# Stability Analysis of Microgrids

**S. Shreyas, D. Harini, K. SurendhiraBabu,K. Venkatasubramani**

***Abstract---*** ***This paper reviews aspects of stability in microgrids. As there are different applications of microgrids, the aspect of stability also varies. This paper reviews and analyses small signal and large signal stabilities, besides dwelling on the different aspects involved in the stability of microgrids. The small and large signals of different types of microgrids are reviewed, alongside the transients and the stability of output voltage. Large signal analysis of generators and individual loads are also encompassed in this paper. This paper also sums up the scope for future research in stabilities of both large and small signals. In addition to this, the methods to improve signal stability is also covered in this paper.***

***Key terms – Microgrid, Small-signal, Large-signal, LyapunovMethod, Eigenvalue Method.***

## I. INTRODUCTION

A microgrid is a small-level grid that is collectively connected to a larger scale grid, called macrogrid, and is however, capable of functioning individually as a separate grid as and when required [1], [2]. It has the advantage of being able to vacillate between disconnected (or island) mode and connected (or macro) mode, making it compatible with different sources of generation, including renewable electricity generation [2]. Microgrids are a means of integration of different distributed energy sources in a single grid. This allows microgrids to be used in aircrafts, or even residential complexes. In addition to this versatility, microgrids offer significant technical, operational as well as economical benefits, which in turn lead to better reliability and better energy optimization. A succinct example of these features is that microgrids to cater to multiple end-user needs. Heating, refrigeration and cooling can all be provided for. Also, waste heat can be used in an efficient manner, by using the same for both heating as well as cooling purposes. [2]

Some of the important parameters to be considered in microgrids are control, stability and protection [34]. Stability studies of microgrids are performed using two main kinds of analyses: small-signal and large-signal. Small scale studies revolve around linearizing a given non linear system, round an operating point [2], [3]. Methods like Eigen value and sensitivity analysis, or Nyquist plots or Routh-Hurwitz criteria are used to study this linearized system [2]. For microgrid applications, small signal models of motors, generators, inverters, rectifiers, induction generators and synchronous generators have been studied extensively [40], [41]. A main disadvantage of small-signal studies is that the domain of validity of the linear analysis is either limited or unknown for the most part. To be more specific, the validity generally exists around the operating point obtained on linearization, which generally turns out to be hyperbolic, yet there is no indication of the exact distance from that point where valid results could be obtained for analysis. Load sharing with control loops and the stability involved are all covered in [5]-[8]. Modelling of VSC sources, and stability as a result, are explained in [9] and [10]. Detailed descriptions of stability issues with VSC sources are covered in [11]-[13].

Large-signal analysis or non-linear stability studies make use of non-linear mathematical modelling, without any linearization that is characteristic in small-signal analysis. The analysis depends largely on the size of the system to be modelled, required specifications or parameters, and the extent of assumptions [1]. The higher the assumption levels, easier is the modelling. Lyapunov-based methods are the most prevalent of methods to model transient stability of microgrids [1], [2]. Transient stability can be defined as the extent to which a power system is able to balance synchronism between the different generators, and reach steady state, when subject to adverse operating conditions like faults, loss of generated units or removal (or) addition of large loads. It is examined in detail in [18]-[20], [42]. The reason behind the prevalence of Lyupanov technique is that it allows an assumption, that allows us to estimate the region of attraction of an operating point, which oftem provides a palatable estimate for the tolerable size of disturbance. This method is also used if the small-signal analysis cannot be performed in lieu of a non-hyperbolic operating point [1]. Such techniques estimate the domain of asymptotic stability, thus aiding in quantifying the magnitude of excursions or deviations that the system can endure or bear. Microgrid stability using inertial or converter-based sources is examined in depth in [21]-[27]. In theory, any large-signal stable system is also a small-signal stable. The reverse case may not always be true.

## II. STABILITY ISSUES IN MICROGRIDS

A microgridcan be represented with the help of an array of loads and sources, as shown in the figure.

