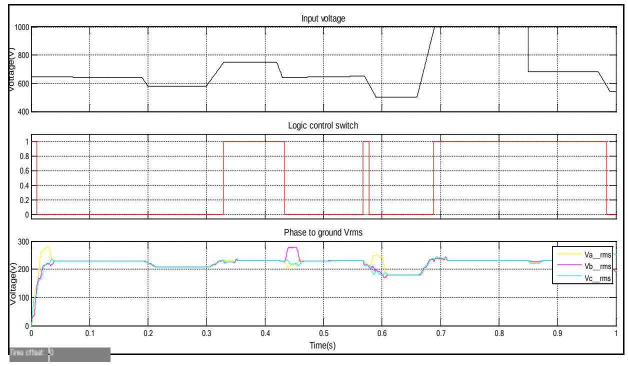


Fig. 6.7: input voltage, logic control switch and phase to ground Vrms of the loads with active EMS to the system

The sensitive and the non-sensitive load are both operating with the system. However, the sensitive load power is permanently connected to the system, and the non-sensitive load power is temporarily and initially connected to the system. The connectivity of the non-sensitive load to the system depends on the capacity of the input voltage.

Fig. 6.7 above shows the input voltage, Logic control switch and phase to ground Vrms. The LCS monitors the system through the d component by determining whether or not the non-sensitive load will be connected to the system. This method tends to maintain the phase to ground Vrms to 230 V by switching ON or OFF the non-sensitive load according the input power capacity. The peak output voltage waveform will be 563 V when the LCS is ON. However, when the load powers are greater than the input power capacity, it causes voltage sags at the output voltage as shown in Fig. 6.8 below.

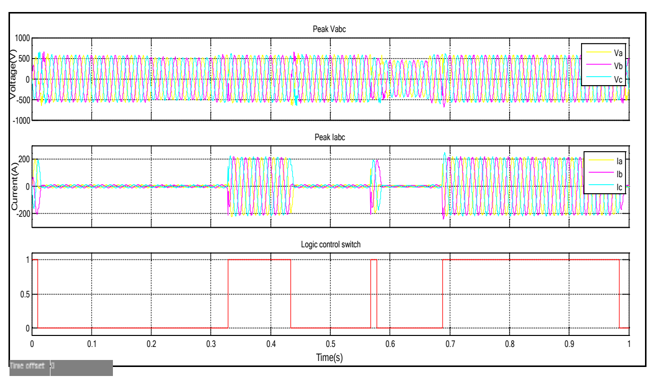


Fig. 6.8: peak output volatge and current in the total load wit active of the EMS to the system

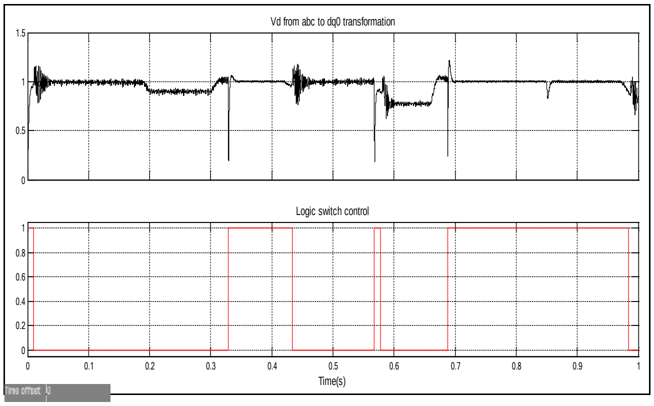


Fig. 6.9: The d component of the dq0 transformation in the total load with activation of the EMS to the system

Fig. 6.9 above shows that the d component of the dq0 transformation is maintained at a constant value despite the input voltage variation. The d component value from the transformation is between 0.99 and 1.01 whilst the LCS is ON. The non-sensitive load is added to the system by the logic control switch when the capacity of the input voltage is able to handle more loads. When the input voltage cannot handle any additional load the logic control switch disconnects the non-sensitive load. Initially, both loads are connected to the system but, LCS removes the non-sensitive load to keep the phase to ground Vrms to 230 V for each phase. Just after the non-sensitive load is removed at 10 ms, there is an overshoot during the transient period when PI controller is applied to change the m_a value to effectively regulate the Vrms and the voltage at the inverter's terminal. So, in the remaining simulation time the non-sensitive load is added at 340 ms and 560 ms and 680 ms respectively and removed at times 440 ms, 580 ms and 980 ms. When, the non-sensitive load is added, it causes a short and quick drop voltage before the PI controller controls it. This explains the stability of the phase to ground Vrms as well as the peak output voltage waveform because the EMS plays a vital role.

7 Conclusion

This research was carried out because microgrid operation is uncertain in terms of resources available, when using distributed generation. In addition, the output voltage of a microgrid depends heavily on weather conditions. So aim was to maintain the power generated eq ual to the power required by the loads, since irregularity in the production of the renewable energy and irregularity in consumption lead to frequency and voltage fluctuations. To achieve this aim load balancing was found to be essential for the functionality of the power system, by making sure that no overloading occurs during the operation of the microgrid system. Systematic control and stability of the system at the inverter, interfacing between the DG infrastructure and the rest of the microgrid system, was also analysed. The results are further improved with EMS in order to maintain the output voltage of the microgrid by switching ON and OFF certain loads depending on the input power. Controlling the demand in electricity by load management contributes to smooth operation in microgrid autonomous mode. In particularly, the Stateflow logical programming environment, a part of SIMULINK, was used to develop an algorithm for load balancing. The environment made it possible to model complex algorithms by combining graphical and tabular representations. This facilitated sequential decision making logic, based on state transition diagrams, flow charts, state transition tables, and truth tables.

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