Optimal Efficiency Optimization through Power-Sharing for Paralleled DC-AC Inverters with Parameters Estimator

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Abstract - In this paper, a global study in terms of control architecture and power management is applied to parallel inverters topology. High bandwidth controllers and low voltage THD are achieved. The losses through the structure are modeled by equivalent voltage sources which implicitly represent all the losses types in the system. An accurate online estimation method allows determining these losses parameters. Then, a new power sharing is defined aiming to maximize the global efficiency of the overall structure. The algorithm is theoretically analyzed with the proposed control and estimation method.

Keywords – Flatness Control, Optimization, Parameters Estimation, Losses Estimation, Parallel Inverters, Power Sharing.

I. INTRODUCTION

In the literature, the parallel connection of three phase systems is proposed for many applications, such as, machine drive systems [1]-[2], rectifiers [3]-[4], active filter [5] and distributed generation systems [6]-[7]. The main interest in such configuration is that, they are useful for solving high power requirements. For example, in [8], a reliability analysis shows that the redundancy of parallel inverters system brought the possibility of achieving compact design and high power density compared to a single large power inverter. This topology enables the ripple current reduction which reduces the size of the output filter [9]. It also allows lower Electro-Magnetic Interferences (EMI) emission than a single inverter and a three level flying capacitor inverter [10]. However, the major concern for parallel operation is the circulating currents in the conduction paths resulting from the common connection of the DC/AC terminals of each inverter. In [11] a definition of the phenomenon is given and it is found that the circulating currents consist of not only the zero-sequence circulating currents, but also the non-zero-sequence circulating currents. In [12] the influence of the dead-time upon this phenomenon is investigated. Commonly, it proves that the circulating currents are essentially generated from the difference of the switching operation associated with the individual units. Those currents can be separated into two components, a low-frequency component close to the fundamental frequency, and a high-frequency component close to the switching frequency [13], [14]. While the high-frequency component can be effectively limited by means of passive components, the low-frequency component needs a special attention. Traditionally, in order to avoid this problem, transformers are used to isolate the direct current flow [15]. However, the transformers are heavy and bulky and they incur both core and copper losses. Commonly, the advised solutions in the literature are based on the modification of the pulse width modulation operation [14], [16] and [17]. Beside this solution, some other works propose the association of the modified switching techniques with physical solutions [18]-[20]. For example, in [18] an improved PWM is associated with intercell transformers (ICT) for the case of two units. The ICT allows the current ripple reduction compared to simple inductor filters, but real practical realization of such solution in the case of N units is very complex. In [15], a common-mode inductors installed in case of two units is recommended to use an interleaving of the PWM operation by 180 degrees. A comparative analysis between sinusoidal PWM, space vector PWM, and discontinuous modulation (DPWM) has showed that the sinusoidal PWM is the best candidate for the parallel inverters with a common DC bus [17]. In [16] it is proposed to install a cascade null-vector control system behind the conventional three-phase harmonic elimination PWM (HEPWM). The improved technique (HEPWM) is good for power conversion between parallel inverters but is not suitable for parallel inverters used in motor drive applications [16]. This paper proposes a one loop controller based on the flatness technique for non-isolated power supply composed of N parallel inverters. In fact, the flat properties of the systems are suitable for their control [21]. By example, in [22] the flatness of the doubly fed induction generator system has been exploited to express the power losses in the system by means of the flat output and its derivatives. This influences the power losses in the system in such a way that an optimal operating point can be achieved [22]. In other works [23]-[26], the planning properties of the flatness technique are used for storage based power systems. Hence, using the planned references of the flat outputs in the control laws avoids the negative effect of noise in the derivative terms [27], [28]. Furthermore, the flatness property allows knowing the behavior of the state variables by knowing the instantaneous behavior of the planned flat outputs [29]. On the other hand, the choice of one loop structure allows to set high effective bandwidth which facilitates the reduction of zero-sequence component currents [11], flatness gives the desired performances concerning the
output voltage THD and fast dynamic in transient conditions [28], [30]. Power or current sharing is an important functionality for parallel power converters to ensure reliable and efficient operation. A first method for controlling parallel inverters is to define one converter as the master which imposes output voltage while the others are slave and only current or power is regulated. Master-slave control has been used in [31] and [32]. Unfortunately, this control strategy does not allow optimizing the global efficiency of the system. Another method found in the literature for DC/DC converters is to use current sharing to manage the output voltage error as done in [33] by using synergetic control. Power repartition based on minimal losses has been used for example in [34]. In this paper, a new power-sharing method is proposed in order to minimize the overall losses of the system, a model taking into account all the losses types in the parallel topology is proposed. A nonlinear observer is then proposed which allows estimating the losses parameters online. It is possible to adapt the power flow into each converter as a function of their internal losses and optimize the system global efficiency.