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**S. Shreyas,** Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology. Chennai, Tamil Nadu, India. (e-mail: shreyasvns23@gmail.com)

**D. Harini,** Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology. Chennai, Tamil Nadu, India.(e-mail: hariharini79@gmail.com)

**K. SurendhiraBabu,** Assistant Professor, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology.Chennai, Tamil Nadu, India.(e-mail: suren.1003@gmail.com)

**K. Venkatasubramani,** Assistant Professor, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology. Chennai, Tamil Nadu, India.(e-mail: venkatakalidass@gmail.com)


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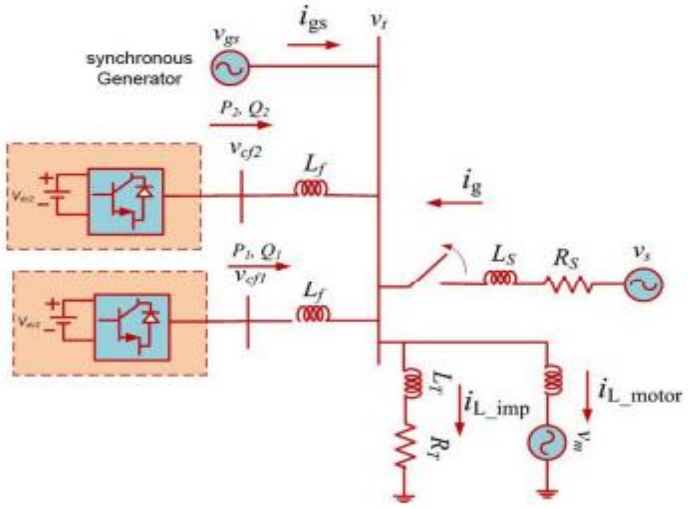


**Fig.1: General representation of a microgrid with DGs and loads**

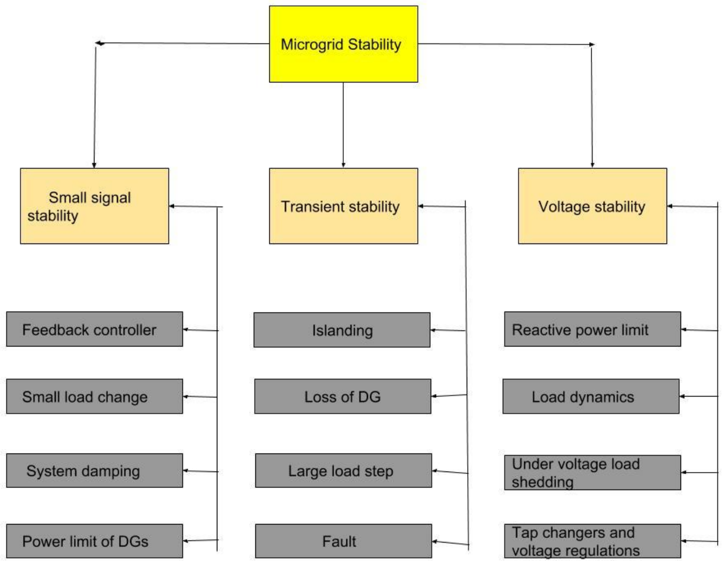


**Fig.2: Different stability issues in microgrids and the reasons**

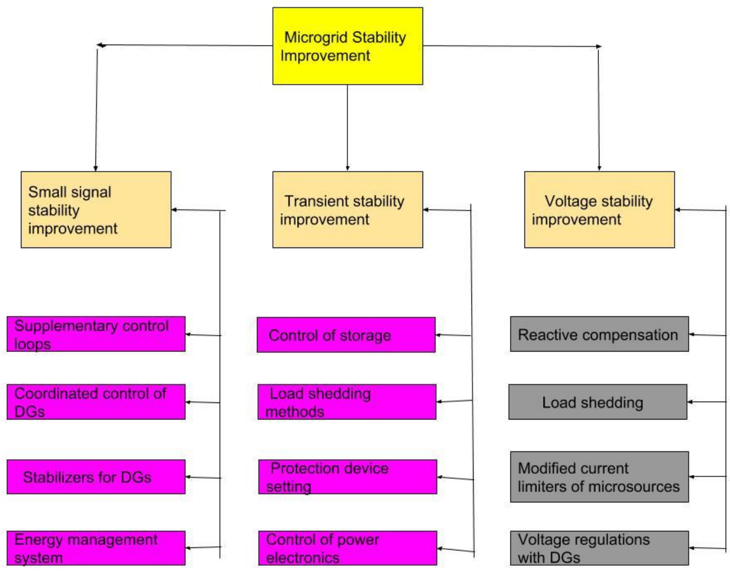


**Fig.3: Different methods of stability improvement**


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Based on usage, microgrids can be classified as:

- Utility microgrid, which is connected to one point of common coupling (PCC), can operate in an isolated island, covers a larger area and comprises of a variety of microsources and loads [34].
- Remote microgrid, which is not connected to the utility microgrid. It operates with decentralized control [34].
- Facility microgrid, commonly connected with hosting utility microgrid and can operate single-handedly in both intended and unintended islands [34].Stability in this case is discussed in [14]-[17]. Distinct control topologies for improving stability in case of an island transient are analysed in [27]-[31].

