Novel method for power quality improvement using active power filter

student details:
name:T.kavitaha
rollno: 09a01d4302
nova college of engg& technology
vegavaram, jangareddigudem,
westgodavari, andhrapradesh
phno:09440182883
email:kaviths.kondaveeti@gmail.com

Guide details:
Name:k.ratnaraju,
associate professor, eee department,
nova college of engg& technology,
vegavaram, jangareddigudem,
westgodavari, andhrapradesh
ph no: 9704195580
email: ratnaraju.11@gmail.com

1. Abstract.

The abundant use of Non-linear loads in distribution system leads to power quality issues, The proliferation of microelectronics processors in a wide range of equipments, from home VCRs and digital clocks to automated industrial assembly lines and hospital diagnostics systems, has increased the vulnerability of such equipment to power quality problems. These problems include a variety of electrical disturbances, which may originate in several ways and have different effects on various kinds of sensitive loads. What were once considered minor variations in power, usually unnoticed in the operation of conventional equipment.

may now bring whole factories to standstill, Voltage quality problems relates to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions). Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched, also contribute substantially to power quality disturbances. are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances.

Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180o. series active power filters compensate current system distortion caused by non-linear loads by imposing a high impedance path to the current harmonics which forces the high frequency currents to flow through the LC passive filter connected in parallel to the load, The principles of operation of shunt, series, and hybrid active power filters has been presented. Also, a brief description of the state of the art in the active power filter market has been described. The

shunt active power filter performance under fault power distribution system was discussed. Simulation and experimental results proved the viability of using active power filters to compensate active

Power filters.

2. POWER DISTRIBUTION SYSTEMS IN POWER QUALITY

In this paper more and the most important international standard define power quality as the physical characteristics of the electrical supply provided under normal operating of

Power supply implies basically voltage quality and supply reliability. Voltage quality problems relates to and availability (focusing especially on long interruptions).

Power quality problems are common in most of quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components. Between the Electrical drives or more sensitive equipment tripped bye the Short-term voltage drops (sags), leading to costly interruption of productions [10].

enhancements solutions. However, with the various power quality solutions available, the obvious question for a consumer or utility facing a particular power quality problem is which equipment provides the better solution.

3 - TO POWER QUALITY PROBLEMS SOLUTIONS

It contain 2approach to this mitigation of power or counteracts the power system disturbances.

A flexible and versatile solution to voltage quality problems is offered by active power filters. power systems and improving power quality. As it will be illustrated in this paper, their performancedepend on the power power filter to improve power quality depends on the source of the problem as can be seen in Table 1.

TABLE I

Active Filter Solutions to Power Quality Problems

ActiveFilter connection	Load on AC supply	AC supply on load
Shuntt	-Current Harmonic filtring -Reactive current compensation -current unbalance -voltage flicker	
Series	-Current Harmonic filtring -Reactive current compensation -current unbalance -voltage flicker -voltage unbalance	-voltage sag/swell -voltage unbalance -voltage distortion -voltage interruption -voltage flicker -voltage notching

IV.- SHUNT ACTIVE POWER FILTERS

Shunt active power filter compensate current sees the non linear load and the active power filter as an ideal resistor. The current compensation characteristic of the shunt active power filter is shown in Fig.1.

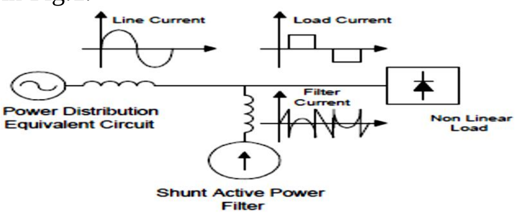
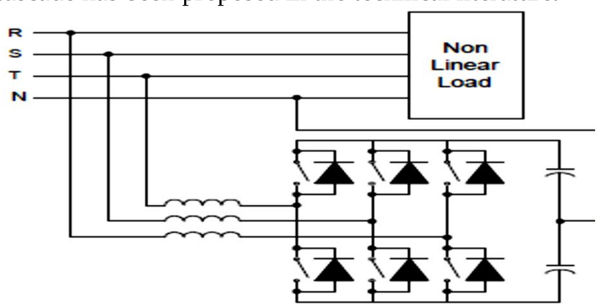