II. STRUCTURE DESCRIPTION AND MODELING

Fig. 1 shows a typical configuration of n-parallel three-phase inverters connected to a load by an LC filter. The PWM techniques are applied to obtain a sinusoidal output voltage with minimal undesired harmonics content. It is proposed to estimate the losses through the parallel inverters by adding three equivalent serial voltage sources \( V_{abcn} \) at the output of each inverter which represent the losses in the conventional model. According to the scheme presented in Fig. 1; the sums of the load currents are equal to zero. Also, the line currents and the AC capacitive currents sums are null, as defined respectively by (1) and (2). The sum of the load currents is zero:

\[
i_{la} + i_{lb} + i_{lc} = 0 \tag{1}
\]

The sum of n modules output currents is also zero:

\[
\sum_{k=1}^{n} (i_{la} + i_{lb} + i_{kc}) = 0 \tag{2}
\]

It is deduced that the sum of the capacitive current is zero and the sum of the capacitive voltage is constant. Then, it is deduced that the system owns \( 3n+5 \) variables and two special relations linking the variables. The parallel voltage-source inverter model is transformed from the three-phase static frame into a synchronous Park frame. The initial values of the three capacitive voltages are null. The voltages at the common AC bus in 0dq frame are written as follows and with \( i_{o1} = 0 \):

\[
\frac{d}{dt} \left[ \begin{array}{c}
V_{ca} \\
V_{qb}
\end{array} \right] = \left[ \begin{array}{cc}
0 & \omega \\
-\omega & 0
\end{array} \right] \left[ \begin{array}{c}
V_{ca} \\
V_{qb}
\end{array} \right] + \frac{1}{L_c} \left( \sum_{k=1}^{n} \left( i_{la} \right) - \left( i_{la} \right) \right) \tag{3}
\]

Regarding (2), the sum of the homopolar currents is null, \( \sum_{k=1}^{n} i_{o_k} = 0 \). Thus the state variables related to the line currents can be reduced by one. Arbitrarily, it is proposed to reduce the homopolar current of the first inverter; \( i_{o1} = -\sum_{k=2}^{n} i_{o_k} \) (it is obvious that any another inverter can be considered). Hence, the \((n-1)\) remaining homopolar currents are independent state variables. Then, the output current dq components of the first inverter are:

\[
\frac{d}{dt} \left[ \begin{array}{c}
\alpha (i_{la}) \\
\beta (i_{la})
\end{array} \right] = \left( \frac{1}{L_c} \right) \left( \begin{array}{c}
\alpha (i_{la}) \\
\beta (i_{la})
\end{array} \right) + \frac{1}{L_c} \left( \frac{V_{ca}}{V_{ca}} \right) - \left( \frac{V_{ca}}{V_{ca}} \right) \tag{4}
\]