## III. ANALYSIS METHODS FOR SMALL SIGNAL STABILITY OF MICROGRID& RESULTS

*Eigenvalue analysis with help of state space models*

The complete model is made linear around a certain operating point, and the resultant matrix is applied to give out the Eigen values [2].

Any independent system can be represented by a set of differential equations, as

$$\dot{x} = f(x,u) (1)$$

where, ***x***represents state variables and ***u*** representsinput variables. Using Taylor's series on (1) we get,

$$\Delta\dot{X} = A\Delta Y + B\Delta u (2)$$

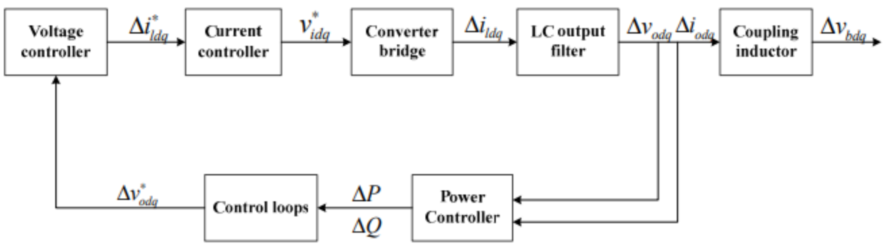


**Fig. 4: Small-signal modelling for inverter**

Then, two further processes are present. One is the *eigenvalue analysis*, whence the stability of the EPS is analysed [3]. It is usedespecially when controller parameters, like droop resistance, or load impedance, or line resistance and reactance, or the filter(s) parameters are changed [2].

The other process is the Sensitivity *coefficient*, which indicates the change in eigenvalues in correlation with the system values.

$$\begin{bmatrix} \Delta\dot{x}_{INV} \\ \Delta i_{lineDQ} \\ \Delta i_{loadDQ} \end{bmatrix} = \mathrm{A} \begin{bmatrix} \Delta x_{INV} \\ \Delta i_{lineDQ} \\ \Delta i_{loadDQ} \end{bmatrix} (3)$$

$$\frac{\partial \lambda_i}{\partial a} = \frac{u_i v_i \frac{\partial A}{\partial \alpha}}{v_i \quad u_i} (4)$$

Equation (4) gives the sensitivity value, where **λ**represents the i<sup>th</sup> eigenvalue.

*Impedance analysis*

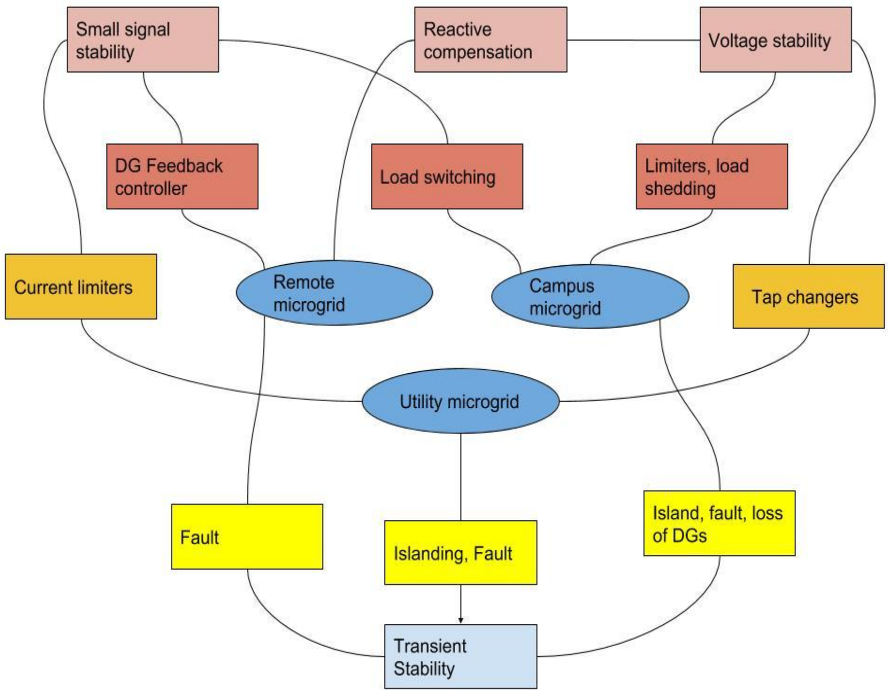


**Fig. 5: Stability issues in different microgrids**


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Each and every load and source is represented by its own input and output impedances. For example, in grid-connection, the inverter behaves like a current source, and sends in a certain value of current into the grid [3].