Fig. 1.- Compensation characteristics of a shunt active power filter

4.1.- Power Circuit Topology

Shunt active power filters are normally implemented voltage applications. Also, active power filters implemented with multiple VSI connected in parallel to a dc bus but in series through a transformer or in cascade has been proposed in the technical literature.



PWM- VSI as
ACTIVE POWER FILTER

Fig. 2- Shunt active power filter topologies implemented with PWM voltage-source inverters.

The use of VSI connected in cascade is an interesting alternative to compensate high power non-

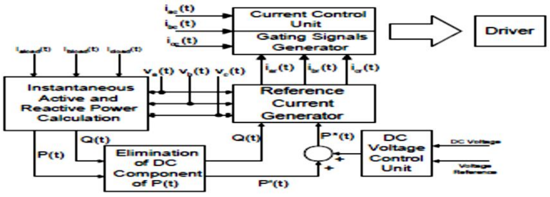


Fig. 4.- The block diagram of a shunt active power filter control scheme.

The current reference circuit generates the reference currents required to compensate the load voltage control unit must keep the total dc bus voltage by changing the amplitude of the fundamental component of the reference current (Fig. 4).

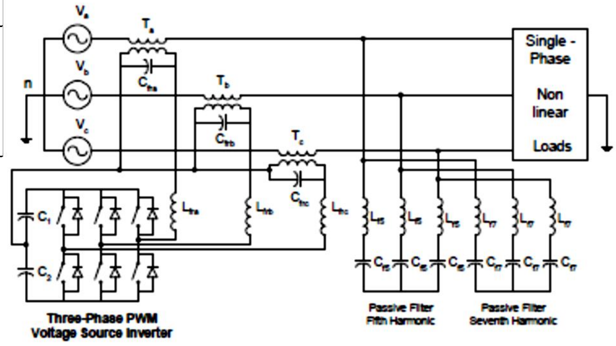
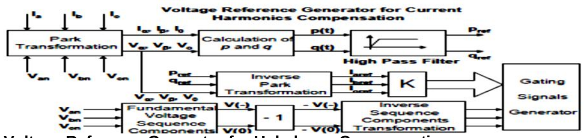


Fig. 5. The proposed series active power filter topology.

5.1.- Control Scheme

The block diagram of the proposed control scheme is shown in Fig. 6. Current and voltage reference way, it is not necessary to sense the current flowing through the neutral conductor.



Voltage Reference Generator for Unbalance Compensation

Fig. 6.The block diagram of the proposed series active power filter control scheme.

Where $p_{ref}$and $q_{ref}$are the instantaneous active and eactive Power associated with harmonics current components.

5.2.- Reference Signals Generator

The compensation characteristics of the series active power filter are defined mainly by the algorithm used tovoltage compensation with minimum time delay. Also it is important that the accuracy of the information contained scheme are independent, the equations used to calculate the voltage reference signals are the following:

$$\begin{bmatrix} v_{a1} \\ v_{a2} \\ v_{a3} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 2 & 3 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

The voltages $\mathbf{v_a}$, $\mathbf{v_b}$, and $\mathbf{v_c}$correspond to the phase to neutral voltages before the series transformer (Fig. 5). unbalance control scheme are obtained by applying the following equations:

$$\begin{pmatrix} v_{refa} \\ v_{refb} \\ v_{refc} \end{pmatrix} = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}\begin{pmatrix} -v_{a0} \\ 0 \\ -v_{a2} \end{pmatrix} \qquad (2)$$