The inductive current of the remaining modules \( K^0 \), modules, with \( k \in \{2, \ldots, n\} \), are:

\[
\frac{d}{dt} \left[ \begin{array}{c}
\alpha (i_{la}^k) \\
\beta (i_{la}^k)
\end{array} \right] = \left( \frac{1}{L_c} \right) \left( \begin{array}{c}
\alpha (i_{la}^k) \\
\beta (i_{la}^k)
\end{array} \right) + \frac{1}{L_c} \left( \frac{V_{ca}}{V_{ca}} \right) - \left( \frac{V_{ca}}{V_{ca}} \right) - \left( \frac{V_{ca}}{V_{ca}} \right) \tag{5}
\]

The voltages \( V_{ca}, V_{cb} \) with \( k \in \{1, \ldots, n\} \) are introduced to the model as voltages drops which represent the losses of the inverters.

III. CONVERTER CONTROL STRATEGY

A. Implementation of controller based on flatness

The concept of differential flat systems was introduced by Fliess and al [35]. Differential flatness is a structural property of a class of nonlinear systems, for which, all system variables can be written in terms of a set of specific variables (the so-called flat outputs) and their derivatives without any integration [35]. More precisely, if the system has a state vector \( x \in \mathbb{R}^n \), and an input vector \( u \in \mathbb{R}^m \), then the system is considered to be differentially flat if a flat output \( y \in \mathbb{R}^m \) can be found in the form:

\[
\begin{cases}
\dot{y} = \Phi(x, u, y, \ldots, u(t)) \\
\dot{x} = \Phi(y, \dot{y}, \ldots, y(t)) \\
u = \psi(y, \dot{y}, \ldots, y(t)) + \phi(x)
\end{cases}
\]

with: \( \text{rank} (\Phi) = n, \text{rank} (\phi) = m \) and \( \text{rank} (\psi) = m \).

B. Flatness Control System

To meet the control objectives, the flat outputs are defined as the energy and the currents errors. According to the control objectives, it is proposed to define the candidate flat outputs vector as follow:

\[
y = [y_c, y_{za}]^T \]

where \( y_c = [y_{ca}, y_{qa}]^T \) represents the electrostatic energy stored in the AC capacitor filters as given by (8). The purpose of these flat outputs components is to set the suitable voltage properties at the point of common coupling (PCC):

\[
y = [y_c, y_{za}]^T \tag{7}
\]

where \( y_c \) is defined by:

\[
y_c = \left( \frac{y_{ca}}{y_{qa}} \right) \frac{\text{sign}(V_{ca}) V_{qa}^2}{\text{sign}(V_{ca}) V_{qa}^2} = \phi_{y_c}(x) \tag{8}
\]

The flat output components \( y_{za} = [y_{za2}, \ldots, y_{zan}]^T \) which represent the currents errors referred to the first inverter, each component of \( y_{za} \) allows to balance the power between the first inverter and the \( k^{th} \) inverter, with \( y_{za} \in \mathbb{R}^3 \forall k \in \{2, \ldots, n\} \), where :
\[
y_{a,b} = \frac{y_{o_k}}{y_{a,b}} = \frac{z_{a,b}}{z_{a,b}} = \left(\frac{l_{a,b}}{l_{a,b}} - l_{a,b}\right) = \phi_{y_{a,b}}(x)
\]

(9)

The control of \( y \) to its reference will provide voltage regulation of the AC capacitive bus. The control of \( y_{a,b} \) to their respective references which will be detailed later will ensure the control of the circulating current and the distribution of powers between the parallel modules. The first component of the vector \( y_{a,b} \) is introduced to minimize circulating currents. For this purpose, it is chosen to control the zero sequence currents of \((n-1)\) modules, which involves the cancellation of the first inverter zero current \( i_{a,ref} \). Using \( y \), given by (8), the voltage vector \( V_{cd,a} \) can be rewritten:

\[
V_{cd,a} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}ight) = \phi_{y_{cd,a}}(y_d)
\]

(10)