$$\mathrm{I}(s) = \left[I_l(s) - v_g(s)/Z_l(s)\right].\frac{1}{1+Z_g(s)/Z_l(s)} \quad (5)$$

The interconnected grid is safe, if and only if the Nyquist ratio is satisfied by the ratio $Z_g(s)/Z_l(s)$. If the impedance ratio $Z_g(s)/Z_l(s)$ lies outside a certain forbidden region, the stability margins obtained will be significant [2].

*Other Non-linear analysis methods*

Both eigenvalue and impedance analyses can both tell if the system is stable in the current state. However, they are not reliable if model analysis and stability of each DG has to be obtained. For that, a non-linear theory is developed. Since the microgrid is a complex structure, it can be described by a non-linear dynamic model. With the theory, the characteristics of each DG can be ascertained [2].Uncertainty is a major hindrance in small signal study. Many of those factors impact the damping ratio and frequency, which in turn, affect the stability of small signals. Existing methods exclude this uncertainty, and are more traditional in approach. Hence the impact of uncertain factors has not been taken into consideration in small-signal modelling.

*Future Trends in Small-Signal Microgrids*

1. Simplification of higher order systems : Higher is the order, more complicated is the modelling; hence, a means to simplify the models is quintessential in small-signal analysis
2. Extensive research on non-linear model : Since the bifurcation theory can provide stability characteristics of every DG, it is a more useful technique than the two others mentioned. However, the model comes with a lot of complications. So, research is required to implement non-linear modelling.
3. Different approach to impedance modelling: As microgrids vary with time, impedance models are not linear and cannot be linearized as a result. However, complex modelling in three phase systems can be avoided with the use of *harmonic linearization.*

**Table 1: Advantages and limitations of different analysis methods**

| Analysis method | Advantage | Disadvantage |
|---|---|---|
| Eigenvector method | Strict criteria and simple principle | Inaccurate system parameters, low efficiency, complicated for higher order systems |
| Impedance method | Easy to find stability when adding source/load, can also be experimentally measured | Tough to linearize three-phase system |
| Other non-linear methods | Stability margins can be derived, and the particular model analysis of each DG possible to obtain | Complicated to model. Also, an appropriate hypothesis is needed. |

## IV. ANALYSIS METHODS FOR LARGESIGNAL STABILITY OF MICROGRID

*Large signal stability tools and methods*

Lyapunov equation occurs in multiple sections of control theory. Stability analysis is a part of control theory in which Lyapunov–based methods are extensively developed. BCU methods have all been derived from it [48]. Such methods look into the critical clearing time with regard to rotor angle stability. Several graphical methods were proposed which were not used universally, as they don't give a closed solution. To initiate the gilt-edge Lyapunov function of non-linear system, genetic algorithms methods are on the pay roll.

*Large signal stability of individual systems*

Normally the electrically based power systems are positioned on integrated power system (IPS) architecture. Off the total power, about 70 to 90% is used for the purpose of propulsion in a ship. The propulsion contributes a huge part in system stability because of its power level [32], [33]. The large-signal analysis is performed intensively using time domain simulations [42], [43].

*Droop-controlled DC to AC inverters*

Converters that transduce DC power to AC power are called droop-controlled inverters (DC to AC). Inverters are mandatory in making microgrids technically feasible [1].

Andrade proposed the modelling of DC to AC inverters aselectrostatic machines [53]. Electrostatic machine are a direct correlation between the capacitance of the DC side and electrostatic machine rotor. Then the equation of motion becomes:

$$\frac{d^2\delta}{dt^2}\mathrm{M} + \mathrm{D}\frac{d\delta}{dt} = \mathrm{P} - \mathrm{P_e}$$

$$\mathrm{M} = \frac{2HK_p\omega_f+1}{K_p\omega_f}, \ \mathrm{D} = \frac{1}{K_p}$$

Using Popov's theorem, Andradedeveloped the Lyapunov function for feeding an infinite bus [53]. The function is given as

$$\mathrm{V} = \frac{1}{2}\mathrm{M}\omega^2 + \mathrm{E}(cos\delta_s - cos(\delta_s+\theta) - \theta sin\delta_s)$$

Lesieutre synthesized energy function of inverters with single micro source infinite bus (SMSIB), which can also be called as *infinite bus* [45].