In order to compensate current harmonics generated by thenon linear loads, the following equations are used (Fig.7):

$$\begin{pmatrix} i_{aref} \\ i_{bref} \\ i_{cref} \end{pmatrix} + \sqrt{\frac{2}{3}}\begin{pmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1}\begin{pmatrix} p_{ref} \\ q_{ref} \end{pmatrix} + \frac{1}{\sqrt{3}}\begin{pmatrix} i_0 \\ i_0 \\ i_0 \end{pmatrix} \qquad (3)$$

where i_0 is the fundamental zero sequence component of the line current and is calculated using the Fortescue transformation (4).

$$i_o = \frac{1}{\sqrt{3}}(i_a + i_b + i_c) \qquad (4)$$

In (3) $\mathbf{p_{ref}}$, $\mathbf{q_{ref}}$, $\mathbf{v_\alpha}$, and $\mathbf{v_\beta}$ are defined according with the system voltage unbalance is eliminated by compensating the negative and zero sequence components which are present in the source voltage, the of i_0 (i_{0ref}), Finally, the general equation that defines the references of the PWM voltage-source inverter required to compensate voltage unbalance and current harmonics is the following:

$$\begin{pmatrix} v_{refa} \\ v_{refb} \\ v_{refc} \end{pmatrix} = k_1\left[\sqrt{\frac{2}{3}}\begin{pmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix}\left(\begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}\right)^{-1}\begin{pmatrix} p_{ref} \\ q_{ref} \end{pmatrix} + \frac{1}{\sqrt{3}}\begin{pmatrix} b_{ref} \\ b_{ref} \\ b_{ref} \end{pmatrix}\right] + k_2\left[\frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}\begin{pmatrix} -v_{a0} \\ 0 \\ -v_{a2} \end{pmatrix}\right] \qquad (5)$$

where K_1 is the gain of the series transformer which is defined as the magnitude of the impedance for high to 1. Also, $i_{0ref} = i_0 - i_{01}$, where i_{01} is the fundamental power filter to the power system. This function cannot be achieved with the proposed scheme as there is no active power storage element in this topology.

5.3.- Gating Signals Generator

The gating signals of the three-phase PWM voltage-source inverter required to compensate forces the inverter switching frequency to be constant is provided by the following circuit.

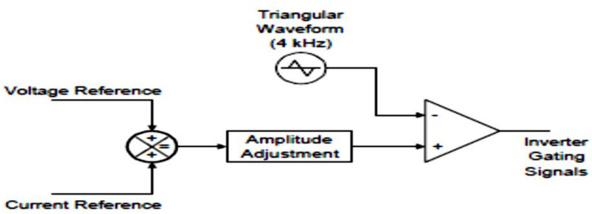


Fig. 7. The block diagram of the proposed gating signals generator.

The higher voltage utilization of the inverter is obtained if the amplitude of the resultant reference voltage waveforms and reference signal current are smaller. If the amplitude is adjusted for transient operating in the inverter which defines a lower voltage utilization factor for steady state operating conditions.

5.4.- Simulated Results

The effect of voltage compensation with the power filter starts compensating at 140 ms. Is shown by the viability of the proposed series active power filter 8.

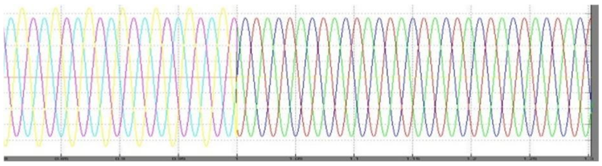
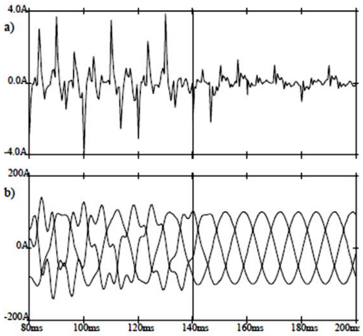


Fig. 8. Simulated waveforms for voltage unbalance harmonic compensator not operating).