From the derivative of \( y_{a,b} \), it is possible to express the line currents \( i_{d,r} \) as a function of \( y_{a,b} \) and \( y_{a,b} \), using (9), (10), (11) and (12):

\[
\frac{\text{d} V_{cd,a}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}ight) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(11)

\[
\frac{\text{d} i_{a,b}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(12)

The expression of the line current \( i_{a,b} \) is then rewritten into the following form:

\[
\left(\frac{i_{a,b}}{\text{d} t} = \phi_{y_{a,b}}(y_{a,b}) - \phi_{y_{a,b}}(y_{a,b})
\]

(13)

The values of the estimated voltage \( V_{f_{ldqm}} \) are assumed to be constants, then their respective derivatives are null. The control vector can be obtained by the derivation of dq currents of the first inverter and the voltages derivative (11), it becomes:

\[
\frac{\text{d} i_{a,b}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(14)

For the \((n-1)\) other inverters, the derivation becomes:

\[
\frac{\text{d} i_{a,b}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

Using the above expressions, the control vector of the first inverter becomes:

\[
\frac{\text{d} V_{cd,a}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(15)

\[
\frac{\text{d} \theta}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(16)

The control vector of one of the \((n-1)\) remaining inverters can be rewritten as following:

\[
\frac{\text{d} V_{cd,a}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(17)

Thus, the flatness conditions are satisfied for the studied system with \( y \), the flat output associated with the input \( u = [V_{d1}, V_{q1}, \ldots, V_{dn}, V_{dn}, V_{qn} \] . Knowing that the references are calculated as follows (references of the current errors = 0):

\[
y_{c,ref} = \frac{1}{2} C_{f} V_{cd,ref}^2, V_{d,ref} = V_{q,ref} = V_{ref} \sqrt{3}/2
\]

(18)

The last step to rule on the flatness of the studied system is the formulation of the input vector \( u = [V_{d1}, V_{q1}, \ldots, V_{dn}, V_{dn}, V_{qn} \] as a function of the candidate flat output components and their derivatives. The control variables deduced from relations (17) and (18), can be written under the following form:

\[
\frac{\text{d} V_{cd,a}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(19)

\[
\frac{\text{d} V_{cd,a}}{\text{d} t} = \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right) - \left(\frac{\text{sign}(y_d)\sqrt{2}y_d}{\text{sign}(y_d)\sqrt{2}y_d}\right)
\]

(20)

The dynamic behavior of the input DC voltage and DC current can be investigated thanks to the following differential equations:

\[
V_{in} = i_{q} \frac{d}{d t} + \frac{d}{d t} + \frac{d}{d t}
\]

(21)

\[
C_{dc} \frac{d^2 V_{in}}{d t^2} = \frac{d}{d t} \sum_{i=1}^{n} (V_{dc[i]} + V_{dc[i]})
\]

(22)

IV. OBSERVABILITY AND ESTIMATOR

For the estimation of parameters \( V_{f_{ldqm}} \) of each inverter, the differential system used to estimate these parameters is then constituted by \((3), (4), (5)\) and can be firstly rewritten into the following form:

\[
X = \frac{1}{2} F(x, u) + \frac{1}{2} g(x, u)
\]

(23)

where \( f \) and \( g \) are nonlinear known functions, \( x \in R^{2n+3} \) and represents the state vector (all variables are supposed to be measured), \( u \) the input vector and \( p \in R^{2n} \) represents the estimated parameters. In this model, the parameters \( V_{f_{ldqm}} \), indirectly representing the losses through the whole system, are supposed to vary slowly so their derivatives are neglected.

A. OBSERVABILITY

The local observability of the system can be investigated by proving that the rank of the matrix \( d\theta \) is equal to \( 5n+3 \) where:

\[
d\theta = \left[ \frac{d\theta}{d t} \right]^{\top}
\]

(24)
for \( N \geq 1 \), \( y \) is the measured state variable vector (in our case \( y = x \)), \( X = [x, p]^T \). For the given system, two inverters in parallel are considered (\( n = 2 \), with \( n = 2 \), it can be easily proved that \( \text{rank}(d\theta) = 13 \). Thus the system is observable.