The reduced order state equations for SMSIB model can be expressed as:

$$\frac{d\delta}{dt} = m_f\Delta P_{i,filt}$$

$$\tau_i\frac{d\Delta P_{i,filt}}{dt} = P_o - \frac{3V_iV_s\sin(\delta)}{X} - \Delta P_{i,filt}$$

The produced energy function is given as follows [44].

$$\mathrm{V} = \frac{m_f\tau_i}{2}(\Delta P_{i,filt})^2 - \frac{3V_iV_s}{X}(\cos\delta - \cos\delta_o) - P_0(\delta-\delta_0)$$

The critical clearing time for droop controlled inverter can be ascertained on imparting an energy function. The large-signal stability bound to a SMSIB can be effected by grid and control parameters.


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The grid impedance effects potential energy, and pseudo kinetic energy is affected by filter time constant.Microgrids are sometimes highly resistive because of a circulating reactive power [54], [55], hence Hart's analysis can be hampered by it.

Large transient event is mandatory to cause loss of synchronism, to a proportional extent [1].

*AC to DC Rectifiers and DC to DC converters*

AC to DC and DC to DC converters play a huge role in power system applications [56]. Converters are stable and reliable when they function individually. Multiple converters can, however, cause loss in stability [57].

Stability of three-phase, two-level rectifier isscrutinized by Umbria. State equations are derived as follows:

$$C\frac{d}{dt}\left(\frac{V_{dc}^2}{2}\right) = (1 + \frac{K_p V_{dc}}{2}(p - p^*))p - \frac{K_q V_{dc}}{2}(q-q^*)q + \frac{2\omega L}{|v_{\alpha\beta}^2|}pq - \frac{v_{dc}^2}{R_l}$$

$$L\frac{dp}{dt} = -\frac{V_{dc}}{2}K_p|v_{\alpha\beta}^2|(p - p^*)$$

$$L\frac{dq}{dt} = = -\frac{V_{dc}}{2}K_q|v_{\alpha\beta}^2|(q - q^*)$$

According to singular perturbation method, it is feasible to melt system down into the fast and slow states [36]. The stability of boundary layer is exponentially stable.

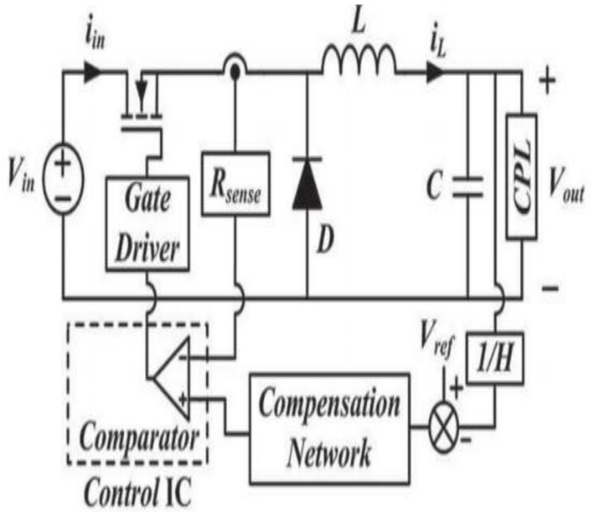



**Fig. 6: Buck converter with constant power load, current controlled**

To clinch the asymptotic stability of the system, the inductance L has to be less than 0,97mH [1]. Simulation is not provided by Umbriato verify the mathematical calculations.

*Motor Loads*

Motors are the electrical equipment(s) that converts electrical power into mechanical power. Drives are used in motors to control their speed and mechanical output torque.

A system included motor load supplied by the DC source through pulse width modulation voltage source inverter [46]. The DC source can be an AC to DC rectifier. Mathematical loads studied are as follows:

(1) Constant power load
(2) Variable power load (reduced order model)
(3) Variable power load with a full order model.