Time

Fig. 9.Simulated waveforms for current harmonic compensation. a) Neutral current flowing to the ac mains before and after compensation. b) Line currents flowing to the ac mains before and after compensation. (Voltage
unbalance compensator not operating).

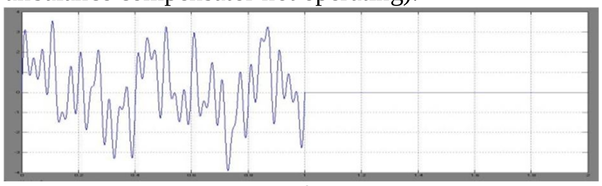


Fig. 10.Simulated results for voltage unbalance and current harmonic compensation, before and after compensation. a) Ac mains neutral current. b) Phase to neutral load voltages. c) Ac source line current.

5.5.- Experimental Results

In order to validate the compensation scheme proposed ihe current waveforms when the series active power filter is not working. Specially Fig. 11-a shows the load current , 11-b illustrates the current that flows to the passive filter and Fig 11-c shows the power system.

Due to the compensation characteristics of the proposed series active power filter the THD of the source current decreases.

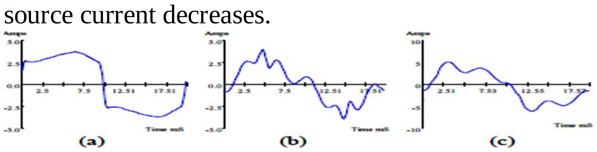


Fig. 11. Experimental current waveforms of the system

without the operation of the series active power filter. (a) Load current. (b) Shunt passive filter current. (c) System current.

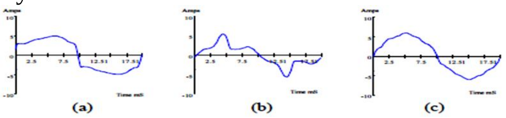


Fig. 12. Experimental current waveforms with the operation of the proposed series active power filter. (a) Load current. (b) Shunt passive filter current. (c) System current.

VI.- HYBRID ACTIVE POWER FILTER

Series active power filter shown in section V. In this scheme, (Fig. 5) is the Active power filters can be used with passive filters combination. current harmonic components cannot be compensated by the series active power filter topology if the passive filters are not connected.

Since the active scheme generated voltage harmonic components across the terminal of the primary windings of the series of the power distribution system there is another possibility to combine the compensation characteristics of passive and active power significantly improved.

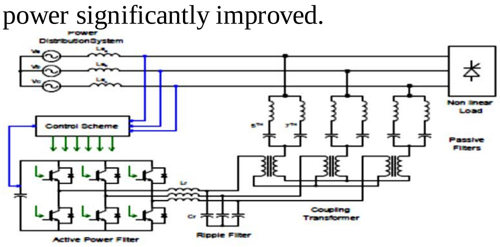


Fig. 13.The hybrid active power filter configuration.

The power factor of the power distribution system can be adjusted by controlling the amplitude of the voltage fundamental component across the coupling transformer. However, the control of the load for application in electrowining process or for compensation of arc furnace. Passive filters do not have enough compensation capability to reduce current harmonics in order to satisfy IEEE Std.519 in all these applications.

Simulated waveforms for this type of compensation are shownin Figs.14.

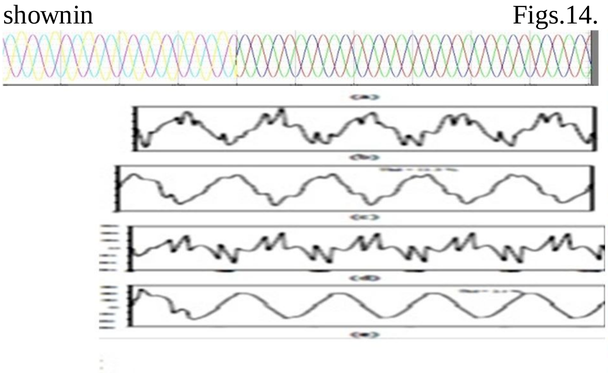


Fig. 14. Simulated results for hybrid active power filter operation. (a) Load Current. (b) Passive filter current. (c) System Current. (d) Passive Filter current. (e) System current.