### B. Definition of the Proposed State-Observer

The choice of the observer is important, a lot of observation techniques exist in literature. Contrary to the Extended Kalman Filter or Luenberger observers [34], the proposed observer doesn’t use a local model around an operating point and is well adapted for nonlinear systems. Its dynamical equations are given by:

\[
\dot{x} = f(x, u) + g(x, u)\theta - S(\ddot{x} - x) \tag{25}
\]

\[
\dot{\theta} = k_s(\ddot{x} - \ddot{x}) + (k_i - g(x, u))S(\ddot{x} - x) \tag{26}
\]

where:

\( \ddot{x} \in \mathbb{R}^{(2n+3)} \) and \( \theta \in \mathbb{R}^{2n} \)

\( S \in \mathbb{R}^{(2n+3) \times (2n+3)} \) a positive-definite matrix

\( k_s, g(x, u) = S \)

\( k_i = k_s \cdot S \)

### D. Losses Minimization

The system model uses a well-known minimization technique called interior-point algorithm [37], for minimizing the losses which are calculated online of the whole system and reshape the power between the two inverters based on this method which generates the optimal line currents as given by (27), these current can be used by (9) to generate \( z_{d_{A_1}} \), with the constraints given by (29)-(31).

\[
x_{\text{opt}} = [i_{d_{A_1} \text{opt}}, i_{d_{A_2} \text{opt}}, i_{q_{A_1} \text{opt}}, i_{q_{A_2} \text{opt}}]^T \tag{27}
\]

The following expression \( F_{\text{opt}} \) gives the total losses of the whole system to be minimized as following:

\[
F_{\text{opt}} = \Sigma_{k=1}^n (V_{d_{A_1}}i_{d_{A_1}} + V_{q_{A_1}}i_{q_{A_1}} + r_f i_{d_{A_1}}^2 + i_{q_{A_1}}^2) \tag{28}
\]

The constraints for obtaining the minimum losses:

\[
P_d = V_d \Sigma_{k=1}^n (i_{d_{A_k}}) + V_d \Sigma_{k=1}^n (i_{q_{A_k}}) \tag{29}
\]

\[
Q_d = V_d \Sigma_{k=1}^n (i_{d_{A_k}}) - V_d \Sigma_{k=1}^n (i_{q_{A_k}}) \tag{30}
\]

\[
\sqrt{i_{d_{A_k}}^2 + i_{q_{A_k}}^2} \leq I_{\text{max}} \tag{31}
\]

where \( I_{\text{max}} \) represent the maximum allowable current for the semiconductors. From the previous algorithm, the relation given by (9) can be recalculated by (32) to give the references as following:

\[
y_{d_{A_k}, \text{ref}} = \begin{cases} 
0 & z_{d_{A_k}, \text{ref}}^T \in \mathbb{R}^{2n} \\
\frac{F_{\text{opt}}}{k_i} & \forall k \in \{2, \ldots, n\} \end{cases} \tag{32}
\]

### V. SIMULATION RESULTS

To validate the proposed algorithm, a simulation model based on Simulink/MatLab has been performed. A two parallel inverters system is considered (i.e. \( n = 2 \)). The system parameters and the control gains associated to the energy and current trajectories are given in table I. The schematic diagram of the proposed system is given in Fig. 2. Fig. 3 (a), (b) show the behavior of the electrostatic energies \( y_{d_{A_k}} \) and \( y_{q_{A_k}} \) of the output filter for a step of the output voltage reference from 90V to 110V which follow perfectly their respective references with the proposed control strategy. In this case, when the two modules are identical, there is no zero-sequence circulating current. In fact, when the switching actions are strictly synchronous, the effect of circulating current is not significant. Fig.4 shows the estimated voltages for the first and the second inverters for a given fixed values of the voltages \( V_{d_{A_k}, \text{ref}} \). These fixed values artificially represent the losses of the system. The online estimation converges to the values inserted in the model as constant voltage sources and then the losses of the system are well estimated. Fig. 5 shows the three phase voltages of the output filter, which are a pure sine waves.