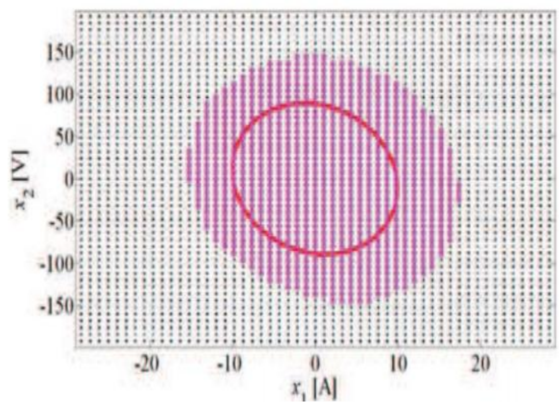
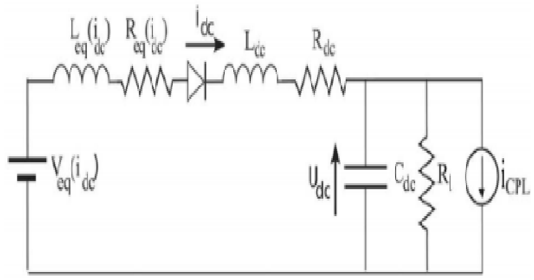



**Fig. 7: Estimated and actual domains of attraction [46]**

*Large-Signal Models OfMicrogrid Systems*

The hybrid AC-DC power system is comprised ofa variable frequency synchronous generator that feeds an 18 pulse variable transformer [52]. High frequency switching behavior are filtered out from switching mode power electronics converters through state-space averaging.



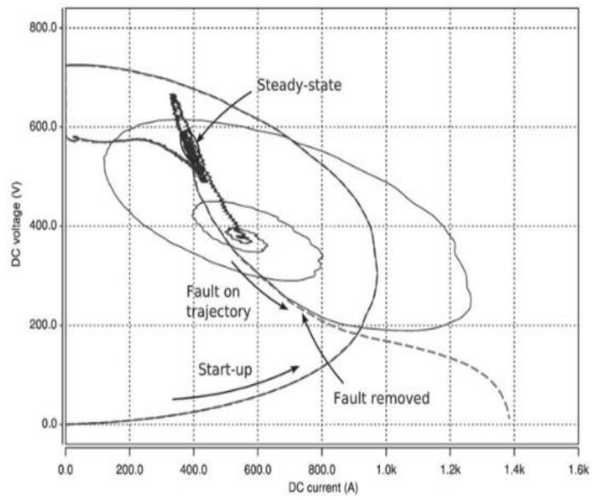



**Fig. 8: Phase system trajectory**

The equivalent model of the system is shown. Rosadostudied a microgrid system using an AC generator usingmotor load [58], [59]. The system was examined under two cases as follows:

(1) load step
(2) fault condition.

Lyapunov function was used to estimate the system's critical clearing time and the asymptotic stability in the domain [59].



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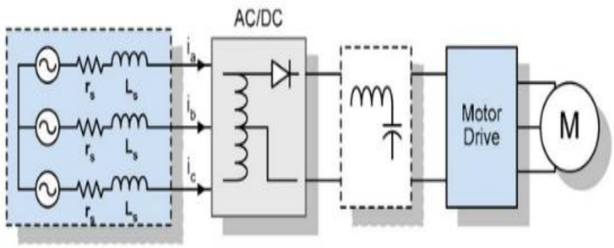


**Fig. 9: System schematic by Rosato**

## V. CONCLUSION

Small-signal and large-signal stabilities play a crucial role in ensuring the proper working of a microgrid system. Small-signal stability can be analysed using three methods. Each method has its own set of advantages and disadvantages. Eigenvalues analysis provides the simplest way of analysis, provided the model is of a low order. The impedance analysis method is more suitable practically as it can be used in case of dynamic loads, but the linearization process is difficult. The non-linear analysis is possibly the best of the three methods, but a lot of research has to be done to make this method feasible for usage.

Considering all the scenarios, we can conclude that the Eigenvalue analysis is the best analysis method that can be used for modelling a small-signal microgrid.

In the stability analysis of large-signal microgrids, the Lyapunov-based study was done. However, the Lyapunov method of analysis is incomplete, and needs to be developed to a more complete form.

Large-signal studies are very crucial to understanding the working ofmicrogrids, as there is no better way to understand the transient performances of microgrids.

Furthermore, recent and future trends in both small-signal and large-signal analyses were studied. A list of the analysis methods requiring further research, in order to have evolved more, has been compiled.

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