VII.- INSTALLATION AND OPERATING EXPERIENCE

7.1.- Active Power Filter Market

Many different electrical companies are offering power the art power electronic technology, they have developed different system to compensates not only current many. These power line conditioners are well as ABB.

In order to protect the consumer from supply voltage disturbances currently active power line conditioner are typically based on IGBT or GTO thyristors voltage. However, if the objective is to reduce the network perturbations due to distorted load currents the shunt-connection (also called DSTATCOM), is more appropriate.

For low voltage application Many shunt active filter consisting of PWM inverters using IGBTs or GTO Thyristors have been used.

For a specific application,

regulation, but also in reducing the voltage unbalance from 3.6 % to 1 %. Shunt active power filters based on GTO voltage source inverters are developed by CEGELEC. The use of such system developed by 5.8 % to 2 %.

Another Japanese company named Meiden, has developed the Multi-Functional Active Filter, also based on voltage-fed PWM IGBTs inverters. This is a shunt 50 to 1000 kVA. The following are the standard specifications of these active power filters.

- *Number of phases*: 3-phase and three wires.
- *Input voltage*: 200, 210, 220 $\pm$ 10%, 400, 420, 440 $\pm$ 10 %, 6600 $\pm$ 10 %.
- *Frequency*: 50/60 Hz $\pm$ 5 %.
- *Nos. of restraint harmonic orders*: 2 to 25 th.
- *Harmonic restraint factor*: 85 % or more at the rated output.
- *Type of rating*: continuos.
- *Response*: 1 ms or less.

For this active power filter the harmonic restraint factor is defined as $1-\frac{I_{H2}}{I_{H1}}X100\%$where I_{H1} are the harmonic currents flowing on the source side when no measure are taken for harmonic suppression, and when harmonics are suppressed using an active filter I_{H2} are the harmonic currents flowing on the source side.

Current Technology Inc. has developed the Harmonix HX3-100 a shunt active power filter designed to compensate tripplen harmonics generated by single-phase non linear loads These zero sequence current components will be flowing through the neutral conductor of the power distribution system. This equipment is able to cancel up to 100 A of zero-sequence harmonics from a three-phase four-wire distribution system. It is shown by technical reports show that the cancellation effectiveness of this active power filter is equal to 94.4 %, that means that the active power filter is able to reduce the rms neutral current from 99.1 A to 6.82 A.

Mitsubishi Electric developed the MELACT-1100 Series of three-phase active power filters with rated power from 50 to 400 kVA in for three-phase power below 1000 kVA, for application in low and medium voltage. Also, Similar to a synchronous condenser Mitsubishi developed the Compact Statcom, that provides reactive power compensation to solve a variety of power system and rated 154 kV and 80 MVA. It was installed on an actual power system at the Inuyama switching substation of the Kansai Electric Power Co. in Japan and continues to operate today.

In order to improve voltage regulation and unbalances in power systems ABB has also been developing active power filters. The approach developed by ABB is based on both shunt and series active power filters implemented with IGCT based voltage source PWM inverters. The series active power filter is designed for to improve voltage regulation. The DSTATCOM can also operate in conjunction with a Battery Energy Storage System (BESS) and with a solid state circuit breaker (SSCB). In this case
this scheme operates as a high power UPS, compensating outage of voltage.