| Table I |
|-----------------|-----------------|
| DC line inductances | \( L = 1 \mbox{mH} \) |
| Output AC filter inductances | \( L_1 = L_2 = 1 \mbox{mH} \) |
| DC bus capacitance | \( C_C = 800 \mbox{mF} \) |
| Output filter capacitance | \( C_f = 40 \mbox{mF} \) |
| AC output voltages | 110V-60Hz |
| DC input voltages | 400V |
| Switching frequency | \( f_s = 15 \mbox{kHz} \) |
| Energy trajectory | \( \xi_e = 0.7, \omega_{\xi_e} = 7000 \mbox{rad/s} \) |
| Current errors trajectory | \( \xi\zeta = 0.7, \omega_{\xi\zeta} = 7000 \mbox{rad/s} \) |

Fig. 3. Behavior of electrostatic energies with the control strategy.

Fig. 4. Estimated line voltage \( V_{d_{A_k}, \text{ref}} \) representing the system losses.

Fig. 5. Three phase voltages \( V_{d_{A_k}, \text{ref}} \) of the output filter for a \( V_{\text{rms}} \) value equal to 110V.
VI. EXPERIMENTAL RESULTS

To verify the validity of the proposed control and optimization methods, experiments are performed on a 5-kW test bench composed of two parallel inverters as shown in Fig. 1 with the parameters listed in Table I. Fig. 6 shows load voltages and currents for a 3.2-kW balanced resistive load. The reported voltage THD is equal to 1.8%. Fig. 7 shows the behavior of $dQ$-axis energies and voltages of the output filter after a step variation of the voltage reference from 55 to 110 V with a resistive load power set to 3.2 kW in steady state. Fig. 8 shows the waveforms of the currents $i_d1$, $i_d2$ and $i_q1$, $i_q2$ and their respective difference which are equal to zero thanks to the current error control method which emphasizes minimizing of the circulating currents. The efficiency of the system with equal power sharing method and with the proposed optimization technique are shown in Fig. 9. The efficiency under the proposed optimization technique is about 1.1% higher than the equal sharing a defaulted system obtained by adding 1.5Ω per phase for the second inverter. These resistances artificially represent a default for the second inverter.

VII. CONCLUSION

In this paper, a control strategy based on the flatness theory is proposed for parallel three-phase inverters with an output LC filter. The flatness of the studied system is demonstrated, and the system value limitations are taken into account in the design of the reference trajectories and the control parameter values. A new method for estimation of the losses is proposed, and the estimations parameters are used to minimize the overall losses, and then optimize the power sharing between the parallel inverters. This optimization method maximizes the global efficiency and minimize the losses of the whole system. The experimental results show the efficiency of the proposed control and optimization method.

![Fig. 6: Load voltages and currents for RMS reference voltage value equal to 110V with a 3.2KW balanced resistive load.](image)

![Fig. 7: Control energies (a) and voltages(b) of the output filter for step of RMS value of reference voltage from 55V to 110V with a 3.2kW balanced resistive load.](image)

![Fig. 8: Experimental results of; (a) $i_d$, $i_q$ and, (b) $i_d$, $i_q$ and their respective differences; under resistive balanced load, 3.2 kW.](image)

![Fig. 9: Experimental results of efficiency load dependence with and without optimization technique.](image)

VIII. REFERENCES


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Fig. 1. Architecture of the complete DC/AC system with n-parallel inverters.

**Power supply with its input filter**

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**Input Inverter 1**

**Input Inverter 2**

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**Circulating current between inverters 1 & 2**

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Fig. 2. Functional diagram of the proposed control.