7.2.- Active Power Filter Under Transient Operating Conditions

Normally, active power filter have been tested and proved in a laboratory environment under steady state operating conditions.
. However, the use of this the operation of circuit breaker could affect the stability of the dc voltage, imposing severe overvoltages to the semiconductor switches. The operation of shunt active power filter under different operating conditions are shown
in the following sections.

i) Operating conditions under source voltage unbalanced

A second order voltage harmonic across the inverter dc bus voltage due to voltage unbalance in the power supply
. This second order harmonic in the dc voltage ac side of the inverter as a third harmonic decreasing the compensation characteristics of the shunt active power filter. The different effects of this
voltage unbalance are shown in the following figures.

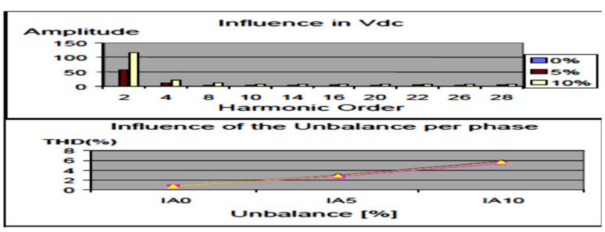


Fig. 15.- Influence of ac voltage unbalance in filter behavior. (a) Inlfluence of the ac voltage unbalance in the inverter dc voltage. (b) Influence of the voltage unbalance in the inverter THD current.

ii) Operating conditions with one phase in open circuit

When power distribution system are protected with fuses it this extreme operating
conditions the current and voltages generated by the shunt active power filter are shown in the following figures.

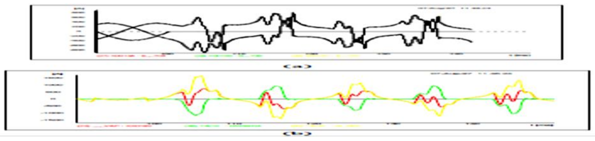


Fig. 16. Operating conditions with one phase in open circuit.(a)Current flowing through the power Distribution
system. (b) Current generated by the active power filter,
reference signal, error signal.

This figures show that with one phase in open loop the active power filter can not compensate the load current of energy required by the active power filter. This increases the amplitude of the active power filter current.

iii) Operating condition with distorted supply voltages

The generation of the reference
signals is affected by the presence of harmonic components in the supply
voltages. The attenuation can be compensated easily, but the time delay can be treated as special phase shift introduced in the matrix transformation, as shown in following equation:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}}.\begin{bmatrix} \cos\delta & -sen\delta \\ -\frac{1}{2}cos\delta + \frac{\sqrt{3}}{2}sen\delta & -\frac{1}{2}sen\delta + \frac{\sqrt{3}}{2}cos\delta \\ -\frac{1}{2}cos\delta + \frac{\sqrt{3}}{2}sen\delta & -\frac{1}{2}sen\delta + \frac{\sqrt{3}}{2}cos\delta \end{bmatrix} - \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \quad (6)$$

whereδ represents the phase shift angle introduced in the
voltage output signal by the filter. Simulated results prove that for small phase shift angles (below 18_o) reference signal required by the filter to compensate current harmonics generated by the non linear loads.

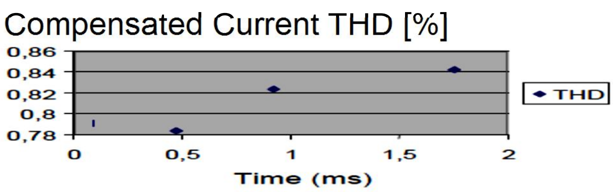


Fig. 17. Influence of the δ phase shift angle in the

compensated source current.

VII.- CONCLUSION

In this paper the use and advantages of applying active power filters to compensation power distribution systems has been presented. The principles of operation of shunt, series,
and hybrid active power filters has been presented. Alos, a brief description of the state of the art in the active power filter market has been described. The shunt active power filter performance under fault power distribution system was discussed. Simulation and experimental results proved the viability of using active power filters to compensate active power filters.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial Support from “FONDECYT” through the 1990413 project.

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